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Sent: Tuesday, March 22, 2022 1:15 PM
To: DRP Ordinance Studies; Elida Luna; DRP Info; firstdistrict@bos.lacounty.gov; HollyJMitchell@bos.lacounty.gov; Sheila; FourthDistrict@bos.lacounty.gov; Barger, Kathryn
Subject: Published Research Indicating 5G/4G Densification Will Increase RF Radiation and Harm People, Wildlife and Trees Part1
Attachments: Expert Letters Filed to FCC Caling For Record Refresh Wireless Radiation .pdf; Washington-Spectator-5G 2022Full article .pdf; Cell Tower Laws in US and International .pdf; EMF and Wildlife Part 2.pdf; Doctor Letters on Health Effects of Cell Tower Radiation .pdf; Risks to Health and Well-Being From Radio-Frequency Radiation Emitted by Cell Phones and Other Wireless Devices davis copy 4.pdf; Thermal and non-thermal health effects of low intensity non-ionizing radiation- An international perspective.pdf; Harvard Report.pdf; New Scientific Developments in Radiofrequency Radiation FCC EHT Remand-5.pdf; European Parliament Report Health Risks of 5G .pdf; 31 - Base Stations and Human Hormone Profiles.pdf; 30 - Subjective symptoms GSM radiation mobile phone base stations.pdf

Please ensure this is on the official record for the March 23 Los Angeles County Planning Board Proposed Changes toCounty Code Title 22:
We are providing information for the Board to ensure they make a well informed decision. Allowing the expansion of wireless networks near homes and schools will adversely impact public health as well as the health of wildlife and trees.

A Climate impact assessment must be done as wireless densification will increase energy consumption. Further an environmental assessment must be done on the proposed networks before deployment as research indicates harm to trees, birds and bees.

All links submitted by reference.

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Theodora Scarato
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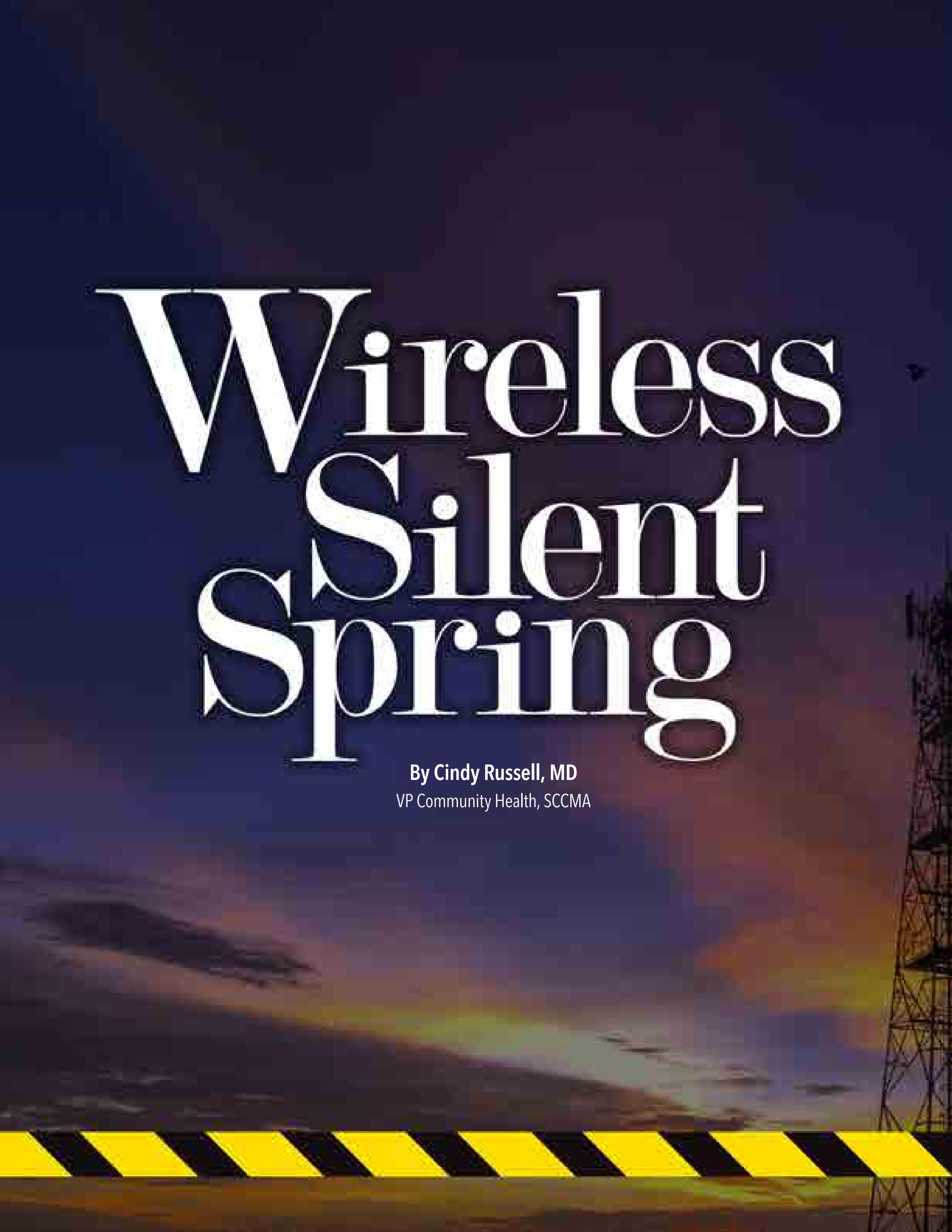


Wireless Silent Spring

By Cindy Russell, MD
VP Community Health, SCCMA

> “Those who dwell among the beauties and mysteries of the earth are never alone or weary of life.”
>
> *Rachel Carson, Author Silent Spring*

IN THE WAR ON INSECTS: NATURE BECOMES SILENT

Our ill-fated desire to control nature as well as our tendency to ignore our own complicity in its destruction for profit was the focus of a seminal 1962 book, “Silent Spring.” This publication is widely credited with ushering in the modern environmental movement. (1) Rachel Carson, a marine biologist, and author of “Silent Spring,” was first a lover of nature and a poet. Through her astute observations of nature, careful documentation and gifted writing, she was able to bring attention to the devastating and long lasting effects of pesticides which continue to impact all wildlife and species, including humans.

Her book contains story after story showing the annihilation of birds, squirrels, fish, earthworms, and beneficial insects after the introduction of ever more toxic pesticides to fight invasive insects such as the Japanese beetle. Funds were endless from the Department of Agriculture who declared that these pesticides were perfectly safe as planes deposited hundreds of pounds of pellets into yards, schools and farms. Water turned into poison and rivers of death for salmon and other species. Bird populations of robins, pheasants, and meadowlarks plummeted along with rabbits, muskrats and cats. Farm animals who were exposed withered and many died. Dogs even fell ill. The Japanese beetle survived, however, as most insects cleverly and rapidly become resistant to these chemicals, which can persist in the soil and waterways for years. While species targeted biologic methods of control and integrated pest management tools have been developed, more and more pesticides have been created leaving us an economically profitable but toxic legacy – DDT, Chlordane, Dieldrin, 2-4 D- Malathion, Glyphosate.

There are many similarities between the silent spring created in cities and farms from pesticides and that of wireless technology with the rapid and widespread adoption of cell towers. Let’s examine the effects of this technology that biologists have found on wildlife and then compare the histories, mechanisms and impacts between pesticides and wireless radiation.

“And it’s not just pigeons — have you seen any sparrows or parrots around, since these towers started springing up?”

K. Pazhaniappan, Secretary,
New Madras Racing Pigeon Association (43)

WIRELESS RADIOFREQUENCY AFFECTS NAVIGATION OF BIRDS AND BEES

It is well known that magnetite, a form of iron ore, is found in a wide variety of organisms. It has been shown that this substance is used to sense the earth’s low energy magnetic field as a directional reference. (Cadiou and McNaughton 2010). Magnetite acts as an internal compass. For over 50 years, scientists have known that migratory birds use the earth’s magnetic field to navigate. As it turns out, a diverse array of animal life also relies upon this geomagnetic field as their GPS for breeding, feeding, migration and survival.

Biologists have unexpectedly discovered that wireless radiofrequency radiation (RFR) disturbs internal magneto-receptors used for orientation. In addition, this non ionizing radiation can have profound impacts on the natural environment by disruption of other complex cellular and biologic processes in mammals, birds, fish, amphibians, insects, trees, plants, seeds and bacteria. Reported adverse effects from radiofrequency radiation that have been identified include abnormal behavior, developmental abnormalities, diminished reproduction and increased mortality. The effects of this radiation may not be immediately apparent with a slow decline in the health of wildlife seen over time with cumulative exposure, adding a new environmental toxin contributing to silent springs in cities, orchards and farms. The more towers, the more additive mix of radiation frequencies saturating the environment, creating an increasingly toxic air space. Non thermal biological effects are not considered in current guidelines. Appropriate safety testing and regulation of this technology is lacking, however, invention, commercialization and deployment of cell towers marches on – 1G, 2G, 3G, 4G, 5G.

THE SKRUNDA RADIO LOCATION CASE

Firstenberg (2017) in his fascinating and well-referenced book, *The Invisible Rainbow: A History of Electricity and Life*, describes both observations and biological controlled experiments performed, mostly in Europe, where a high power early warning Radio Location Station tower was in place for over 25 years. (12) Studies performed during and after the tower was removed demonstrated that it caused not only human symptoms including documented memory, attention and motor deficits in children, but also affected widespread forest health with loss of birds, thinner growth rings on trees, poor seed germination, and loss of duckweed, among other effects. (3) When these towers were removed, not only did the health of the local residents improve, the forest recovered.

BIRD MIGRATION DISRUPTED MORE BY WEAK MAGNETIC FIELDS

Biologists have discovered that birds’ magnetic compass orientation appears more vulnerable to weak broadband electromagnetic fields. Pakhomov (2017), Schwarze (2016), Wiltschko (2015). A German scientist, Svenja Engles (2014) lead the research project to confirm this effect. He and his German graduate students exposed migratory European robins to the background electromagnetic noise present in unscreened wooden huts at the University of Oldenburg city campus and found the birds were confused and could not orient using their magnetic compass. If grounded or screened with aluminum their orientation reappeared, but disappeared again if broadband radiofrequencies were generated inside the huts. He did not believe the effects at first and repeated the same double-blinded experiment many times in seven years and with different graduate students to confirm the effect before publishing his results.

WHEN HOMING PIGEONS CAN’T FIND HOME

Modern communications systems with a proliferation of cell towers in cities and now in rural areas, create continuous pulsating artificial radiofrequency wave mixtures that can alter local magnetic fields and thus impair bird migration and orientation of pollinators. In a straight line, sight cell towers can transmit 20 miles or more. In 1998, soon after cell towers were installed in Pennsylvania, pigeon races ended in disaster as up to 90% of birds were disoriented and lost their navigational skills. This was reported in a *New York Times* article December 6, 1998, “When Homing Pigeons Don’t Go Home Again.” (2)

The problem of lost homing pigeons is becoming commonplace, leaving pigeon racing aficionados very concerned. (6)(13) A 2013 *British Pigeon Insider* article notes that pigeon keepers in England reported the loss of dozens of pigeons during races, as well as abnormal frantic behavior near cell towers and declining pigeon reproduction as cell towers have been reproducing in cities and farms. Another article in *Wired* magazine cites one pigeon fancier who lost two-thirds of his pigeons after a tower was installed next to his farm.

FATAL ATTRACTION: COLLISIONS WITH CELL TOWERS

The Audubon Society reports that each year up to 50 million birds, representing 230 different species, die in collisions with communication towers at night. (8) This occurs when they hit the tall, antenna-sporting structures or associated guy-wires that support the cables. It has been found that at night birds are lured into the deadly metal structures by the steady beam of red lights on the tops of the towers. The lights are required by law for airline safety but the birds see this as a guiding light and shift from using geomagnetic signals and instead head straight for the beam.

An FAA study showed that small migratory birds become confused when they reach the light and either hit the tower or they continue to fly

cell towers were placed on their fire stations. A pilot study of firemen was completed in 2004 and brain scans confirmed those with symptoms had evidence of adverse brain alterations. Because of this, the International Association of Firefighters has developed a policy to ask for exemptions from cell tower placement on or adjacent to fire stations with new cell tower legislation. (19) It is codified in California's AB57 (2015). (18)

THE DECLINE OF BIRDS, BEES AND WILDLIFE WITH INCREASING RADIOFREQUENCY RADIATION

Researchers are now attributing wireless radiation from cellular communications to be a significant contributing cause of bee "colony collapse disorder," insect disappearance, the decline in house sparrows in London (Balmori 2007) (Everaert 2007), as well as the steady deterioration of the worlds bird population with now more than 40% of bird species under critical threat. Insects are not only important pollinators, they are the base of the food chain for birds, amphibians, reptiles and mammals. A Yale report highlights a 2014 study by Stanford professor Rudolfo Drizo, which revealed that 42% of the 3,623 terrestrial invertebrate species on the International Union for Conservation of Nature [IUCN] Red List, are classified as threatened with extinction. He notes, "human impacts on animal biodiversity are an under-recognized form of global environmental change." (5)

around the tower until exhausted and they fall to the ground. Flashing red lights seem to reduce the number of fatal bird collisions. (11) Longcore (2013) studied the numbers and types of birds killed by cell towers in the U.S. and Canada and found "Neotropical migrants suffer the greatest mortality; 97.4% of birds killed are passerines, mostly warblers (Parulidae, 58.4%), vireos (Vireonidae, 13.4%), thrushes (Turdidae, 7.7%), and sparrows (Emberizidae, 5.8%). Thirteen birds of conservation concern in the United States or Canada suffer annual mortality of 1–9% of their estimated total population." A 2015 FAA guideline strongly encouraged operators of all tall cell towers to switch to flashing red lights by 2016. In November of 2016 about 750 tall towers (above 350 feet) had been switched, leaving about 15,000 more to go, according to an American Bird Conservancy report. (24)

CELL TOWERS NOT HEALTHY FOR BIRDS OR FIREMEN

Government agencies, however, are becoming more aware. The Department of Interior wrote a letter in 2014 to the National Telecommunications and Information Administration regarding the DOI concerns about the First Responder Network Authority (FirstNet) and their regulations regarding cell towers and the protection of wildlife, especially migratory birds.(15) FirstNet is a public-private partnership with AT&T and because of its stated duty to public safety it has significant preemptions. (17) The DOI stated, "the proposals lack provisions necessary to conserve migratory bird resources, including eagles. The proposals also do not reflect current information regarding the effects of communication towers to birds." FirstNet noted that the DOI "requested that FirstNet's procedures include a process for ensuring compliance with the Bald and Golden Eagle Protection Act ('BGEPA'), Migratory Bird Treaty Act ('MBTA'), and Executive Order (E.O.) 13186, Responsibilities of Federal Agencies to Protect Migratory Birds." (16)

The DOI is not the only one concerned about FirstNet towers. Although public safety is important, what happens when the device intended for safety causes an unintended threat to others? Some firemen have experienced a variety of neurologic symptoms consistent with electrosensitivity (headaches, dizziness, brain fog, sleep deprivation, irritability) when

WIRELESS RADIATION AND COLONY COLLAPSE DISORDER

Bees are a critical pollinator species for agricultural productivity. (20) Of the 100 crops that provide 90% of the world's food supply, 71 are pollinated by bees, according to the U.N. Environmental Program, #Friday Fact. (21) The report also notes that to produce 1 kilogram of honey, a bee must visit four million flowers and fly a distance equivalent to going around the Earth four times. Bee numbers have plummeted in Europe, the United States and around the world in the last two decades. Contributing factors affecting the health and reproduction of bees include pesticides, global climate change, loss of habitat and air pollution with new research pointing towards microwave radiation as an important and yet unrecognized cause for concern. Bees, as well as birds, contain magnetite magneto-receptors in their abdomen.

Electromagnetic microwave radiation has been shown to disrupt bee behavior and may cause worker bees to emit a piping signal to swarm. The bees have also demonstrated aggression after 30 minutes of cell phone exposure. Favre (2017)

A cell phone placed next to a bee hive appears to cause a slow destruction of the hive. (Dallo 2015) concludes in his research, "significant decrease in colony strength, honey stores, pollen reserves, number of foragers returning to their hives and egg laying capacity of queens in test colonies. Cell phone radiations disturbed navigational skills of foragers."

Lazaro (2016) looked at the effect of mobile communication antennas on the abundance and composition of wild pollinators, including wild bees, hoverflies, bee flies, remaining flies, beetles, butterflies, and wasps on two Greek islands with variable distances from cell towers, carefully measuring the radiofrequency radiation. He found negative effects in all groups except butterflies.

Belgian entomologist Marie-Claire Cammaerts (2017) has done a number of studies on RFR and found that insects are particularly sensitive. She writes, "Before the invention of the wireless technology, plenty of active insects fed on crops, flowers, fruits, where they ate, drank, collected nectar, and numerous dead insects were found crushed on cars. Nowadays, all this no longer occurs at such an extent [2]. Bees may be particularly affected by manmade electromagnetism [21,22,23] – When crossing such electromagnetic fields, bees may no longer remember their way, may no longer fly in the correct direction, and may become unable to go back to their hive."

These are truly alarming findings and serve as a dire warning on further wireless expansion, especially with regards to sensitive wildlife areas and agricultural rural zones that depend on pollination.

5G ESPECIALLY HARMFUL TO INSECTS: THE RESONANCE EFFECT AND PHASED ARRAYS

Proposed 5G millimeter wavelengths are a similar size to insects and this creates a damaging vibrational effect known as resonance on the organism. Resonance is a well-known phenomenon in physics. A common example is that of a wine glass which shatters when an opera star reaches a high C note, vibrating air molecules matching the glasses natural oscillating frequency. In general, mechanical resonance occurs when the frequency of an oscillation matches the system's or its subcomponent's natural frequency and this results in increasingly intensified additive vibration with more energy being absorbed, causing more disturbance of the system. At low power an effect is greatly magnified. Thielens (2018) looked at this effect on four different insects exposed to electromagnetic fields from 2 to 120 GHz. He noted, "The insects show a maximum in absorbed radio frequency power at wavelengths that are comparable to their body size – This could lead to changes in insect behavior, physiology, and morphology over time due to an increase in body temperatures, from dielectric heating."

In addition, a newer technology previously used in the military for early warning missile radar systems, PAVE PAWS, is incorporated into these 5G systems and called phased arrays. (29) These powerful "beam steering" arrays scan back and forth from tower to device for easier connection with an individual's movement, to detect the device, similar to the surface-to-air missile systems. (30) They are also used in AM and FM Broadcast stations and planned for automotive sensors and satellites. What effect will this increase in power and density of environmental radiation have on our beneficial insects and pollinators?

REVIEW STUDIES POINT TO WILDLIFE HARM

Balmori (2015) states in his latest review "Current evidence indicates that exposure at levels that are found in the environment (in urban areas and near base stations) may particularly alter the receptor organs to orient in the magnetic field of the earth. These results could have important implications for migratory birds and insects, especially in urban areas, but could also apply to birds and insects in natural and protected areas where there are powerful base station emitters of radiofrequencies.

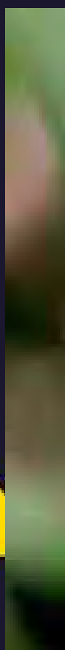
Cucurachi (2012) in reviewing 113 peer-reviewed publications revealed, "In about two thirds of the reviewed studies ecological effects of RF-EMF was reported at high as well as at low dosages. The very low dosages are compatible with real field situations, and could be found under environmental conditions."

The Ministry of Environment and Forest in India (MOE 2010) examined all available peer reviewed research on the impacts of wireless radiofrequency (RF) on living organisms at the time, including birds and bees. They found that 593 of the 919 articles showed adverse impacts. In each category of organism, over 60% of the research indicated harm to that biological species.

TREES DAMAGED BY CELL TOWERS

Aspen trees reproduce primarily from sprouting from the roots. If a stem dies, another fresh shoot is sent up. "Clones" of tree stands are thus created that can live hundreds to thousands of years. The health of Aspen tree stands is determined by mature trees with shoots and saplings in between. In Colorado, Aspen trees have been on the decline for decades but rapid mortality has been observed in clones since 2004. (25) A preliminary experiment on trembling Aspen trees points to ambient elec-

> "The exponential increase of mobile telephony has led to a pronounced increase in electromagnetic fields in the environment that may affect pollinator communities and threaten pollination as a key ecosystem service."
>
> *Lazaro 2016*



> "When crossing such electromagnetic fields, bees may no longer remember their way, may no longer fly in the correct direction, and may become unable to go back to their hive."
>
> *Marie-Claire Cammaerts (2017)*

tromagnetic radiation from a variety of sources (cell towers, satellites, RF from electric power generation) causing poor growth and smaller leaves. Seedlings shielded from surrounding low level background RF radiation produced vigorous shoot growth, no necrotic lesions and rich pigmentation in the leaves due to anthocyanin production, versus unshielded seedlings which had a high percentage of leaf necrotic tissue and a reduction in shoot length. (Haggerty 2009)

Waldmann-Selsam et al (2016) clearly demonstrated, in a robust four year study with accurate RF emission testing, cell tower radiation causing the death of nearby trees over time. He notes, "These results are consistent with the fact that damage afflicted on trees by mobile phone towers usually start on one side, extending to the whole tree over time."

ARE BEE DRONES THE ANSWER? "SMART" OR DUMB POLLINATION?

Wireless technology, however convenient, has consequences. High tech has invaded every corner of our lives and will soon be used in agriculture to pollinate crops as bee colony collapses disorder worsens. In a CNN article "This 'bee' drone is a robotic flower pollinator" the developer notes "It could conceivably be used in large-scale farming, even in hydroponic farming." (22)

As cell towers and wireless systems proliferate, will we continue to ignore their role in harming life sustaining ecosystems? Will we create dead zones in cities where urban or rural farmers will not be able to grow food or have a vegetable garden? Agriculture is already under siege from many other environmental threats. Without bees there will be no pollination or honey. Without birds there will be no seed dispersal.

The tech industry may advise us to use the very technology that is harming ecosystems by using bee drones to pollinate our crops. Walmart has already filed a patent for a robotic bee. (23) These high tech insects would be directed by 4G or 5G radiation to operate via the Internet of Things. Because the size of 5G frequencies matches that of insects, this radiation acts as an insecticide (Yadav 2014). What about ownership of drones, privacy, security and adverse effects on sensitive native bees and flowers, e-waste and energy consumption with the use of these drones? Many questions with no answers but predictable negative consequences. We have been there before with pesticides, asbestos, lead, mercury, with new emerging toxins being regularly introduced. The fallout on public and environmental health continues.

SCIENTISTS APPEAL TO THE UN FOR PROTECTIVE HEALTH AND ENVIRONMENTAL STANDARDS

Scientists who study radiofrequency radiation note a serious lack of monitoring and protocols to study the impacts of wireless technology and biologists are calling for precaution in the placement of cell towers with further expansion of wireless broadband. As of August 30, 2018, 244 EMF scientists from 41 nations have signed an Appeal calling upon the United Nations, the WHO and the UNEP to address the public health and environmental concerns raised in an extensive and growing body of scientific evidence on the broad adverse impacts of wireless radiation. (33)

GETTING SMARTER: PREVENTION VERSUS TREATMENT

Solving the real problems causing the decline in wildlife seems smarter than always trying to develop a new and potentially more toxic industry to fix it. Indeed, pesticides, habitat loss, over fishing, overhunting, overpopulation, global climate change, environmental toxins, plastics in the ocean have had a devastating impact on species. The World Wildlife Fund and the Zoological Society of London reports that over half of the earth's wildlife has been lost in the last 40 years. (27)

Prevention is far easier and more economical than treating a problem, especially if the problem becomes irreversible (global climate change). Physicians prescribe medications to treat chronic diseases of our modern cul-

> "Everything is reversible because everything is unfortunately of humankind's making."
>
> *Tris Allinson, Bird Life's senior global scientist, on the decline of birds*

ture. They are now recognizing, however, that many of these synthetic medications, while useful, can cause side effects that may be worse than the disease being treated. Current medical care is focused more on cure or treatment than prevention or precaution, causing continuing escalation of health care costs. Would it be better, instead, to encourage lifestyle changes to promote health and wellness with a holistically healthy diet, exercise and policies to reduce environmental toxic exposures?

WHAT IS A SAFE LEVEL OF RADIOFREQUENCY? STANDARDS ONLY LOOK AT HEAT

Current guidelines for radiofrequency exposure are set at levels that cause tissue heating, the assumed cause of harm from this radiation. The balance of scientific evidence now indicates that there are significant adverse effects of this wireless radiation at non-thermal levels. (Belpomme 2018) Environmental effects on wildlife and plants confirms this. The mechanism has been found to be related to calcium channel membrane effects and oxidation.

BIOINITIATIVE REPORT

Sage, Carpenter, Blank and other scientists note in the BioInitiative Report that non-thermal bio-effects are clearly established. The Bioinitiative Report reviewed studies looking at the lowest levels of non-thermal, non-ionizing radiofrequency that did not cause harmful biological effects. Their conclusions, based on peer reviewed research, indicated that there should be a "scientific benchmark of 0.003 uW/cm2 or three nanowatts per centimeter squared for 'lowest observed effect level' for RFR is based on mobile phone base station-level studies." They also suggest "Applying a ten-fold reduction to compensate for the lack of long-term exposure – or for children as a sensitive subpopulation." This would be a recommended precautionary action exposure level of 0.0003 uW/cm2. (Bioinitiative 2012) Our current U.S. guideline is 200 uW/cm2 to 1000 uW/cm2 for RF radiation depending on frequency. This is a substantial difference and indicates a need for re-evaluation of FCC safety standards and consideration of published scientific research indicating non-thermal effects. (NTP 2018)

INDEPENDENT SCIENCE IGNORED

Professor Emeritus of Biochemistry at Washington State University, Dr. Martin Pall, has written extensively on this subject. In a recent paper "5G: Great Risk for EU, US and International Health," he looked at eight distinct types of harm from electromagnetic field exposure. This included DNA damage, carcinogenicity, endocrine, nervous system and reproductive effects. Of 22 robust independent research review papers on non-thermal EMF effects published on or before 2013, 20 were ignored by the latest report of the European Commission's Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR).

There is an urgent need for government agencies to adopt a realistic biologically based radiofrequency exposure standard to replace the 20-year-old thermal (SAR) standard, which is far too permissive and not protective of human or environmental health.

WIRELESS SILENT SPRING: PARALLELS BETWEEN PESTICIDES AND WIRELESS RADIATION

In rereading Rachel Carson's book, *Silent Spring*, I was struck by the many similarities between pesticides and wireless radiation.

BOTH ARE INVISIBLE

Pesticides act as an invisible poison that works on a cellular level and can abruptly or slowly cause disease. You cannot see or taste it on your food or smell it as it drifts through the neighborhoods and enters creeks.

Wireless radiation is similarly silent to most. You typically cannot hear, feel or see radiofrequency radiation unless you are electrosensitive. Cellular and biologic damage however is occurring.

BOTH ARE UNIVERSAL IN OUR ENVIRONMENT

Pesticides are routinely sprayed in homes, gardens, on trees, in forests to strike insects far and wide. Biomonitoring studies nationwide and in California show pesticides still present in blood, urine and breast milk. (California Biomonitoring) (CDC Biomonitoring NHANES)

Wireless radiation is found almost ubiquitously in homes, businesses and schools to connect us to the world and with each other instantaneously. This is supported by well over 300,000 cell towers in the U.S. not counting private cell towers. The continuous pulsating waves of radiation stray into any nearby living organism, be it human, pet or wildlife.

LIFE LONG EXPOSURES: CRADLE TO GRAVE

Pesticides and their sometimes more toxic residues are now found in all human cord blood, urine and breast milk, and in children who do not eat organic foods. (Bradman 2003) (Curl 2003) (Lu 2006) (Salama 2017) (CDC Biomonitoring)

Exposure to wireless radiation now begins in the fetus with cell towers along with a host of wireless devices in the homes (i.e. cell phones, Tablets, Wi-Fi routers, smart meters, and now baby toys, smart cribs and wearable technology).

NON SELECTIVE TARGETS TO LIVING ORGANISMS WITH INDISCRIMINANT HARM

Pesticides are sprayed in large areas to kill a few flying insects but end up harming all species and the balance of nature with ecosystem effects. (EPA Persistent Organic Pollutants)

Wireless radiation is sprayed in all directions to find the intended device but also penetrates all living organisms causing cellular damage with ecosystem effects. (Balmori 2010), (Cucurachi 2012) (Sivani S and

Saravanamuttu 2013) (NTP 2018)

BOTH CAUSE A VARIETY OF ADVERSE BIOLOGICAL EFFECTS

Pesticides can have many toxic biologic impacts and are associated with malignant, neurodegenerative, respiratory, reproductive, developmental, and metabolic diseases in humans. DDT and its metabolite DDE was found to cause blindness in fish and can act as an endocrine disruptor, mutagen and carcinogen. Women exposed to DDT before puberty are five times more likely to develop breast cancer. Glyphosate is linked to cancer. (Creesey 2015) (Soto 2015) (Mostafalou S and Abdollahi M 2013, 2017)

Wireless 2G radiation was found to cause DNA damage and increase the risk of cancer of the heart and brain in a recent 10 year, $25 million dollar National Toxicology Program study (NTP 2018). Non-ionizing radiation from 3G and 4G cell towers have been found to cause nonspecific symptoms of electrosensitivity in some living within 300 meters of a cell tower including insomnia, dizziness, brain fog, fatigue, depression and heart palpitations. Cell phone radiation has been associated with harm to the reproductive system, neurologic system, immune system and hematologic system. (Bioinitiative Report 2014) (Oceana Report)

BOTH ARE CHILDREN OF WAR

Pesticides were first developed as agents of chemical warfare. They happened to kill the research insects and thus became commercialized for that purpose after the war. We can now buy pesticides in the grocery store.

Radiofrequency microwave technology was developed in World War II. Known as radar, it has many military uses including for surveillance, missile control, air traffic control, moving target indication, weapons location and vehicle search. (39) At the end of the war, microwave ovens were developed after an engineer discovered a candy bar in his pocket had melted when he was near the magnetron power source. (38) Millimeter technology (95GHz) has been developed for crowd control (Active Denial System). (40) The recent health problems of Cuban, Canadian and Chinese diplomats and their families has been attributed to microwave radiofrequency radiation effects from either RF surveillance or deliberate attacks. (36). Our homes typically have many wireless devices such as cell phones, cordless phones, Wi-Fi, smart meters as well as microwave ovens.

BOTH ARE BIOACTIVE: TOXICITY THROUGH OXIDATION

Pesticide toxicity can take various forms with a direct neurotoxic effect, DNA damage, immune suppression and endocrine disruption through disturbance of many cellular processes. (Mostafalou S and Abdollahi M. 2013, 2017) Newer research on the mechanisms of toxicity of pesticides is focusing on oxidative damage (free radical formation) as the result of a multistep process causing cellular disruption, tissue damage, chronic disease and cell death. (Agrawal 2010) Antioxidants have been shown to lessen the toxic effects of pesticides as well as chemicals. (Akefe 2017)

Wireless radiofrequency radiation has also been shown to have a primary mechanism of harm from oxidation. Yamenko (2016) looked at 100 studies of RF radiation both in vivo and in vitro and found 93 showed oxidation as a mechanism of toxicity. Research on antioxidants including curcumin, vitamin C, vitamin E, melatonin show protection against the effects of non-ionizing radiation with a reduction in oxidative stress.

ADDITIVE TOXIC MIXTURES MORE HARMFUL

Pesticide exposure does not happen in isolation. Typically, we are exposed to a mix of pesticides in the food we eat. These pesticides circulate in our system for a variable length of time from hours to years and can be stored in our fat or breast milk. The toxic interactions can be long term. A conventional potato has 41 pesticides, 14 of which are classified as carcinogens. (44) EWG tested strawberries and found about 22 pesticides in a conventionally grown berry. Research has shown that mixes of chemicals and pesticides have additive and synergistic toxic effects. For approval, however, these pesticides are studied only one at a time and without their "inactive" ingredients.

The more pesticides we are exposed to the greater the mix of adverse effects on the immune system, reproduction, carcinogenicity, as our protective enzyme and antioxidant mechanisms are overwhelmed. One pesticide can act as a mutagen, the next an endocrine disruptor and the next suppress your immune system to promote cancer. A true toxic triad of effects.

Wireless technology has continued to evolve and expand. The 1G analogue system worked well but did not carry much data. While new generations have been introduced to the marketplace to serve our unquenchable appetite for instant wireless information and communication, the old will still be in place – 2G, 3G, 4G. With the latest proposed 5G technology and the Internet of Things, industry aims to integrate this with other wireless generations, and even open up any remaining radiofrequency spectrum, creating a blanket of mixed frequency wireless radiation wildlife and humans will be exposed.

Radiation emissions are not only from cell towers, but also in remotely-controlled stratospheric balloons (Loon Project) and proposed low orbiting satellites, greatly increasing ambient levels of electromagnetic radiation (EMR). Like pesticides there has been inadequate research into the mix of frequencies we are exposed to. The 2018 NTP study, which found clear evidence of carcinogenicity, looked only at 2G technology. There are no government plans for testing of 3G, 4G or 5G individually or in combination. Synergistic effects of wireless radiation and toxic chemicals has

> “Doubt is our product since it is the best means of competing with the “body of fact” that exists in the minds of the general public. It is also the means of establishing a controversy.” (22)
>
> *Tobacco executive, from Doubt is Their Product, David Michaels*

also not been attempted. Despite a virtual research vacuum on 5G high frequency radiation, federal and state legislation is being introduced and quickly approved to ensure the rapid deployment of this technology by removing local jurisdiction and limiting fees for cities and counties to use the public right of way. (32)

SENSITIVE HUMAN POPULATIONS IN BOTH

Pesticides appear more toxic to some people who do not have the metabolic pathways to transform and excrete them. For organochlorine pesticides such as DDT and Lindane it has been shown that there are genetic variations in the cytochrome P450 system to break down these pesticides, causing increased risk of disease. (Docea 2017) Those pesticide workers with paranoxonase genetic polymorphism suffer chronic toxicity exhibited by nausea, dizziness, headaches, fatigue and gait disturbance. Symptoms in those individuals with multiple chemical sensitivity are similar. (Lee 2003) (Rossi 2018)

Wireless radiofrequency radiation is observed to cause non-specific symptoms of headaches, dizziness, insomnia, nausea, irritability, depression and heart palpitations in those who are electrosensitive. This was first reported by NASA in military personnel working on radar and was called “microwave illness.” (NASA 1981) Although some claim this could be a psychologic condition, researchers have identified a high correlation of symptoms to inflammatory and other biomarkers which can aid the diagnosis. Belpomme (2015) conducted a large clinical study and found laboratory biomarkers that connect multiple chemical sensitivity to electrosensitivity. It also has been noted that having these conditions causes predictable isolation and fear which can lead to neuropsychiatric symptoms. (41)

INDUSTRY DECEPTION

Pesticides have been well protected by the industry that created them. An investigation of over 20,000 documents including internal scientific studies, meeting minutes and memos from federal regulatory agencies and manufacturers was led by the Center for Media and Democracy and the Bioscience Research Project resulting in “The Poison Papers” of 2018. (46) Concealment, political manipulation, cover-up and collusion were found, along with suppression of fraudulent independent research and secrecy of the toxic effects of chemicals and pesticides.

Wireless telecommunications have been regulated by the Federal Communications Commission (FCC) since the 1996 Telecommunications Act was passed. The Environmental Protection Agency was relieved of their oversight duty of radiofrequency radiation prior to that. This 1996 Act assumed, even before testing, that there were no health or environmental effects of this radiation. It is specified in the law that health and environmental effects cannot be used as an argument to deny cell tower placement. This has hampered attempts to monitor or identify health effects in the United States. Harvard’s Center for Ethics investigation of the wireless industry, written by Norm Alster, resulted in a publication called “Captured Agency: How the Federal Communications Industry is Dominated by the Industries it Presumably Regulates.” (47) Highlighted is industries exorbitant lobbying influence to the tune of about $400 million a year according to the Center for Responsive Politics. A revolving door in Washington was also noted with telecom industry executives filling the critical “independent” government positions.

In her book, “Disconnect,” Dr. Devra Davis documents industry manipulation along with discrediting of scientists who have identified and published literature on the adverse health effects of wireless radiation. (48)

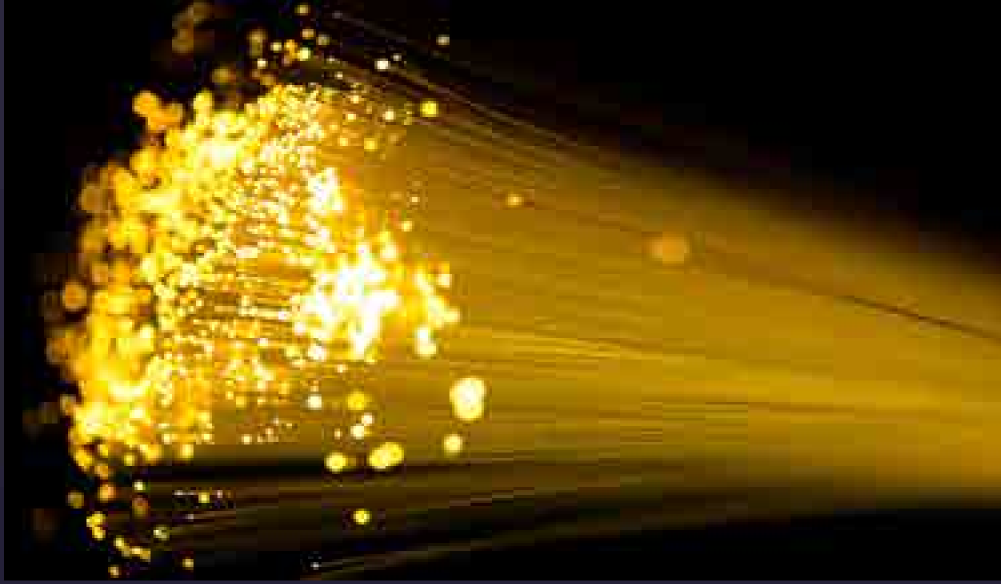
OUR FATE IS THAT OF NATURE

We are just beginning to understand the fragile biologic complexities of the earths living creatures as we simultaneously document natures decline under the dismissing hand of mankind. Many have warned that our fate will follow that of nature. The expansion of wireless technologies for human convenience will require more cell towers on every street corner. This will threaten natural ecosystems in favor of immersive and invasive technology which is contributing to both negative environmental, physical and mental health effects, especially on our youth.

SAFER SECURE ALTERNATIVES: FIBEROPTIC, CABLE AND LANDLINES

The internet has become a necessity to most people. It can be provided in a safer manner to reduce EMR exposure. Alternatives such as fiberoptic networks and cable exist that are faster, more fire resistant, use less energy and are cheaper in the long run. (49) Traditional copper landlines are reliable in emergencies, are cheap, already built, and connect everyone without risk. Why remove them? We can have the benefits of faster, dependable and more private communications without compromising public or environmental health.

Recommendations by Biologists and Scientists in a 2010 Report by the Ministry of Environment and Forests in India to Protect Wildlife from EMR (paraphrased) (MOE 2010)



1. Electromagnetic radiation (EMR) should be recognized as a pollutant.
2. Create laws to protect urban flora and fauna from EMR.
3. Create protected areas with no cell towers.
4. Require bold signs on the dangers of radiation to be displayed on all cell tower structures.
5. Perform regular independent auditing of EMR/RF in urban localities – schools, hospitals, residential, recreational and ecologically sensitive areas.
6. Require blinking red lights on cell towers to protect birds at night.
7. Create laws to enable removal of existing problematic mobile towers to protect human or environmental health.
8. Require ecological assessment and review of sites identified for installing towers before their installation in wildlife, ecologically sensitive or conservational important areas.
9. Strictly control installation of mobile towers near wildlife protected areas, breeding areas, bee colonies, zoos, and identify with scientific studies appropriate distances from tower structures as part of pre-installation review.
10. The locations of cell phone towers and other EMF radiating towers along with their frequencies should be made available on public domain. This information would help in monitoring the population of birds and bees in and around the mobile towers and also in and/or around wildlife protected areas.
11. Public consultation to be made mandatory before installation of cell phone towers in any area. The Forest Department should be consulted before installation of cell phone towers. The distance at which these towers should be installed should be studied on a case by case basis.
12. The government should educate the public about the dangers of EMR and need for precaution, placing signs in wildlife areas and zoos.
13. To prevent overlapping high radiation fields, new towers should not be permitted within a radius of one kilometer of existing towers.
14. If new towers must be built, construct them to be above 80 feet and below 199 feet tall to avoid the requirement for aviation safety lighting. Construct un-guyed towers with platforms that will accommodate possible future co-locations and build them at existing 'antenna farms,' away from areas of high migratory bird traffic, wetlands and other known bird areas.

ABUNDANCE OF LIFE AND DIVERSITY OR A WIRELESS SILENT SPRING?

Natures communication systems evolved using minute electromagnetic signals in tune with the earth and each other. They are being overwhelmed now with manmade artificial electromagnetic radiation, that in combination with other well established environmental threats spells disaster. Rachel Carson called for humans to "act responsibly, carefully, and as stewards of the living earth." Science and observation is warning us that a thoughtful approach to all of man-kinds activities is imperative, to favor the protection of biodiversity over profit, innovation or convenience. We need to take a lesson from nature that acts slowly and deliberately to create a healthy balance. Rapid shifts in technology are changing our social structure and separating us from reality, each other and the natural world. There are no limits to "disruptive" 21st century wireless technology nor any meaningful safeguards. If we don't slow down and think about the risks as well as the benefits of high tech, will it quietly lead us to a wireless silent spring and then to a silent Earth?

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Radiation Analysis in a Gradual 5G Network Deployment Strategy

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***Abstract*—In a world where many overlapping 2G, 3G, and 4G electromagnetic radiation sources already exist, concerns regarding the potential increase in these radiation levels following the roll-out of 5G networks are growing. The deployment of 5G is expected to increase power density levels drastically, given the limitations of mmWave communications that impose a notably higher number of base stations to cover a given area of interest. In this paper, we propose a gradual deployment strategy of a 5G network for a small area in downtown Austin, Texas, using the already existing 4G LTE sites of the area. The radiated power density of the proposed 5G network is then analyzed according to several electromagnetic field (EMF) exposure limits and compared to the radiation levels of the same area where only the LTE network is present. Simulation results for the selected area demonstrate the significant increase in radiation levels resulting from the addition of 5G cell towers.**

***Index Terms*—5G, Network Planning, Radiation Analysis**

I. Introduction

The notably large bandwidth available in the millimeter-wave (mmWave) band and the potential multi-gigabit-per-second (Gbps) data rates that can be achieved for future communication services have made mmWave communications a key part of Fifth Generation (5G) mobile networks. Despite the promising advantages of millimeter wave communications in terms of improved quality of service requirements, its usage for the 5G wireless standards comes at significant costs. First, working with such high frequencies will reduce coverage ranges of base transceiver stations (BTS). For proper coverage of an area, a densification of 5G BTSs is required to achieve the same coverage provided for this same area by today's 4G BTSs. Also, high propagation loss and increased signal blockage occurs, motivating the introduction of multi-antenna approaches such as Massive MIMO [1], [2].

This potential addition of a large number of transmitters gives rise to another problem that needs to be considered, which is the increase in radiation levels in the rolled-out 5G network. Although these transmissions are non-ionizing radiations, they cause thermal heating at the eyes and skin level. Extensive heating for long periods of time is when adverse health effects may occur. These health concerns have stimulated interest in the biological safety of mmWave transmissions. In this respect, several exposure limits have been specified in standards and regulations developed by commissions and organizations that many governments will rely on when future 5G networks are deployed. However, these regulations have contradicting limits, many of which have remained the same before the year 2000. Therefore, designing a 5G network with radiation levels that complies with all the safety limits is a difficult task given the current regulations.

Despite the ongoing standardization of 5G technology, several works in the literature have presented 5G network deployment studies. The cost and coverage implications of deploying a 5G network in Britain has been presented in [3] where it was shown that full coverage had exponentially rising costs due to network densification. Additional 5G network designs for different cities were presented in [4]–[6] without any consideration for the constraints of electromagnetic radiations or the implications of the environment in mmWave propagation. Network design has been studied under such radiation constraints in [7], [8] but for 4G networks. Power density assessment of 5G cellular nodes in an indoor environment has been presented in [9] where results showed that the peak power density remained below the specified threshold and can thus be deemed safe for the general public. However, not all of the guidelines and exposure limits were considered in this work and the simulation did not represent a real-world scenario.

To the best of our knowledge, no work has provided a thorough analysis of the deployment of 5G networks in terms of its impact on the increase in radiation levels. Existing work in the literature has either focused on the cost (e.g., [3]) or radiation levels for older standards (e.g., [7]). To this end, this paper presents a mmWave-based 5G network deployment strategy given pre-existing LTE nodes in a small geographical area in Austin, Texas. We then approximate the power density levels that would be experienced in such outdoor environments and analyze their variations and compliance with the specified exposure limits for different transmission powers and transmit antenna gains. We also compare this radiated power density in the deployed 5G network to the power density levels of the same area when only the pre-existing LTE BTSs are present.

The rest of this paper is organized as follows: Section II presents the 5G simulation environment considered in this work. The proposed deployment strategy of the 5G network in a small area in downtown Austin, Texas is presented in Section III. Radiation analysis of the deployed network is performed in Section IV. Concluding remarks follow in Section V.

II. 5G Environment Setup

A. Pathloss Model

The close-in free space reference distance (CI) path loss model [10] is considered. It is defined by the following equation:

$$PL^{CI}(f,d)[\text{dB}] = FSPL(f,1m) + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma^{CI} \quad (1)$$

where the free space path loss (FSPL) for a frequency of operation f is given by:

$$FSPL(f,1m) = 20\log_{10}\left(\frac{4\pi f}{c}\right) \quad (2)$$

The CI path loss model can be rewritten as:

$$PL^{CI}(f,d)[\text{dB}] = 20\log_{10}\left(\frac{4\pi f}{c}\right) + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma^{CI} \quad (3)$$

where:

- n: is the single model parameter or the path loss exponent
- d_0**:** is the reference distance taken as 1 meter
- d: is the distance in meters between the BTS and the mobile station
- X_σ^{CI}: a zero mean Gaussian random variable with standard deviation σ in dB. It represents large scale channel fluctuations due to shadow fading (SF). The standard deviation of this random variable is given by:

$$\begin{aligned}\sigma^{CI} &= \sqrt{\sum X_\sigma^{CI^2}/N} \\ &= \sqrt{(PL^{CI} - FSPL - n10\log_{10}(d))/N}\end{aligned} \quad (4)$$

where N represents the number of measured path loss data points

The values for parameters n and SF vary from one scenario to another. Table I presents the values of these model parameters in different environmental setups, which have been obtained by ray tracing and measurements in [11].

TABLE I: CI Model parameters for different environments [12]

Scenario	CI Model Parameters
UMa-LOS	n = 2.0, SF = 4.1 dB
UMa-NLOS	n = 3.0, SF = 6.8 dB
UMi-S.C.-LOS	n = 1.98, SF = 3.1 dB
UMi-S.C.-NLOS	n = 3.19, SF = 8.2 dB
UMi-O.S.-LOS	n = 1.85, SF = 4.2 dB
UMi-O.S.-NLOS	n = 2.89, SF = 7.1 dB

UMa: denotes Urban Macrocell (Tx Heights $>$ 25 m), **UMi:** denotes Urban Microcell (Tx Heights $<$ 25 m), **LOS:** denotes line-of-sight, **NLOS:** denotes no line-of-sight, **S.C.:** denotes Street Canyon, **O.C.:** denotes Open Square

B. mmWave Specific Attenuation Factors

In mmWave propagation, attenuation due to atmospheric and weather conditions constitutes an important factor to consider [13]. Specifically, we will consider oxygen attenuation $O(d)$ and rain attenuation $R(d)$, which are both dependant on the separation distance d. Oxygen attenuation has been observed to be equal 16dB/km in [14], and hence can be obtained by the following:

$$O(d)[\text{dB}] = \frac{16d}{1000} = 0.016d \quad (5)$$

The rain attenuation factor depends on the climate of the zone under study. The International Telecommunication Union (ITU) have segmented these zones and provide measurements for the rain rates of each zone [15]. Based on these measurements and considering that the area under study in this paper will be in Austin, Texas, the rain attenuation rate will be taken to be 3.5 dB/Km. This loss can then be obtained using:

$$R(d)[\text{dB}] = \frac{3.5d}{1000} = 0.0035d \quad (6)$$

C. Link Budget Estimation

The link budget equation upon which the cell radius will be estimated can now be defined as:

$$P_{Rx}[\text{dBm}] = EIRP[\text{dBm}] - PL^{CI} - O(d) - R(d) + G_{Rx} \quad (7)$$

where P_{Rx} is the power received by the mobile station, G_{Rx} is the antenna gain in dBi of the mobile station, and the effective isotropic radiated power (EIRP) is given by:

$$EIRP[\text{dBm}] = P_{Tx} + G_{Tx} - L_{Tx} \quad (8)$$

where P_{Tx} is the transmission power in dBm of the BTS, G_{Tx} is the transmitting antenna gain in dBi, and L_{Tx} is the cable loss in dB due to possible antenna mismatch. Table II lists the values chosen for each parameter of the link budget equation.

TABLE II: Simulation Parameters

Parameter	Value
Frequency f	28 GHz
Max EIRP	43 dBm
Antenna Gain G_{Tx}	24 dBi
Transmission Power P_{Tx}	19 dBm
Receiver Antenna Gain G_{Rx}	0 dBi
Cable Losses L_{Tx}	0 dB

D. Identifying Cell Ranges

By using the link budget equation in (7) and considering the simulation parameters given in Table II, the separation distance can be found for several receiver sensitivities. The calculated distance constitutes the cell range for a given BTS that satisfies the received power requirement. These calculations are summarized in Table III. A main observation is that the resulting cell ranges become significantly smaller when the receiver sensitivity is higher. Cell ranges that are too small (below 10 meters) are not considered since such small ranges are not desirable for real deployment.

III. Network Deployment

We now consider a small geographical area in downtown Austin, Texas, to deploy the 5G network. A diagrammatic view of our proposed strategy is shown in Fig. 1. The selected area is shown in Fig. 2(a) and delimited in red on the map of Fig. 2(b). This area already contains several locations where LTE sites are already built and which will be the starting points of the gradual 5G network deployment strategy. The initial LTE cell tower locations are obtained from an online cell tower database (www.opencellid.org). We consider a worst case scenario where no line-of-sight components are available.

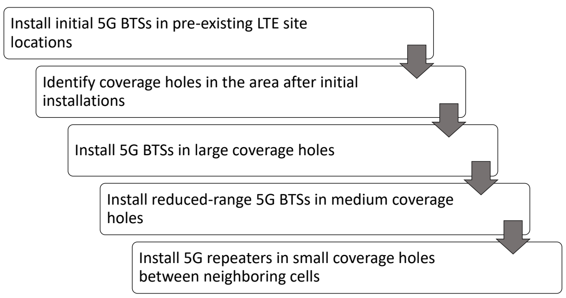
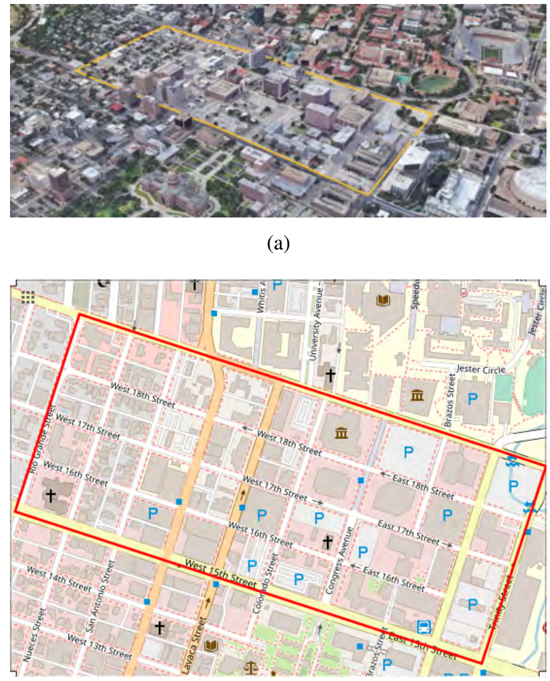


Fig. 1: Gradual Deployment Strategy

The first step of deployment starts by building 5G BTSs in the areas where LTE BTSs already exist, a technique known as co-siting. The main aim of co-siting is to reduce capital expenditures (CapEx) required to erect the 5G sites and minimize the operational expenditures (OpEx) needed to sustain their operation. UMa-NLOS towers will be placed in these locations. The receiver sensitivity is considered to be -78 dBm which, according to Table III, sets the cell range of each UMa to be 53 meters. The coverage of the initial BTSs installed is shown in Fig. 3, after slightly changing the location of the BTS within the same area it is built on, which may be any building rooftop, to lessen interference and provide better coverage. It can be noticed that these initial cells do not provide coverage to the whole area due to the small cell range of each BTS. Theoretically, this range can be increased but would demand the EIRP to be increased above the allowed limit of 43 dBm, by increasing the transmission power and selecting a higher-gain massive MIMO antenna configuration

The next step is the identification of coverage holes, as shown in Fig. 4. Large coverage holes are can be noticed, where several UMa towers can be distributed to provide good coverage. Smaller coverage hole are also be identified. Some of these holes are very small areas between neighboring cells where 5G repeaters, such as the one described in [16], can be placed to cover these small holes. Other small holes are not small enough to be fixed merely by the placement of a repeater, and are neither too big to place a BTS with a cell



(a)

(b)

Fig. 2: Geographical area of interest in Austin, Texas (a) Satellite View (b) Map View

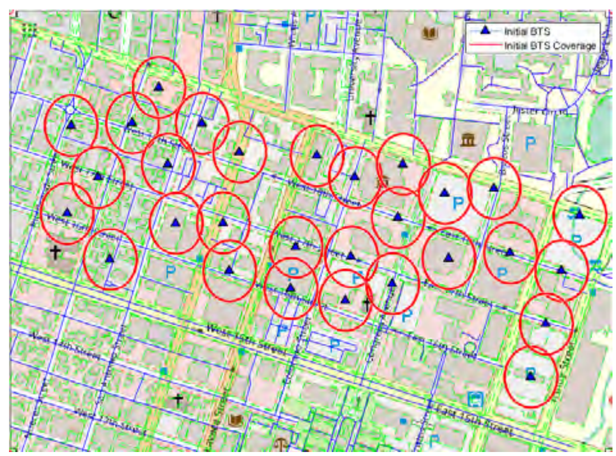


Fig. 3: Coverage of initial 5G BTSs built at the locations of pre-existing LTE cell towers

range of 53 meters. In such locations, reduced-range towers can be placed to provide coverage. The coverage range for these towers can be shrinked by reducing transmission power and choosing smaller MIMO antennas. We calculate the cell range for the reduced-range BTS towers to be approximately 30 meters and estimate the coverage of the 5G repeater to be 15 meters. The final design of the deployed 5G network is shown in Fig. 5. It can be observed that the deployment of a 5G network in an area as small as the one presented requires a densification of cell towers and signal repeaters, which in turn will cause much more radiation.

TABLE III: Calculated Cell Ranges for Several Receiver Sensitivities in Various Environments

Receiver Sensitivity	Cell Range (meters) for EIRP = 43 dBm					
	UMa-LOS	UMa-NLOS	UMi-S.C.-LOS	UMi-S.C.-NLOS	UMi-O.S.-LOS	UMi-O.S.-NLOS
-78 dBm	302	53	334	38.5	385	60
-70 dBm	165	29.7	186	22.3	216	33
-65 dBm	105.5	22	120	15.7	139	22.5
-60 dBm	65	14.1	74.5	11	85	15.3
-55 dBm	38.5	×	44.5	×	55	×
-50 dBm	22.6	×	26	×	27	×
-47 dBm	16.2	×	18.6	×	20	×

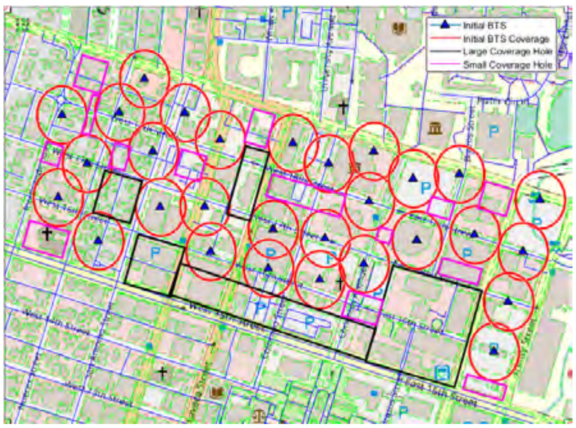


Fig. 4: Coverage holes identified after initial BTS installations

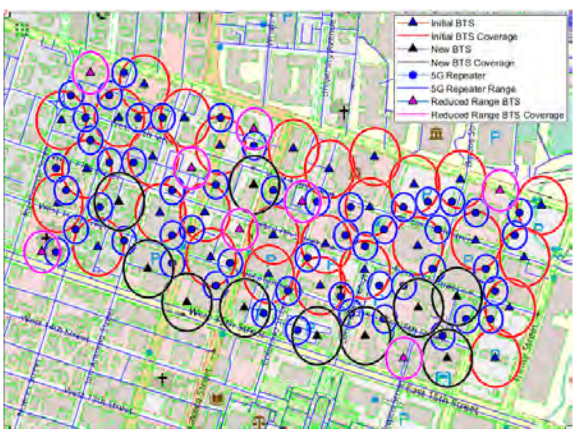


Fig. 5: Deployed 5G Network

IV. Radiation Analysis

A. Exposure Limits

Although mmWave radiation is non-ionizing, the absorption of mmWave energy in the human body causes heating to the skin and eyes. This has caused serious concerns in terms of potential health risks that might come along with the introduction of 5G networks [17]. For this reason, before introducing mmWave devices into the market, they need to comply to several exposure limits that have been specified in several standards and specifications. The specific absorption rate (SAR) has often been used as the metric to determine exposure compliance. The SAR measures the amount of energy absorbed by the human body while using a mobile phone. However, at high frequencies, this absorption is restricted to the skin level and thus it would be difficult to use the SAR as a measure for exposure limits at mmWave frequencies. The power density (P_D) measured in W/m^2 has been the preferred metric in the mmWave domain.

For the frequency range of 2 to 300 GHz, the IEEE C95.1-2019 standard [18] specifies a limit power density value of 10 W/m^2 in restricted environment and 50 W/m^2 in unrestricted environments. These correspond to an averaging time of 30 minutes. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) 2020 guidelines for limiting exposure to electromagnetic fields [19] specify the general public exposure limit at 10 W/m^2 for frequencies between 2 and 300 GHz with the averaging time being 30 minutes. Similar limits are specified by the Federal Communications Commission (FCC) in [20] where a restriction of 10 W/m^2 for the general public has been set. In contrast, the institute for building biology and sustainability (IBN) in Germany have specified the exposure limit to be less than 0.1 $\mu W/m^2$ in their 2015 Standard of Building Biology Measurement Technique (SBM-2015) [21], which is a million-fold lower than what is specified by the aforementioned guidelines. This suggests that negative health effects can occur at levels much lower than 10 W/m^2. Finally, the Chinese ministry of health [22] have set the power density exposure limit to 0.1 W/m^2.

TABLE IV: General Public Power Density Restrictions for the Frequency Range of 2 to 300 GHz

	IEEE C95.1-2019	ICNIRP	FCC	China	SBM-2015
P_D Limit (W/m^2)	10	10	10	0.1	10^{-6}

B. Power Density Assessment

The power density P_D radiated by a transmit antenna can be expressed at a far-field distance d using the following:

$$P_D = \frac{G_{Tx} P_{Tx}}{4\pi d^2} \tag{9}$$

The far-field distance is defined as the Fraunhofer distance expressed by:

$$d_{far-field} = \frac{2D^2}{\lambda} \tag{10}$$

where D is the largest dimension of the antenna and λ is the wavelength that corresponds to a frequency of operation. For distances less than the far-field distance, the power density cannot be computed using (9) and there would be a need to resort to numerical modeling methods such as the finite element method or finite-difference time domain.

C. Results

Fig. 6 shows the value of the power density for several choices of transmission power and transmit antenna gain in the distance range of 1 to 5 meters. For the proposed 5G network, we considered a transmission power of 19 dBm and a transmit antenna gain of 24 dBi. This corresponds to a value of 1.59 W/m^2 at 1 meters which drops to 0.06 W/m^2 at 5 meters. These values comply with the limits set by IEEE, ICNIRP, and FCC, since they are much lower than 10 W/m^2, but do not comply with SBM-2015 and Chinese Ministry of Health regulations. Fig. 7 shows the variations of the power density over the range of 20 to 50 meters. At 50 meters, which is at proximity of the cell edge, the power density drops further to $6.35 \times 10^{-4} W/m^2$ which is still much higher than the limit of the SBM-2015 guidelines. As shown in both Fig. 6 and Fig. 7, increasing the transmission power or choosing an antenna with a higher gain leads to an increase in the radiated power density. To comply with the limit set by China, the total EIRP needs to be dropped to achieve a power density below 0.1 W/m^2 which comes at the expense of a reduced cell range (below 50 meters). This makes it more difficult to plan cost-efficient 5G networks.

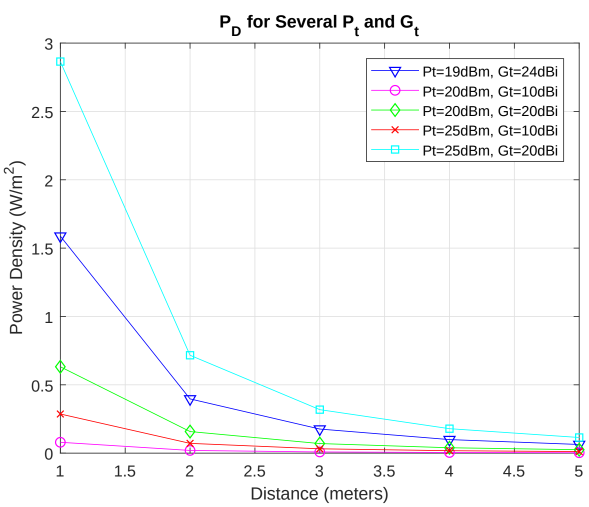


Fig. 6: Power Densities for Several Transmission Powers and Antenna Gains for the range of 1 to 5 meters

Cumulative Distribution Function (CDF) plots for the power density levels experienced in both the pre-existing LTE network and the newly deployed 5G network are shown in Fig. 8. The additional radiations imposed by the 5G network significantly increase the probability of being exposed to power density levels of more than 0.5 W/m^2 and that could reach up to the range of 2 to 2.5 W/m^2, while such power

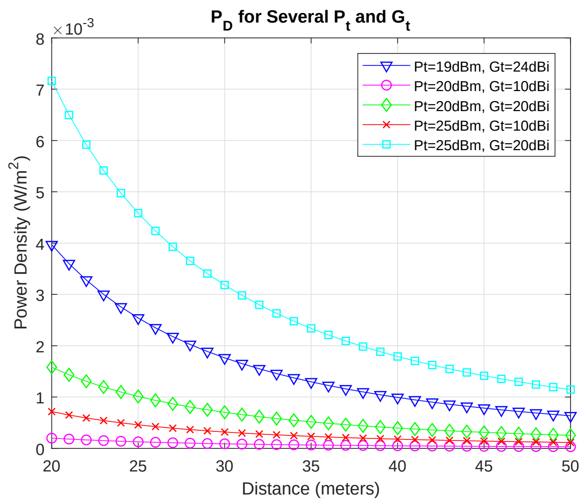


Fig. 7: Power Densities for Several Transmission Powers and Antenna Gains for the range of 20 to 50 meters

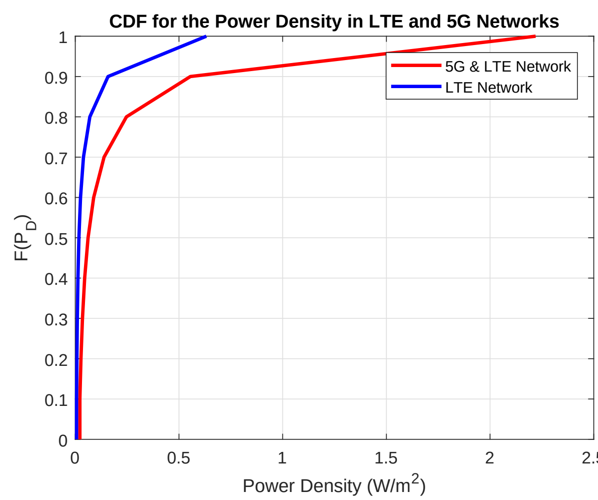


Fig. 8: CDF for the power densities levels for both pre-existing LTE and deployed 5G network

density levels were not experienced in the pre-existing LTE network. This is why the CDF of the power density in the pre-exisitng LTE network reaches the limiting factor of 1 for a power density around 0.65 W/m^2

Fig. 9 shows a heat-map representing the radiated power by the LTE BTSs in the area under study before deploying the 5G network, where a simplified path loss model [23] is considered for an urban macrocell. In Fig. 10, a similar heat-map is shown after the deployment of the 5G network. The remarkable increase in radiation levels after integrating 5G infrastructure with the original LTE network can be easily observed through the predominance of the red color in the heat map.

The presented results clearly show that the potential radiation levels that will be reached upon the roll out of 5G networks do not comply with all of the aforementioned exposure limits. This suggests that 5G mobile networks can not yet be classified as safe for the public, and demands serious considerations before using mmWave communications for 5G networks, given the potential harms it could afflict on the public. This paves the way to the consideration of hybrid transmission techniques including traditional electromagnetic waves, free-space optics and visible light communication

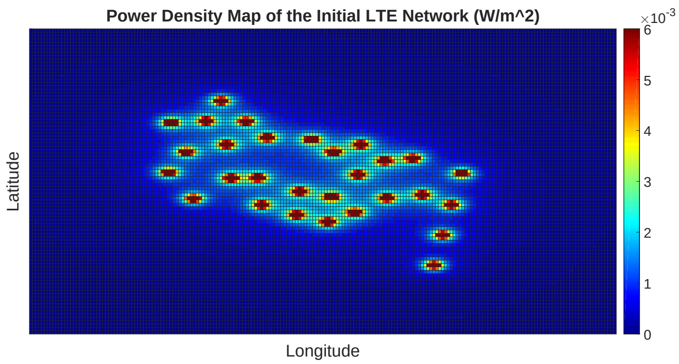


Fig. 9: Power Density Map of the Initial LTE Network

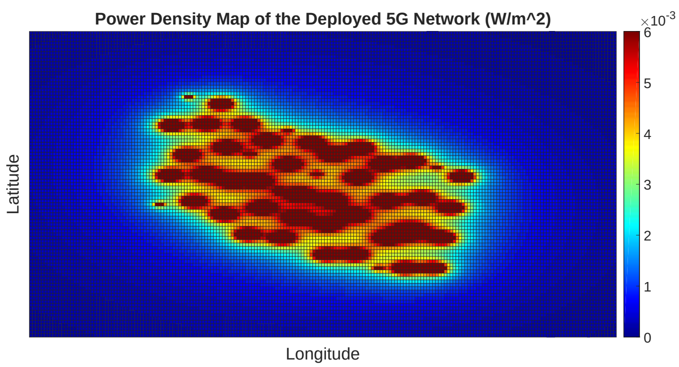


Fig. 10: Power Density Map of the Deployed 5G Network

V. Conclusion

This paper presented an analysis of the radiation levels in a deployed 5G network in an urban outdoor environment. Under the constraints of exposure limits, several challenges face the design and planning of such radiation aware 5G networks. Cell ranges need to be reduced to comply with the maximum allowed radiated power, requiring the densification of small cells in small areas and making it more costly to deploy these radiation-aware 5G networks. Although in this work we considered the maximum allowed EIRP prior to network deployment, results showed power density levels that do not satisfy all the exposure limits set by several sources. In this regard, a positive impact can be imposed by radiation-aware 5G networks on several levels. On a governmental level, the exposure limits for the power density need to be revised using today's data and approaches to bridge the gap between the thresholds specified by the different institutes and commissions. On a technological and scientific level, the radiation exposure constraint can open the door for innovative 5G solutions targeted to limit the health risks and economic barriers associated with this problem. This work can be extended by developing an analytical framework to efficiently rank and rate different cell allocation alternatives to minimize the potential radiations given a carefully chosen list of key performance indicators.

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Main Regularities and Health Risks from Exposure to Non-Thermal Microwaves of Mobile Communication

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Abstract — **Various responses to non-thermal microwaves (MW) from mobile communication including adverse health effects related to electrohypersensitivity, cancer risks, neurological effects, and reproductive impacts have been reported while some studies reported no such effects. This presentation provides an overview of the complex dependence of the MW effects on various physical and biological variables, which account for, at least partially, an apparent inconsistence in the published data. Among other variables, dependencies on carrier frequency, polarization, modulation, intermittence, electromagnetic stray fields, genotype, physiological traits, and cell density during exposure were reported. Nowadays, biological and health effects of 5G communication, which will use microwaves of extremely high frequencies (millimeter waves MMW, wavelength 1- 10 mm), are of significant public concern. It follows from available studies that MMW, under specific conditions of exposure at very low intensities below the ICNIRP guidelines, can affect biological systems and human health. Both positive and negative effects were observed in dependence on exposure parameters. In particular, MMW inhibited repair of DNA damage induced by ionizing radiation at specific frequencies and polarizations. To what extend the 5G technology and the Internet of Things will affect the biota and human health is definitely not known. However, based on possible fundamental role of MMW in regulation of homeostasis and almost complete absence of MMW in atmosphere due to effective absorption, which suggests the lack of adaptation to this type of radiation, the health effects of chronic MMW exposures may be more significant than for any other frequency range.**

Keywords — **Thermal and non-thermal effects of microwaves, Millimeter waves, 5G mobile communication, Health risks, Cancer, Physical mechanisms.**

I. Thermal versus Non-Thermal Microwave Effects, Their Main Regularities

Exposures to microwaves (MW, 300 MHz-300 GHz) vary in many parameters: incident power density (PD), specific absorption rate (SAR), frequency/wavelength, polarization (linear, ellipsoidal, circular, unpolarized), continuous wave (CW) and pulsed fields, modulation (amplitude, frequency, phase, complex), far field/near field, static magnetic field (SMF) and stray electromagnetic fields (EMF) of extremely low frequency (ELF, 3-300 Hz) at the location of exposure, overall duration and intermittence of exposure (interrupted, continuous), short-term acute and prolonged chronic exposures. With increased SAR, so-called thermal effects of MW are usually observed that result in significant MW-induced heating. SAR is a main determinate of thermal MW effects. The SAR based safety limits, which intend to protect from the thermal MW effects, were developed based on computer simulation of the MW energy absorption in standardized male phantoms. Thus, they do not take into account individual variability in voxel SAR distribution, which may be observed in dependence on polarization, frequency, age, sex, and pregnancy status [1-8]. In addition, the mobile phone SAR values are usually obtained when the phone is positioned about 2 cm from the standard male phantom head, a condition, which is not usually maintained during mobile phone calls. Other aforementioned physical variables of MW exposure have been linked to occurrence of so-called non-thermal (NT) biological effects, which are induced by MW at intensities well below measurable heating [9-21] [22]. The classification of MW effects into thermal and non-thermal is not based on physics of interaction between MW and biological tissues but rather reflects experimental observation of heating induced by MW exposure, which at SAR levels higher than 2 W/kg may result in thermal injury. Of note, slight temperature increase is also observed in the head tissues during exposure to mobile handset radiation, but this increase is too weak to produce thermal injury [23] and even to be sensed by the exposed subjects [24] while some mobile phone users reported sensation of warmth around the ear [25].

Vilenskaya and co-authors [26] and Devyatkov [27] have reported pioneering data on the NT effects of millimeter waves (MMW, 30-300 GHz, wavelength 1-10 mm in vacuum, to be used in 5G mobile communication) upon exposure of various biological objects. Webb was the first to establish the highly resonant effects of ultra-weak MMW on the induction of λ-phage in lysogenic bacterial E. coli cells [28]. These findings were subsequently corroborated by independent research groups [29, 30]. In these and subsequent studies the observed spectra of MMW action were found to have the following regularities: (1) strong dependence on frequency (frequency windows of resonance type), (2) there was a specific PD threshold below which no effect was observed, and above which the effects of exposure depended only weakly on power over several orders of magnitude (so-called

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978-1-7281-0878-0/19/$31.00 ©2019 IEEE

sigmoid or S-shaped dependence), (3) the occurrence of MMW effects depended on the duration of exposure, a certain minimum duration of exposure was necessary for an effect to manifest itself. These important regularities of NT MMW effects have previously been confirmed by independent laboratories and reviewed [9, 14-16, 22, 31-34].

Since that time, multiple studies performed by diverse research groups over the World have provided strong evidence for the NT MW effects and have also indicated that there are several consistent regularities in occurrence of these effects: (i) dependence on frequency of “resonance-type” within multiple, while relatively narrow frequency windows; (ii) narrowing of these frequency windows with decreasing intensity of exposure; (iii) dependence on modulation, pulse modulated MW being usually more effective as CW MW; (iv) dependence on polarization, right- or left-circular polarization being more defective then opposite circular and linear polarization specifically for each resonance; (v) power windows and sigmoid dependence on PD within specific intensity windows including super-low PD comparable to intensities from base stations; (vi) thresholds on duration of exposure (coherence time); (vii) dependence on post-exposure time, intermittence and duration of exposure resulting in interplay between accumulated effect and adaptation to exposure; (viii) dependence on cell density suggesting electromagnetic cell-to-cell interaction during exposure; (ix) dependence on several physiological conditions during exposure, such as concentration of divalent ions, oxygen and radical scavengers, stage of cell growth; (x) dependence on genotype. Cell type, sex, age, individual differences, and SMF and stray ELF EMF during exposure can be of importance for the NT MW effects [20, 35]. The data showing dependence of MW effects on extremely low frequency and static magnetic fields at the location of exposure suggested a strategy for reducing health effects from MW of mobile communication.

II. Reproducibility Issues

Eventual non-reproducibility of the NT MW effects in replication studies is a subject of continues debate. As a matter of fact, dependence of the NT MW effects on several biological variables and physical parameters represents an important issue for considering in replication studies. Contrary to some statements, no one from positive studies (reporting NT MW effects) has been dismissed in a valid replication. One of the first studies on MMW effects was published by Webb [36]. The regulation of gene expression for the induction of prophage λ in lysogenic Escherichia coli has been extensively studied at the molecular level. The chain of events leading to induction by DNA-damaging factors, and the involvement of the RecA bacterial protein are well known. Webb has demonstrated, however, that the switching of the prophage genes from lysogenic to lytic development can be accomplished by exposure to MMW at the resonance frequency of 70.4 GHz. We followed the requirements described by Webb [37] as essential for MMW induction of prophage λ and replicated his data [37].

Of note, no one negative study (showing no effects) has been independently replicated. The most representative so far international panel of 30 scientists has stated in the monograph of the International Agency for Research on Cancer (IARC) on carcinogenesis of radiofrequency (RF, 30 kHz - 300 GHz) radiations, pages 101-102: "The reproducibility of reported effects may be influenced by exposure characteristics (including SAR or power density, duration of exposure, carrier frequency, type of modulation, polarization, continuous versus intermittent exposures, pulsed-field variables, and background electromagnetic environment), biological parameters (including cell type, growth phase, cell density, sex, and age) and environmental conditions (including culture medium, aeration, and antioxidant levels)" [35]. The IARC international panel admitted also that some of the inconsistencies between RF studies could be due to differences in species, page 416 [35], and other biological factors, page 104: "Biological systems are complex and factors such as metabolic activity, growth phase, cell density, and antioxidant level might alter the potential effects of RF radiation". Multiple physical variables that may affect study results were considered in the IARC monograph on pages 385-387 [35].

III. Health Risks

Results of several studies of RF effects on sperm quality have recently been reviewed and subjected to meta-analysis using random effect models, in order to determine whether exposure to RF emitted from mobile phones affects human sperm [38]. The sperm quality was measured using parameters, which are most frequently used in clinical settings to assess fertility by motility, viability and concentration. Exposure to mobile phones was associated with reduced sperm motility and viability, while the effects on concentration were more equivocal. These results, being consistent through observational in vivo and experimental in vitro studies, suggested that exposure from mobile phones negatively affects sperm quality.

Most epidemiologic studies indicate detrimental effects of chronic exposure radiation from mobile phones including increased brain cancer risks in heavy mobile phone users, while lower quality studies underestimated this risk [39-42] [43]. The reported brain cancer risk was dependent on type of signal and mutual position of the affected organ and mobile phone.

The majority of studies with chronic exposure to EMF from mobile phones showed detrimental effects including those related to carcinogenicity and also indicated mechanism of these effects, which is based on induction of reactive oxygen species (ROS) [44, 45]. In particular, few recent meta-analyses of available case-control studies have consistently shown that long term mobile phone use (usually $\geq$ 10 years) is associated with statistically significant increased risks of brain tumors (gliomas and acoustic neuromas) while no such association is seen at shorter usage [39-42]. An increased incidence of glioma in the brain and malignant schwannoma in the heart has recently been found in rats in the National Toxicology Program (NTP) study [46]. Acoustic neuroma, also called vestibular schwannoma, is a similar type of tumor as the malignant schwannoma found in the heart, also benign. Thus, the NTP results, which were obtained upon chronic

MW exposure of laboratory animals, have supported epidemiological human studies, which have found increased risk for glioma and acoustic neuroma.

The NTP findings along with recent replicated animal studies from Germany [47], supplemented other studies and provided sufficient evidence for carcinogenicity of mobile phone exposure in animals. Studies with chronic exposures have also provided evidence for possible mechanisms of MW effects, which involve production of reactive oxygen/nitrogene species. Taking into account the evidence from human epidemiological studies, MW exposure from mobile phones was suggested to be classified as human carcinogen according to the generally accepted Bradford Hill criteria [35, 48]. The interadvisory group of 29 scientists from 18 countries of the International Agency for Research on Cancer (IARC), which is a part of the World Health Organization, has recently stated that the majority of NTP data on carcinogenic bioassay provided evidence for re-evaluating the RF-induced carcinogenesis [49].

Other potential health effects of MW exposure including nervous system diseases and hypersensitivity to electromagnetic fields have recently been reviewed [50, 51].

IV. MOBILE BASE STATIONS

Population's exposure to microwaves from base stations continuously grows. Recent studies with individual RF dosimeters indicated that the mobile phone base stations is a major source of whole body exposure to RF [52]. Very few studies are available on effects of MW-exposure from mobile base stations. Notably, most of them indicate adverse health effects, including cancer, fertility and prenatal development under chronic exposures of humans [1-9], mammals [10] and birds [11]. Accumulated dose during chronic exposure seems to be important parameter for assessment of cancer risks from base stations. In Taiwan, Li et al. performed a population-based case-control study and considered cancer incidence cases ≤15 years, which were admitted in 2003-2007 for all neoplasm including leukemia and brain tumors [53]. The cancer risks were estimated versus annual summarized power (ASP, W-year) accumulated during chronic exposures to each of the 71,185 base stations in service in 1998-2007. The annual power density (APD, W-year/km^2) was computed from all base stations. RF exposure of each study case was indicated by the averaged APD within 5 years prior to the neoplasm diagnosis. A was significantly associated with an increased cancer risks for all neoplasm. Thus, this study found a significantly increased risk of all neoplasm in children with higher than median averaged APD (about 168 W-year/km^2) exposure to base stations.

V. PHYSICAL MECHANISMS

There is an emerging notion that physics of non-equilibrium and nonlinear systems should underlie the physical mechanisms of the NT MW effects [54-63]. According to theoretical analysis of available experimental data on the MW effects at super-weak PD these effects should be considered in frame of quantum-mechanical approach [56, 64]. A fundamental quantum-mechanical mechanism has been suggested by Fröhlich who postulated that biological systems exhibit coherent longitudinal vibrations of electrically polar structures such as biological membranes [57]. According to the Fröhlich's mechanism, when the metabolically driven energy supply exceeds a critical level, the polar structure enters a condition in which a steady state of non-linear oscillation is reached. The Fröhlich's mechanism has also predicted the existence of a resonant interaction of MMW with biosystems [65, 66]. Possible biophysical mechanisms for the NT MW effects have been reviewed elsewhere [67].

VI. 5G VERSUS GSM/UMTS

We tested some signals from GSM (Global System for Mobile Communication, 2G) and UMTS (Universal Mobile Telecommunications System, 3G) mobile phones [68, 69]. Contrary to GSM phones, mobile phones of the 3rd generation irradiate wide-band signal. UMTS MWs may result in higher biological effects due to presence of selective resonance frequency windows.

Most current discussion regarding MW health effects is focused on the 5G mobile communication, which is promptly enrolled in different countries and uses frequency ranges similar to 2G/3G/4G plus MMW. It follows from available studies that MW, under specific conditions of exposure at ultra-weak intensities below the ICNIRP guidelines, can affect biological systems and human health. Both positive and negative effects were observed in dependence on exposure parameters. In particular, MMW inhibited repair of DNA damage induced by ionizing radiation at specific frequencies, modulations and polarizations [21].

While MMW are almost completely absorbed within 1-2 mm in biologically equivalent tissues, it may penetrate much deeper in live human body. Biological objects including human being are not in thermodynamical equilibrium. Thus, except for considering penetration of 5G/MMW into biologically equivalent tissues being in thermodynamical equilibrium, the response of live human body should also be considered. Alive body represents a complicated system with fundamental frequencies; many of them lie in the MMW range. In particular, the acupuncture system (meridians of organs) has been considered as a waveguide system for these MMW fundamental modes in the Soviet/Russian literature. From this point of view, MW penetrates human body far deeply as compared to "dead" model phantoms. Electromagnetic origin of Chinese meridians has been studied in several Soviet research teams. For example, Sit'ko et al. described the frequency of 56.46 GHz, which was found during an ordinary search for therapeutic frequencies based on sensorial reactions of a patient with duodenal ulcer [70]. Negative sensation (defined as spastic contraction of musculus quadricepts femoris) was repeatedly observed under applying MMW at this frequency. This sensory reaction allowed tracking the Chinese stomach meridian by using a static magnet at 4 mT. Exposure at the frequency of 56.46 GHz has worsened health condition of the patient. Thus, this exposure was aborted and the patient received treatment at the resonance therapeutic frequency found by typical positive sensations. After successful healing the duodenal ulcer at the MMW resonance therapeutic frequency, the negative response of the patient to the frequency of 56.46 GHz disappeared.

When a very fast RF pulse enters a human body, it generates a burst of energy (a Brillouin precursor) that can travel much deeper than predicted by the conventional models [71]. Brillouin precursors can be formed by high-speed data signals as used in 5G.

VII. Conclusions

To what extend the 5G technology and the Internet of Things will affect the human health is definitely not known. However, based on possible fundamental role of MMW in regulation of homeostasis [72] and almost complete absence of MMW in atmosphere due to effective absorption, which suggests the lack of adaptation to this type of radiation, the health effects of chronic MMW exposures may be more significant than for any other frequency range. From the health perspectives, implementation of the 5G technology is premature. Extended research with chronic exposure of human cells, animals and man is needed to exclude potentially harmful 5G signals.

Acknowledgements

This study was supported by the Slovak Research and Development Agency (APVV-15-0250) and the Grant Agency VEGA (2/0089/18) of the Slovak Republic.

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J Cancer Sci Clin Ther 2021; 5 (2): 250-285 *DOI: 10.26502/jcsct.5079117*

Commentary

Aspects on the International Commission on Non-Ionizing Radiation Protection (ICNIRP) 2020 Guidelines on Radiofrequency Radiation

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Received: 04 May 2021; **Accepted:** 10 May 2021; **Published**: 21 May 2021

Citation: Lennart Hardell, Mona Nilsson, Tarmo Koppel, Michael Carlberg. Aspects on the International Commission on Non-Ionizing Radiation Protection (ICNIRP) 2020 Guidelines on Radiofrequency Radiation. Journal of Cancer Science and Clinical Therapeutics 5 (2021): 250-285.

Abstract

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) published 2020 updated guidelines on radiofrequency (RF) radiation in the frequency range 100 kHz to 300 GHz. Harmful effects on human health and the environment at levels below the guidelines are downplayed although evidence is steadily increasing. Only thermal (heating) effects are acknowledged and therefore form the basis for the guidelines. Despite the increasing scientific evidence of non-thermal effects, the new ICNIRP guidelines are not lower compared with the previous levels. Expert groups from the WHO, the EU Commission and Sweden are to a large extent made up of members from ICNIRP, with no representative from the many scientists who are critical of the ICNIRP standpoint.

Keywords: EU; WHO; ICNIRP; 5G; Microwave radiation

1. Introduction

Wireless technologies, such as mobile phones, cordless phones, base stations, WiFi, 2G, 3G, 4G and 5G emit radiofrequency (RF) radiation, also called microwave radiation. For a long time there has been concern among laymen and a large part of the scientific community that such radiation may be a health hazard and also have a negative effect on the environment including birds [1], insects [2] and plants [3,4].

The seminal first early warning on brain tumor risk associated with exposure to RF radiation from mobile phones was published some 20 years ago [5, 6]. In the following case-control studies by the Hardell group, in addition to mobile phones, also use of cordless phones (DECT) was assessed. These studies confirmed an increased risk for brain tumors, i.e. glioma, for both types of wireless phones [7]. Similar findings were reported for acoustic neuroma [8].

In May 2011 the International Agency for Research on Cancer (IARC) at the World Health Organization (WHO) evaluated RF radiation in the frequency range 30 kHz–300 GHz to be a possible human carcinogen, Group 2B [9, 10].The IARC decision on mobile phones was based mainly on two sets of case-control human studies: the Hardell group studies from Sweden [11-13] and the IARC Interphone study [14, 15]. Both provided supportive evidence of increased risk for brain and head tumors, i.e. glioma and acoustic neuroma. Later published studies by the Hardell group [7, 8] and the French CERENAT (CEREbral tumors: a NATional study) study on glioma and meningioma [16] supported an increased risk for brain tumors and use of mobile and cordless phones. However, risks associated with the use of cordless phones was assessed only by the Hardell group, although cordless phones emit RF radiation of similar type as mobile phones.

The increasing scientific evidence on cancer risks from RF radiation, as well as other health effects, has had little or mostly no effect on preventive measurements. This is due to scientific disagreements and controversies. Some influential organizations are downplaying the health risks, i.e. the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the World Health Organization (WHO), the European Union (EU) and the Swedish Radiation Safety Authority (SSM), see next section. It has been discussed that by now such exposure might be classified as carcinogenic to humans, Group 1, according to the IARC classification [17-19]. However, only an IARC evaluation can make that classification.

Because of the controversies and the lobbying by influential organizations, including the telecom industry, precautionary measures are not taken and the public is not informed about health risks [20, 21]. People in general are, as a consequence, not taking preventive measures when using the handheld wireless phone, WiFi, or when exposed to RF radiation from base stations. Increasing ambient RF radiation gives higher total human exposure [22, 23] in addition to the widespread use of mobile and cordless phones.

During the last decades, the scientific evidence on other health effects than cancer has also increased. By January 2021, 255 scientists from 44 nations and 15 supporting scientists from 11 nations concluded that these effects occur well below most international and national guidelines recommended by ICNIRP, (see next section).

“Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being in humans. Damage goes well beyond the human race, as there is growing evidence of harmful effects to both plant and animal life.” [24].

The scientific evidence on the carcinogenic potential of RF radiation in laboratory studies has long been accumulating, but has mostly been ignored or dismissed by e.g., ICNIRP, the WHO, the EU and the SSM. The increased cancer risk in humans for RF radiation is clearly supported by recent animal studies [25-27] and mechanistic studies, both induction of reactive oxygen species (ROS) [28], and DNA damage [29-31]. The history on carcinogenic effects in laboratory studies started several decades ago.

Co-carcinogenic effects of RF radiation exposure and benzopyrene in mice were published already in 1982 [32]. The study showed that 2,450 MHz of RF radiation at either 50 or 150 W/m^2 promoted carcinogenesis. These levels exceed the ICNIRP guidelines, see below. The authors concluded that the resulting acceleration of development of spontaneous and chemically induced cancers indicated the carcinogenic potential of RF radiation.

Two studies published in 1990 demonstrated that 2,450 MHz continuous-wave RF radiation exerted a biphasic effect on glioma cells [33] and lymphocytes [34]. Cell proliferation was found at a specific absorption rate (SAR) of ≤50 W/kg, whereas a higher SAR suppressed DNA and RNA synthesis. These effects were reported to be non-thermal, i.e. not caused by heating.

A statistically significant increased incidence of primary malignant diseases was found in exposed animals compared with sham exposure in a study on 200 rats exposed to 2,450 MHz pulsed RF radiation for 21.5 h/day for 25 months compared with 200 controls. SAR ranged between 0.144 and 0.4 W/kg, depending on the rat's weight [35]. This was one of the first large scale studies to be conducted. Consequently the results in the U.S. National Toxicology Program (NTP) [25-26] and the Ramazzini Institute [27] studies are in line with these findings.

A study on mice carrying a lymphomagenic oncogene exposed to RF radiation showed a statistically significant increased risk for malignant lymphoma [36]. A total of 100 mice were sham-exposed and 101 were exposed for two 30-min periods per day for up to eighteen months to 900 MHz pulsed RF radiation with power densities of 2.6-13 W/m^2 (SAR 0.008-4.2 W/kg; mean, 0.13-1.4 W/kg). These results were not confirmed in the study by Utteridge et al. [37] which has been noted not to be a replication study [10, 38].

A co-carcinogenic effect was found in a study on mice exposed to a Universal Mobile Telecommunications System (UMTS) test signal from the fetal period for up to 24 months [39]. Animals were exposed to UMTS fields with intensities of 0 (sham), 4.8 and 48 W/m^2. The low-dose group was subjected to additional prenatal ethylnitrosourea (ENU) treatment. The group that was ENU-treated and UMTS-exposed at 4.8 W/m^2 exhibited an increased rate of lung tumors and an increased incidence of lung carcinomas as compared with the controls treated with ENU alone.
A tumor promoting effect was studied in another study on ENU-treated mice. The exposure levels were 0 (sham), 0.04, 0.4 and 2 W/kg SAR. The numbers of lung and liver tumors

in exposed animals were statistically significant higher compared with those in sham-exposed controls, as were the numbers of malignant lymphoma. A tumor-promoting effect of RF radiation was found at low to moderate levels (0.04 and 0.4 W/kg SAR), which were well below the exposure limits for users of mobile phones, 2 W/kg (of tissue) to the head [40].

Numerous published studies report effects or damage in terms of oxidative stress, damage to DNA, gene and protein expression, breakdown of the blood-brain barrier and damage to the brain and other organs of the body [41, 42]. There is also increasing evidence of adverse (chronic) health effects from long-term exposure. This was already reported as the "microwave syndrome" or "radiofrequency sickness" some fifty years ago. Reported health effects in scientific studies during the last decades from exposure to mobile phone towers, WiFi and mobile phones are consistent with the reported effects from RF radiation (microwaves) half a century ago [43, 44]. Furthermore, repeated studies show harmful effects from prenatal exposure, both in animal studies and in humans [45, 46].

Many countries around the world rely on guidelines for maximum allowed exposure from ICNIRP, supported and recommended by the WHO [47]. In Europe, most countries also follow the recommendations from the EU Commission that are based on ICNIRP and the EU expert group Scientific Committee on Emerging and Newly Identified Health Risk (SCENIHR). In 2020 ICNIRP published updated guidelines [48] based on the reviews and opinions from the WHO 2014 environmental health criteria public consultation report, SCENIHR 2015 [49] and the Scientific Council on Electromagnetic Fields at the Swedish Radiation Safety Authority (SSM) 2015, 2016, 2018 [50-52].

In this article we discuss how these organizations have evaluated the increasing evidence of harmful effects of RF radiation at levels below most national guidelines and limits for RF radiation exposure. The same individuals reappear in several of these organizations' expert groups, see Table 1, and there are no representatives in these groups from the many scientists that disagree with their conclusions [24]. We discuss primarily cancer risks in Appendix B of the ICNIRP updated guidelines [48].

WHO 2014 core group	**ICNIRP**	**IEEE**	**EU**	**SSM**	**EMF Scientist Appeal**	**The 5G Appeal EU**
Emilie van Deventer, project leader	X	X	-	X	-	-
Simon Mann	X	-	-	-	-	-
Maria Feychting	X	-	-	X	-	-
Gunnhild Oftedal	X	-	-	-	-	-
Eric van Rongen	X	X	X	X	-	-
Maria Rosaria Scarfi	X	-	X	X	-	-
Denis Zmirou	-	-	-	-	-	

SCENIHR 2015	ICNIRP	IEEE	WHO	SSM	EMF Scientist	5G Appeal EU
Theodoros Samaras	-	X	-	-	-	-
Norbert Leitgeb	-	-	-	-	-	-
Anssi Auvinen	X	-	-	-	-	-
Heidi Danker Hopfe	-	-	-	X	-	-
Kjell Hansson Mild	-	-	-	-	-	-
Mats Olof Mattsson	X	X	-	-	-	-
Hannu Norppa	-	-	-	-	-	-
James Rubin	-	-	X	-	-	-
Maria Rosaria Scarfi	X	-	X	X	-	-
Joachim Schüz	-	-	-	-	-	-
Zenon Sienkiewicz	X	-	-	-	-	-
Olga Zeni	-	-	X	-	-	-
SSM 2016	ICNIRP	IEEE	WHO	EU	EMF Scientist	5G Appeal EU
Anke Huss	From 2020	-	-	-	-	-
Clemens Dasenbrock	X	-	-	-	-	-
Emilie van Deventer	X	X	X	-	-	-
Eric van Rongen	X	X	X	X	-	-
Heidi Danker-Hopfe	-	-	-	X	-	-
Lars Klaeboe	-	-	-	-	-	-
Maria Rosaria Scarfi	X	-	X	X	-	-
Martin Röösli	X	-	X	-	-	-

Table 1: Many persons in expert groups at the WHO, the EU commission and in Sweden are current or former members in ICNIRP, and other expert groups, with no representative from the scientific community with opinions as expressed in EMF Scientist Appeal or 5G Appeal. For further details see ICNIRP [72,135,136,140,141,143-146], IEEE [137,145], EU [86,138,145], SSM [71,142], EMF Scientist Appeal [24], the 5G Appeal EU [139].

2. Evaluating Organizations

2.1. ICNIRP

ICNIRP is a non-governmental organization (NGO) based in Germany that has obtained major influence world-wide on health risks from RF radiation through its recommended guidelines for limiting RF radiation exposure [48, 53, 54]. These guidelines are recommended by the EU Commission, the WHO and are adopted by the majority of the countries around the globe.

ICNIRP was started in 1992 as an “independent commission”. It is registered in Germany and located in Munich at the same address as the German Federal Office for Radiation Protection [55].

ICNIRP maintains the same attitude to health effects from RF-radiation as the Institute of Electrical and Electronics Engineers (IEEE) and its standards setting committee, the International Committee on Electromagnetic Safety (ICES). This committee and ICNIRP, are both standard setting organizations for frequencies between 0 Hz to 300 GHz.

ICES have many industry and military representatives among its members [56]. ICES within IEEE also sets limits for RF exposure which are in line with the ICNIRP opinion that there are only immediate thermal effects and no effects below those that cause immediate effects due to increased temperature. This perception was established in the 1950’s and a decade later used when the first thermal based standard for radiofrequency radiation was set in the USA in 1966 [57]. Several members of ICNIRP are also present or former members of IEEE/ICES [58].

The biophysicist Michael Repacholi from Australia was ICNIRP’s first chairman and he is since 1996 an emeritus member [59]. Experts from various countries constitute the “main commission” of ICNIRP; a chair, a vice chair and 11 other members. Further scientists are elected by this commission to the scientific expert group (SEG). New and continuing members to the commission are elected by the members of the main commission. Nominations can be submitted by the members of the Commission itself, the Executive Council of IRPA (the International Radiation Protection Association) or the IRPA Associate Societies. It seems as if no scientist that is critical to the thermal paradigm on RF radiation risks, advocated by ICNIRP, is elected as a member of the Commission.

ICNIRP published its first guidelines on RF radiation in 1998 [53]. These were updated in 2009 with no changes [54]. Only short-term thermal (heating) effects were acknowledged to form the basis for the exposure guidelines. Long-term exposure and non-thermal effects were considered not to be established, thus excluding a large number of peer-reviewed scientific studies on negative health and biological effects from RF-radiation below the ICNIRP guidelines. In 2020 ICNIRP [48] published new guidelines on health risks based on documents from: the WHO 2014 draft, the EU SCENIHR 2015 report and the Swedish SSM reports 2015, 2016 and 2018.

It should be noted that not one of these five reviews has been published after peer-review in a scientific journal. Critique from the scientific community has been expressed against several of these reviews but has been ignored. Furthermore, these older documents do not cover the most recent research. In the following comments are given to these three reviews since the ICNIRP 2020 is based on these older evaluations with no new and further evaluation of its own [48].

2.2 The WHO Public Consultation Environmental Health Criteria Document, 2014

The WHO EMF Project, responsible for the 2014 document, was established in 1996. ICNIRP's chairman Michael Repacholi suggested in 1995 that WHO should start the EMF Project [60]. In 1995, while Repacholi still was chairman of ICNIRP, he became the head of the WHO International Electromagnetic Fields Project, and then head of the WHO EMF Project in 1996 [61], where he remained until 2006 [62]. A close colloboration between WHO and ICNIRP was initiated. In November 1998 the WHO EMF Project commenced a process aimed at the harmonization of EMF standards worldwide according to the ICNIRP guidelines [63]. Benefits to trade was given as one main argument to this specific project. The 100 times lower limits (compared to ICNIRP) in Eastern Europe were described as problematic [63].

The possibility of industry funding to the project was arranged already before the start of the project: "In 1995 WHO reached agreement consistent with these policies with Royal Adelaide Hospital (RAH), Australia to collect funds on behalf of the EMF Project. A memorandum of understanding allowed RAH to collect funds from government, professional associations and industry." [64]. This financial situation was ended in 2006 after disclosure by investigating journalists that showed that approximately half of the funding for the WHO EMF Project came from telecom industry organizations; GSM Association, Mobile Manufacturers Forum (MMF) and Forschungsgemeinschaft Funk e.V. (FGF) [65, 66].

Since 2006 the project leader of the WHO EMF project is Emilie van Deventer, an electrical engineer and longtime member of the industry organization IEEE [67]. She is the founder and former chairperson of the IEEE Joint Chapter on Electromagnetics and Radiation [68]. Her background is in "electromagnetic characterization of high-speed circuits for telecommunications applications, computationa electromagnetics (RF frequency and time domain techniques), electromagnetic compatibility, antenna modelling and design" and does not include medical training [69, 70]. She is the WHO EMF Project observer at the ICNIRP's main commission as well as a member of the SSM expert group from 2010 to 2017 [60, 71, 72].

The WHO EMF Project is in principle synonymous with ICNIRP. The same individuals that propose the ICNIRP guidelines are also acting as experts evaluating hazards from RF radiation on behalf of the WHO. This kind of double position situation is a potential conflict of interest according to the Ethical Board of the Karolinska Institute, Stockholm, Sweden 2008 (Dnr 3753-2008-609).

In 2005-2006 the personnel at the WHO EMF Project were Michael Repacholi, Emilie van Deventer, Chiyoi Ohkubo [62], Richard Saunders [73], Eric van Rongen and Lisa Ravenscroft [60]. All except Ravenscroft are current or former members of ICNIRP. In fact, at a meeting at WHO, Geneva in March 2017, Dr Maria Neira, at that time Director for Public Health and Environment at WHO, stated that ICNIRP is an Non-Governmental organization (NGO) with an official relationship with WHO that "helps us a lot in our analyses" and their members work as WHO's experts [74]. The WHO EMF Project has for many years been criticized for its collaboration with the industry; electrical, military and telecom [75].

A draft of a Monograph on health effects of electromagnetic field (EMF) exposure was released by WHO in 2014 [76]. It was open for public consultation until December 31, 2014, but has never been published as a final version and it is unclear why it was never finalized.

Out of the six experts in the WHO core group responsible for the draft, four were active members and one was a former member of ICNIRP [74], a fact that illustrates that WHO continues to be almost identical with ICNIRP, see Table 1. Many critical comments were sent to the WHO. One example is the "No confidence" letter sent by The BioInitiative Working Group in December 2016 to the WHO EMF Program Manager that concluded that the experts writing the WHO draft were to a large extent ICNIRP members.

"The BioInitiative Working Group urges the World Health Organization to make changes to the WHO RF EHC [Environmental Health Criteria] Core Group membership to more fairly reflect membership and expertise of the 2011 IARC RF Working Group. At present the WHO RF EHC Core Group is indistinguishable from ICNIRP (1, 2) undermining credibility of the process and ensuring doubt about conclusions." [77].

This letter was followed by another letter from the BioInitiative Working Group in January 2017 including suggestion of experts to replace present persons in the Core Group as well as Additional Experts [78].

A call for Protection from Non-ionizing Electromagnetic Field Exposure was made by the International EMF Scientist Appeal.

"By not taking action, the WHO is failing to fulfil its role as the preeminent international public health agency…. The WHO is calling for all nations to adopt the ICNIRP guidelines to encourage international harmonization of standards… It is our opinion that, because the ICNIRP guidelines do not cover long-term exposure and low-intensity effects, they are insufficient to protect public health." [24].

In total forty-seven NGOs also submitted a critical statement regarding the WHO draft on December 15, 2014. The WHO draft was criticized for the absence of pluralism among the selected experts, for biased reporting of scientific results and the "promiscuity between the WHO and ICNIRP." [79].

A press release was furthermore issued on February 24, 2017 by the European coordination of organizations for an EMF exposure regulation which truly protects public health. They stated that "The Conflict of Interest Scandal is repeating itself in the WHO" [80].

In a letter of concern dated March 1, 2017 the Russian National Committee on Non-Ionizing Radiation Protection wrote to the WHO: "It has just come to our attention that the WHO RF Working group consists mainly from present and past ICNIRP members.….the private self-elected organization ICNIRP, similar as majority of the current WHO RF WG [Working Group] members, does not recognize the non-thermal RF effects,…" [81].

In 2016 at a seminar at SSM in Stockholm Emilie van Deventer said that they had received 700 comments on the draft including references to "at least 300 papers that we had missed" [82].

It is unclear how WHO reacted to the critique. The Monograph is still unfinished. Instead the WHO has called for a new systematic review of this topic.

It should be noted that WHO in 2014 issued the following statement: "THIS IS A DRAFT DOCUMENT FOR PUBLIC CONSULTATION. PLEASE DO NOT QUOTE OR CITE." Nevertheless, this WHO Monograph draft from 2014, issued by a group dominated by ICNIRP members, was used as a basis for the ICNIRP guidelines 2020.

2.3. The European Commission SCENIHR opinion 2015

In 2015 the European Commission's expert group on electromagnetic fields, SCENIHR, released its report "Opinion on potential health effects of exposure to electromagnetic fields (EMF)" [49]. It was an update of the previous SCENIHR Opinions of 19 January 2009 "Health effects of exposure to EMF" and 6 July 2009 "Research needs and methodology to address the remaining knowledge gaps on the potential health effects of EMF" [83].

SCENIHR is one of three "Independent Scientific Committees" that provide the EU Commission, and through the Commission the other European institutions, with scientific advice regarding consumer safety, public health and the environment [84]. The Committee is also supposed to "…draw the Commission's attention to the new or emerging problems which may pose an actual or potential threat".

According to the Commission decision 2008, article 15 [85], the experts "…shall undertake to act independently of any external influence" and "shall make a declaration of commitment to act in the public interest and a declaration of interests indicating either the absence or existence of any direct or indirect interest which might be considered prejudicial to their independence". However, this committee has a history of being unbalanced in terms of representation from both sides of the scientific controversy on RF radiation. No representatives from the scientific community that are of the opinion that there is increasing evidence of harmful effects have participated; at least no person has declared other opinion than the ICNIRP view.

The 2007 SCENIHR [86] working group's chair was Anders Ahlbom from Sweden, ICNIRP commission member 1996-2008 and contributing to the ICNIRP guidelines 1998. Mats-Olof Mattsson, from Sweden, was one of the groups' three experts.

The 2009 SCENIHR [87] working group was identical to the 2007 group, but Mats-Olof Mattsson, from 2013 member of ICNIRP SEG, replaced Ahlbom as chair [88]. Eric van Rongen, member of ICNIRP and ICES as well as working with the WHO EMF Project, was now among the external experts [87].

The 2015 SCENIHR working group was made up of Theodoros Samaras and Norbert Leitgeb (retired) and ten additional external experts [89]. Of the ten external experts, four are former or present members of ICNIRP main commission or SEG (Anssi Auvinen, Mats-Olof Mattsson, Maria Rosaria Scarfi and Zenon Sienkiewicz). Both Mattsson and Samaras are members of ICES/ IEEE [56].

2.3.1 Main conclusions 2015

The quotes in this section are from the SCENIHR report 2015 [49]:

"Overall, the epidemiological studies on mobile phone RF EMF exposure do not show an increased risk of brain tumours. Furthermore, they do not indicate an increased risk for other cancers of the head and neck region.…The results of cohort and incidence time trend studies do not support an increased risk for glioma while the possibility of an association with acoustic neuroma remains open."

Other effects from RF-radiation such as different health symptoms, also known as the microwave syndrome [43], neurological diseases and other health outcomes, were also dismissed with various arguments. The conclusion of no brain tumor risks from RF radiation relied upon several studies with methodological shortcomings resulting in underestimated risks, for instance the Danish cohort study [90, 91], the UK Benson study [92] as well as the Cefalo study [93], see below. Joachim Schüz, who was a member of SCENIHR 2015 working group that drafted SCENIHR 2015, was also coauthor of these three studies [94].

Increased cancer risks in other epidemiological studies [7, 8, 14, 15, 16] were downplayed by SCENIHR [49] with reference to a few brain tumor incidence trend reports, the Danish cohort and a UK cohort:

"The fact that incidence rates of glioma and meningioma do not rise in the age groups of highest mobile phone prevalence provides evidence that common use of mobile phones is unlikely to be associated with an increased risk of those brain tumours. This is confirmed by the Danish cohort study that rules out risks that would affect large segments of the population. Evidence against an association also arises from the large-scale UK million women study."

2.3.2. Methodological issues

2.3.2.1. The Danish Cohort (2001, 2006, 2011): This study, funded by Danish telecom operators, first published in 2001 [90] and last updated in 2011 [91], reported no increased risks of tumors in the central nervous system. It was based on 420,095 mobile phone private subscribers. This group's incidence of brain tumors was compared with the incidence within the rest of the Danish population (control group). However, there are severe methodological faults that led to erroneous results:

- Inclusion only of mobile phone private subscribers in Denmark between 1982 and 1995 in the exposure group.
- Exclusion of the most exposed group, consisting of 200,507 corporate users of mobile phones [90]. They were instead included in the unexposed control group if not private subscribers.
- Users with mobile phone subscription after 1995 were not included in the exposed group and were thus treated as unexposed: "individuals with a subscription in 1996 or later were classified as non-users" [91].
- Actual exposure data is unknown and no analysis by laterality (the side were the phone is hold in relation to the position of the tumor) was performed.
- All users of cordless (DECT) phones were treated as unexposed for that exposure although they were also exposed to the same kind of RF radiation as from mobile phone use. The Hardell group has shown that use of cordless phones increases risk of glioma and acoustic neuroma tumors [7, 8].

Professor Michael Kundi of the Medical University of Vienna expressed the opinion that the Danish study is "the most severely biased study among all studies published so far” [95]. Certainly, there were severe methodological flaws. The study [90, 91, 96] was regarded by IARC in the 2011 evaluation [9, 10] to be uninformative regarding cancer risks due to serious exposure misclassification. However, it is included by SCENIHR [49], WHO [76], SSM [97] and ICNIRP as evidence of no risk [98, 99]. The statement by SSM 2013 [97] that: “The Danish cohort studies make an important contribution to the total assessment in the field.” is remarkable taking the critique of the study that should have been well known to the SSM expert panel. The many shortcomings in the study were discussed in a peer-reviewed article [100] concluding that: “After reviewing the four publications on the Danish cohort study, one might rightly wonder whether this cohort was initially set up to show no increased risk.”

2.3.2.2. The Benson UK study (2013): This cohort study of 791,710 women in the Million Women Study was started during 1996-2001 [92]. Data on mobile phone use was collected at one time between 1999 and 2005, without questions separating heavy users from light users. Mobile phone use was based on the answers to a few questions posed at the time when the women were recruited to the study: "About how often do you use a mobile phone?", "Never, less than once a day, or every day?” Those who did use a mobile phone were also asked "for how long?". At the end of the study in 2009, a random sample of participants were asked two more questions about their mobile phone use, but these answers were never used in the analyses. Use of cordless (DECT) phone was not assessed. Due to limitations in the study design, such as no comprehensive assessment of life-time mobile phone use, the study is uninformative and should not be used as scientific evidence of lack of cancer risk. In fact the authors concluded that:

“The main limitation of the study is that mobile phone use was reported at baseline and may have changed subsequently. Almost all women who reported daily use of mobile phones at baseline were still using a mobile phone at least once a week when asked again 8.8 years later. However, some women who reported not using a mobile phone at baseline began use subsequently; and this might dilute our estimates of relative risk towards the null” [92].

2.3.2.3. The CEFALO Study (2011): The CEFALO study on brain tumor risk for children aged 7-19 using mobile phones [93] is claimed in the SCENIHR 2015 report [49] to have found no increased risk. The children in the study were diagnosed with a brain tumor during 2004-2008. The study showed several statistically non-significant increased odds ratios (ORs). However, a press release issued by one of the authors, Maria Feychting at the Karolinska Institute in Stockholm, stated that “Reassuring results from first study on young mobile users and cancer risk…The so called CEFALO study does not show an increased brain tumor risk for young mobile users.” [101]. She was vice chair of ICNIRP 2012-2020, member of ICNIRP SEG 2000-2012, and is currently SEG member since 2020. Maria Feychting was also member of the WHO core group responsible for the WHO 2014 draft. Martin Röösli, member of ICNIRP Commission since 2016, the SSM expert group since 2010, as well as member of the WHO 2014 external expert group, was also coauthor of this study (corresponding author). Martin Röösli also claimed in a press-release that the results were reassuring of no risk [102].

The study has several shortcomings and one major shortcoming is the assessment of RF exposure from cordless phones that was not included in the total RF radiation exposure. Furthermore, the scientists did not assess total exposure from cordless phones (DECT). Instead the authors analyzed "…ever used cordless phones, and the cumulative duration and number of calls with cordless phones in the first 3 years of use." This is a scientifically invalid method to study risk associated with an agent [103]. Thereby four to sixteen years of potential exposure were disregarded in the study age group 7-19 years. It is most questionable since use of the cordless phone increases by age.

This is more startling since no such time limit was made in the questionnaire sent to the Ethical Board at Karolinska Institute, Stockholm (DNR2005/1562-3). There were four questions on use of a cordless phone (summary): 1. When did you first start using a cordless phone? 2. How often did [child] answer the cordless phone? 3. How often does [child] speak on the cordless phone? 4. When [child] talks on the cordless phone, which phrase fits the best? (about 1 min, about 3 min, about 6 min, about 10 min or more).

No doubt even with these few questions it would have been possible to assess lifetime cumulative use of the cordless phones. According to the questions there is no reason or possibility to limit to only the first three years of use. Furthermore, it is not probable that a child would only use the cordless phone for three years and then stop the habit. To note is also an e-mail (personal communication) from Martin Röösli to one of the authors (MN) on August 17, 2011 in which he regarding cordless phones stated that "We also asked about ever using it and we requested the age range that they have used the phone". No doubt with that information, which was not given in the article, it would have been possible to calculate whole lifetime cumulative exposure.
Thus, it is evident that limiting use to only first three years would bias the results towards unity, particularly as children tend to increase their phone use with increasing age, which is also shown in the CEFALO study. In spite of this, SCENIHR [49] gave the impression that all cordless phone use was included by claiming that "Use of cordless phones showed no increased OR (1.09; CI 0.81-1.45), not even in the group of highest cumulative use." This claim is most misleading. Highest group for cumulative use available in the study was only 70+ hours. Further, the authors intentionally omitted the real highest users by limiting the exposure to the first three years of use. It is remarkable that this misleading claim in the SCENIHR report was written by one of the authors of CEFALO (Joachim Schüz), who also was coauthor of the Danish cohort and the Benson study.

In a comment, the Hardell group wrote [103]:

"Further support of a true association was found in the results based on operator-recorded use [of mobile phones] for 62 cases and 101 controls, which for time since first subscription > 2.8 years yielded [odds ratio] OR 2.15 (95% [confidence interval] CI 1.07-4.29) with a statistically significant trend (P = 0.001)….. We consider that the data contain several indications of increased risk, despite low exposure, short latency period, and limitations in the study design, analyses and interpretation".

In fact, all ORs on mobile phone use were >1.0 according to Table 2 in the article [93]. For both ipsilateral and contralateral mobile phone use statistically significant increased risks were obtained for highest group of cumulative numbers of calls; OR = 2.91, 95% CI = 1.09-7.76 and OR = 4.82, 95 % CI = 1.21-19.24, respectively. For central or unknown location a statistically significant decreased risk was found based on low numbers. It should be noted that there are missing numbers of cases and controls in different strata in e.g. Table 5 in the article [93], no explanation is given as we have discussed [103]. The anatomical distribution for brain tumors in children differs from adults [104]. Thus, there are more central and brain stem tumors, facts not considered by Aydin et al. [93] In children the distribution of RF radiation differs from adults with larger part of the brain more exposed due to e.g. smaller head and thinner bone [105]. Thus, the laterality analysis should be interpreted with caution.

2.3.3. Critical comments on SCENIHR [49]

There were in total 186 critical comments submitted to EU by different persons and organizations [106]. Less than 30 percent of these comments were taken into account, a few yielding minor clarifications in the text but without changes of the SCENIHR major conclusions. The BioInitiative Group was among many others that expressed critical comments to the SCENIHR: "In summary, the preliminary SCENIHR conclusion that glioma risk is weaker now is not scientifically justified. The only way that conclusion could be reached by SCENIHR is to exclude critical studies that present evidence to the contrary, i.e. studies that report the risk of glioma (and acoustic neuroma) is stronger now than in 2009" [107].

2.4. The reports from the Swedish Radiation Safety Authority (SSM) 2015, 2016 and 2018 [50-52]

The expert group on electromagnetic fields at SSM was created in June 2002. Between 2003 and 2010 it was called the "Independent Expert Group on Electromagnetic Fields". During that period Anders Ahlbom, member of ICNIRP main commission 1996-2008, and SCENIHR member 2007-2009, was the head of the expert group and his colleague Maria Feychting, longtime member of ICNIRP and member of the WHO 2014 core group, was the group's secretary. From 2013 and until today, the expert group was renamed as the "Scientific Council on Electromagnetic Fields".

Between 2003 and 2019 the SSM group has published thirteen reports in English on its webpage [71]. All reports since 2003 have consistently refuted or ignored evidence of health risks from non-thermal exposure in line with the views by ICNIRP, the WHO and the SCENIHR.

Since the first report in 2003 until today around half of the group's members have also been present or previous ICNIRP members. In consequence the conclusions have generally been that there are no health risks below the limits recommended by ICNIRP. No scientist critical to the ICNIRP view has ever been part of this group. Here are some examples of conclusions from the SSM reports (2015 – 2018) that are included as basis for the present ICNIRP guidelines.

2.4.1. SSM 2015

"In terms of exposure from mobile phone base stations or other RF-EMF transmitters, no new evidence has become available indicating a causal link between exposure and symptoms or Electromagnetic Hypersensitivity (EHS)…. New studies on mobile phone use and tumours in the brain using retrospective exposure assessment are in line with previous research, which means that increased risks were observed in some of the most extreme exposure categories. However, it is not clear to what extent these risk estimates are affected by recall bias… New studies on associations between sperm quality and mobile phone use are of low quality and cannot be used to evaluate a potential association with RF-EMF exposure" [50].

The 2015 SSM report raised the issue that recall bias might have affected brain cancer risk estimates. However the study by Momoli et al. [108] showed that recall bias did not affect the risk of glioma in the Canadian component of the Interphone study [14]. In addition, it should be noted that the 2020 ICNIRP guidelines [48] refer to recall bias in the case-control studies of the Interphone study but do not mention the analysis by Momoli et al. Also, as displayed below, recall bias cannot explain the results in the Hardell group studies.

2.4.2. SSM 2016

"Most research in the past decade has been done into a possible relation between mobile phone use and brain tumours. Epidemiological studies have provided weak indications for an association between frequent and long-term use of a mobile phone and gliomas (malign tumours of the brain tissue) and vestibular schwannomas (also called acoustic neuromas, a benign tumour of the vestibulocochlear nerve that connects the ear to the inner brain). The evidence is not very clear and unequivocal, however. Altogether it provides no or at most little indications for a risk for up to approximately 15 years of mobile phone use" [51].

In a press release, at the time of the publication of the 2016 report, this Swedish authority claimed that the suspicion that mobile phones or wireless networks could be a health risk to humans or to the environment had become weaker during the past 13 years since the first of the group's report [109]. This contrasted with the increasing scientific evidence of the opposite [24]. In Table 2 results for meta-analysis of highest cumulative use in hours of mobile phone use in case-control studies is given and the results for acoustic neuroma are given in Table 3. Clearly these results from the different studies available in 2016 are in contrast to the statement by SSM.

	All			**Ipsilateral**		
	Ca/Co	OR	95 % CI	Ca/Co	OR	95 % CI
Interphone 2010 [14]						
Cumulative use ≥1,640 h	210/154	1.40	1.03 – 1.89	100/62	1.96	1.22 – 3.16
Coureau et al 2014 [16]						
Cumulative use ≥896 h	24/22	2.89	1.41 – 5.93	9/7	2.11	0.73 – 6.08
Hardell, Carlberg 2015 [7]						
Cumulative use ≥1,640 h	211/301	2.13	1.61 – 2.82	138/133	3.11	2.18 – 4.44
Meta-analysis						
Cumulative use ≥1,640 h*	445/477	1.90	1.31 – 2.76	247/202	2.54	1.83 – 3.52

*≥896 h used for Coureau et al.

Table 2: Numbers of exposed cases (Ca) and controls (Co) and odds ratio (OR) with 95 % confidence interval (CI) for glioma in case-control studies in the highest category of cumulative use in hours for mobile phone use, for further details see [42].

	All			Ipsilateral		
	Ca/Co	OR	95 % CI	Ca/Co	OR	95 % CI
Interphone 2010 [15]						
Cumulative use ≥1,640 h	77/107	1.32	0.88 – 1.97	47/46	2.33	1.23 – 4.40
Hardell et al. 2013 [8]						
Cumulative use ≥1,640 h	27/301	2.40	1.39 – 4.16	19/133	3.18	1.65 – 6.12
Meta-analysis						
Cumulative use ≥1,640 h	104/408	1.73	0.96 – 3.09	66/179	2.71	1.72 – 4.28

Table 3: Numbers of exposed cases (Ca) and controls (Co) and odds ratio (OR) with 95 % confidence interval (CI) for acoustic neuroma in case-control studies in the highest category of cumulative use in hours for mobile phone use, for further details see [42].

2.4.3. SSM 2018

This annual report was the twelfth in this series and covered studies published from October 2015 up to and including March 2017. Oxidative stress effects reported below ICNIRP guidelines was discussed but the relevance for human "direct health effects" was claimed to be "unclear". The conclusion was that "No new health risks have been identified." [52].

It is clear that the SSM expert group has not made a sound and objective scientific evaluation of health risks associated with RF radiation exposure. We note that SSM in April 2020 published a new report from the SSM expert group which concluded: "The results of the research review give no reason to change any reference levels [ICNIRP's] or recommendations in the field". Of the ten members in the scientific group five were present or past members of ICNIRP [110].

3. ICNIRP 2020 Evaluation

Eric van Rongen, chair of the ICNIRP Commission 2016-2020, claimed in a press release regarding the new ICNIRP guidelines 2020 that the 1998 version was "conservative in most cases" and "still provide adequate protection for current technologies". He also argued that: "The most important thing for people to remember is that 5G technologies will not be able to cause harm when these new guidelines are adhered to" [111].

Many other incorrect statements were made in the recent ICNIRP paper [48] contrary to an objective evaluation of the available scientific evidence. In the following the section on cancer is reviewed. That section claims:

"There is a large body of literature concerning cellular and molecular processes that are of particular relevance to cancer. Although there are reports of effects of radiofrequency EMFs on a number of these endpoints, there is no substantiated evidence of health-relevant effects (Vijayalaxmi and Prihoda 2019)".

Already in the first paragraph in the report evidence on biological effects from RF radiation is dismissed without scientific foundation. This continues regarding cancer risks. Mostly not even references are given to the discussed studies, or with erroneous references. The uninformed reader may take the statements at face value and not understand that they are, in fact, not correct.

3.1. Animal studies

Regarding animal studies yielding a promoting effect from RF radiation [39, 40] ICNIRP states that "…interpretation of these results and their applicability to human health [is] difficult, and, therefore, there is a need for further research to better understand these results". In the next paragraph the recent animal NTP studies [25, 26] and Ramazzini Institute results [27] are disregarded, stating that "…no consistency was seen across these two studies" and "within the context of other animal and human carcinogenicity research (HCN 2014, 2016), their findings do not provide evidence that radiofrequency EMFs are carcinogenic".

On the contrary, as discussed above, animal studies indicate that RF radiation may both promote and initiate cancer. In a review, the Hardell group concluded that:

"There is clear evidence that RF radiation causes cancer/tumor at multiple sites, primarily in the brain (glioma) and head (acoustic neuroma). There is also evidence of an increased risk of developing other tumor types. The results are similar in both the NTP studies (19, 20) and the Ramazzini Institute findings (34). Based on the IARC preamble to the monographs, RF radiation should be classified as Group 1: The agent is carcinogenic to humans" [19].

In a note published by ICNIRP in 2018 it was claimed that the histopathological evaluation in the NTP study was not blinded as to exposure status [112]. This was rebutted by one of those responsible for the NTP study [113]. However, it seems to have had no impact on the ICNIRP evaluation [48]. ICNIRP claims that the animal studies "do not provide evidence that radiofrequency EMFs are carcinogenic," while an independent peer review of the NTP data concluded that this study provided 'clear evidence of carcinogenic activity', see Table 4 in a comment on the NTP study [19]. A comprehensive discussion of the ICNIRP evaluation was published by Melnick as a correspondence with "focuses on ICNIRP's false claims about the methodology, interpretation, and relevance of the National Toxicology Program studies on cell phone radiation" [114]. This included misleading statements by ICNIRP on e.g., the pathology review procedure, rat survival rates, multiple comparisons, but also excluding discussion of other end points such as DNA strand breaks in the brain cells, and increased incidence of cardiomyopathy. Melnick concluded that "ICNIRP should promote precautionary advice for the general public rather than trying to justify their decision to dismiss findings of adverse health effects caused by RF-EMFs and thereby retain their 20+ y-old exposure guidelines that are based on protection against thermal effects from acute exposure". In the response, ICNIRP seemed not to make a serious scientific rebuttal of the statements by Melnick "except for one minor issue", i.e., the description of the NTP study as "whole of life" rather than "most of life" [115].

3.2. Brain tumor risks from mobile phone use

Regarding epidemiological studies first a study by Martin Röösli et al. [116] is cited by ICNIRP. Röösli is, as mentioned earlier, both member of the ICNIRP commission, the WHO 2014 external experts and the SSM experts. The article has several limitations. The results on use of cordless phones as risk factor for brain tumors are not discussed. Regarding glioma risk all results on cumulative use of wireless phones were not discussed and ipsilateral or contralateral use in relation to tumor localization in the brain were omitted from the meta-analyses. These results are important and have shown a consistent pattern of increased risk.

There were several other limitations in the article [116], such as including the Danish cohort study [90] in the meta-analyses. As discussed above, the study has severe errors of exposure classification and was therefore evaluated to be uninformative regarding carcinogenesis in the IARC 2011 evaluation [10] including Martin Röösli as one participating member.

Regarding the thirteen country Interphone study on glioma [14] and acoustic neuroma [15] ICNIRP concludes that the studies do "…not provide evidence of an increased risk", which is not correct [48]. On the contrary regarding glioma cumulative call-time of mobile phones ≥1,640 h resulted in OR = 1.40, 95 % CI = 1.03–1.89, increasing to OR = 1.87, 95% CI = 1.09–3.22 for glioma in the temporal lobe, the most exposed part of the brain. Ipsilateral mobile phone use yielded OR = 1.96, 95% CI = 1.22–3.16 for all glioma, cumulative use ≥1,640 h. Furthermore, a statistically significant increased risk for glioma was seen in the group 2–4 years for regular use, with 1–1.9 years use as reference category, OR = 1.68, 95% CI = 1.16–2.41, see Appendix 2 [14]. The highest OR was seen in the 10+ years category for regular use, OR = 2.18, 95% CI = 1.43–3.31.

In parts of Interphone, RF radiation dose was estimated as total cumulative specific energy (TCSE; J/kg) absorbed at the tumor's estimated center [117]. The risk increased with increasing TCSE 7+ years before diagnosis, OR = 1.91, 95% CI = 1.05 - 3.47 (p-trend = 0.01) in the highest quintile. Comparing with glioma in other parts of the brain, increased ORs were found for tumors in the most exposed part of the brain in those with 10+ years of mobile phone use, OR = 2.80, 95% CI = 1.13 - 6.94.

Similar results were reported by Grell et al. [118]:

"we found a statistically significant association between the intracranial distribution of gliomas and the self-reported location of the phone…Taken together, our results suggest that ever using a mobile phone regularly is associated with glioma localization in the sense that more gliomas occurred closer to the ear on the side of the head where the mobile phone was reported to have been used the most".

Canadian data from the Interphone Study were evaluated separately [108]. For glioma, when comparing those in the highest quartile of use (>558 lifetime hours) to those who were no regular users, the OR was 2.0, 95% CI = 1.2 - 3.4. After adjustment for selection and recall biases somewhat higher OR was found, 2.2, 95 % CI = 95% CI = 1.3 - 4.1, indicating that such bias did not cause the results.

Also for acoustic neuroma, the Interphone study yielded statistically significant increased risk. Thus, ipsilateral cumulative mobile phone use > 1,640 hours gave OR = 2.33, 95 % CI = 1.23-4.40 [15].

Regarding the Hardell group studies ICNIRP [48] writes: "…a set of case-control studies from the Hardell group in Sweden report significantly increased risks of both acoustic neuroma and malignant brain tumors already after less than five years since the start of mobile phone use, and at quite low levels of cumulative call time.” No reference is given to the studies, indicating they have not been seriously evaluated. ICNIRP’s writing is not consistent with what the studies reported. In the shortest latency time >1- 5 years period overall mobile phone use yielded for glioma OR = 1.2, 95 % CI = 0.98-1.5 increasing to OR = 2.3, 95 % CI = 1.6-3.4 in the latency period > 20 years (p trend = 0.01). Similar results were found for cordless phones although based on low numbers in the longest latency period. The lowest quartile of cumulative wireless phone use gave OR = 1.2, 95 % CI = 0.9-1.4 increasing to OR = 2.0, 95 % CI = 1.6-2.6 in the fourth quartile (p trend < 0.0001) [7]. Thus, as the published results show no statistically significant increased risk was found in total in the shortest latency group contrary to what ICNIRP stated, although somewhat higher risk was found for ipsilateral use.

For acoustic neuroma, the Hardell group reported use of wireless phone (mobile and/or cordless phone) with latency time >1-5 years in total OR = 1.2, 95 % CI = 0.8-1.6 increasing to OR = 4.4, 95 % CI = 2.2-9.0 (p trend = 0.003) for latency > 20 years [8]. The risk increased with cumulative use of wireless phone; first quartile OR = 1.2, 95 % CI = 0.8-1.7 and fourth quartile OR = 2.2, 95 % CI =1.5 – 3.4, p trend = 0.03. Thus, the results were similar as for glioma. These results were dismissed by ICNIRP.

In addition, ICNIRP claims that the Hardell group results may be caused by recall bias. For meningioma no statistically significant increased risk was found in the same study. Using meningioma cases as “controls” (the comparison entity) still yielded statistically significant increased risk for glioma and mobile phone use; ipsilateral use OR = 1.4, 95 % CI = 1.1-1.8, contralateral OR = 1.0, 94 % CI = 0.7-1.4 and for cordless phone use ipsilateral OR = 1.4, 95 % CI = 1.1-1.9, contralateral OR = 1.1, 95 % CI = 0.8-1.6 [7]. Similar results were found for acoustic neuroma using meningioma cases as the comparison group [8]. These results clearly show that the increased risks for glioma and acoustic neuroma were not caused by recall bias.

The CERENAT study by Coureau et al. [16] was omitted by ICNIRP. The study strengthened the evidence of increased risk for glioma associated with mobile phone use. Life-long cumulative duration ≥896 h gave OR=2.89, 95% CI 1.41 - 5.93 for glioma. Number of calls ≥18,360 gave OR=2.10, 95% CI 1.03 - 4.31. Higher risks were obtained for the highest exposed area, (temporal tumor), as well as occupational and urban mobile phone use. The Danish cohort study on mobile phone use with serious methodological limitations was however discussed in ICNIRP 2020, adding to the no-risk paradigm.

Furthermore, ICNIRP claims that “Studies of other types of tumors have also not provided evidence of an increased tumor risk in relation to mobile phone use. Only one study is available on mobile phone use in children and brain tumor risk. No increased risk of brain tumors was observed.” This is yet another incorrect statement [93]. The CEFALO study, as discussed previously, showed increased risks in spite of methodological shortcomings.

3.3. Thyroid cancer

In 2016 the Hardell group published increasing incidence of thyroid cancer in the Nordic countries especially during the last two decades [119]. The thyroid gland is a target organ for RF radiation from smartphones, which was discussed as an etiologic factor. A case-control study on mobile phone use suggested an increased risk for thyroid cancer associated with long-term use [120]. The same material was used to study genotype-environment interaction between single nucleotide polymorphism (SNPs) and mobile phone use [121]. The study showed that mobile phone use increased the risk for thyroid cancer when genetic variants were present within some genes. It was concluded that pathways related to DNA repair may be involved in the increased risk. The study was published online 6 December 2019, that is well before the ICNIRP 2020 publication. ICNIRP omitted completely to discuss the increasing incidence of thyroid cancer and the association with mobile phone use. The statement by ICNIRP of no risk for other tumor types is not correct. The increasing incidence of thyroid cancer in the Nordic countries is confirmed in our recent publication [122].

3.4. Brain tumor incidence

Another example by ICNIRP that misguides the reader is the statement “trends in brain cancer incidence rates from a large number of countries or regions…have not found any increase in the incidence since mobile phones were introduced.” This is not correct. Philips et al. [123] reported a statistically significant increasing incidence of glioblastoma multiforme in UK during 1995-2015. Similar results were published from USA [124]. In Sweden, the Hardell group published increasing rates of brain tumors based on the Swedish National Inpatient Register and the Causes of Death Register [125]. The same group also published an increasing incidence of brain tumors in the Swedish Cancer Register [126]. ICNIRP seems to have overlooked facts that would contradict their claim that the results showing brain tumor risk are “not consistent with trends in brain cancer trends”.

3.5. Transmitters, base stations and cancer

According to ICNIRP, studies on exposure to environmental RF radiation “have not provided evidence of an increased cancer risk either in children or in adults”. No references to that statement are given. In a review by Khurana et al. [127] two of three studies reported increased incidence of cancer at a distance < 350 m [128] or < 400 m [129] from a base station. Dode et al. [130] reported increased cancer mortality in an area within 500 m from a base station in Belo Horizonte, Brazil. A study from Taiwan found a statistically significant increased risk of all neoplasms in children with higher-than-median RF radiation exposure to mobile phone base stations [131]. A cause-effect relationship between RF radiation in occupational and military settings, mainly communication equipment and radar, and hematolymphatic malignancies was reported by Peleg et al. [18]. They concluded that available research “make a coherent case for a cause-effect relationship and classifying RFR exposure as a human carcinogen (IARC group 1)”. DNA damage and oxidative stress were associated with living in a vicinity of base stations in a study from India which is also of interest in this context [132]. It would have been pertinent for ICNIRP to review the literature.

There are also studies showing increased risk for childhood leukemia from RF transmitters. One of the authors of the ICNIRP 2020 guidelines, commission member Martin Röösli, stated at a seminar organized by SSM in 2016 that until 2003 all but one results on transmitters had shown increased risk for childhood leukemia: “it was quite impressive that [for] almost all the studies for different type of leukemias basically they reported significantly increased risk. So it was not a random sample of risk estimates. All but one risk estimates were above 1” [133]. This is in obvious contrast to the claim in ICNIRP 2020.

4. Conflicts of Interests

The conclusion by ICNIRP is not objective and lacks scientific credibility according to a research report that investigated ICNIRP commissioned by two European Parliament Members published in June 2020 [58]. Industry funding has been found to influence the results on research on RF radiation and health effects. However, ICNIRP does not take this into account although ICNIRP members themselves have reported that industry-funded scientific research seems to influence the results by reporting less findings showing adverse health effects of EMF compared to independent research [134].

The composition of ICNIRP is very one-sided according to the EU report [58]:

"ICNIRP has been, and is still, dominated by physical scientists… ..As one can read in the 45 portraits of the members of the ICNIRP commission and of the Scientific Expert Group (SEG), they all share the same position on the safety issues: non-ionising radiation poses no health threats and the only effects it has are thermal".

The EU report [58] pointed to the fact that ICNIRP's chairman Eric van Rongen, in 2016 invited the industry organization ICES to comment and thereby influence the upcoming ICNIRP 2020 guidelines [48]. The report concludes that it is:

"clear from ICES minutes that ICNIRP worked very closely with IEEE/ICES on the creation of the new RF safety guidelines that were published in March 2020. And this implies that large telecom-companies such as Motorola and others, as well as US military, had a direct influence on the ICNIRP guidelines, which are still the basis for EU-policies in this domain".

The EU report [58] also highlights several ICNIRP experts' financial ties to the industry. As described in that report, it should be noted that for example the European Food and Safety Authority (EFSA) considers conflict of interests as "any situation where an individual has an interest that may compromise or be reasonably perceived to compromise his or her capacity to act independently and in the public interest in relation to the subject of the work performed at EFSA". Apart from the telecom industry funding of the WHO EMF project, while it was led by ICNIRP's first chairman Michael Repacholi [74] (1996-2006), the EU report documents that "the majority of ICNIRP-scientists did perform research partly funded by industry".

As cited in the EU Report [58], Professor David Carpenter, Environmental Health Sciences at the University of Albany, USA, considers the "perversion that can result due to conflicts of interests" to be "one of the greatest problems in scientific discovery…When funding for scientists comes from an organization or corporation with desires to present a clean bill of health to the public, there is strong motivation to give the funder what they want, if only to continue receipt of funding."

To act both on behalf of ICNIRP to set guidelines supposed to protect against harmful health effects of RF radiation, and at the same time evaluate the health risks representing other organizations, may constitute a conflict of interest, i.e. according to the opinion of the Ethical board of the Karolinska Institute, Stockholm, Sweden. Many of the ICNIRP commission and SEG members act on behalf of several organizations thereby evaluating their own ICNIRP guidelines validity on behalf of other organizations. This kind of conflict of interest adds to those in terms of telecom funding and connection to ICES, see Table 1 [24, 71, 72, 86, 135-146].

5. Guidelines for RF Radiation Exposure

The new ICNIRP 2020 guidelines were developed with 5G in mind, especially considering frequencies that are higher to the presently used mobile phone communications. ICNIRP recognizes citizens' concerns regarding safety of 5G, however the new guidelines show no reduction of safety limits. The premise for safeguarding human health has remained the same – to avoid thermal effects. ICNIRP's 2020 guidelines [48] are based, like in 1998 [53], only on thermal effects, i.e. the RF radiation from mobile communications devices can be high as long as it causes no tissue heating. This may be problematic for mm waves as the radiation can cause heating effects on the surface of the skin. A systematic review on 5G safety limits based on thermal dose concluded that: "The results also show that the peak-to-average ratio of 1,000 tolerated by the International Council on Non-Ionizing Radiation Protection guidelines may lead to permanent tissue damage after even short exposures, highlighting the importance of revisiting existing exposure guidelines" [147]. Furthermore, some organs are more susceptible to RF radiation damage so local dosimetry is more appropriate for characterizing organ-specific risk [10].

Currently the mobile communications reside on frequencies up to 2,600 MHz band, with some minor exceptions beyond that frequency. 5G frequencies are expected to be using bands all over the higher radiofrequency spectrum, including previous 2G and 3G bands. Main 5G frequencies, however, will be at 3.4 to 4.2 GHz. Later, millimeter waves will also be deployed to provide 5G services, these are expected to reside at frequencies of 24-28 and 39 GHz. Millimeter wave base stations are expected to cover mainly high public density areas, such as city squares, transportation hubs, business and shopping centers and other public areas.

With the new reference levels [48] ICNIRP differentiates whole body exposure and exposure to small areas of the body introducing two separate classes of reference levels. ICNIRP grants higher exposure when assessing compliance by reference values; basic restrictions however have remained the same. ICNIRP claims, that this is because of better scientific understanding with respect to the 1998 guidelines. In Table 4 we compare ICNIRP reference levels between the 1998 [53] and the 2020 guidelines [48]. The calculated values are for arbitrary frequencies per each designated band; mobile communications frequency bands differ from region to region. Table 4 characterizes bands used in most European countries.

In their 1998 guidelines, at frequencies over 10 MHz, the reference levels are based on electric and magnetic field strengths for the whole-body SAR basic restrictions, derived by computer simulations and experimental data [53]. The 2020 guidelines introduce reference levels for local exposure [48]. In 2020 whole body reference levels, the averaging time has been increased from 6 min to 30 min, which ICNIRP argues is to better match the time taken for body core temperature to rise [48].

Frequency (MHz)	Example usage	ICNIPR 1998 [53] reference level, 6 min	ICNIPR 2020 [48] reference levels, whole body exposure, 30 min	ICNIPR 2020 [48] reference levels, local exposure, 6 min
800	LTE	4	4	18.2
900	GSM, UMTS	4.5	4.5	20.1
1,800	GSM	9	9	36.6
1,900	DECT	9.5	9.5	38.3
2,100	UMTS	10	10	40
2,400	WiFi 2G	10	10	40
2,600	LTE	10	10	40
3,500	5G, WiMax	10	10	40
5,500	WiFi 5G	10	10	40
26,000	5G	10	10	30.9

Table 4: Comparison of ICNIRP 1998 and 2020 reference levels across common mobile communication frequencies, time averaged (W/m²).

The ICNIRP 2020 [48] reference levels are based on time averaged exposure over 6 min or 30 min, see Table 4. However, supra-additive effects between pulses from different RF radiation sources may give much higher peak radiation from short time pulses than the power density average. Using time averaging in reference values, as in the ICNIRP guidelines, definitely underestimates the risk.

Year	Power Density Limit (μW/m^2)	Name	Description
1966	100,000,000	ANSI C95.1 [149]	Based on thermal effects and 0.1-hour (or 6 minute) averaging time.
1991	10,000,000	ANSI/IEEE C95.1-1991 [150]	Based on thermal effects.
1996	10,000,000 5,800,000	FCC [151]	USA: 5,800,000 averaged over a 30-minute period (869 MHz), previously recommended in 1986 by NCRP; 10,000,000 for PCS frequencies (1.85-1.99 GHz).
1998	10,000,000 9,000,000 4,500,000	ICNIRP [53]	10,000,000 for 2–300 GHz 9,000,000 for 1800 MHz and 4,500,000 for 900 MHz averaged over 6 min.

2001	1,000	Salzburg Resolution [152]	
2001	100	EU Parliament STOA 2001 [153]	
2002	1	New Salzburg Precautionary Exposure Limit Indoor [154]	Maximum indoor exposure recommendation for GSM base stations proposed by the Public Health Office of the Government of Salzburg.
2009	See 1998	ICNIRP [54]	Confirmation of ICNIRP 1998.
2012	3-6	Bioinitiative 2012 Recommendation [44]	
2016	0,1-100	Europa EM EMF Guidelines [41]	For frequencies between GSM 900 to WiFi 5,6 GHz depending on sensitivity, night time or daytime exposure.
2020	400 MHz: 10,000,000 800 MHz: 18,200,000 1,800 MHz: 36,600,000 2,000 MHz: 40,000,000 6 GHz: 40,000,000 60 GHz: 26,600,000 300 GHz: 20,000,000	ICNIRP 2020 [48]	General public, local exposure, averaged over 6 min. For whole body exposure see Table 4.

Table 5: Guidelines by different organizations for radiofrequency radiation in µW/m².

In a recent review, average exposure limit was suggested to be considerably lower, 0.1 V/m; 26.5 µW/m² [148]. This guideline is comparable with the BioInitative Report from 2012 [44] with a scientific benchmark of 30-60 µW/m², and for chronic exposure to sensitive persons and children 3-6 µW/m². The EUROPAEM EMF guidelines published daytime RF radiation exposure to be 10-1,000 µW/m², nighttime 1-100 µW/m², and for sensitive persons 0.1-10 µW/m² [41]. All these guidelines by independent research groups without conflicts of interest are very much lower than the ICNIRP guidelines. These lower guidelines are aimed at preventing health effects and hazards, Table 5 [41, 44, 48, 53, 54, 149-154].

6. Discussion

As a general rule ICNIRP, WHO, SCENIHR and SSM have for many years dismissed available studies showing harmful effects from non-thermal RF exposure and have based their conclusions mainly on studies showing no effects. Results showing risk are criticized, disregarded or not even cited while studies showing no risks are accepted as evidence of no risk in spite of severe methodological problems. Many statements by these agencies are misleading and not correct. They are easily rebutted by reading the relevant publications.

In fact, these activities are not in line with prevention of health hazards. Previously the precautionary principle in cancer prevention was discussed exemplified by e.g. asbestos, certain pesticides and RF radiation [155, 156]. It was noted that cancer prevention is usually very cost-effective. In a recent article we gave historical examples on lost opportunities based on early warnings with RF radiation as one more recent example [157].

In 2018 there was a call to dismantle ICNIRP and replace the organization with independent scientists [158]: "ICNIRP's mandate to issue exposure guidelines needs to be seriously questioned. ICNIRP is not independent of industry ties as it claims… Its opinions are not objective, not representative of the body of scientific evidence, but are biased in favor of industry."

The EU report investigating ICNIRP concluded in June 2020 that "for really independent scientific advice we cannot rely on ICNIRP." [58].

Our review reveals, with focus on cancer risks, an almost systematic downplaying of health risks from RF radiation by a group of persons that dominate the expert evaluations, see Table 1. Many of them reappear in several of these organizations' expert groups and also in other groups not described in this paper. One striking example is ICNIRP's chairman Eric van Rongen who also appeared in the WHO core group of six experts 2014 as well as one of SSM's eight experts and SCENIHR's nine experts in 2009 as well as secretary of the Health Council of the Netherlands expert group [159]. Another example is Maria Feychting, ICNIRP member since 2000, who was one of WHO's six core group experts behind the WHO 2014 draft, secretary of the SSM expert group evaluations 2003-2010, on the AGNIR (UK) expert group from 2009 and a Norwegian expert group in 2012 [160]. A third example is Martin Röösli, member of ICNIRP, the WHO external experts for the WHO draft 2014, the SSM expert group since 2010 and a Swiss expert group [99].

Our review also notes that there is a clear relationship between ICNIRP and ICES, which is dominated by industry representatives. Eric van Rongen, has been a member of ICES since 2000, ICNIRP member since 2001 and elected chair of ICNIRP in 2016, vice chair since 2020. From ICES annual report 2016 it was reported that:

"The new ICNIRP Chairman and one of the new members of the 14 member committee are also ICES members and ICNIRP is now willing to discuss harmonization of the exposure limits found in IEEE Stds C95.1TM-2005 and C95.6TM-2002 and the ICNIRP Guidelines. At a June 2016 Mobile Manufacturers Forum Workshop in Ghent, Belgium, the new ICNIRP Chairman, Dr. van Rongen, presented "ICNIRP's proposed HF guidelines" and extended an invitation to ICES to comment on the proposed guidelines. TC95 formed a 19 member task group to draft a document to comment on the ICNIRP proposed guidelines. The document was circulated to the TC95 membership for comment and a final document submitted to ICNIRP in time for discussion at the ICNIRP September meeting." [56].

The TC 95 committee's objective is "Development of standards for the safe use of electromagnetic energy in the range of 0 Hz to 300 GHz". These standards are based on the same scientifically invalid approach as the ICNIRP guidelines. In this TC95 committee, in which many members come from the military or the telecom industry, or are consultants to them, ICNIRP's chairman Eric van Rongen, Michael Repacholi, ICNIRP's first chairman and leader of the WHO EMF project 1996-2006, Theodoros Samaras (chairman SCENIHR) and Mats-Olof Mattson, Chairman SCENIHR 2009 and member of ICNIRP, are also found.

All these expert groups dominated by ICNIRP consequently reach similar conclusions that there are no health effects below ICNIRP guidelines. No representative from the scientific community that is of the opinion that there is increasing evidence of health risks below the ICNIRP guidelines, e.g. as expressed in the EMF Scientists Appeal [24], has ever been a member of the expert groups at the WHO, the EU, the SSM or ICNIRP. Certainly scientists who do not discount evidence of health effects from exposure to RF radiation that are observed at exposures below guideline levels should be represented.

The resistance to the abundant and growing scientific evidence on health risks is remarkable and not within the realm of public health. This behavior, due to the ICNIRP influence and dominant role in several other expert groups, is detrimental to human health and leads to suffering and even premature death that could have been prevented. Furthermore, it must be stressed that in general there is lack of persons with medical education and competence not only in the evaluating bodies but also in several research teams producing questionable results as exemplified in this text.

ICNIRP is not representative of the scientific community since it does not include representatives from scientists that agree there is evidence of harmful effects at levels well below ICNIRPs limits although these scientists are in majority in the scientific community [24].

7. Conclusion

ICNIRP's conclusion [48] on cancer risks is: "In summary, no effects of radiofrequency EMFs on the induction or development of cancer have been substantiated." This conclusion is not correct and is contradicted by scientific evidence. Abundant and convincing evidence of increased cancer risks and other negative health effects are today available. The ICNIRP 2020 guidelines allow exposure at levels known to be harmful. In the interest of public health, the ICNIRP 2020 guidelines should be immediately replaced by truly protective guidelines produced by independent scientists.

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CLB-07850; No. of pages: 5; 4C:

Clinical Biochemistry xxx (2011) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Clinical Biochemistry

journal homepage: www.elsevier.com/locate/clinbiochem

Case Report

How does long term exposure to base stations and mobile phones affect human hormone profiles?

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ARTICLE INFO

Article history:
Received 9 December 2010
received in revised form 2 November 2011
accepted 6 November 2011
Available online xxxx

Keywords:
Mobiles
Base stations
Radio frequency radiation
Hormone profiles

ABSTRACT

Objectives: This study is concerned with assessing the role of exposure to radio frequency radiation (RFR) emitted either from mobiles or base stations and its relations with human's hormone profiles.

Design and methods: All volunteers' samples were collected for hormonal analysis.

Results: This study showed significant decrease in volunteers' ACTH, cortisol, thyroid hormones, prolactin for young females, and testosterone levels.

Conclusion: The present study revealed that high RFR effects on pituitary–adrenal axis.

Introduction

Because of the increase in the usage of wireless communication devices of mobile phones in recent years, there is an anxious concern on the possible hazardous effects of prolonged exposure to radio frequency radiation (RFR) [1]. In considering the biological effects of RFR, the intensity and frequency of the radiation and exposure duration are important determinants of the responses.

It has been reported that exposure to RFR could affect the nervous system [2]. Hardell et al. found that cell phone users had an increased risk of malignant gliomas [3]. Subjecting human spermatozoa to RFR showed decrease in sperms motility and vitality and increase in DNA fragmentation [4]. The authors hypothesize that the high sporadic incidence of the clinical symptoms of the autoimmune multiple Sclerosis disease [5] may be a result of long exposure to RFR from mobiles.

This study is concerned with assessing the effect of RFR emitted from mobile phones and base stations on human hormone profiles, with anticipation to offer recommendations to assure health care and safety for humans continuously exposed to radio frequency radiation.

Design and methods

Study subjects

This study was conducted for 6 years on 82 mobile phone volunteers with age ranges 14–22 years ($n = 41$) and 25–60 years ($n = 41$). Those users were divided into three subgroups according to the time of their exposure to RFR: (weak $n = 19$), (moderate $n = 9$), and (strong $n = 13$) per day, in addition to 20 negative control subjects.

On the other hand, volunteers exposed to RFR emitted from base stations ($n = 34$) were selected with age ranges 14–22 years ($n = 17$), and 25–60 years ($n = 17$) and living at distances 20–100 m and 100–500 m apart from the base station. Additional 10 subjects of each age range living at a distance more than 500 m apart from the base station were considered as negative control group.

The source of the RFR (base stations or mobile phones) was GSM-950 MHz magnetic field and the ICNIRP-Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic field (up to 300 GHz) (International Commission on Non-Ionizing Radiation Protection). The present study was approved by the Ethics Committee of National Research Centre.

Volunteers inclusion criteria

Volunteers participated in the study fulfilled the following inclusion criteria: age 14–60 years, mobile phone users, or living at distances 20–100 m and 100–500 m apart from the base station.

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0009-9120/$ – see front matter
doi:10.1016/j.clinbiochem.2011.11.006

Please cite this article as: Eskander EF, et al, How does long term exposure to base stations and mobile phones affect human hormone profiles?, Clin Biochem (2011), doi:10.1016/j.clinbiochem.2011.11.006

Blood samples collection

Blood samples of the volunteers were analyzed for estimation of the following hormones: plasma ACTH, serum cortisol, total T_3, T_4, prolactin, progesterone, and testosterone levels. All volunteers followed for 6 years and the blood samples were collected regularly from mobile phone users, volunteers exposed to RFR emitted from base stations, and the controls for time intervals after 1 year, 3 years and 6 years for hormonal analysis. The determination of the hormonal profile was performed on serum samples whereas ACTH was detected in EDTA plasma. The whole blood was collected in EDTA tube.

Blood samples were withdrawn from females to measure serum prolactin and progesterone levels. Whereas, blood samples were withdrawn from males to measure serum testosterone level. Blood samples were withdrawn from both males and females to measure plasma ACTH level, serum cortisol, total T_3 and T_4 levels.

Methods

Plasma ACTH, serum total T_3, and T_4 levels were determined quantitatively using DSL-ELISA Kits provided by (Diagnostic Systems Laboratories Inc.). Measurement of serum cortisol level was carried out using ELISA kit provided by Adaltis Italia SPA Company (Italy). Serum prolactin, progesterone, and testosterone concentrations were measured using ELISA kit supplied by (DRG International, Inc., USA).

Statistical analysis

The data were analyzed using SPSS program (Statistical Package for the Social Science; SPSS Inc., Chicago, IL, USA, 2001).

Results

Volunteers mean hormone values

Follow up data were available for all volunteers who were exposed to RFR either from mobiles or base stations. The clinical features of all individuals were summarized in tables.

Tables 1 and 2 illustrate that persons of ages 14–22 years or 25–60 years who were exposed, for time intervals extended to 6 years, to RFR either from mobile phones or from base stations suffered significant decreases in their plasma ACTH and serum cortisol levels as compared to the control group. High significant decrease ($P<0.01$) in plasma ACTH and serum cortisol levels was observed for persons exposed to RFR from base stations at distances extended from 20 to 500 m for a period of 6 years as compared to the control group.

Tables 1 and 2, also show that persons of ages 14–22 years and 25–60 years who were exposed, for time intervals extended to 6 years, to RFR either from mobile telephones or from base stations suffered high significant ($P<0.01$) decrease in their serum T_3 and T_4 levels.

Tables 1 and 2 show that young females (14–22 years) exposed to RFR from mobile phones or from base stations at distances 20–100 m and 100–500 m suffered decrease in their serum prolactin level and the rate of decrease significantly rose with increased time of exposure from 1 year up to 6 years. Conversely, the serum prolactin level for adult females (25–60 years) showed significant increase along the time of exposure 1 year up to 6 years.

Table 1 shows that serum progesterone levels in young and adult females exposed to RFR from mobile phones were non-significantly changed through exposure for 1 year up to 6 years as compared to healthy controls.

Table 2 shows that both young (14–22 years) and adult (25–60 years) females exposed to RFR from base stations did not suffer any change in their serum progesterone levels throughout the first year of exposure. However, with increasing exposure periods from 3 up to 6 years they suffered significant decrease in their serum progesterone levels.

Tables 1 and 2 illustrate that both young males (14–22 years) and adult males (25–60 years) exposed to RFR from mobile phones or from base stations experienced gradual decrease in their serum testosterone level with increasing the period of exposure.

Discussion

The intensity and frequency of RFR and exposure duration are important determinants of the cumulative effect that could occur and lead to an eventual breakdown of homeostasis and adverse health consequences. Therefore, greater commitment from policy makers, health care officials and providers is needed to raise public awareness about the hazardous outcomes of long term exposure to RFR.

As mentioned in our results, persons who were exposed to RFR suffered significant decreases in their ACTH and cortisol levels as compared to controls. This result is agreed with the previous study indicating that cortisol levels were decreased after exposure to RF [12]. The current result is in contradiction with a previous study indicating that electromagnetic fields have a slight elevation in human cortisol production [6] and with other previous study suggesting that cortisol concentration as a marker of adrenal gland function was not affected with RFR [11]. Djeridane et al. (2008) added that ACTH was not disrupted by RFR emitted by mobile phones [12].

Our results reveal that persons who were exposed to RFR either from mobile phones or base stations suffered highly significant decrease in their serum T_3 and T_4 levels which agree in case of low T_4 levels and disagree in case of low T_3 concentrations with previous study which suggested that serum T_3 remains in normal range [7].

In the present study, females exposed to RFR from mobile phones or base stations suffered change in their serum prolactin level and the rate of change significantly rose with increased time of exposure which is in converse with previous studies indicating that serum prolactin concentration remained within normal ranges after exposure to radiocellular phones [8,12]. Therefore, it is suggested that the menstrual cycle and the pregnancy will be affected by changing the level of serum prolactin which seems necessary to be optimized in these two processes.

Our study suggested that serum progesterone levels in young and adult females exposed to RFR from mobile phones non-significantly changed from 1 year up to 6 years as compared to healthy controls. So, the menstrual cycle and pregnancy may not be affected by serum progesterone concentration. Previous study revealed that microwaves produced significant increases in serum progesterone level only in pregnant rats [9].

In the present study, both young and adult males exposed to RFR from mobile phones or base stations experienced gradual decrease in their serum testosterone level with increasing the period of exposure which is almost the same as previously recent reported studies suggested that exposure to mobile radiation leads to reduction in serum testosterone and it possibly affects reproductive functions [10,11]. The present study is in converse with a previous study indicating that testosterone was not disrupted by RFR emitted by mobile phones [12].

In conclusion, the present study revealed that high RFR emitted from either mobile phone or base station has tangible effects on pituitary–adrenal axis represented in the reduction of ACTH and consequently cortisol levels. Also, exposure to RFR is associated with decrease in the release of thyroid hormones.

Moreover, our data suggested that each of serum prolactin in young females, and testosterone levels in males significantly dropped due to long-term exposure to RFR. Conversely, the serum prolactin levels for the adult females significantly rose with increasing exposure time. Finally, the degenerative effects of exposure to RFR were more pronounced for persons who used mobile phones for long periods of 6 years. Also, the effect of this type of radiation was more

Please cite this article as: Eskander EF, et al, How does long term exposure to base stations and mobile phones affect human hormone profiles?, Clin Biochem (2011), doi:10.1016/j.clinbiochem.2011.11.006

Table 1
Plasma ACTH, serum cortisol, T3, T4, prolactin, progesterone, and testosterone of volunteers exposed to RFR from mobile phones.

Hormones (mean ± SE)	Groups											
	Controls						Mobile phone users					
	1 Year		3 Years		6 Years		1 Year					
	Age_1	Age_2	Age_1	Age_2	Age_1	Age_2	Age_1			Age_2		
							S	M	W	S	M	W
Plasma ACTH (pg/mL)	61.1 ± 1.1	63.2 ± 0.1	59.9 ± 0.2	62.3 ± 1.0	59.9 ± 0.3	60.2 ± 1.7	49.1 ± 0.3[b]	55.0 ± 1.1[b]	59.2 ± 0.1[NS]	53.2 ± 1.2[b]	58.3 ± 0.4[b]	62.1 ± 1.1[NS]
Serum cortisol (μg/mL)	30.0 ± 1.2	31.2 ± 0.1	30.0 ± 0.1	31.7 ± 0.3	29.9 ± 0.2	28.8 ± 2.3	20.3 ± 1.1[b]	27.3 ± 0.1[a]	30.1 ± 0.3[NS]	23.9 ± 1.0[b]	28.2 ± 0.9[b]	30.3 ± 1.1[NS]
Serum T_3 (ng/dL)	105.2 ± 1.3	102.0 ± 1.1	101.7 ± 1.2	98.6 ± 2.1	103.6 ± 1.1	99.0 ± 1.4	96.3 ± 1.2[b]	100.0 ± 0.6[b]	102.1 ± 1.3[NS]	93.9 ± 1.1[b]	98.1 ± 0.3[a]	99.0 ± 0.7[a]
Serum T_4 (μg/dL)	7.8 ± 0.6	6.9 ± 1.4	7.7 ± 1.1	6.5 ± 0.7	7.1 ± 0.3	6.6 ± 2.1[b]	6.9 ± 0.1[NS]	7.0 ± 0.1[NS]	6.9 ± 0.1[NS]	6.3 0.8[b]	6.2 ± 1.2[NS]	6.0 ± 1.0[NS]
Serum prolactin (ng/mL)	17.8 ± 1.1	17.2 ± 1.2	17.3 ± 1.1	16.9 ± 1.3	17.0 ± 2.1	16.8 ± 0.5	14.9 ± 1.4[a]	14.7 ± 0.3[a]	17.3 ± 0.2[NS]	18.3 ± 0.1[a]	16.9 ± 0.3[a]	17.1 ± 0.2[NS]
Serum progesterone (pg/mL)	14.0 ± 1.3	17.1 ± 1.0	13.8 ± 1.2	16.9 ± 0.9	12.9 ± 1.3	16.8 ± 0.2	12.3 ± 1.1[NS]	12.2 ± 1.2[NS]	14.1 ± 0.7[NS]	16.1 ± 1.4[NS]	17.6 ± 0.3[NS]	16.5 ± 0.4[a]
Serum testosterone (pg/mL)	29.5 ± 1.2	25.2 ± 1.6	28.9 ± 1.8	24.3 ± 0.6	28.4 ± 0.3	24.0 ± 0.1	25.2 ± 0.2[a]	24.9 ± 0.1[a]	23.7 ± 0.4[a]	22.7 ± 1.2[a]	23.8 ± 0.4[NS]	19.9 ± 0.1[a]

Age_1: represents age from 14 to 22 years, Age_2: represents age from 25 to 60 years.S: represents Strong, M: represents Moderate, W: represents Weak.N Control = 10, N Strong = 13, N Moderate = 9, N Weak = 19.Strong use: more than 60 min/day, Moderate use: between 30–60 min/day, Weak use: less than 10 min/day.NS: non-significant change when comparing mobile phone users with controls.aSignificant difference at $P > 0.05$ when comparing mobile phone users with controls.bSignificant difference at $P > 0.01$ when comparing mobile phone users with controls.

Table 1 (*continued*)

Hormones (mean ± SE)	Groups											
	Mobile phone users											
	3 Years						6 Years					
	Age_1			Age_2			Age_1			Age_2		
	S	M	W	S	M	W	S	M	W	S	M	W
Plasma ACTH (pg/mL)	45.3 ± 0.6[b]	51.2 ± 1.3[b]	55.0 ± 1.1[b]	50.2 ± 0.4[b]	55.1 ± 1.1[b]	60.0 ± 0.3[b]	40.3 ± 0.4[b]	41.3 ± 1.1[b]	47.2 ± 0.2[b]	48.2 ± 0.4[b]	51.3 ± 1.3[b]	57.2 ± 1.1[b]
Serum cortisol (μg/mL)	18.3 ± 1.4[b]	20.2 ± 1.1[b]	25.1 ± 0.1[b]	20.3 ± 1.1[b]	25.9 ± 0.9[b]	20.3 ± 1.2[b]	18.0 ± 0.1[b]	17.3 ± 1.1[b]	20.3 ± 0.2[b]	17.0 ± 0.2[b]	22.0 ± 0.4[b]	24.1 ± 0.2[b]
Serum T_3 (ng/dL)	87.2 ± 1.3[b]	90.2 ± 1.6[b]	94.3 ± 1.1[b]	89.8 ± 1.1[b]	92.9 ± 1.3[b]	95.0 ± 1.1[b]	80.3 ± 1.1[b]	84.2 ± 0.5[b]	85.7 ± 1.1[b]	83.2 ± 1.3[b]	80.3 ± 1.1[b]	90.2 ± 0.7[b]
Serum T_4 (μg/dL)	7.9 ± 1.1[b]	7.6 ± 1.7[NS]	7.1 ± 1.3[NS]	6.4 ± 0.3[NS]	6.3 ± 0.8[NS]	6.1 ± 0.3[NS]	10.5 ± 0.1[b]	9.5 ± 1.1[NS]	8.9 ± 0.4[b]	7.4 ± 0.9[NS]	7.7 ± 1.3[NS]	8.0 ± 1.1[NS]
Serum prolactin (ng/mL)	17.4 ± 1.2[a]	9.8 ± 0.3[b]	9.7 ± 0.1[b]	23.5 ± 0.2[b]	19.2 ± 1.1[b]	18.7 ± 0.9[b]	10.1 ± 1.0[b]	8.7 ± 0.3[a]	8.7 ± 0.4[NS]	24.9 ± 0.1[b]	21.1 ± 0.3[b]	20.6 ± 0.1[b]
Serum progesterone (pg/mL)	13.9 ± 0.2[NS]	13.6 ± 0.7[NS]	13.4 ± 0.4[NS]	15.1 ± 0.3[a]	14.9 ± 0.1[a]	13.0 ± 0.5[b]	12.9 ± 0.2[a]	11.8 ± 0.1[a]	10.9 ± 0.3[a]	14.8 ± 1.1[b]	13.5 ± 1.3[NS]	12.8 ± 0.1[NS]
Serum testosterone (pg/mL)	19.8 ± 0.1[b]	18.7 ± 0.2[a]	16.5 ± 0.1[a]	17.5 ± 0.2[b]	16.9 ± 1.1[a]	16.1 ± 0.3[a]	13.1 ± 0.4[b]	12.7 ± 0.2[b]	12.3 ± 0.1[b]	11.1 ± 1.1[b]	11.4 ± 0.2[b]	9.8 ± 0.3[b]

Table 2
Plasma ACTH, serum cortisol, T3, T4, prolactin, progesterone, and testosterone of volunteers exposed to RFR from base stations.

Hormones (mean ± SE)	Groups								
	Controls (distance 500 m)						Volunteers exposed to RFR from base stations		
	1 Year		3 Years		6 Years		1 Year		
	Age$_1$	Age$_2$	Age$_1$	Age$_2$	Age$_1$	Age$_2$	Age$_1$		Age$_2$
							D_1	D_2	D_1
Plasma ACTH (pg/mL)	62.8 ± 1.2	58.3 ± 0.9	62.5 ± 0.3	58.4 ± 0.5	62.4 ± 0.7	58.9 ± 0.1[a]	61.9 ± 0.2[NS]	62.3 ± 0.1[NS]	57.9 ± 1.3[NS]
Serum cortisol (µg/mL)	33.3 ± 2.6	30.1 ± 1.4	32.9 ± 1.1	30.3 ± 1.4	32.7 ± 1.1	29.9 ± 1.9	32.4 ± 1.2[NS]	32.9 ± 0.3[NS]	28.8 ± 1.6[NS]
Serum T3 (ng/ dl)	108.3 ± 1.6	100.0 ± 1.1	107.0 ± 1.9	100.0 ± 0.1	107.0 ± 0.1	99.9 ± 1.2	107.0 ± 1.1[NS]	107.9 ± 0.4[NS]	106.0 ± 1.1[NS]
Serum T4 (µg/dL)	7.2 ± 1.3	6.3 ± 0.3	6.8 ± 1.2	6.3 ± 0.1	6.7 ± 1.2	6.2 ± 2.4	6.9 ± 0.3[NS]	7.1 ± 1.1[NS]	5.9 ± 1.1[NS]
Serum prolactin (ng/mL)	18.3 ± 1.1	14.3 ± 1.6	18.0 ± 1.0	13.9 ± 1.2	18.0 ± 1.2	13.1 ± 0.2	17.6 ± 0.2[NS]	17.6 ± 1.3[NS]	19.1 ± 0.3[b]
Serum progesterone (pg/mL)	12.4 ± 1.1	10.0 ± 0.8	12.3 ± 1.6	10.0 ± 0.5	12.2 ± 1.9	9.8 ± 2.4	12.3 ± 1.1[NS]	12.3 ± 1.0[NS]	10.1 ± 0.9[NS]
Serum testosterone (pg/mL)	27.1 ± 0.3	24.2 ± 1.1	26.3 ± 1.1	23.2 ± 1.3	25.8 ± 1.4	22.9 ± 2.1	243 ± 1.1[b]	24.9 ± 1.9[NS]	20.1 ± 1.1[b]

Q2

Age$_1$: represents age from 14 to 22 years, Age$_2$: represents age from 25 to 60 years. D_1: represents distance from 20 to 100 m, D_2: represents distance from 100 to 500 m. N Control = 10, N Strong = 13, N Moderate = 9, N Weak = 19. NS: non-significant change when comparing persons exposed to base stations with controls. aSignificant difference at $P > 0.05$ when comparing persons exposed to base stations with controls. bSignificant difference at $P > 0.01$ when comparing persons exposed to base stations with controls.

Table 2 (*continued*)

Hormones (mean ± SE)	Groups								
	Volunteers exposed to RFR from base stations								
	1 Year	3 Years				6 Years			
	Age$_2$	Age$_1$		Age$_2$		Age$_1$		Age$_2$	
	D_2	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2
Plasma ACTH (pg/mL)	58.0 ± 0.9[NS]	51.8 ± 1.7[b]	54.6 ± 1.1[b]	54.2 ± 0.6[b]	45.2 ± 1.8[NS]	47.3 ± 1.3[b]	48.3 ± 1.4[b]	40.7 ± 0.3[b]	43.1 ± 1.1[b]
Serum cortisol (µg/mL)	29.1 ± 1.3[NS]	27.2 ± 1.2[b]	27.4 ± 2.1[NS]	25.6 ± 0.1[b]	26.6 ± 1.1[NS]	21.2 ± 0.4[b]	22.4 ± 1.1[b]	22.9 ± 1.1[b]	24.2 ± 0.3[b]
Serum T3 (ng/ dl)	100.1 ± 0.2[NS]	97.3 ± 1.6[b]	98.1 ± 0.9[b]	97.4 ± 1.1[NS]	98.2 ± 1.9[NS]	78.0 ± 1.1[b]	82.3 ± 1.9[b]	91.3 ± 1.5[b]	93.4 ± 1.9[b]
Serum T4 (µg/dL)	6.1 ± 0.3[NS]	4.4 ± 1.8[NS]	4.9 ± 0.3[NS]	5.1 ± 0.3[b]	5.9 ± 0.8[NS]	2.7 ± 0.1[b]	2.8 ± 1.2[b]	3.8 ± 1.2[b]	3.9 ± 1.9[b]
Serum prolactin (ng/mL)	19.6 ± 1.1[b]	97.3 ± 1.6[b]	98.1 ± 0.9[b]	97.4 ± 1.1[NS]	98.2 ± 1.9[NS]	78.0 ± 1.1[b]	82.3 ± 1.9[b]	91.3 ± 1.5[b]	93.4 ± 1.9[b]
Serum progesterone (pg/mL)	10.5 ± 1.1[NS]	4.4 ± 1.8[NS]	4.9 ± 0.3[NS]	5.1 ± 0.3[b]	5.9 ± 0.8[NS]	2.7 ± 0.1[b]	2.8 ± 1.2[b]	3.8 ± 1.2[b]	3.9 ± 1.9[b]
Serum testosterone (pg/mL)	20.3 ± 1.6[NS]	20.2 ± 0.4[b]	20.9 ± 0.9[b]	18.1 ± 1.1[b]	18.6 ± 1.3[b]	11.8 ± 0.3[b]	10.9 ± 1.6[b]	15.3 ± 1.2[b]	16.1 ± 1.5[b]

Please cite this article as: Eskander EF, et al, How does long term exposure to base stations and mobile phones affect human hormone profiles?, Clin Biochem (2011), doi:10.1016/j.clinbiochem.2011.11.006

obvious for persons living nearby base stations and exposed for a period of 6 years.

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Please cite this article as: Eskander EF, et al, How does long term exposure to base stations and mobile phones affect human hormone profiles?, Clin Biochem (2011), doi:10.1016/j.clinbiochem.2011.11.006

Research on the Impacts to Bees from Electromagnetic Radiation

Electromagnetic fields from power lines, cell phones, cell towers and wireless has been shown to negatively impact pollinators, bees and our environment in numerous peer reviewed research studies.

Research has found electromagnetic radiation can alter bee behavior, induce biochemical changes and impact bee reproduction.

SUMMARY

- Experimental studies by Favre 2017 found exposed bees exhibited behaviors naturally produced by disturbed honeybees and the authors concluded that "The present data strongly suggest that honeybee colonies are affected and disturbed by electromagnetic waves (RF-EMF)."
- Ulrich Warnke's review article cites multiple studies and posits that electrical, magnetic and electromagnetic fields disrupt the orientation and navigation of many birds and pollinators.
- Published research has found a myriad of effects after electromagnetic radiation exposure including inducing artificial worker piping (Favre, 2011), disrupting navigation abilities (Goldsworthy, 2009; Sainudeen, 2011; Kimmel et al., 2007) decreasing rate egg laying rate (Sharma and Kumar, 2010) and reducing colony strength (Sharma and Kumar, 2010; Harst et al., 2006). Neelima Kumar and colleagues (2011) found cell phone radiation influences honey bees' behavior and physiology.

CONCLUSION

As Clarke et al. (2013) has reported, bees have a particular sensory modality allowing them to detect electric fields, and thus they are particularly susceptible to large amounts of electromagnetic radiation.

Colony Collapse Disorder may be caused by a combination of several factors including pesticides, chemicals and parasitic infection. Researchers are proposing that the stress of increasing electromagnetic radiation exposure has stressed and weakened bee populations which results in bee's decreased ability to maintain their health when also exposed to increased pesticides, chemicals and infections. The bee's resistance to environmental stressors is weakened by EMF exposure.

NEWS ARTICLES

Herriman, Sasha. "Study links bee decline to cell phones." *CNN* (30 June 2010).

Chokshi, Niraj. "If Cell Phones Are Behind the Bee Decline, What Are They Doing to Humans?" The Atalantic (30 June 2010).

- "In a study at Panjab University in Chandigarh, northern India, researchers fitted cell phones to a hive and powered them up for two fifteen-minute periods each day. After three months, they found the bees stopped producing honey, egg production by the queen bee halved, and the size of the hive dramatically reduced."
- "Andrew Goldsworthy, a biologist from Imperial College, London, told CNN that the reason may have to do with radiation from cell phones and cell towers disturbing the molecules of the chemical cryptochrome, which bees and other animals use for navigation."

Derbyshire, David. "Why a mobile phone ring may make bees buzz off: Insects infuriated by handset signals." Daily Mail (13 May 2011).

- After phones were activated, the bees emitted "piping" calls –announce the start of swarming.

SCIENCE

Balmori, Alfonso. "Anthropogenic radiofrequency electromagnetic fields as an emerging threat to wildlife orientation." Science of The Total Environment, vol. 518–519, 2015, pp. 58–60

- Radio frequency noise interferes with the primary process of magnetoreception. Existing guidelines do not adequately protect wildlife. Further research in this area is urgent.

Cucurachi, C., et al. "A review of the ecological effects of radiofrequency electromagnetic fields (RF-EMF)." Environment International, vol. 51, 2013, pp. 116–40.

- A review of 113 studies found RF-EMF had a significant effect on birds, insects, plants and other organisms in 70% of the studies. Development of birds and insects are most strongly affected.

Goldsworthy, Andrew. "The Birds, the Bees and Electromagnetic Pollution: How electromagnetic fields can disrupt both solar and magnetic bee navigation and reduce immunity to disease all in one go." 2009.

- Documentation of the increasing evidence that disappearing birds and bees is partially due to electromagnetic pollution from cell towers, cell phones, DECT cordless phones and Wifi. "It appears capable of interfering with their navigation systems and also their circadian rhythms, which in turn reduces their resistance to disease. The most probable reason is that these animals use a group of magnetically-sensitive substances called cryptochromes for magnetic and solar navigation and also to control the activity of their immune systems."

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Biological effects from exposure to electromagnetic radiation emitted by cell tower base stations and other antenna arrays

B. Blake Levitt and Henry Lai

Abstract: The siting of cellular phone base stations and other cellular infrastructure such as roof-mounted antenna arrays, especially in residential neighborhoods, is a contentious subject in land-use regulation. Local resistance from nearby residents and landowners is often based on fears of adverse health effects despite reassurances from telecommunications service providers that international exposure standards will be followed. Both anecdotal reports and some epidemiology studies have found headaches, skin rashes, sleep disturbances, depression, decreased libido, increased rates of suicide, concentration problems, dizziness, memory changes, increased risk of cancer, tremors, and other neurophysiological effects in populations near base stations. The objective of this paper is to review the existing studies of people living or working near cellular infrastructure and other pertinent studies that could apply to long-term, low-level radiofrequency radiation (RFR) exposures. While specific epidemiological research in this area is sparse and contradictory, and such exposures are difficult to quantify given the increasing background levels of RFR from myriad personal consumer products, some research does exist to warrant caution in infrastructure siting. Further epidemiology research that takes total ambient RFR exposures into consideration is warranted. Symptoms reported today may be classic microwave sickness, first described in 1978. Nonionizing electromagnetic fields are among the fastest growing forms of environmental pollution. Some extrapolations can be made from research other than epidemiology regarding biological effects from exposures at levels far below current exposure guidelines.

Key words: radiofrequency radiation (RFR), antenna arrays, cellular phone base stations, microwave sickness, nonionizing electromagnetic fields, environmental pollution.

Résumé : La localisation des stations de base pour téléphones cellulaires et autres infrastructures cellulaires, comme les installations d'antennes sur les toitures, surtout dans les quartiers résidentiels, constitue un sujet litigieux d'utilisation du territoire. La résistance locale de la part des résidents et propriétaires fonciers limitrophes repose souvent sur les craintes d'effets adverses pour la santé, en dépit des réassurances venant des fournisseurs de services de télécommunication, à l'effet qu'ils appliquent les standards internationaux d'exposition. En plus de rapports anecdotiques, certaines études épidémiologiques font état de maux de tête, d'éruption cutanée, de perturbation du sommeil, de dépression, de diminution de libido, d'augmentations du taux de suicide, de problèmes de concentration, de vertiges, d'altération de la mémoire, d'augmentation du risque de cancers, de trémulations et autres effets neurophysiologiques, dans les populations vivant au voisinage des stations de base. Les auteurs révisent ici les études existantes portant sur les gens, vivant ou travaillant près d'infrastructures cellulaires ou autres études pertinentes qui pourraient s'appliquer aux expositions à long terme à la radiation de radiofréquence de faible intensité « RFR ». Bien que la recherche épidémiologique spécifique dans ce domaine soit rare et contradictoire, et que de telles expositions soient difficiles à quantifier compte tenu des degrés croissants du bruit de fond des RFR provenant de produits de myriades de consommateurs personnels, il existe certaines recherches qui justifient la prudence dans l'installation des infrastructures. Les futures études épidémiologiques sont nécessaires afin de prendre en compte la totalité des expositions à la RFR ambiante. Les symptômes rapportés jusqu'ici pourraient correspondre à la maladie classique des micro-ondes, décrite pour la première fois en 1978. Les champs électromagnétiques non-ionisants constituent les formes de pollution environnementale croissant le plus rapidement. On peut effectuer certaines extrapolations à partir de recherches autres qu'épidémiologiques concernant les effets biologiques d'expositions à des degrés bien au-dessous des directives internationales.

Mots-clés : radiofréquence de faible intensité « RFR », les installations d'antennes, des stations de base pour téléphones cellulaires, la maladie classique des micro-ondes, les champs électromagnétiques non-ionisants, pollution environnementale.

[Traduit par la Rédaction]

Received 30 April 2010. Accepted 6 August 2010. Published on the NRC Research Press Web site at er.nrc.ca on 5 November 2010.

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1. Introduction

Wireless technologies are ubiquitous today. According to the European Information Technology Observatory, an industry-funded organization in Germany, the threshold of 5.1 billion cell phone users worldwide will be reached by the end of 2010 — up from 3.3 billion in 2007. That number is expected to increase by another 10% to 5.6 billion in 2011, out of a total worldwide population of 6.5 billion.[2] In 2010, cell phone subscribers in the U.S. numbered 287 million, Russia 220 million, Germany 111 million, Italy 87 million, Great Britain 81 million, France 62 million, and Spain 57 million. Growth is strong throughout Asia and in South America but especially so in developing countries where landline systems were never fully established.

The investment firm Bank of America Merril-Lynch estimated that the worldwide penetration of mobile phone customers is twice that of landline customers today and that America has the highest minutes of use per month per user.[3] Today, 94% of Americans live in counties with four or more wireless service providers, plus 99% of Americans live in counties where next generation, 3G (third generation), 4G (fourth generation), and broadband services are available. All of this capacity requires an extensive infrastructure that the industry continues to build in the U.S., despite a 93% wireless penetration of the total U.S. population.[4]

Next generation services are continuing to drive the build-out of both new infrastructure as well as adaptation of pre-existing sites. According to the industry, there are an estimated 251 618 cell sites in the U.S. today, up from 19 844 in 1995.[4] There is no comprehensive data for antennas hidden inside of buildings but one industry-maintained Web site (www.antennasearch.com), allows people to type in an address and all antennas within a 3 mile (1 mile = 1.6 km) area will come up. There are hundreds of thousands in the U.S. alone.

People are increasingly abandoning landline systems in favor of wireless communications. One estimate in 2006 found that 42% of all wireless subscribers used their wireless phone as their primary phone. According to the National Center for Health Statistics of the U.S. Centers for Disease Control (CDC), by the second half of 2008, one in every five American households had no landlines but did have at least one wireless phone (Department of Health and Human Services 2008). The figures reflected a 2.7% increase over the first half of 2008 — the largest jump since the CDC began tracking such data in 2003, and represented a total of 20.2% of the U.S. population — a figure that coincides with industry estimates of 24.50% of completely wireless households in 2010.[5] The CDC also found that approximately 18.7% of all children, nearly 14 million, lived in households with only wireless phones. The CDC further found that one in every seven American homes, 14.5% of the population, received all or almost all of their calls via wireless phones, even when there was a landline in the home. They called these "wireless-mostly households."

The trend away from landline phones is obviously increasing as wireless providers market their services specifically toward a mobile customer, particularly younger adults who readily embrace new technologies. One study (Silke et al. 2010) in Germany found that children from lower socioeconomic backgrounds not only owned more cell phones than children from higher economic groups, but also used their cell phones more often — as determined by the test groups' wearing of personal dosimetry devices. This was the first study to track such data and it found an interesting contradiction to the assumption that higher socioeconomic groups were the largest users of cell services. At one time, cell phones were the status symbol of the wealthy. Today, it is also a status symbol of lower socioeconomic groups. The CDC found in their survey discussed above that 65.3% of adults living in poverty or living near poverty were more likely than higher income adults to be living in households with wireless only telephones. There may be multiple reasons for these findings, including a shift away from cell phone dialogues to texting in younger adults in higher socioeconomic categories.

In some developing countries where landline systems have never been fully developed outside of urban centers, cell phones are the only means of communication. Cellular technology, especially the new 3G, 4G, and broadband services that allow wireless communications for real-time voice communication, text messaging, photos, Internet connections, music and video downloads, and TV viewing, is the fastest growing segment of many economies that are in otherwise sharp decline due to the global economic downturn.

There is some indication that although the cellular phone markets for many European countries are more mature than in the U.S., people there may be maintaining their landline use while augmenting with mobile phone capability. This may be a consequence of the more robust media coverage regarding health and safety issues of wireless technology in the European press, particularly in the UK, as well as recommendations by European governments like France and Germany[6] that citizens not abandon their landline phones or wired computer systems because of safety concerns. According to OfCom's 2008 *Communications Market Interim Report* (OfCom 2008), which provided information up to December 2007, approximately 86% of UK adults use cell phones. While four out of five households have both cell phones and landlines, only 11% use cell phones exclusively, a total down from 28% noted by this group in 2005. In addition, 44% of UK adults use text messaging on a daily basis. Fixed landline services fell by 9% in 2007 but OfCom notes that landline services continue to be strong despite the fact that mobile services also continued to grow by 16%. This indicates that people are continuing to use both landlines and wireless technology rather than choosing one over the other in the UK. There were 51 300 UK base station sites in

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[3] http://www.ctia.org/advocacy/research/index.cfm/AID/10377. (Accessed October 2010.)
[4] http://www.ctia.org/advocacy/research/index.cfm/AID/10323. (Accessed October 2010.)
[5] http://www.ctia.org/advocacy/research/index.cfm/AID/10323. (Accessed October 2010.)
[6] http://www.icems.eu/docs/deutscher_bundestag.pdf and http://www.icems.eu/docs/resolutions/EP_EMF_resolution_2APR09.pdf. (Accessed October 2010.)

the beginning of 2009 (two-thirds installed on existing buildings or structures) with an estimated 52 900 needed to accommodate new 3G and 4G services by the end of 2009.

Clearly, this is an enormous global industry. Yet, no money has ever been appropriated by the industry in the U.S., or by any U.S. government agency, to study the potential health effects on people living near the infrastructure. The most recent research has all come from outside of the U.S. According to the CTIA – The Wireless Association, "If the wireless telecom industry were a country, its economy would be bigger than that of Egypt, and, if measured by GNP (gross national product), [it] would rank as the 46th largest country in the world." They further say, "It took more than 21 years for color televisions to reach 100 million consumers, more than 90 years for landline service to reach 100 million consumers, and less than 17 years for wireless to reach 100 million consumers."[7]

In lieu of building new cell towers, some municipalities are licensing public utility poles throughout urban areas for Wi-Fi antennas that allow wireless Internet access. These systems can require hundreds of antennas in close proximity to the population with some exposures at a lateral height where second- and third-storey windows face antennas. Most of these systems are categorically excluded from regulation by the U.S. Federal Communications Commission (FCC) or oversight by government agencies because they operate below a certain power density threshold. However, power density is not the only factor determining biological effects from radiofrequency radiation (RFR).

In addition, when the U.S. and other countries permanently changed from analog signals used for television transmission to newer digital formats, the old analog frequencies were reallocated for use by municipal services such as police, fire, and emergency medical dispatch, as well as to private telecommunications companies wanting to expand their networks and services. This creates another significant increase in ambient background exposures.

Wi-Max is another wireless service in the wings that will broaden wireless capabilities further and place additional towers and (or) transmitters in close proximity to the population in addition to what is already in existence. Wi-Max aims to make wireless Internet access universal without tying the user to a specific location or "hotspot." The rollout of Wi-Max in the U.S., which began in 2009, uses lower frequencies at high power densities than currently used by cellular phone transmission. Many in science and the activist communities are worried, especially those concerrned about electromagnetic-hypersensitivity syndrome (EHS).

It remains to be seen what additional exposures "smart grid" or "smart meter" technology proposals to upgrade the electrical powerline transmission systems will entail regarding total ambient RFR increases, but it will add another ubiquitous low-level layer. Some of the largest corporations on earth, notably Siemens and General Electric, are involved. Smart grids are being built out in some areas of the U.S. and in Canada and throughout Europe. That technology plans to alter certain aspects of powerline utility metering from a wired system to a partially wireless one. The systems require a combination of wireless transmitters attached to homes and businesses that will send radio signals of approximately 1 W output in the 2.4000–2.4835 GHz range to local "access point" transceivers, which will then relay the signal to a further distant information center (Tell 2008). Access point antennas will require additional power density and will be capable of interfacing with frequencies between 900 MHz and 1.9 GHz. Most signals will be intermittent, operating between 2 to 33 seconds per hour. Access points will be mounted on utility poles as well as on free-standing towers. The systems will form wide area networks (WANs), capable of covering whole towns and counties through a combination of "mesh-like" networks from house to house. Some meters installed on private homes will also act as transmission relays, boosting signals from more distant buildings in a neighborhood. Eventually, WANs will be completely linked.

Smart grid technology also proposes to allow homeowners to attach additional RFR devices to existing indoor appliances, to track power use, with the intention of reducing usage during peak hours. Manufacturers like General Electric are already making appliances with transmitters embedded in them. Many new appliances will be incapable of having transmitters deactivated without disabling the appliance and the warranty. People will be able to access their home appliances remotely by cell phone. The WANs smart grids described earlier in the text differ significantly from the current upgrades that many utility companies have initiated within recent years that already use low-power RFR meters attached to homes and businesses. Those first generation RFR meters transmit to a mobile van that travels through an area and "collects" the information on a regular billing cycle. Smart grids do away with the van and the meter reader and work off of a centralized RFR antenna system capable of blanketing whole regions with RFR.

Another new technology in the wings is broadband over powerlines (BPL). It was approved by the U.S. FCC in 2007 and some systems have already been built out. Critics of the latter technology warned during the approval process that radiofrequency interference could occur in homes and businesses and those warnings have proven accurate. BPL technology couples radiofrequency bands with extremely low frequency (ELF) bands that travel over powerline infrastructure, thereby creating a multi-frequency field designed to extend some distance from the lines themselves. Such couplings follow the path of conductive material, including secondary distribution lines, into people's homes.

There is no doubt that wireless technologies are popular with consumers and businesses alike, but all of this requires an extensive infrastructure to function. Infrastructure typically consists of freestanding towers (either preexisting towers to which cell antennas can be mounted, or new towers specifically built for cellular service), and myriad methods of placing transceiving antennas near the service being called for by users. This includes attaching antenna panels to the sides of buildings as well as roof-mountings; antennas hidden inside church steeples, barn silos, elevator shafts, and any number of other "stealth sites." It also includes camouflaging towers to look like trees indigenous to areas where they are placed, e.g., pine trees in northern climates, cacti

[7] CTIA website: http://www.ctia.org/advocay/research/index.cfm/AID/10385. (Accessed 9 December 2008.)

in deserts, and palm trees in temperate zones, or as chimneys, flagpoles, silos, or other tall structures (Rinebold 2001). Often the rationale for stealth antenna placement or camouflaging of towers is based on the aesthetic concerns of host communities.

An aesthetic emphasis is often the only perceived control of a municipality, particularly in countries like America where there is an overriding federal preemption that precludes taking the “environmental effects” of RFR into consideration in cell tower siting as stipulated in Section 704 of *The Telecommunications Act of 1996* (USFCC 1996). Citizen resistance, however, is most often based on health concerns regarding the safety of RFR exposures to those who live near the infrastructure. Many citizens, especially those who claim to be hypersensitive to electromagnetic fields, state they would rather know where the antennas are and that hiding them greatly complicates society’s ability to monitor for safety.[8]

Industry representatives try to reassure communities that facilities are many orders of magnitude below what is allowed for exposure by standards-setting boards and studies bear that out (Cooper et al. 2006; Henderson and Bangay 2006; Bornkessel et al. 2007). These include standards by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) used throughout Europe, Canada, and elsewhere (ICNIRP 1998). The standards currently adopted by the U.S. FCC, which uses a two-tiered system of recommendations put out by the National Council on Radiation Protection (NCRP) for civilian exposures (referred to as uncontrolled environments), and the International Electricians and Electronics Engineers (IEEE) for professional exposures (referred to as controlled environments) (U.S. FCC 1997). The U.S. may eventually adopt standards closer to ICNIRP. The current U.S. standards are more protective than ICNIRP’s in some frequency ranges so any harmonization toward the ICNIRP standards will make the U.S. limits more lenient.

All of the standards currently in place are based on RFRs ability to heat tissue, called thermal effects. A longstanding criticism, going back to the 1950s (Levitt 1995), is that such acute heating effects do not take potentially more subtle non-thermal effects into consideration. And based on the number of citizens who have tried to stop cell towers from being installed in their neighborhoods, laypeople in many countries do not find adherence to exisitng standards valid in addressing health concerns. Therefore, infrastructure siting does not have the confidence of the public (Levitt 1998).

2. A changing industry

Cellular phone technology has changed significantly over the last two decades. The first wireless systems began in the mid-1980s and used analog signals in the 850–900 MHz range. Because those wavelengths were longer, infrastructure was needed on average every 8 to 10 miles apart. Then came the digital personal communications systems (PCS) in the late 1990s, which used higher frequencies, around 1900 GHz, and digitized signals. The PCS systems, using shorter wavelengths and with more stringent exposure guidelines, require infrastructure approximately every 1 to 3 miles apart. Digital signals work on a binary method, mimicking a wave that allows any frequency to be split in several ways, thereby carrying more information far beyond just voice messages.

Today’s 3G network can send photos and download music and video directly onto a cell phone screen or iPod. The new 4G systems digitize and recycle some of the older frequencies in the 700 to 875 MHz bands to create another service for wireless Internet access. The 4G network does not require a customer who wants to log on wirelessly to locate a “hot spot” as is the case with private Wi-Fi systems. Today’s Wi-Fi uses a network of small antennas, creating coverage of a small area of 100 ft ($\sim$30 m) or so at homes or businesses. Wi-fi can also create a small wireless computer system in a school where they are often called wireless local area networks (WLANs). Whole cities can make Wi-Fi available by mounting antennas to utility poles.

Large-scale Wi-Fi systems have come under increasing opposition from citizens concerned about health issues who have legally blocked such installations (Antenna Free Union[9]). Small-scale Wi-Fi has also come under more scrutiny as governments in France and throughout Europe have banned such installations in libraries and schools, based on precautionary principles (REFLEX Program 2004).

3. Cell towers in perspective: some definitions

Cell towers are considered low-power installations when compared to many other commercial uses of radiofrequency energy. Wireless transmission for radio, television (TV), satellite communications, police and military radar, federal homeland security systems, emergency response networks, and many other applications all emit RFR, sometimes at millions of watts of effective radiated power (ERP). Cellular facilities, by contrast, use a few hundred watts of ERP per channel, depending on the use being called for at any given time and the number of service providers co-located at any given tower.

No matter what the use, once emitted, RFR travels through space at the speed of light and oscillates during propagation. The number of times the wave oscillates in one second determines its frequency.

Radiofrequency radiation covers a large segment of the electromagnetic spectrum and falls within the nonionizing bands. Its frequency ranges between 10 kHz to 300 GHz; 1 Hz = 1 oscillation per second; 1 kHz = 1000 Hz; 1 MHz = 1 000 000 Hz; and 1 GHz = 1 000 000 000 Hz.

Different frequencies of RFR are used in different applications. Some examples include the frequency range of 540 to 1600 kHz used in AM radio transmission; and 76 to 108 MHz used for FM radio. Cell-phone technology uses frequencies between 800 MHz and 3 GHz. The RFR of 2450 MHz is used in some Wi-Fi applications and microwave cooking.

Any signal can be digitized. All of the new telecommunications technologies are digitized and in the U.S., all TV is

[8] See, for example, www.radiationresearch.org. (Accessed October 2010.)

[9] http://www.antennafreeunion.org/. (Accessed October 2010.)

broadcast in 100% digital formats — digital television (DTV) and high definition television (HDTV). The old analog TV signals, primarily in the 700 MHz ranges, will now be recycled and relicensed for other applications to additional users, creating additional layers of ambient exposures.

The intensity of RFR is generally measured and noted in scientific literature in watts per square meter (W/m^2); milliwatts per square centimetre (mW/cm^2), or microwatts per square centimetre ($\mu W/cm^2$). All are energy relationships that exist in space. However, biological effects depend on how much of the energy is absorbed in the body of a living organism, not just what exists in space.

4. Specific absorption rate (SAR)

Absorption of RFR depends on many factors including the transmission frequency and the power density, one's distance from the radiating source, and one's orientation toward the radiation of the system. Other factors include the size, shape, mineral and water content of an organism. Children absorb energy differently than adults because of differences in their anatomies and tissue composition. Children are not just "little adults". For this reason, and because their bodies are still developing, children may be more susceptible to damage from cell phone radiation. For instance, radiation from a cell phone penetrates deeper into the head of children (Gandhi et al. 1996; Wiart et al. 2008) and certain tissues of a child's head, e.g., the bone marrow and the eye, absorb significantly more energy than those in an adult head (Christ et al. 2010). The same can be presumed for proximity to towers, even though exposure will be lower from towers under most circumstances than from cell phones. This is because of the distance from the source. The transmitter is placed directly against the head during cell phone use whereas proximity to a cell tower will be an ambient exposure at a distance.

There is little difference between cell phones and the domestic cordless phones used today. Both use similar frequencies and involve a transmitter placed against the head. But the newer digitally enhanced cordless technology (DECT) cordless domestic phones transmit a constant signal even when the phone is not in use, unlike the older domestic cordless phones. But some DECT brands are available that stop transmission if the mobile units are placed in their docking station.

The term used to describe the absorption of RFR in the body is specific absorption rate (SAR), which is the rate of energy that is actually absorbed by a unit of tissue. Specific absorption rates (SARs) are generally expressed in watts per kilogram (W/kg) of tissue. The SAR measurements are averaged either over the whole body, or over a small volume of tissue, typically between 1 and 10 g of tissue. The SAR is used to quantify energy absorption to fields typically between 100 kHz and 10 GHz and encompasses RFR from devices such as cellular phones up through diagnostic MRI (magnetic resonance imaging).

Specific absorption rates are a more reliable determinant and index of RFR's biological effects than are power density, or the intensity of the field in space, because SARs reflect what is actually being absorbed rather than the energy in space. However, while SARs may be a more precise model, at least in theory, there were only a handful of animal studies that were used to determine the threshold values of SAR for the setting of human exposure guidelines (de Lorge and Ezell 1980; de Lorge 1984). (For further information see Section 8). Those values are still reflected in today's standards.

It is presumed that by controlling the field strength from the transmitting source that SARs will automatically be controlled too, but this may not be true in all cases, especially with far-field exposures such as near cell or broadcast towers. Actual measurement of SARs is very difficult in real life so measurements of electric and magnetic fields are used as surrogates because they are easier to assess. In fact, it is impossible to conduct SAR measurements in living organisms so all values are inferred from dead animal measurements (thermography, calorimetry, etc.), phantom models, or computer simulation (FDTD).

However, according to the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) *Health Effects of Exposure to EMF*, released in January of 2009:

> . . . recent studies of whole body plane wave exposure of both adult and children phantoms demonstrated that when children and small persons are exposed to levels which are in compliance with reference levels, exceeding the basic restrictions cannot be excluded [Dimbylow and Bloch 2007; Wang et al. 2006; Kuhn et al., 2007; Hadjem et al., 2007]. While the whole frequency range has been investigated, such effects were found in the frequency bands around 100 MHz and also around 2 GHz. For a model of a 5-year-old child it has been shown that when the phantom is exposed to electromagnetic fields at reference levels, the basic restrictions were exceeded by 40% [Conil et al., 2008]. . .. Moreover, a few studies demonstrated that multipath exposure can lead to higher exposure levels compared to plane wave exposure [Neubauer et al. 2006; Vermeeren et al. 2007]. It is important to realize that this issue refers to far field exposure only, for which the actual exposure levels are orders of magnitude below existing guidelines. (p. 34–35, SCENIHR 2009)

In addition to average SARs, there are indications that biological effects may also depend on how energy is actually deposited in the body. Different propagation characteristics such as modulation, or different wave-forms and shapes, may have different effects on living systems. For example, the same amount of energy can be delivered to tissue continuously or in short pulses. Different biological effects may result depending on the type and duration of the exposure.

5. Transmission facilities

The intensity of RFR decreases rapidly with the distance from the emitting source; therefore, exposure to RFR from transmission towers is often of low intensity depending on one's proximity. But intensity is not the only factor. Living near a facility will involve long-duration exposures, sometimes for years, at many hours per day. People working at home or the infirm can experience low-level 24 h exposures. Nighttimes alone will create 8 h continuous exposures. The current standards for both ICNIRP, IEEE and the NCRP (adopted by the U.S. FCC) are for whole-body exposures averaged over a short duration (minutes) and are based on results from short-term exposure studies, not for long-term, low-level exposures such as those experienced by people living or working near transmitting facilities. For such populations, these can be involuntary exposures, unlike cell phones where user choice is involved.

There have been some recent attempts to quantify human SARs in proximity to cell towers but these are primarily for occupational exposures in close proximity to the sources and questions raised were dosimetry-based regarding the accuracy of antenna modeling (van Wyk et al. 2005). In one study by Martínez-Búrdalo et al. (2005) however, the researchers used high-resolution human body models placed at different distances to assess SARs in worst-case exposures to three different frequencies — 900, 1800, and 2170 MHz. Their focus was to compute whole-body averaged SARs at a maximum 10 g averaged SAR inside the exposed model. They concluded that for

> . . . antenna–body distances in the near zone of the antenna, the fact that averaged field values are below reference levels, could, at certain frequencies, not guarantee guidelines compliance based on basic restrictions.
> (p. 4125, Martínez-Búrdalo et al. 2005)

This raises questions about the basic validity of predicting SARs in real-life exposure situations or compliance to guidelines according to standard modeling methods, at least when one is very close to an antenna.

Thus, the relevant questions for the general population living or working near transmitting facilities are: Do biological and (or) health effects occur after exposure to low-intensity RFR? Do effects accumulate over time, since the exposure is of a long duration and may be intermittent? What precisely is the definition of low-intensity RFR? What might its biological effects be and what does the science tell us about such exposures?

6. Government radiofrequency radiation (RFR) guidelines: how spatial energy translates to the body's absorption

The U.S. FCC has issued guidelines for both power density and SARs. For power density, the U.S. guidelines are between 0.2–1.0 mW/cm^2. For cell phones, SAR levels require hand-held devices to be at or below 1.6 W/kg measured over 1.0 g of tissue. For whole body exposures, the limit is 0.08 W/kg.

In most European countries, the SAR limit for hand-held devices is 2.0 W/kg averaged over 10 g of tissue. Whole body exposure limits are 0.08 W/kg.

At 100–200 ft ($\sim$30–60 m) from a cell phone base station, a person can be exposed to a power density of 0.001 mW/cm^2 (i.e., 1.0 μW/cm^2). The SAR at such a distance can be 0.001 W/kg (i.e., 1.0 mW/kg). The U.S. guidelines for SARs are between 0.08–0.40 W/kg.

For the purposes of this paper, we will define low-intensity exposure to RFR of power density of 0.001 mW/cm^2 or a SAR of 0.001 W/kg.

7. Biological effects at low intensities

Many biological effects have been documented at very low intensities comparable to what the population experiences within 200 to 500 ft ($\sim$60–150 m) of a cell tower, including effects that occurred in studies of cell cultures and animals after exposures to low-intensity RFR. Effects reported include: genetic, growth, and reproductive; increases in permeability of the blood–brain barrier; behavioral; molecular, cellular, and metabolic; and increases in cancer risk. Some examples are as follows:

- Dutta et al. (1989) reported an increase in calcium efflux in human neuroblastoma cells after exposure to RFR at 0.005 W/kg. Calcium is an important component in normal cellular functions.
- Fesenko et al. (1999) reported a change in immunological functions in mice after exposure to RFR at a power density of 0.001 mW/cm^2.
- Magras and Xenos (1997) reported a decrease in reproductive function in mice exposed to RFR at power densities of 0.000168–0.001053 mW/cm^2.
- Forgacs et al. (2006) reported an increase in serum testosterone levels in rats exposed to GSM (global system for mobile communication)-like RFR at SAR of 0.018–0.025 W/kg.
- Persson et al. (1997) reported an increase in the permeability of the blood–brain barrier in mice exposed to RFR at 0.0004–0.008 W/kg. The blood–brain barrier is a physiological mechanism that protects the brain from toxic substances, bacteria, and viruses.
- Phillips et al. (1998) reported DNA damage in cells exposed to RFR at SAR of 0.0024–0.024 W/kg.
- Kesari and Behari (2009) also reported an increase in DNA strand breaks in brain cells of rats after exposure to RFR at SAR of 0.0008 W/kg.
- Belyaev et al. (2009) reported changes in DNA repair mechanisms after RFR exposure at a SAR of 0.0037 W/kg. A list of publications reporting biological and (or) health effects of low-intensity RFR exposure is in Table 1.

Out of the 56 papers in the list, 37 provided the SAR of exposure. The average SAR of these studies at which biological effects occurred is 0.022 W/kg — a finding below the current standards.

Ten years ago, there were only about a dozen studies reporting such low-intensity effects; currently, there are more than 60. This body of work cannot be ignored. These are important findings with implications for anyone living or working near a transmitting facility. However, again, most of the studies in the list are on short-term (minutes to hours) exposure to low-intensity RFR. Long-term exposure studies are sparse. In addition, we do not know if all of these reported effects occur in humans exposed to low-intensity RFR, or whether the reported effects are health hazards. Biological effects do not automatically mean adverse health effects, plus many biological effects are reversible. However, it is clear that low-intensity RFR is not biologically inert. Clearly, more needs to be learned before a presumption of safety can continue to be made regarding placement of antenna arrays near the population, as is the case today.

Table 1. List of studies reporting biological effects at low intensities of radiofrequency radiation (RFR).

Reference	Frequency	Form of RFR	Exposure duration	SAR (W/kg)	Power density ($\mu W/cm^2$)	Effects reported
Balmori (2010) (in vivo) (eggs and tadpoles of frog)	88.5–1873.6 MHz	Cell phone base station emission	2 months		3.25	Retarded development
Belyaev et al. (2005) (in vitro)	915 MHz	GSM	24, 48 h	0.037		Genetic changes in human white blood cells
Belyaev et al. (2009) (in vitro)	915 MHz, 1947 MHz	GSM, UMTS	24, 72 h	0.037		DNA repair mechanism in human white blood cells
Blackman et al. (1980) (in vitro)	50 MHz	AM at 16 Hz		0.0014		Calcium in forebrain of chickens
Boscol et al. (2001) (in vivo) (human whole body)	500 KHz–3 GHz	TV broadcast			0.5	Immunological system in women
Campisi et al. (2010) (in vitro)	900 MHz	CW (CW– no effect observed) AM at 50 Hz	14 days, 5, 10, 20 min per day		26	DNA damage in human glial cells
Capri et al. (2004) (in vitro)	900 MHz	GSM	1 h/day, 3 days	0.07		A slight decrease in cell proliferation when human immune cells were stimulated with mitogen and a slight increase in the number of cells with altered distribution of phosphatidylserine across the membrane
Chiang et al. (1989) (in vivo) (human whole body)	Lived and worked close to AM radio and radar installations for more than 1 year				10	People lived and worked near AM radio antennas and radar installations showed deficits in psychological and short-term memory tests
de Pomerai et al. (2003) (in vitro)	1 GHz		24, 48 h	0.015		Protein damages
D'Inzeo et al. (1988) (in vitro)	10.75 GHz	CW	30–120 s	0.008		Operation of acetylcholine-related ion-channels in cells. These channels play important roles in physiological and behavioral functions
Dutta et al. (1984) (in vitro)	915 MHz	Sinusoidal AM at 16 Hz	30 min	0.05		Increase in calcium efflux in brain cancer cells
Dutta et al. (1989) (in vitro)	147 MHz	Sinusoidal AM at 16 Hz	30 min	0.005		Increase in calcium efflux in brain cancer cells
Fesenko et al. (1999) (in vivo) (mouse- wavelength in mm range)	From 8.15–18 GHz		5 h to 7 days direction of response depended on exposure duration		1	Change in immunological functions
Forgacs et al. (2006) (in vivo) (mouse whole body)	1800 MHz	GSM, 217 Hz pulses, 576 µs pulse width	2 h/day, 10 days	0.018		Increase in serum testosterone
Guler et al. (2010) (In vivo) (rabbit whole body)	1800 MHz	AM at 217 Hz	15 min/day, 7 days		52	Oxidative lipid and DNA damages in the brain of pregnant rabbits

Table 1 (*continued*).

Reference	Frequency	Form of RFR	Exposure duration	SAR (W/kg)	Power density ($\mu W/cm^2$)	Effects reported
Hjollund et al. (1997) (in vivo) (human partial or whole body)	Military radars				10	Sperm counts of Danish military personnel, who operated mobile ground-to-air missile units that use several RFR emitting radar systems, were significantly lower compared to references
Ivaschuk et al. (1997) (in vitro)	836.55 MHz	TDMA	20 min	0.026		A gene related to cancer
Jech et al. (2001) (in vivo) (human partial body exposure-narcoleptic patients)	900 MHz	GSM— 217 Hz pulses, 577 µs pulse width	45 min	0.06		Improved cognitive functions
Kesari and Behari (2009) (in vivo) (rat whole body)	50 GHz		2 h/day, 45 days	0.0008		Double strand DNA breaks observed in brain cells
Kesari and Behari (2010) (in vivo) (rat whole body)	50 GHz		2 h/day, 45 days	0.0008		Reproductive system of male rats
Kesari et al. (2010) (in vivo) (rat whole body)	2450 MHz	50 Hz modulation	2 h/day, 35 days	0.11		DNA double strand breaks in brain cells
Kwee et al. (2001) (in vitro)	960 MHz	GSM	20 min	0.0021		Increased stress protein in human epithelial amnion cells
Lebedeva et al. (2000) (in vivo) (human partial body)	902.4 MHz	GSM	20 min		60	Brain wave activation
Lerchl et al. (2008) (in vivo) (hamster whole body)	383 MHz 900 and 1800 MHz	TETRA GSM	24 h/day, 60 days	0.08		Metabolic changes
Magras and Xenos (1997) (in vivo) (mouse whole body)	“Antenna park”	TV and FM-radio	Exposure over several generations		0.168	Decrease in reproductive function
Mann et al. (1998) (in vivo) (human whole body)	900 MHz	GSM pulse-modulated at 217 Hz, 577 µs width	8 h		20	A transient increase in blood cortisol
Marinelli et al. (2004) (in vitro)	900 MHz	CW	2–48 h	0.0035		Cell’s self-defense responses triggered by DNA damage
Markovà et al. (2005) (in vitro)	915 and 905 MHz	GSM	1 h	0.037		Chromatin conformation in human white blood cells
Navakatikian and Tomashevskaya (1994) (in vivo) (rat whole body)	2450 MHz 3000 MHz	CW (no effect observed) Pulse-modulated 2 µs pulses at 400 Hz	Single (0.5–12hr) or repeated (15–60 days, 7–12 h/day) exposure, CW–no effect	0.0027		Behavioral and endocrine changes, and decreases in blood concentrations of testosterone and insulin
Nittby et al. (2008) (in vivo) (rat whole body)	900 MHz,	GSM	2 h/week, 55 weeks	0.0006		Reduced memory functions
Novoselova et al. (1999) (in vivo) (mouse whole body – wavelength in mm range)	From 8.15–18 GHz		1 s sweep time – 16 ms reverse, 5 h		1	Functions of the immune system
Novoselova et al. (2004) (in vivo) (mouse whole body – wavelength in mm range)	From 8.15–18 GHz		1 s sweep time16 ms reverse, 1.5 h/day, 30 days		1	Decreased tumor growth rate and enhanced survival

Table 1 (*continued*).

Reference	Frequency	Form of RFR	Exposure duration	SAR (W/kg)	Power density (μW/cm²)	Effects reported
Panagopoulos et al. (2010) (in vivo) (fly whole body)	900 and 1800 MHz	GSM	6 min/day, 5 days		1–10	Reproductive capacity and induced cell death
Panagopoulos and Margaritis (2010*a*) (in vivo) (fly whole body)	900 and 1800 MHz	GSM	6 min/day, 5 days		10	'Window' effect of GSM radiation on reproductive capacity and cell death
Panagopoulos and Margaritis (2010*b*) (in vivo) (fly whole body)	900 and 1800 MHz	GSM	1–21 min/day, 5 days		10	Reproductive capacity of the fly decreased linearly with increased duration of exposure
Pavicic and Trosic (2008) (in vitro)	864 and 935 MHz	CW	1–3 h	0.08		Growth affected in Chinese hamster V79 cells
Pérez-Castejón et al. (2009) (in vitro)	9.6 GHz	90% AM	24 h	0.0004		Increased proliferation rate in human astrocytoma cancer cells
Persson et al. (1997) (in vivo) (mouse whole body)	915 MHz	CW and pulse-modulated (217 Hz, 0.57 ms; 50 Hz, 6.6 ms)	2–960 min; CW more potent	0.0004		Increase in permeability of the blood–brain barrier
Phillips et al. (1998) (in vitro)	813.5625 MHz 836.55 MHz	iDEN TDMA	2, 21 h 2, 21 h	0.0024		DNA damage in human leukemia cells
Pologea-Moraru et al. (2002) (in vitro)	2.45 GHz		1 h		15	Change in membrane of cells in the retina
Pyrpasopoulou et al. (2004) (in vivo) (rat whole body)	9.4 GHz	GSM (50 Hz pulses, 20 μs pulse length)	1–7 days postcoitum	0.0005		Exposure during early gestation affected kidney development
Roux et al. (2008*a*) (in vivo) (tomato whole body)	900 MHz				7	Gene expression and energy metabolism
Roux et al. (2008*b*) (in vivo) (plant whole body)	900 MHz				7	Energy metabolism
Salford et al. (2003) (in vivo) (rat whole body)	915 MHz	GSM	2 h	0.02		Nerve cell damage in brain
Sarimov et al. (2004) (in vitro)	895–915 MHz	GSM	30 min	0.0054		Human lymphocyte chromatin affected similar to stress response
Schwartz et al. (1990) (in vitro)	240 MHz	CW and sinusoidal modulation at 0.5 and 16 Hz, effect only observed at 16 Hz modulation	30 min	0.00015		Calcium movement in the heart
Schwarz et al. (2008) (in vitro)	1950 MHz	UMTS	24 h	0.05		Genes in human fibroblasts
Somosy et al. (1991) (in vitro)	2.45 GHz	CW and 16 Hz square-modulation, modulated field more potent than CW		0.024		Molecular and structural changes in cells of mouse embryos

Table 1 (*concluded*).

Reference	Frequency	Form of RFR	Exposure duration	SAR (W/kg)	Power density (μW/cm^2)	Effects reported
Stagg et al. (1997) (in vitro)	836.55 MHz	TDMA duty cycle 33%	24 h	0.0059		Glioma cells showed significant increases in thymidine incorporation, which may be an indication of an increase in cell division
Stankiewicz et al. (2006) (in vitro)	900 MHz	GSM 217 Hz pulses, 577 ms width		0.024		Immune activities of human white blood cells
Tattersall et al. (2001) (in vitro)	700 MHz	CW	5–15 min	0.0016		Function of the hippocampus
Velizarov et al. (1999) (in vitro)	960 MHz	GSM 217 Hz square-pulse, duty cycle 12%	30 min	0.000021		Decrease in proliferation of human epithelial amnion cells
Veyret et al. (1991) (in vivo) (mouse whole body)	9.4 GHz	1 μs pulses at 1000 pps, also with or without sinusoidal AM between 14 and 41 MHz, response only with AM, direction of response depended on AM frequency		0.015		Functions of the immune system
Vian et al. (2006) (in vivo) plant	900 MHz				7	Stress gene expression
Wolke et al. (1996) (in vitro)	900, 1300, 1800 MHz 900 MHz	Square-wave modulated at 217 Hz CW, 16 Hz, 50 Hz, and 30 KHz modulations		0.001		Calcium concentration in heart muscle cells of guinea pig
Yurekli et al. (2006) (in vivo) (rat whole body)	945 MHz	GSM, 217 Hz pulse-modulation	7 h/day, 8 days	0.0113		Free radical chemistry

Note: These papers gave either specific absorption rate, SAR, (W/kg) or power density (μW/cm^2) of exposure. (Studies that did not contain these values were excluded). AM, amplitude-modulated or amplitude-modulation; CW, continuous wave; GSM, global system for mobile communication; iDEN, integrated digital enhanced network; TDMA, time division multiple access, TETRA, terrestrial trunked radio; UMTS, universal mobile telecommunications system.

8. Long-term exposures and cumulative effects

There are many important gaps in the RFR research. The majority of the studies on RFR have been conducted with short-term exposures, i.e., a few minutes to several hours. Little is known about the effects of long-term exposure such as would be experienced by people living near telecommunications installations, especially with exposures spanning months or years. The important questions then are: What are the effects of long-term exposure? Does long-term exposure produce different effects from short-term exposure? Do effects accumulate over time?

There is some evidence of cumulative effects. Phillips et al. (1998) reported DNA damage in cells after 24 h exposure to low-intensity RFR. DNA damage can lead to gene mutation that accumulates over time. Magras and Xenos (1997) reported that mice exposed to low-intensity RFR became less reproductive. After five generations of exposure the mice were not able to produce offspring. This shows that the effects of RFR can pass from one generation to another. Persson et al. (1997) reported an increase in permeability of the blood–brain barrier in mice when the energy deposited in the body exceeded 1.5 J/kg (joule per kilogram) — a measurement of the total amount of energy deposited. This suggests that a short-term, high-intensity exposure can produce the same effect as a long-term, low-intensity exposure, and is another indication that RFR effects can accumulate over time.

In addition, there is some indication that test animals become more sensitive to radiation after long-term exposure as seen in two of the critical experiments that contributed to the present SAR standards, called the "behavior–disruption experiments" carried out in the 1980s.

In the first experiment, de Lorge and Ezell (1980) trained rats on an auditory observing-response task. In the task, an animal was presented with two bars. Pressing the right bar would produce either a low-pitch or a high-pitch tone for half a second. The low-pitch tone signaled an unrewarded situation and the animal was expected to do nothing. However, when the high-pitch tone was on, pressing the left bar would produce a food reward. Thus, the task required continuous vigilance in which an animal had to coordinate its motor responses according to the stimulus presented to get a reward by choosing between a high-pitch or low-pitch tone. After learning the task, rats were then irradiated with 1280 MHz or 5620 MHz RFR during performance. Disruption of behavior (i.e., the rats could not perform very well) was observed within 30–60 min of exposure at a SAR of 3.75 W/kg for 1280 MHz, and 4.9 W/kg for 5620 MHz.

In another experiment, de Lorge (1984) trained monkeys on a similar auditory observing response task. Monkeys were exposed to RFR at 225, 1300, and 5800 MHz. Disruption of performance was observed at 8.1 mW/cm^2 (SAR 3.2 W/kg) for 225 MHz; at 57 mW/cm^2 (SAR 7.4 W/kg) for 1300 MHz; and at 140 mW/cm^2 (SAR 4.3 W/kg) for 5800 MHz. The disruption occurred when body temperature was increased by 1°C.

The conclusion from these experiments was that "... disruption of behavior occurred when an animal was exposed at an SAR of approximately 4 W/kg, and disruption occurred after 30–60 minutes of exposure and when body temperature increased by 1°C" (de Lorge 1984). Based on just these two experiments, 4 W/kg has been used in the setting of the present RFR exposure guidelines for humans. With theoretical safety margins added, the limit for occupational exposure was then set at 0.4 W/kg (i.e., 1/10 of the SAR where effects were observed) and for public exposure 0.08 W/kg for whole body exposures (i.e., 1/5 of that of occupational exposure).

But the relevant question for establishing a human SAR remains: Is this standard adequate, based on so little data, primarily extrapolated from a handful of animal studies from the same investigators? The de Lorge (1984) animal studies noted previously describe effects of short-term exposures, defined as less than one hour. But are they comparable to long-term exposures like what whole populations experience when living or working near transmitting facilities?

Two series of experiments were conducted in 1986 on the effects of long-term exposure. D'Andrea et al. (1986*a*) exposed rats to 2450 MHz RFR for 7 h a day, 7 days per week for 14 weeks. They reported a disruption of behavior at an SAR of 0.7 W/kg. And D'Andrea et al. (1986*b*) also exposed rats to 2450 MHz RFR for 7 h a day, 7 days per week, for 90 days at an SAR of 0.14 W/kg and found a small but significant disruption in behavior. The experimenters concluded, "... the threshold for behavioral and physiological effects of chronic (long-term) RFR exposure in the rat occurs between 0.5 mW/cm^2 (0.14 W/kg) and 2.5 mW/cm^2 (0.7 W/kg)" (p. 55, D'Andrea et al. 1986*b*).

The previously mentioned studies show that RFR can produce effects at much lower intensities after test animals are repeatedly exposed. This may have implications for people exposed to RFR from transmission towers for long periods of time.

Other biological outcomes have also been reported after long-term exposure to RFR. Effects were observed by Baranski (1972) and Takashima et al. (1979) after prolonged, repeated exposure but not after short-term exposure. Conversely, in other work by Johnson et al. (1983), and Lai et al. (1987, 1992) effects that were observed after short-term exposure disappeared after prolonged, repeated exposure, i.e., habituation occurred. Different effects were observed by Dumansky and Shandala (1974) and Lai et al. (1989) after different exposure durations. The conclusion from this body of work is that effects of long-term exposure can be quite different from those of short-term exposure.

Since most studies with RFR are short-term exposure studies, it is not valid to use their results to set guidelines for long-term exposures, such as in populations living or working near cell phone base stations.

9. Effects below 4 W/kg: thermal versus nonthermal

As described previously, current international RFR exposure standards are based mainly on the acute exposure experiments that showed disruption of behavior at 4 W/kg. However, such a basis is not scientifically valid. There are many studies that show biological effects at SARs less than 4 W/kg after short-term exposures to RFR. For example, since the 4 W/kg originated from psychological and (or) behavioral experiments, when one surveys the EMF literature on behavioral effects, one can find many reports on behavioral effects observed at SARs less than 4 W/kg, e.g., D'Andrea et al. (1986*a*) at 0.14 to 0.7 W/kg; DeWitt et al. (1987) at 0.14 W/kg; Gage (1979) at 3 W/kg ; King et al. (1971) at 2.4 W/kg; Kumlin et al. (2007) at 3 W/kg; Lai et al. (1989) at 0.6 W/kg; Mitchell et al. (1977) at 2.3 W/kg (1977); Navakatikian and Tomashevskaya (1994) at 0.027 W/kg; Nittby et al. (2008) at 0.06 W/kg; Schrot et al. (1980) at 0.7 W/kg; Thomas et al. (1975) at 1.5 to 2.7 W/kg; and Wang and Lai (2000) at 1.2 W/kg.

The obvious mechanism of effects of RFR is thermal (i.e., tissue heating). However, for decades, there have been questions about whether nonthermal (i.e., not dependent on a change in temperature) effects exist. This is a well-discussed area in the scientific literature and not the focus of this paper but we would like to mention it briefly because it has implications for public safety near transmission facilities.

Practically, we do not actually need to know whether RFR effects are thermal or nonthermal to set exposure guidelines. Most of the biological-effects studies of RFR that have been conducted since the 1980s were under nonthermal conditions. In studies using isolated cells, the ambient temperature during exposure was generally well controlled. In most animal studies, the RFR intensity used usually did not cause a significant increase in body temperature in the test animals. Most scientists consider nonthermal effects as established, even though the implications are not fully understood.

Scientifically, there are three rationales for the existence of nonthermal effects:

1. Effects can occur at low intensities when a significant increase in temperature is not likely.
2. Heating does not produce the same effects as RFR exposure.
3. RFR with different modulations and characteristics produce different effects even though they may produce the same pattern of SAR distribution and tissue heating.

Low-intensityeffects have been discussed previously (see Section 7.). There are reports that RFR triggers effects that are different from an increase in temperature, e.g., Wachtel et al. (1975); Seaman and Wachtel (1978); D'Inzeo et al. (1988). And studies showing that RFR of the same frequency and intensity, but with different modulations and waveforms, can produce different effects as seen in the work of Baranski (1972); Arber and Lin (1985); Campisi et al. (2010); d'Ambrosio et al. (2002); Frey et al. (1975); Oscar and Hawkins (1977); Sanders et al. (1985); Huber et al. (2002); Markkanen et al. (2004); Hung et al. (2007); and Luukkonen et al. (2009).

A counter-argument for point 1 is that RFR can cause micro-heating at a small location even though there is no measurement change in temperature over the whole sample. This implies that an effect observed at low intensities could be due to localized micro-heating, and, therefore, is still considered thermal. However, the micro-heating theory could not apply to test subjects that are not stationary, such as in the case of Magras and Xenos (1997) who reported that mice exposed to low-intensity RFR became less reproductive over several generations. "Hot spots" of heating move within the body when the subject moves in the field and, thus, cannot maintain sustained heating of certain tissue.

The counter argument for point 2 is that heating by other means does not produce the same pattern of energy distribution as RFR. Thus, different effects would result. Again, this counter argument does not work on moving objects. Thus, results supporting the third point are the most compelling.

10. Studies on exposure to cell tower transmissions

From the early genesis of cell phone technology in the early 1980s, cell towers were presumed safe when located near populated areas because they are low-power installations in comparison with broadcast towers. This thinking already depended on the assumption that broadcast towers were safe if kept below certain limits. Therefore, the reasoning went, cell towers would be safer still. The thinking also assumed that exposures between cell and broadcast towers were comparable. In certain cities, cell and broadcast tower transmissions both contributed significantly to the ambient levels of RFR (Sirav and Seyhan 2009; Joseph et al. 2010).

There are several fallacies in this thinking, including the fact that broadcast exposures have been found unsafe even at regulated thresholds. Adverse effects have been noted for significant increases for all cancers in both men and women living near broadcast towers (Henderson and Anderson 1986); childhood leukemia clusters (Maskarinec et al. 1994; Ha et al. 2003; Park et al. 2004); adult leukemia and lymphoma clusters, and elevated rates of mental illness (Hocking et al. 1996; Michelozzi et al. 2002; Ha et al. 2007); elevated brain tumor incidence (Dolk et al. 1997*a*, 1997*b*); sleep disorders, decreased concentration, anxiety, elevated blood pressure, headaches, memory impairment, increased white cell counts, and decreased lung function in children (Altpeter et al. 2000); motor, memory, and learning impairment in children (Kolodynski and Kolodynski 1996), nonlinear increases in brain tumor incidence (Colorado Department of Public Health 2004); increases in malignant melanoma (Hallberg and Johansson 2002); and nonlinear immune system changes in women (Boscol et al. 2001). (The term "nonlinear" is used in scientific literature to mean that an effect was not directly proportional to the intensity of exposure. In the case of the two studies mentioned previously, adverse effects were found at significant distances from the towers, not in closer proximity where the power density exposures were higher and therefore presumed to have a greater chance of causing effects. This is something that often comes up in low-level energy studies and adds credence to the argument that low-level exposures could cause qualitatively different effects than higher level exposures.)

There is also anecdotal evidence in Europe that some communities have experienced adverse physical reactions after the switch from analog TV broadcast signals to the new digital formats, which can be more biologically complex

Three doctors in Germany, Cornelia Waldmann-Selsam, MD, Christine Aschermann, MD, and Markus Kern, MD, wrote (in a letter to the U.S. President, entitled *Warning — Adverse Health Effects From Digital Broadcast Television*)[10], that on 20 May 2006, two digital broadcast television stations went on the air in the Hessian Rhoen area. Prior to that time that area had low radiation levels, which included that from cell phone towers of which there were few. However, coinciding with the introduction of the digital signals, within a radius of more than 20 km, there was an abrupt onset of symptoms for constant headaches, pressure in the head, drowsiness, sleep problems, inability to think clearly, forgetfulness, nervousness, irritability, tightness in the chest, rapid heartbeat, shortness of breath, depression, apathy, loss of empathy, burning skin, sense of inner burning, leg weakness, pain in the limbs, stabbing pain in various organs, and weight gain. They also noted that birds fled the area. The same symptoms gradually appeared in other locations after digital signals were introduced. Some physicians accompanied affected people to areas where there was no TV reception from terrestrial sources, such as in valleys or behind mountain ranges, and observed that many people became symptom free after only a short time. The digital systems also require more transmitters than the older analog systems and, therefore, somewhat higher exposure levels to the general population are expected, according to the 2009 SCENIHR Report (SCENIHR 2009).

Whether digital or analog, the frequencies differ between broadcast and cell antennas and do not couple with the human anatomy in whole-body or organ-specific models in the same ways (NCRP 1986; ICNIRP 1998). This difference in how the body absorbs energy is the reason that all standards-setting organizations have the strictest limitations between 30–300 MHz — ranges that encompass FM broadcast where whole body resonance occurs (Cleveland 2001). Exposure allowances are more lenient for cell technology in frequency ranges between 300 MHz and 3 GHz, which encompass cellular phone technology. This is based on the assumption that the cell frequencies do not penetrate the body as deeply and no whole-body resonance can occur.

There are some studies on the health effects on people living near cell phone towers. Though cell technology has been in existence since the late 1980s, the first study of populations near cell tower base stations was only conducted by Santini et al. (2002). It was prompted in part by complaints of adverse effects experienced by residents living near cell base stations throughout the world and increased activism by citizens. As well, increasing concerns by physicians to understand those complaints was reflected in professional organizations like the ICEMS (International Committee on Electromagnetic Safety) Catania Resolution[11], the Irish Doctors Environmental Association (IDEA)[12], and the Freiburger Appeal[13].

Santini conducted a survey study of 530 people (270 men, 260 women) on 18 nonspecific health symptoms (NSHS) in relation to self-reported distance from towers of <10 m, 10 to 50 m, 50 to 100 m, 100 to 200 m, 200 to 300 m, and >300 m. The control group compared people living more than 300 m (approximately 1000 ft) or not exposed to base stations. They controlled for age, presence of electrical transformers (<10 m), high tension lines (<100 m), and radio/TV broadcast transmitters (<4 km), the frequency of cell phone use (>20 min per day), and computer use (>2 h per day). Questions also included residents' location in relation to antennas, taking into account orientations that were facing, beside, behind, or beneath antennas in cases of roof-mounted antenna arrays. Exposure conditions were defined by the length of time living in the neighborhood (<1 year through >5 years); the number of days per week and hours per day (<1 h to >16 h) that were spent in the residence.

Results indicated increased symptoms and complaints the closer a person lived to a tower. At <10 m, symptoms included nausea, loss of appetite, visual disruptions, and difficulty in moving. Significant differences were observed up through 100 m for irritability, depressive tendencies, concentration difficulties, memory loss, dizziness, and lower libido. Between 100 and 200 m, symptoms included headaches, sleep disruption, feelings of discomfort, and skin problems. Beyond 200 m, fatigue was significantly reported more often than in controls. Women significantly reported symptoms more often than men, except for libido loss. There was no increase in premature menopause in women in relation to distance from towers. The authors concluded that there were different sex-dependent sensitivities to electromagnetic fields. They also called for infrastructure not to be sited <300 m (~1000 ft) from populations for precautionary purposes, and noted that the information their survey captured might not apply to all circumstances since actual exposures depend on the volume of calls being generated from any particular tower, as well as on how radiowaves are reflected by environmental factors.

Similar results were found in Egypt by Abdel-Rassoul et al. (2007) looking to identify neurobehavioral deficits in people living near cell phone base stations. Researchers conducted a cross-sectional study of 85 subjects: 37 living inside a building where antennas were mounted on the rooftop and 48 agricultural directorate employees who worked in a building ($\sim$10 m) opposite the station. A control group of 80 who did not live near base stations were matched for age, sex, occupation, smoking, cell phone use, and educational level. All participants completed a questionnaire containing personal, educational, and medical histories; general and neurological examinations; a neurobehavioral test battery (NBTB) involving tests for visuomotor speed, problem solving, attention, and memory, in addition to a Eysenck personality questionnaire (EPQ).

Their results found a prevalence of neuropsychiatric complaints: headaches, memory changes, dizziness, tremors, depressive symptoms, and sleep disturbance were significantly higher among exposed inhabitants than controls. The NBTB indicated that the exposed inhabitants exhibited a significantly lower performance than controls in one of the tests of attention and short-term auditory memory (paced auditory

[10] http://www.notanotherconspiracy.com/2009/02/warning-adverse-health-effects-from.html. (Accessed October 2010.)
[11] http://www.icems.eu/resolution.htm
[12] http://www.ideeaireland.org/emr.htm
[13] http://www.laleva.cc/environment/freiburger_appeal.html

serial addition test (PASAT)). Also, the inhabitants opposite the station exhibited a lower performance in the problem-solving test (block design) than those who lived under the station. All inhabitants exhibited a better performance in the two tests of visuomotor speed (digit symbol and Trailmaking B) and one test of attention (Trailmaking A) than controls.

Environmental power-density data were taken from measurements of that building done by the National Telecommunications Institute in 2000. Measurements were collected from the rooftop where the antennas were positioned, the shelter that enclosed the electrical equipment and cables for the antennas, other sites on the roof, and within an apartment below one of the antennas. Power-density measurements ranged from 0.1–6.7 $\mu W/cm^2$. No measurements were taken in the building across the street. The researchers noted that the last available measurements of RFR in 2002 in that area were less than the allowable standards but also noted that exposures depended on the number of calls being made at any given time, and that the number of cell phone users had increased approximately four times within the 2 years just before the beginning of their study in 2003. They concluded that inhabitants living near mobile phone base stations are at risk for developing neuropsychiatric problems, as well as some changes in the performance of neurobehavioral functions, either by facilitation (over-stimulation) or inhibition (suppression). They recommended the standards be revised for public exposure to RFR, and called for using the NBTB for regular assessment and early detection of biological effects among inhabitants near base stations (Abdel-Rassoul et al. 2007).

Hutter et al. (2006) sought to determine cognitive changes, sleep quality, and overall well-being in 365 rural and urban inhabitants who had lived for more than a year near 10 selected cell phone base stations. Distance from antennas was 24 to 600 m in rural areas, and 20 to 250 m in the urban areas. Field strength measurements were taken in bedrooms and cognitive tests were performed. Exposure to high-frequency EMFs was lower than guidelines and ranged from 0.000002 to 0.14 $\mu W/cm^2$ for all frequencies between 80 MHz and 2 GHz with the greater exposure coming from mobile telecommunications facilities, which was between 0.000001 and 0.14 $\mu W/cm^2$. Maximum levels were between 0.000002 and 0.41 $\mu W/cm^2$ with an overall 5% of the estimated maximum above 0.1 $\mu W/cm^2$. Average levels were slightly higher in rural areas (0.005 $\mu W/cm^2$) than in urban areas (0.002 $\mu W/cm^2$). The researchers tried to ascertain if the subjective rating of negative health consequences from base stations acted as a covariable but found that most subjects expressed no strong concerns about adverse effects from the stations, with 65% and 61% in urban and rural areas, respectively, stating no concerns at all. But symptoms were generally higher for subjects who expressed health concerns regarding the towers. The researchers speculated that this was due to the subjects with health complaints seeking answers and consequently blaming the base station; or that subjects with concerns were more anxious in general and tended to give more negative appraisals of their body functions; and the fact that some people simply give very negative answers.

Hutter's results were similar to those of Santini et al. (2002) and Abdel-Rassoul et al. (2007). Hutter found a significant relationship between symptoms and power densities. Adverse effects were highest for headaches, cold hands and feet, cardiovascular symptoms, and concentration difficulties. Perceptual speed increased while accuracy decreased insignificantly with increasing exposure levels. Unlike the others, however, Hutter found no significant effects on sleep quality and attributed such problems more to fear of adverse effects than actual exposure. They concluded that effects on well-being and performance cannot be ruled out even as mechanisms of action remain unknown. They further recommended that antenna siting should be done to minimize exposure to the population.

Navarro et al. (2003) measured the broadband electric field (E-field) in the bedrooms of 97 participants in La Nora, Murcia, Spain and found a significantly higher symptom score in 9 out of 16 symptoms in the groups with an exposure of 0.65 V/m (0.1121 $\mu W/cm^2$) compared with the control group with an exposure below 0.2 V/m (0.01061 $\mu W/cm^2$), both as an average. The highest contributor to the exposure was GSM 900/1800 MHz signals from mobile telecommunications. The same researchers also reported significant correlation coefficients between the measured E-field and 14 out of 16 health-related symptoms with the five highest associations found for depressive tendencies, fatigue, sleeping disorders, concentration difficulties, and cardiovascular problems. In a follow up work, Oberfeld et al. (2004) conducted a health survey in Spain in the vicinity of two GSM 900/1800 MHz cell phone base stations, measuring the E-field in six bedrooms, and found similar results. They concluded that the symptoms are in line with "microwave syndrome" reported in the literature (Johnson-Liakouris 1998). They recommended that the sum total for ambient exposures should not be higher than 0.02 V/m — the equivalent of a power density of 0.00011 $\mu W/cm^2$, which is the indoor exposure value for GSM base stations proposed by the Public Health Office of the Government of Salzburg, Austria in 2002[14].

Eger et al. (2004) took up a challenge to medical professionals by Germany's radiation protection board to determine if there was an increased cancer incidence in populations living near cell towers. Their study evaluated data for approximately 1000 patients between the years of 1994 and 2004 who lived close to cell antennas. The results showed that the incidence of cancer was significantly higher among those patients who had lived for 5 to 10 years at a distance of up to 400 m from a cell installation that had been in operation since 1993, compared with those patients living further away, and that the patients fell ill on an average of 8 years earlier than would be expected. In the years between 1999 and 2004, after 5 years operation of the transmitting installation, the relative risk of getting cancer had tripled for residents in proximity of the installation compared with inhabitants outside of the area.

Wolf and Wolf (2004) investigated increased cancer incidence in populations living in a small area in Israel exposed

[14] http://www.salzburg.gv.at/umweltmedizin. (Accessed October 2010.)

to RFR from a cell tower. The antennas were mounted 10 m high, transmitting at 850 MHz and 1500 W at full-power output. People lived within a 350 m half circle of the antennas. An epidemiologic assessment was done to determine whether the incidence of cancer cases among individuals exposed to the base station in the south section of the city of Netanya called Irus (designated area A) differed from expected cancer rates throughout Israel, and in the town of Netanya in general, as compared with people who lived in a nearby area without a cell tower (designated area B). There were 622 participants in area A who had lived near the cell tower for 3 to 7 years and were patients at one health clinic. The exposure began 1 year before the start of the study when the station first came into service. A second cohort of individuals in area B, with 1222 participants who received medical services at a different clinic located nearby, was used as a control. Area B was closely matched for environment, workplace, and occupational characteristics. In exposure area A, eight cases of different types of cancer were diagnosed in a period of 1 year, including cancers of the ovary (1), breast (3), Hodgkins lymphoma (1), lung (1), osteoid osteoma (1), and hypernephroma (1). The RFR field measurements were also taken per house and matched to the cancer incidents. The rate of cancers in area A was compared with the annual rate of the general population (31 cases per 10 000) and to incidence for the entire town of Netanya. There were two cancers in area B, compared to eight in area A. They also examined the history of the exposed cohort (area A) for malignancies in the 5 years before exposure began and found only two cases in comparison to eight cases 1 year after the tower went into service. The researchers concluded that relative cancer rates for females were 10.5 for area A, 0.6 for area B, and 1.0 for the whole town of Netanya. Cancer incidence in women in area A was thus significantly higher (p <0.0001) compared with that of area B and the whole city. A comparison of the relative risk revealed that there were 4.15 times more cases in area A than in the entire population. The study indicated an association between increased incidence of cancer and living in proximity to a cell phone base station. The measured level of RFR, between 0.3 to 0.5 μW/cm^2, was far below the thermal guidelines.

11. Risk perception, electrohypersensitivity, and psychological factors

Others have followed up on what role risk perception might play in populations near cell base stations to see if it is associated with health complaints.

Blettner et al. (2008) conducted a cross-sectional, multiphase study in Germany. In the initial phase, 30 047 people out of a total of 51 444, who took part in a nationwide survey, were also asked about their health and attitudes towards mobile phone base stations. A list of 38 potential health complaints were used. With a response rate of 58.6%, 18.0% were concerned about adverse health effects from base stations, 10.3% directly attributed personal adverse effects to them. It was found that people living within 500 m, or those concerned about personal exposures, reported more health complaints than others. The authors concluded that even though a substantial proportion of the German population is concerned about such exposures, the observed higher health complaints cannot be attributed to those concerns alone.

Kristiansen et al. (2009) also explored the prevalence and nature of concerns about mobile phone radiation, especially since the introduction of new 3G–UMTS (universal mobile telecommunications system) networks that require many more towers and antennas have sparked debate throughout Europe. Some local governments have prohibited mobile antennas on public buildings due to concerns about cancer, especially brain cancer in children and impaired psychomotor functions. One aim of the researchers was risk assessment — to compare people's perceptions of risk from cell phones and masts to other fears, such as being struck by lightening. In Denmark, they used data from a 2006 telephone survey of 1004 people aged 15+ years. They found that 28% of the respondents were concerned about exposure to mobile phone radiation and 15% about radiation from masts. In contrast, 82% of respondents were concerned about other forms of environmental pollution. Nearly half of the respondents considered the mortality risk of 3G phones and masts to be of the same order of magnitude as being struck by lightning (0.1 fatalities per million people per year), while 7% thought it was equivalent to tobacco-induced lung cancer (approximately 500 fatalities per million per year). Among women, concerns about mobile phone radiation, perceived mobile phone mortality risk, and concerns about unknown consequences of new technologies, increased with educational levels. More than two thirds of the respondents felt that they had not received adequate public information about the 3G system. The results of the study indicated that the majority of the survey population had little concern about mobile phone radiation, while a minority is very concerned.

Augner et al. (2009) examined the effects of short-term GSM base station exposure on psychological symptoms including good mood, alertness, and calmness as measured by a standardized well-being questionnaire. Fifty-seven participants were randomly assigned to one of three different exposure scenarios. Each of those scenarios subjected participants to five 50 min exposure sessions, with only the first four relevant for the study of psychological symptoms. Three exposure levels were created by shielding devices, which could be installed or removed between sessions to create double-blinded conditions. The overall median power densities were 0.00052 μW/cm^2 during low exposures, 0.0154 μW/cm^2 during medium exposures, and 0.2127 μW/cm^2 during high-exposure sessions. Participants in high- and medium-exposure scenarios were significantly calmer during those sessions than participants in low-exposure scenarios throughout. However, no significant differences between exposure scenarios in the "good mood" or "alertness" factors were found. The researchers concluded that short-term exposure to GSM base station signals may have an impact on well-being by reducing psychological arousal.

Eltiti et al. (2007) looked into exposures to the GSM and UMTS exposures from base stations and the effects to 56 participants who were self-reported as sensitive to electromagnetic fields. Some call it electro-hypersensitivity (EHS) or just electrosensitivity. People with EHS report that they suffer negative health effects when exposed to electromagnetic fields from everyday objects such as cell phones, mobile phone base stations, and many other common things in modern societies. EHS is a recognized functional impairment in Sweden. This study used both open provocation and double-blind tests to determine if electrosensitive and control individuals experienced more negative health effects when exposed to base-station-like signals compared with sham exposures. Fifty-six electrosensitive and 120 control participants were tested first in an open provocation test. Of these, 12 electrosensitive and six controls withdrew after the first session. Some of the electrosensitive subjects later issued a statement saying that the initial exposures made them too uncomfortable to continue participating in the study. This means that the study may have lost its most vulnerable test subjects right at the beginning, possibly skewing later outcomes. The remainder completed a series of double-blind tests. Subjective measures of well-being and symptoms, as well as physiological measures of blood-volume pulse, heart rate, and skin conductance were obtained. They found that during the open provocation, electrosensitive individuals reported lower levels of well-being to both GSM and UMTS signals compared with sham exposure, whereas controls reported more symptoms during the UMTS exposure. During double-blind tests the GSM signal did not have any effect on either group. Electrosensitive participants did report elevated levels of arousal during the UMTS condition, but the number or severity of symptoms experienced did not increase. Physiological measures did not differ across the three exposure conditions for either group. The researchers concluded that short-term exposure to a typical GSM base-station-like signal did not affect well-being or physiological functions in electrosensitive or control individuals even though the electrosensitive individuals reported elevated levels of arousal when exposed to a UMTS signal. The researchers stated that this difference was likely due to the effect of the order of the exposures throughout the series rather than to the exposure itself. The researchers do not speculate about possible data bias when one quarter of the most sensitive test subjects dropped out at the beginning.

In follow-up work, Eltiti et al. (2009) attempted to clarify some of the inconsistencies in the research with people who report sensitivity to electromagnetic fields. Such individuals, they noted, often report cognitive impairments that they believe are due to exposure to mobile phone technology. They further said that previous research in this area has revealed mixed results, with the majority of research only testing control individuals. Their aim was to clarify whether short-term (50 min) exposure at 1 $\mu W/cm^2$ to typical GSM and UMTS base station signals affects attention, memory, and physiological endpoints in electrosensitive and control participants. Data from 44 electrosensitive and 44 matched-control participants who performed the digit symbol substitution task (DSST), digit span task (DS), and a mental arithmetic task (MA), while being exposed to GSM, UMTS, and sham signals under double-blind conditions were analyzed. Overall, the researchers concluded that cognitive functioning was not affected by short-term exposure to either GSM or UMTS signals. Nor did exposure affect the physiological measurements of blood-volume pulse, heart rate, and skin conductance that were taken while participants performed the cognitive tasks. The GSM signal was a combined signal of 900 and 1800 MHz frequencies, each with a power flux density of 0.5 $\mu W/cm^2$, which resulted in combined power flux density of 1 $\mu W/cm^2$ over the area where test subjects were seated. Previous measurements in 2002 by the National Radiological Protection Board in the UK, measuring power density from base stations at 17 sites and 118 locations (Mann et al. 2002), found that in general, the power flux density was between 0.001 $\mu W/cm^2$ to 0.1 $\mu W/cm^2$, with the highest power density being 0.83 $\mu W/cm^2$. The higher exposure used by the researchers in this study was deemed comparable by them to the maximum exposure a person would encounter in the real world. But many electrosensitive individuals report that they react to much lower exposures too. Overall, the electrosensitive participants had a significantly higher level of mean skin conductance than control subjects while performing cognitive tasks. The researchers noted that this was consistent with other studies that hypothesize sensitive individuals may have a general imbalance in autonomic nervous system regulation. Generally, cognitive functioning was not affected in either electrosensitives or controls. When Bonferroni corrections were applied to the data, the effects on mean skin conductance disappeared. A criticism is that this averaging of test results hides more subtle effects.

Wallace et al. (2010) also tried to determine if short-term exposure to RFR had an impact on well-being and what role, if any, psychological factors play. Their study focused on “Airwave”, a new communication system being rolled out across the UK for police and emergency services. Some police officers have complained about skin rashes, nausea, headaches, and depression as a consequence of using Airwave two-way radio handsets. The researchers used a small group of self-reported electrosensitive people to determine if they reacted to the exposures, and to determine if exposures to specific signals affect a selection of the adult population who do not report sensitivity to electromagnetic fields. A randomized double-blind provocation study was conducted to establish whether short-term exposure to a terrestrial trunked radio (TETRA) base station signal has an impact on health and well-being in individuals with electrosensitivity and controls. Fifty-one individuals with electrosensitivity and 132 age- and gender-matched controls participated first in an open provocation test, while 48 electrosensitive and 132 control participants went on to complete double-blind tests in a fully screened semi-anechoic chamber. Heart rate, skin conductance, and blood pressure readings provided objective indices of short-term physiological response. Visual analogue scales and symptom scales provided subjective indices of well-being. Their results found no differences on any measure between TETRA and sham (no signal) under double-blind conditions for either control or electrosensitive participants and neither group could detect the presence of a TETRA signal above chance (50%). The researchers noted, however, that when conditions were not double-blinded, the electrosensitive individuals did report feeling worse and experienced more severe symptoms during TETRA compared with sham exposure. They concluded that the adverse symptoms experienced by electrosensitive individuals are caused by the belief of harm from TETRA base stations rather than because of the low-level EMF exposure itself.

It is interesting to note that the three previously mentioned studies were all conducted at the same Electromagnetics and Health Laboratory at the University of Essex, Essex, UK, by the same relative group of investigators. Those claiming to be electrosensitive are a small subgroup in the population, often in touch through Internet support groups. In the first test, many electrosensitives dropped out because they found the exposures used in the study too uncomfortable. The drop-out rate decreased with the subsequent studies, which raises the question of whether the electrosensitive participants in the latter studies were truly electrosensitive. There is a possibility that a true subgroup of electrosensitives cannot tolerate such study conditions, or that potential test subjects are networking in a way that preclude their participation in the first place. In fact, researchers were not able to recruit their target numbers for electrosensitive participants in any of the studies. The researchers also do not state if there were any of the same electrosensitive participants used in the three studies. Nor do they offer comment regarding the order of the test methods possibly skewing results.

Because of uncertainty regarding whether EMF exposures are actually causing the symptoms that electrosensitives report, and since many electrosensitives also report sensitivities to myriad chemicals and other environmental factors, it has been recommended (Hansson Mild et al. 2006) that a new term be used to describe such individuals — idiopathic environmental intolerance with attribution to electromagnetic fields (IEI-EMF).

Furubayashi et al. (2009) also tried to determine if people who reported symptoms to mobile phones are more susceptible than control subjects to the effect of EMF emitted from base stations. They conducted a double-blind, cross-over provocation study, sent questionnaires to 5000 women and obtained 2472 valid responses from possible candidates. From those, they were only able to recruit 11 subjects with mobile phone related symptoms (MPRS) and 43 controls. The assumption was that individuals with MPRS matched the description of electrosensitivity by the World Health Organization (WHO). There were four EMF exposure conditions, each of which lasted 30 min: (*i*) continuous, (*ii*) intermittent, (*iii*) sham exposure with noise, and (*iv*) sham exposure without noise. Subjects were exposed to EMF of 2.14 GHz, 10 V/m (26.53 $\mu W/cm^2$) wideband code division multiple access (W-CDMA), in a shielded room to simulate whole-body exposure to EMF from base stations, although the exposure strength they used was higher than that commonly received from base stations. The researchers measured several psychological and cognitive parameters immediately before and after exposure, and monitored autonomic functions. Subjects were asked to report on their perception of EMF and level of discomfort during the experiment. The MPRS group did not differ from the controls in their ability to detect exposure to EMF. They did, however, consistently experience more discomfort in general, regardless of whether or not they were actually exposed to EMF, and despite the lack of significant changes in their autonomic functions. The researchers noted that others had found electrosensitive subjects to be more susceptible to stress imposed by task performance, although they did not differ from normal controls in their personality traits. The researchers concluded that the two groups did not differ in their responses to real or sham EMF exposure according to any psychological, cognitive or autonomic assessment. They said they found no evidence of any causal link between hypersensitivity symptoms and exposure to EMF from base stations. However, this study, had few MPRS participants.

Regel et al. (2006) also investigated the effects of the influence of UMTS base-station-like signals on well-being and cognitive performance in subjects with and without self-reported sensitivity to RFR. The researchers performed a controlled exposure experiment in a randomized, double-blind crossover study, with 45 min at an electric field strength of 0 V/m, 1.0 V/m (0.2653 $\mu W/cm^2$), or 10.0 V/m (26.53 $\mu W/cm^2$), incident with a polarization of 45° from the left-rear side of the subject, at weekly intervals. A total of 117 healthy subjects that included 33 self-reported sensitive subjects and 84 nonsensitive subjects, participated in the study. The team assessed well-being, perceived field strength, and cognitive performance with questionnaires and cognitive tasks and conducted statistical analyses using linear mixed models. Organ-specific and brain-tissue-specific dosimetry, including uncertainty and variation analysis, was performed. Their results found that in both groups, well-being and perceived field strength were not associated with actual exposure levels. They observed no consistent condition-induced changes in cognitive performance except for two marginal effects. At 10 V/m (26.53 $\mu W/cm^2$) they observed a slight effect on speed in one of six tasks in the sensitive subjects and an effect on accuracy in another task in nonsensitive subjects. Both effects disappeared after multiple endpoint adjustments. They concluded that they could not confirm a short-term effect of UMTS base-station-like exposure on well-being. The reported effects on brain functioning were marginal, which they attributed to chance. Peak spatial absorption in brain tissue was considerably smaller than during use of a mobile phone. They concluded that no conclusions could be drawn regarding short-term effects of cell phone exposure or the effects of long-term base-station-like exposures on human health.

Siegrist et al. (2005) investigated risk perceptions associated with mobile phones, base stations, and other sources of EMFs through a telephone survey conducted in Switzerland. Participants assessed both risks and benefits associated with nine different sources of EMF. Trust in the authorities regulating these hazards was also assessed. Participants answered a set of questions related to attitudes toward EMF and toward mobile phone base stations. Their results were: high-voltage transmission lines are perceived as the most risky source of EMF; and mobile phones and base stations received lower risk ratings. Trust in authorities was positively associated with perceived benefits and negatively associated with perceived risks. Also, people who use their mobile phones frequently perceived lower risks and higher benefits than people who use their mobile phones infrequently. People who believed they lived close to a base station did not significantly differ in their perceived level of risks associated with mobile phone base stations from people who did not believe they lived close to a base station. A majority of participants favored limits to exposures based on worst-case scenarios. The researchers also correlated perceived risks with other beliefs and found that belief in paranormal phenomena is related to level of perceived risks associated with

EMF. In addition, people who believed that most chemical substances cause cancer also worried more about EMF than people who did not believe that chemical substances are harmful. This study found the obvious — that some people worry more about environmental factors than others across a range of concerns.

Wilen et al. (2006) investigated the effects of exposure to mobile phone RFR on people who experience subjective symptoms when using mobile phones. Twenty subjects with MPRS were matched with 20 controls without MPRS. Each subject participated in two experimental sessions, one with true exposure and one with sham exposure, in random order. In the true exposure condition, the test subjects were exposed for 30 min to an RFR field generating a maximum SAR (1 g) in the head of 1 W/kg through an indoor base station antenna attached to signals from a 900 MHz GSM mobile phone. Physiological and cognitive parameters were measured during the experiment for heart rate and heart rate variability (HRV), respiration, local blood flow, electrodermal activity, critical flicker fusion threshold (CFFT), short-term memory, and reaction time. No significant differences related to RFR exposure conditions and no differences in baseline data were found between subject groups with the exception for reaction time, which was significantly longer among the test subjects than among the controls the first time the test was performed. This difference disappeared when the test was repeated. However, the test subjects differed significantly from the controls with respect to HRV as measured in the frequency domain. The test subjects displayed a shift in the low/high frequency ratio towards a sympathetic dominance in the autonomous nervous system during the CFFT and memory tests, regardless of exposure condition. They interpreted this as a sign of differences in the autonomous nervous system regulation among persons with MPRS and persons with no such symptoms.

12. Assessing exposures

Quantifying, qualifying, and measuring radiofrequency (RF) energy both indoors and outdoors has frustrated scientists, researchers, regulators, and citizens alike. The questions involve how best to capture actual exposure data — through epidemiology, computer estimates, self-reporting, or actual dosimetry measurements. Determining how best to do this is more important than ever, given the increasing background levels of RFR. Distance from a generating source has traditionally been used as a surrogate for probable power density but that is imperfect at best, given how RF energy behaves once it is transmitted. Complicated factors and numerous variables come into play. The wearing of personal dosimetry devices appears to be a promising area for capturing cumulative exposure data.

Neubauer et al. (2007) asked the question if epidemiology studies are even possible now, given the increasing deployment of wireless technologies. They examined the methodological challenges and used experts in engineering, dosimetry, and epidemiology to critically evaluate dosimetric concepts and specific aspects of exposure assessment regarding epidemiological study outcomes. They concluded that, at least in theory, epidemiology studies near base stations are feasible but that all relevant RF sources have to be taken into account. They called for pilot studies to validate exposure assessments and recommended that short-to-medium term effects on health and well-being are best investigated by cohort studies. They also said that for long-term effects, groups with high exposures need to be identified first, and that for immediate effects, human laboratory studies are the preferred approach. In other words, multiple approaches are required. They did not make specific recommendations on how to quantify long-term, low-level effects on health and well-being.

Radon et al. (2006) compared personal RF dosimetry measurements against recall to ascertain the reliability of self-reporting near base stations. Their aim was to test the feasibility and reliability of personal dosimetry devices. They used a 24 h assessment on 42 children, 57 adolescents, and 64 adults who wore a Maschek dosimeter prototype, then compared the self-reported exposures with the measurements. They also compared the readings of Maschek prototype with those of the Antennessa DSP-090 in 40 test subjects. They found that self-reported exposures did not correlate with actual readings. The two dosimeters were in moderate agreement. Their conclusion was that personal dosimetry, or the wearing of measuring devices, was a feasible method in epidemiology studies.

A study by Frei et al. (2009) also used personal dosimetry devices to examine the total exposure levels of RFR in the Swiss urban population. What they found was startling — nearly a third of the test subjects' cumulative exposures were from cell base stations. Prior to this study, exposure from base stations was thought to be insignificant due to their low-power densities and to affect only those living or working in close proximity to the infrastructure. This study showed that the general population moves in and out of these particular fields with more regularity than previously expected. In a sample of 166 volunteers from Basel, Switzerland, who agreed to wear personal exposure meters (called exposimeters), the researchers found that nearly one third of total exposures came from base stations. Participants carried an exposimeter for 1 week (2 separate weeks in 32 participants) and also completed an activity diary. Mean values were calculated using the robust regression on order statistics (ROS) method. Results found a mean weekly exposure to all RFR and (or) EMF sources was 0.013 $\mu W/cm^2$ (range of individual means 0.0014–0.0881 $\mu W/cm^2$). Exposure was mainly from mobile phone base stations (32.0%), mobile phone handsets (29.1%), and digital enhanced cordless telecommunications (DECT) phones (22.7%). People owning a DECT phone (total mean 0.015 $\mu W/cm^2$) or mobile phone (0.014 $\mu W/cm^2$) were exposed more than those not owning a DECT or mobile phone (0.010 $\mu W/cm^2$). Mean values were highest in trains (0.116 $\mu W/cm^2$), airports (0.074 $\mu W/cm^2$), and tramways or buses (0.036 $\mu W/cm^2$) and were higher during daytime (0.016 $\mu W/cm^2$) than nighttime (0.008 $\mu W/cm^2$). The Spearman correlation coefficient between mean exposure in the first and second week was 0.61. Another surprising finding of this study contradicted Neubauer et al. (2008) who found that a rough dosimetric estimate of a 24 h exposure from a base station (1–2 V/m) (i.e., 0.2653–1.061 $\mu W/cm^2$) corresponded to approximately 30 min of mobile phone use. But Frei et al. (2009) found, using the exposimeter, that cell phone use was 200 times higher than the average base station exposure contribution in self-selected volunteers (0.487 versus 0.002 μW/cm²). This implied that at the belt, backpack, or in close vicinity to the body, the mean base station contribution corresponds to about 7 min of mobile phone use (24 h divided by 200), not 30 min. They concluded that exposure to RFR varied considerably between persons and locations but was fairly consistent for individuals. They noted that cell phones, base stations, and cordless phones were important sources of exposure in urban Switzerland but that people could reduce their exposures by replacing their cordless domestic phones with conventional landlines at home. They determined that it was feasible to combine diary data with personal exposure measurements and that such data was useful in evaluating RFR exposure during daily living, as well as helpful in reducing exposure misclassification in future epidemiology studies.

Viel et al. (2009) also used personal exposure meters (EME SPY 120 made by Satimo and ESM 140 made by Maschek) to characterize actual residential exposure from antennas. Their primary aim was to assess personal exposures, not ambient field strengths. Two hundred randomly selected people were enrolled to wear measurement meters for 24 h and asked to keep a time–location–activity diary. Two exposure metrics for each radiofrequency were then calculated: the proportion of measurements above the detection limit of 0.05 V/m (0.0006631 μW/cm²) and the maximum electric field strength. Residential addresses were geocoded and distances from each antenna were calculated. They found that much of the time-recorded field strength was below the detection level of 0.05 V/m, with the exception of the FM radio bands, which had a detection threshold of 12.3%. The maximum electric field was always lower than 1.5 V/m (0.5968 μW/cm²). Exposure to GSM and digital cellular system (DCS) frequencies peaked around 280 m in urban areas and 1000 m from antennas in more suburban/rural areas. A downward trend in exposures was found within a 10 km distance for FM exposures. Conversely, UMTS, TV3, and TV 4 and 5 signals did not vary with distance. The difference in peak exposures for cell frequencies were attributed to microcell antennas being more numerous in urban areas, often mounted a few meters above ground level, whereas macrocell base stations in less urban areas are placed higher (between 15 and 50 m above ground level) to cover distances of several kilometres. They concluded that despite the limiting factors and high variability of RF exposure assessments, in using sound statistical technique they were able to determine that exposures from GSM and DCS cellular base stations actually increase with distance in the near source zone, with a maximum exposure where the main beam intersects the ground. They noted that such information should be available to local authorities and the public regarding the siting of base stations. Their findings coincide with Abdel-Rassoul et al. (2007) who found field strengths to be less in the building directly underneath antennas, with reported health complaints higher in inhabitants of the building across the street.

Amoako et al. (2009) conducted a survey of RFR at public access points close to schools, hospitals, and highly populated areas in Ghana near 50 cell phone base stations. Their primary objective was to measure and analyze field strength levels. Measurements were made using an Anritsu model MS 2601A spectrum analyzer to determine the electric field level in the 900 and 1800 MHz frequency bands. Using a GPS (global positioning system), various base stations were mapped. Measurements were taken at 1.5 m above ground to maintain line of sight with the RF source. Signals were measured during the day over a 3 h period, at a distance of approximately 300 m. The results indicated that power densities for 900 MHz at public access points varied from as low as 0.000001 μW/cm² to as high as 0.001 μW/cm². At 1800 MHz, the variation of power densities was from 0.000001 to 0.01 μW/cm². There are no specific RFR standards in Ghana. These researchers determined that while their results in most cites were compliant with the ICNIRP standards, levels were still 20 times higher than values typically found in the UK, Australia, and the U.S., especially for Ghana base stations in rural areas with higher power output. They determined that there is a need to reduce RFR levels since an increase in mobile phone usage is foreseen.

Clearly, predicting actual exposures based on simple distance from antennas using standardized computer formulas is inadequate. Although power density undoubtedly decreases with distance from a generating source, actual exposure metrics can be far more complex, especially in urban areas. Contributing to the complexity is the fact that the narrow vertical spread of the beam creates a low RF field strength at the ground directly below the antenna. As a person moves away or within a particular field, exposures can become complicated, creating peaks and valleys in field strength. Scattering and attenuation alter field strength in relation to building placement and architecture, and local perturbation factors can come into play. Power density levels can be 1 to 100 times lower inside a building, depending on construction materials, and exposures can differ greatly within a building, depending on numerous factors such as orientation toward the generating source and the presence of conductive materials. Exposures can be twice as high in upper floors than in lower floors, as found by Anglesio et al. (2001).

However, although distance from a transmitting source has been shown to be an unreliable determinant for accurate exposure predictions, it is nevertheless useful in some general ways. For instance, it has been shown that radiation levels from a tower with 15 nonbroadcast radio systems will fall off to hypothetical natural background levels at approximately 1500 ft (~500 m) (Rinebold 2001). This would be in general agreement with the lessening of symptoms in people living near cell towers at a distance over 1000 ft (~300 m) found by Santini et al. (2002) .

The previously mentioned studies indicate that accuracy in both test design and personal dosimetry measurements are possible in spite of the complexities and that a general safer distance from a cell tower for residences, schools, daycare centers, hospitals, and nursing homes might be ascertained.

13. Discussion

Numerous biological effects do occur after short-term exposures to low-intensity RFR but potential hazardous health effects from such exposures on humans are still not well established, despite increasing evidence as demonstrated throughout this paper. Unfortunately, not enough is known about biological effects from long-term exposures, especially as the effects of long-term exposure can be quite different from those of short-term exposure. It is the long-term, low-intensity exposures that are most common today and increasing significantly from myriad wireless products and services.

People are reporting symptoms near cell towers and in proximity to other RFR-generating sources including consumer products such as wireless computer routers and Wi-Fi systems that appear to be classic "microwave sickness syndrome," also known as "radiofrequency radiation sickness." First identified in the 1950s by Soviet medical researchers, symptoms included headache, fatigue, ocular dysfunction, dizziness, and sleep disorders. In Soviet medicine, clinical manifestations include dermographism, tumors, blood changes, reproductive and cardiovascular abnormalities, depression, irritability, and memory impairment, among others. The Soviet researchers noted that the syndrome is reversible in early stages but is considered lethal over time (Tolgskaya et al. 1973).

Johnson-Liakouris (1998) noted there are both occupational studies conducted between 1953 and 1991 and clinical cases of acute exposure between 1975 and 1993 that offer substantive verification for the syndrome. Yet, U.S. regulatory agencies and standards-setting groups continue to quibble about the existence of microwave sickness because it does not fit neatly into engineering models for power density, even as studies are finding that cell towers are creating the same health complaints in the population. It should be noted that before cellular telecommunications technology, no such infrastructure exposures between 800 MHz and 2 GHz existed this close to so many people. Microwave ovens are the primary consumer product utilizing a high RF intensity, but their use is for very brief periods of time and ovens are shielded to prevent leakage above 1000 $\mu W/cm^2$ — the current FDA standard. In some cases, following the U.S. Telecommunications Act of 1996 preemption of local health considerations in infrastructure siting, antennas have been mounted within mere feet of dwellings. And, on buildings with roof-mounted arrays, exposures can be lateral with top floors of adjacent buildings at close range.

It makes little sense to keep denying health symptoms that are being reported in good faith. Though the prevalence of such exposures is relatively new to a widespread population, we, nevertheless, have a 50 year observation period to draw from. The primary questions now involve specific exposure parameters, not the reality of the complaints or attempts to attribute such complaints to psychosomatic causes, malingering, or beliefs in paranormal phenomenon. That line of argument is insulting to regulators, citizens, and their physicians. Serious mitigation efforts are overdue.

There is early Russian and U.S. documentation of long-term, very low-level exposures causing microwave sickness as contained in *The Johns Hopkins Foreign Service Health Status Study* done in 1978 (Lilienfield et al. 1978; United States Senate 1979). This study contains both clinical information, and clear exposure parameters. Called the Lilienfield study, it was conducted between 1953 and 1976 to determine what, if any, effects there had been to personnel in the U.S. Embassy in Moscow after it was discovered that the Soviet government had been systematically irradiating the U.S. government compound there.

The symptoms reported were not due to any known tissue heating properties. The power densities were not only very low but the propagation characteristics were remarkably similar to what we have today with cell phone base stations. Lilienfield recorded exposures for continuous-wave, broad-band, modulated RFR in the frequency ranges between 0.6 and 9.5 GHz. The exposures were long-term and low-level at 6 to 8 h per day, 5 days per week, with the average length of exposure time per individual between 2 to 4 years. Modulation information contained phase, amplitude, and pulse variations with modulated signals being transmitted for 48 h or less at a time. Radiofrequency power density was between 2 and 28 $\mu W/cm^2$ — levels comparable to recent studies cited in this paper.

The symptoms that Lilienfield found included four that fit the Soviet description for dermographism — eczema, psoriasis, allergic, and inflammatory reactions. Also found were neurological problems with diseases of peripheral nerves and ganglia in males; reproductive problems in females during pregnancy, childbearing, and the period immediately after delivery (puerperium); tumor increases (malignant in females, benign in males); hematological alterations; and effects on mood and well-being including irritability, depression, loss of appetite, concentration, and eye problems. This description of symptoms in the early literature is nearly identical to the Santini, Abdel-Rassoul, and Narvarro studies cited earlier, as well as the current (though still anecdotal) reports in communities where broadcast facilities have switched from analog to digital signals at power intensities that are remarkably similar. In addition, the symptoms in the older literature are also quite similar to complaints in people with EHS.

Such reports of adverse effects on well-being are occurring worldwide near cell infrastructure and this does not appear to be related to emotional perceptions of risk. Similar symptoms have also been recorded at varying distances from broadcast towers. It is clear that something else is going on in populations exposed to low-level RFR that computer-generated RFR propagation models and obsolete exposure standards, which only protect against acute exposures, do not encompass or understand. With the increase in so many RFR-emitting devices today, as well as the many in the wings that will dramatically increase total exposures to the population from infrastructure alone, it may be time to approach this from a completely different perspective.

It might be more realistic to consider ambient outdoor and indoor RFR exposures in the same way we consider other environmental hazards such as chemicals from building materials that cause sick building syndrome. In considering public health, we should concentrate on aggregate exposures from multiple sources, rather than continuing to focus on individual source points like cell and broadcast base stations. In addition, whole categorically excluded technologies must be included for systems like Wi-Fi, Wi-Max, smart grids, and smart metering as these can greatly increase ambient radiation levels. Only in that way will low-level electromagnetic energy exposures be understood as the broad environmental factor it is. Radiofrequency radiation is a form of energetic air pollution and it should be controlled as such. Our current predilection to take this one product or service at a time does not encompass what we already know beyond reasonable doubt. Only when aggregate exposures are better understood by consumers will disproportionate resistance to base station siting bring more intelligent debate into the public arena and help create safer infrastructure. That can also benefit the industries trying to satisfy customers who want such services.

Safety to populations living or working near communications infrastructure has not been given the kind of attention it deserves. Aggregate ambient outdoor and indoor exposures should be emphasized by summing up levels from different generating source points in the vicinity. Radiofrequency radiation should be treated and regulated like radon and toxic chemicals, as aggregate exposures, with appropriate recommendations made to the public including for consumer products that may produce significant RFR levels indoors. When indoor consumer products such as wireless routers, cordless/DECT phones, leaking microwave ovens, wireless speakers, and (or) security systems, etc. are factored in with nearby outdoor transmission infrastructure, indoor levels may rise to exposures that are unsafe. The contradictions in the studies should not be used to paralyze movement toward safer regulation of consumer products, new infrastructure creation, or better tower siting. Enough good science exists regarding long-term low-level exposures — the most prevalent today — to warrant caution.

The present U.S. guidelines for RFR exposure are not up to date. The most recent IEEE and NCRP guidelines used by the U.S. FCC have not taken many pertinent recent studies into consideration because, they argue, the results of many of those studies have not been replicated and thus are not valid for standards setting. That is a specious argument. It implies that someone tried to replicate certain works but failed to do so, indicating the studies in question are unreliable. However, in most cases, no one has tried to exactly replicate the works at all. It must be pointed out that the 4 W/kg SAR threshold based on the de Lorge studies have also not been replicated independently. In addition, effects of long-term exposure, modulation, and other propagation characteristics are not considered. Therefore, the current guidelines are questionable in protecting the public from possible harmful effects of RFR exposure and the U.S. FCC should take steps to update their regulations by taking all recent research into consideration without waiting for replication that may never come because of the scarcity of research funding. The ICNIRP standards are more lenient in key exposures to the population than current U.S. FCC regulations. The U.S. standards should not be "harmonized" toward more lenient allowances. The ICNIRP should become more protective instead. All standards should be biologically based, not dosimetry based as is the case today.

Exposure of the general population to RFR from wireless communication devices and transmission towers should be kept to a minimum and should follow the "As Low As Reasonably Achievable" (ALARA) principle. Some scientists, organizations, and local governments recommend very low exposure levels — so low, in fact, that many wireless industries claim they cannot function without many more antennas in a given area. However, a denser infrastructure may be impossible to attain because of citizen unwillingness to live in proximity to so many antennas. In general, the lowest regulatory standards currently in place aim to accomplish a maximum exposure of 0.02 V/m, equal to a power density of 0.0001 $\mu W/cm^2$, which is in line with Salzburg, Austria's indoor exposure value for GSM cell base stations. Other precautionary target levels aim for an outdoor cumulative exposure of 0.1 $\mu W/cm^2$ for pulsed RF exposures where they affect the general population and an indoor exposure as low as 0.01 $\mu W/cm^2$ (Sage and Carpenter 2009). In 2007, *The BioInitiative Report, A rationale for a biologically based public exposure standard for electromagnetic fields (ELF and RF)*, also made this recommendation, based on the precautionary principle (Bioinitiative Report 2007).

Citizens and municipalities often ask for firm setbacks from towers to guarantee safety. There are many variables involved with safer tower siting — such as how many providers are co-located, at what frequencies they operate, the tower's height, surrounding topographical characteristics, the presence of metal objects, and others. Hard and fast setbacks are difficult to recommend in all circumstances. Deployment of base stations should be kept as efficient as possible to avoid exposure of the public to unnecessary high levels of RFR. As a general guideline, cell base stations should not be located less than 1500 ft (~500 m) from the population, and at a height of about 150 ft (~50 m). Several of the papers previously cited indicate that symptoms lessen at that distance, despite the many variables involved. However, with new technologies now being added to cell towers such as Wi-Max networks, which add significantly more power density to the environment, setback recommendations can be a very unpredictable reassurance at best. New technology should be developed to reduce the energy required for effective wireless communication.

In addition, regular RFR monitoring of base stations should be considered. Some communities require that ambient background levels be measured at specific distances from proposed tower sites before, and after, towers go online to establish baseline data in case adverse effects in the population are later reported. The establishment of such baselines would help epidemiologists determine what changed in the environment at a specific point in time and help better assess if RFR played a role in health effects. Unfortunately, with so much background RFR today, it is almost impossible to find a clean RFR environment. Pretesting may have become impossible in many places. This will certainly be the case when smart grid technologies create a whole new blanket of low-level RFR, with millions of new transceivers attached to people's homes and appliances, working off of centralized RFR hubs in every neighborhood. That one technology alone has the ability to permanently negate certain baseline data points.

The increasing popularity of wireless technologies makes understanding actual environmental exposures more critical with each passing day. This also includes any potential effects on wildlife. There is a new environmental concept taking form — that of "air as habitat" (Manville 2007) for species such as birds, bats, and insects, in the same way that water is considered habitat for marine life. Until now, air has been considered something "used" but not necessarily "lived in" or critical to the survival of species. However, when air is considered habitat, RFR is among the potential pollutants with an ability to adversely affect other species. It is a new area of inquiry deserving of immediate funding and research.

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Consolidated Case Nos. 19-70123, 19-70124, 19-70125, 19-70136, 19-70144, 19-70145, 19-70146, 19-70147, 19-70326, 19-70339, 19-70341, and 19-70344

IN THE UNITED STATES COURT OF APPEALS FOR THE NINTH CIRCUIT

Sprint Corporation,

Petitioner,

v.

City of Bowie, Maryland, et al.,

Intervenors,

v.

Federal Communications Commission and United States of America

Respondents.

On Petition for Review of Order of the Federal Communications Commission

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AMICUS BRIEF OF THE BERKSHIRE-LITCHFIELD ENVIRONMENTAL COUNCIL (BLEC) AS *AMICUS CURIAE* IN SUPPORT OF PETITIONER MONTGOMERY COUNTY, MARYLAND

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CORPORATE DISCLOSURE STATEMENT

Amicus curiae The Berkshire-Litchfield Environmental Council (BLEC) has no parent corporation. It has no stock, and therefore, no publicly held company owns ten percent (10%) or more of its stock.

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INTEREST OF THE *AMICUS CURIAE*[1]

The Berkshire-Litchfield Environmental Council (BLEC) is a 501(c)(3) non-profit organization that focuses on environmental issues affecting the Northwest Corner of Connecticut and the Berkshires region of Massachusetts. BLEC addresses diverse environmental subjects, particularly infrastructure, including the environmental effects of low-level radiofrequency radiation (RFR) to humans and myriad other species associated with the siting of telecommunications infrastructure. Founded in 1970, BLEC holds educational forums on emerging environmental issues with speakers from federal agencies and researchers from around the world.

BLEC President, Starling W. Childs, is a lecturer at the Yale School of Forestry and President of EECOS Inc. Environmental Consultants. Mr. Childs has been a consultant on numerous infrastructure projects throughout the country. He has lectured on the environmental effects of electromagnetic fields to flora and fauna.

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[1] All parties consent and/or do not oppose the filing of this brief. No counsel of any party to this proceeding authored any part of this brief. No party or party's counsel, or person other than amicus and its members, contributed money to the preparation or submission of this brief.

BLEC Communications Director, Ms. B. Blake Levitt, is a longtime medical/science journalist, author, and former New York Times contributor. She is also co-author, with Dr. Henry C. Lai, of *Biological effects from exposure to electromagnetic radiation emitted by cell tower base stations and other antenna arrays*.[2]

The signatories of supporters of this *Amicus Curiae* Brief are listed in Exhibit S attached to the Appendix being filed concurrently herewith.

INTRODUCTION AND SUMMARY OF ARGUMENT

Amicus addresses the court in support of MONTGOMERY COUNTY, MARYLAND v. FEDERAL COMMUNICATIONS COMMISSION and UNITED STATES OF AMERICA, PETITION FOR REVIEW, regarding the inadequacy of FCC's radiofrequency radiation (RFR) standards to protect public health in light of FCC rulings promoting 5G development as written *In the Matter of Accelerating Wireless Broadband Deployment by Removing Barriers to Infrastructure*

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[2] B. Levitt, et al., *Biological effects from exposure to electromagnetic radiation emitted by cell tower base stations and other antenna arrays*, ENVIRON. REV. (2010), http://www.nrcresearchpress.com/doi/pdf/10.1139/A10-018 (**Exhibit A**).

Investment, Declaratory Ruling and Third Report and Order (WT Docket No. 17-79; WC Docket No. 17-84; FCC 18-133), and released on September 27, 2018.

The FCC's Order substantially reduces the ability of Petitioner Montgomery County, Maryland ("Petitioner"), and local/state governmental entities across the country, to manage telecommunication carriers' rights to access, occupy, and use government property and rights-of-way. The FCC adopted this Order without adequately addressing comments submitted by Petitioner and other interested parties. Notably, the FCC inadequately addressed Petitioner's comments regarding the FCC's existing, and outdated, radiofrequency emission standards and their ability to sufficiently protect the health and safety of citizens residing in Montgomery County, Maryland.

Amicus respectfully submits this brief to demonstrate the necessity of updating the FCC's outdated public safety limits to account for biologically based standards which reflect the health impacts of chronic exposure to low-intensity, non-thermal, wireless radiofrequency microwave radiation, especially in light of the anticipated implementation of 5G wireless technologies.

Given the negative biological and environmental effects of chronic exposure to low-intensity, non-thermal radiofrequency radiation related to 5G wireless technologies, as demonstrated by multiple studies, it is vital that this Court set aside the FCC's Order until the FCC updates its standards to adequately protect the health and environmental concerns of Montgomery County, Maryland and local/state governmental entities alike.

ARGUMENT

I. The FCC Has A Historic Pattern of Disregarding Safety Issues Related to Radiofrequency Radiation.

The FCC voted to expedite the buildout of the 5G communications network in 2016. This was endorsed by then Chairman Thomas Wheeler on public record at the National Press Club when he stated the FCC wanted the U.S. to be "… first out the gate …" adding that "… Turning innovators loose is far preferable to expecting committees and regulators to define the future."[3] Chairman Wheeler indicated disregard for regulatory processes, especially those within FCC's

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[3] *Prepared Remarks of FCC Chairman Tom Wheeler, 'The Future of Wireless: A Vision for U.S. Leadership in a 5G World'* (June 20, 2016), https://transition.fcc.gov/Daily_Releases/Daily_Business/2016/db0620/DOC-339920A1.pdf (**Exhibit B**).

purview for protecting the public's health, safety and welfare.

The problems in Chairman Wheeler's logic were obvious, most notably that the FCC is a licensing and engineering entity that *relies* on other agencies for guidance outside of FCC's range of expertise. It has no fundamental right to move ahead without it. FCC is the first to point out that it is not a health or environmental agency, yet it is lauding innovators over those very regulators who know far more about the subject of safety. FCC's clearly stated intention was to circumvent its statutory deference to those other agencies which are capable of slowing down 5G's buildout.

Thus FCC, rather than follow traditional legal mandates for careful, thorough review, committed instead to the buildout of a whole new wireless network, using novel frequency ranges and unusual wave propagation characteristics in a new/untested technology, with unknown global consequences far into the future. FCC's approach is guaranteed to create another ubiquitous layer of radiofrequency radiation (RFR) – a biologically active exposure – in frequencies not now in widespread use. At a time when other industrialized countries are calling for caution regarding wireless exposures[4], the U.S. is going in the opposite direction as evidenced by Chairman Wheeler's enthusiasm for 5G, which intentionally avoided any in-depth review. This enthusiasm for 5G with no oversight has only intensified at FCC under current Chairman Ajit Pai.

Knowledgeable professionals have been addressing FCC over RFR safety and infrastructure siting issues for decades, only to be met with the same institutional disregard. Recent examples include filings at FCC by amicus, as well as the BioInitiative Working Group and many others. The BioInitiative Working Group is a collaborative of international scientists based in the U.S. that has provided, through Cindy Sage, MA, co-editor along with David O. Carpenter, MD., and principal author of the BioInitiative Reports (2007 and 2012) and a founder of the international BioInitiative Working Group, expert testimony and scientific briefings to: The European Environmental

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[4] Don Maisch, *Are community concerns over the 5G network rollout based on unfounded anxiety or valid evidence?* (May 2, 2019), https://betweenrockandhardplace.wordpress.com/2019/04/25/guest-blog-from-dr-don-maisch-australia-are-community-concerns-over-the-5g-network-rollout-based-on-unfounded-anxiety-or-valid-evidence/ (**Exhibit C**).

Agency (Denmark), European Commission (Brussels), UK Health Protection Agency, UK Children with Leukemia registered charity, various international health agencies, U.S. Department of Justice, FCC, FDA, public utilities commissions, LEED, state legislative committees, and numerous state and municipal agencies and commissions.

There were over 900 responses to FCC's request for comments in 2013 regarding their review of RFR exposures, a majority urging FCC to upgrade to a more protective model. Comment examples include:

- In 2013, amicus B. Blake Levitt filed comments with Henry C. Lai, Ph.D., calling for stricter radiofrequency radiation exposure standards in: The Matter of Reassessment of Federal Communications Commission Radiofrequency Exposure Limits and Policies and Proposed Changes in the Commission's Rules Regarding Human Exposure to Radiofrequency Electromagnetic Fields.[5]
- In 2016, amicus filed comments at FCC re: Proceedings 14-177, 15-256, 10-112, and 97-95[6] regarding then FCC Chairman

[5] Comments for ET Docket Nos. 013-84, 03-137 (filed Aug. 24, 2013), https://ecfsapi.fcc.gov/file/7520939733.pdf (**Exhibit D**).
[6] Comments for ET Docket Nos. 14-177, 15-256, 10-112, 97-95 (filed

Thomas Wheeler's call for comments on 5G.

- In 2013, Cindy Sage, MA filed comments with Lennart Hardell, MD, Ph.D., and Martha Herbert, MD, Ph.D., on behalf of the BioInitiative Working Group opposing the proposed relaxation of public safety standards based on evidence for brain tumors, damage to sperm and reproduction, and fetal and neonatal harm in: The Matter of Reassessment of Federal Communications Commission Radiofrequency Exposure Limits and Policies (ET Docket No. 13-84), and Proposed Changes in the Commission's Rules Regarding Human Exposure to Radiofrequency Electromagnetic Fields (ET Docket No. 03-137).[7]
- In 2013, Cindy Sage, MA filed comments with David Carpenter, MD on behalf of the BioInitiative Working Group calling for biologically-based public exposure standards addressing

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Jul. 12, 2018), http://nebula.wsimg.com/d47146dc1eb6dede8e10446de2df0507?AccessKeyId=045114F8E0676B9465FB&disposition=0&alloworigin=1 (**Exhibit E**).

[7] Comments for ET Docket Nos. 013-84, 03-137, https://ecfsapi.fcc.gov/file/7520940711.pdf (**Exhibit F**).

nonthermal (low-intensity) chronic exposure to radiofrequency microwave exposure in: The Matter of Reassessment of Federal Communications Commission Radiofrequency Exposure Limits and Policies (ET Docket No. 13-84), and Proposed Changes in the Commission's Rules Regarding Human Exposure to Radiofrequency Electromagnetic Fields (ET Docket No. 03-137).[8]

- In 2014, Cindy Sage, MA filed Reply Comments with David Carpenter, MD on behalf of the BioInitiative Working Group documenting that there is no reasonable basis for time-averaging nor spatially averaged measured values of radiofrequency radiation, and that the biologically-relevant time period during which pulsed RF causes disruption of key biological systems should be the basis for determining acceptable safety limits in: The Matter of Reassessment of Federal Communications Commission Radiofrequency Exposure Limits and Policies (ET Docket No. 13-84), and

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[8] Comments for ET Docket Nos. 013-84, 03-137, https://ecfsapi.fcc.gov/file/7520939956.pdf (**Exhibit G**).

Proposed Changes in the Commission's Rules Regarding Human Exposure to Radiofrequency Electromagnetic Fields (ET Docket No. 03-137).[9]

- In 2017, Cindy Sage, MA filed comments with Lennart Hardell and David Carpenter on behalf of the BioInitiative Working Group opposing the FCC's proposal to streamline siting of new wireless facilities without the FCC first completing its ongoing investigations into health impacts of human exposure to radiofrequency electromagnetic fields in: FCC Docket 16-421 *Streamlining Deployment of Small Cell Infrastructure by Improving Wireless Siting Policies.*[10]

Most of the concerns today are in the health and environmental categories when it comes to the effects of wireless technologies, not on how to make the technology work. Radiofrequency radiation is highly biologically active across a range of frequencies and intensities. The 5G system is designed at present to function in the Super High Frequency

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[9] Comments for ET Docket Nos. 013-84, 03-137, https://ecfsapi.fcc.gov/file/7520957942.pdf (**Exhibit H**).
[10] FCC Docket 16-421 https://bioinitiative.org/small-cell-antenna-rollout/ (**Exhibit I**).

(SHF) and the Extremely High Frequency (EHF) gigahertz (GHz) ranges using millimeter waves between 3 GHz and 300 GHz, at or below intensities allowed by current FCC exposure limits, but that should instill no confidence. The current FCC standards were designed to prevent heating (thermal effects), shock and electrocution; FCC standards are for acute high-intensity, short-term exposures capable of heating tissue in adults. There are no FCC exposure limits (yet) for nonthermal, low-intensity chronic exposures. While most exposures today are long-term, chronic, and low-intensity, a systematically growing body of evidence[11] finds those to be as biologically active, if not more so, than the thermal effects regulated today. The 5G system, which will require literally millions of new antennas mounted everywhere, is exactly the kind of exposure that most alarms

[11] Joel Moskowitz, *Scientific and policy developments regarding the health effects of electromagnetic radiation exposure from cell phones, cell towers, Wi-Fi, Smart Meters, and other wireless technology* (last updated June 10, 2019), https://www.saferemr.com.

scientists,[12] legislators,[13,14,15,16] and citizens alike.[17]

In light of the $28-million multi-year study released in 2018 by

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[12] Martin Pall, *5G: Great risk for EU, U.S. and International Health! Compelling Evidence for Eight Distinct Types of Great Harm Caused by Electromagnetic Field (EMF) Exposures and the Mechanism that Causes Them* (2018), https://einarflydal.files.wordpress.com/2018/04/pall-to-eu-on-5g-harm-march-2018.pdf.

[13] Sen. Blumenthal Press Conference (Dec. 3, 2018), http://www.ctn.state.ct.us/ctnplayer.asp?odID=15794&fbclid=IwAR2MoOv8RN8BmqbmFwjbzDPVO2PddCnwg-h0BiuudyStgvfO2sh_seBmp_E.

[14] *At Senate Commerce Hearing, Blumenthal Raises Concerns on 5G Wireless Technology's Potential Health Risks* (Feb. 7, 2019), https://www.blumenthal.senate.gov/newsroom/press/release/at-senate-commerce-hearing-blumenthal-raises-concerns-on-5g-wireless-technologys-potential-health-risks.

[15] *Eshoo Introduces Legislation to Restore Local Control in Deployment of 5G* (Jan. 15, 2019), https://eshoo.house.gov/news-stories/press-releases/eshoo-introduces-legislation-to-restore-local-control-in-deployment-of-5g/.

[16] Letters from Congress to FCC (**Exhibit K**): **(1)** Sens. Feinstein and Blumenthal to FCC Chairman Ajit Pai (Jan. 30, 2019), https://www.feinstein.senate.gov/public/_cache/files/2/6/26b80f01-7ca7-46ce-b26e-c9863a6ecbea/80446A9A6B1AEE016FE9E8C064E68C25.1.30.19-df-blumenthal-letter-to-pai-re-5g.pdf (frivolous lawsuits); **(2)** Rep. Peter DeFazio to FCC Chairman Ajit Pai (Apr. 15, 2019), https://www.eugene-or.gov/DocumentCenter/View/46057/Rep-Peter-DeFazio---Letter-to-FCC-on-5G (5G health effects and RF proceeding); and **(3)** Rep. Thomas R. Suozzi to FCC Chairman Ajit Pai (Apr. 16, 2019), https://docs.fcc.gov/public/attachments/DOC-357620A5.pdf (5G, NTP, and RF standards).

[17] Lloyd Burrell, *Citizens Up In Arms Against 5G Wireless Tech Roll Out: Are Their Concerns Justified?*, GREENMEDINFO (Mar. 27, 2018), http://www.greenmedinfo.com/blog/citizens-arms-against-5g-wireless-technology-roll-out-are-their-concerns-justified.

The National Toxicology Program (NTP) at the National Institutes of Health (NIH), which found a causal relationship between RFR in cell phone frequencies and malignant brain cancers (glioma), as well as malignant nerve tumors (schwannomas) of the heart in male rats,[18] amicus and supporters strongly recommend that the courts demand FCC apply the brakes and not move forward until all of the current biological information is taken into consideration, *biologically based standards are enacted that are more stringent than today's,* and the appropriate agencies consulted. To do otherwise is a severe overreach of FCC's traditional role in responsibly managing the nation's airwaves. Current FCC rulings throw all sane caution to the wind regarding small cell siting and violate longstanding federal laws requiring extensive review in advance of such FCC actions.

II. 5G Is Unlike Any Communications Technology Previously Implemented.

5G stands for "Fifth Generation" – a massively complex network of machine-to-machine communications made up of cloud-based wireless

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[18] *Cell Phone Radio Frequency Radiation,* NATIONAL TOXICOLOGY PROGRAM (Nov. 2018), http://ntp.niehs.nih.gov/results/areas/cellphones/index.html.

transceivers, ground-based fiber-optic wires and wireless antenna systems that will enable full buildout of the "Internet of Things," including driverless cars, interconnectivities between cell phones and 'smart' homes/businesses, and faster telecom services/entertainment to businesses and consumers among myriad applications yet-to-be-imagined. There are serious concerns at all levels of government, in business and many private sectors about such massive interconnectivity regarding cybersecurity, safety, health, privacy, and liability to investors – concerns that may be irreconcilable given how technology will function in the hyper-connected 5G world. One of the world's largest insurance companies has classified 5G mobile networks as "HIGH" level emerging risk to the global insurance and reinsurance industry[19] due in part to health issues.

Spectrum allocated for 5G is spread across a range of frequencies between the Super High Frequency (SHF) and the Extremely High Frequency (EHF) bands between 3 GHz and 300 GHz, also known as

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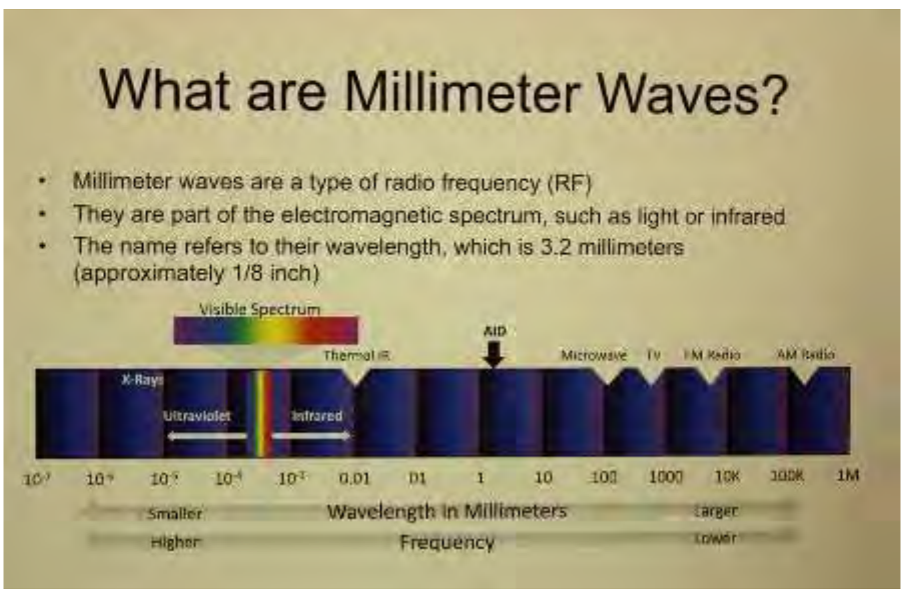
19 *Swiss Re Institute's 2019 SONAR report examines new and "slow-burner" emerging risks like the public health implications of climate change* (May 22, 2019), https://www.swissre.com/media/news-releases/nr-20190522-sonar2019.html.

millimeter wave (MMW) bands. Current cell technology functions in the Ultra High Frequency (UHF) bands between 300 megahertz (MHz) and 3 GHz. 5G may end up functioning close to the lower regions of the laser frequencies visible to other species. These upper ranges are in fact the only area of the nonionizing bands of the electromagnetic spectrum that are relatively untouched. Most others are completely filled in with civilian, government, and military uses. The FCC has licensed frequencies at 24, 28, 37, 39 and 47 GHz, and plans to open spectrum up to 90 GHz for 5G.



The FCC also plans to open up multiple wide areas of other bands for 5G too. This is the first time since the advent of telecommunication in the 1990's that the FCC has opened this much spectrum – more than the 1-through-4G systems combined. 5G makes use of digitized millimeter waves (MMW) that function best in narrow beams/bands that do not wrap well around obstacles like buildings, is easily deflected by trees, weather, and structures, and has poor penetration ability. But new antenna designs have overcome those limitations and can now aim and process the radiation into coherent signals that easily penetrate buildings, people, and all flora and fauna. According to Chairman Wheeler in 2016, 5G will require millions of new antennas, as well as hundreds of billions of microchips. He called 5G "infrastructure intensive."[20]

5G system(s), although markedly different in every conceivable way from former generations of communications technology, currently fall under the same restrictions of the Telecommunications Act of 1996 that prohibited states and communities from taking the "environmental effects" of radiofrequency radiation into consideration in infrastructure siting if the emissions are within FCC limits.[21] This is an egregious mistake because 5G is unlike anything we have ever seen before.

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[20] *See* n.3.

[21] *FCC Fact Sheet: New National Wireless Tower Siting Policies* (Apr. 23, 1996), http://wireless.fcc.gov/fact1.pdf.

Not only are the frequencies allocated for 5G in much higher electromagnetic spectrum ranges than anything used for civilian telecommunications before, but because signal propagation is so difficult in the MMW bands, 5G uses untested beam-steering technology that follows the device, not the user, and signaling characteristics like phased array with time-varying overlapping wave banks that hit living cells constantly from multiple angles, and at speeds so fast that there is no possible biological recovery time between exposures. Phased array signaling is known to cause unusual biological effects, capable of delivering RF energy deep within body tissue[22], not just the superficial skin-deep effects FCC assumes. 5G is quite simply the most labyrinthine wireless network ever created. There is already discussion of 6G with telecoms using even higher laser frequencies that other species can actually see – all without environmental review under NEPA. The higher the frequency, the more inherent power it packs, capable of physiological effects. Yet no specific allowance is being made at FCC for any of these differences regarding 5G exposures or rewriting the standards accordingly. When the standards were enacted in 1996,

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[22] *See* n.4.

such exposures to the general population at such close proximity as small cells bring, were unimaginable.

Even pre-5G small cells are problematic. Small cells, mostly using 4G technology, are being installed on utility poles in neighborhoods within mere feet of people's homes.[23] While 4G bears little resemblance to 5G, incorporated into 4G's newest antenna designs are hundreds of tiny 5G antennas that can be remotely activated at will. Thus, 4G small cells today are Trojan horses for 5G.

Toward the 5G initiative, the FCC also enacted rules being challenged in this court[24] that gave distributed antenna systems (DAS) and small cell technology – precursors of how 5G will operate in combination with fiber-optic cable – expedited review at the local level for both environmental effects (NEPA) and national historic significance

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[23] *FAQ about Wireless Facilities on Wooden Utility and Wooden Streetlight Pole* (Dec. 2015), http://default.sfplanning.org/currentplanning/wireless/FAQ_Wireless_Facilities_on_Poles.pdf (**Exhibit L**).

[24] *Acceleration of Broadband Deployment by Improving Wireless Facilities Siting Policies Acceleration of Broadband Deployment: Expanding the Reach and Reducing the Cost of Broadband Deployment by Improving Policies Regarding Public Rights of Way and Wireless Facilities Siting 2012 Biennial Review of Telecommunications Regulations*, WT Docket Nos. 13-238, 11-59, 13-32 (adopted Oct. 17, 2014, released Oct. 21, 2014).

(NHPA). These are historically sacrosanct tools that local governments use to determine suitability for any proposal, not just telecomm infrastructure.

That this buildout will bring increasing levels of RFR to the living environment is a given at a time when there are serious concerns in many countries about just such exposures. Yet former FCC Chairman Wheeler showed marked disregard toward other countries that have elected to study 5G's effects before buildout. Chairman Wheeler expressly said that technology should drive policy, not the other way around. The U.S., therefore, will be the first nation to give total license to the companies that stand to profit most, with virtually no scrutiny for safety.

Both former FCC chairman Wheeler and current chairman Ajit Pai see FCC's role as making spectrum available but thereafter letting the technology sector take the lead. As such, 5G will basically be unregulated for health effects. And since FCC appears averse to micromanaging technological development, that means we are missing a critical opportunity to make recommendations or requirements for safer devices and infrastructure.

A deep "sleeper" issue afoot at FCC concerns the increase in *unlicensed* RFR uses and exposure allowances that play a critical role in 5G. FCC intends to increase the RFR exposure allowances to a less stringent level for unlicensed devices at 100 Watts effective radiating power (ERP) which could include most small cell antennas very close to the population and many devices, thereby increasing RFR with even less overall regulation. No cumulative effects are taken into consideration with unlicensed spectrum.

These are enormous missed opportunities, given what is known – and continuing to emerge – about health and environmental RFR exposures. There's compelling science, at vanishingly low intensities, leading to:

- The 2011 International Agency for Research on Cancer (IARC) at the World Health Organization (WHO) classified RFR as a 2B (possible) human carcinogen.[25] Newer research calls for RFR reclassification as 2A (probable) carcinogen, or to Group 1 (known) carcinogen.

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[25] *IARC Classifies Radiofrequency Electromagnetic Fields as Possibly Carcinogenic to Humans* (May 31, 2011), http://www.iarc.fr/en/media-centre/pr/2011/pdfs/pr208_E.pdf.

- The BioInitiative Report[26] concluded in 2007 that the evidence for health risks from electromagnetic fields (EMF/RFR) generated by wireless technologies was sufficient to take public health action, and in 2012 that the evidence had substantially increased since 2007. Based on a review of over 1800 new scientific studies since 2007, current FCC guidelines are inadequate to protect the public from chronic exposure to very low-intensity (non-thermal) electromagnetic fields and EMF/RFR. The 2012 BioInitiative Report was prepared by 29 authors from ten countries. Peer-reviewed author credentials include: 10 MD's, 21 Ph.D.'s, and three MsC, MA or MPH's. Among the authors are three former presidents and five full members of the BioElectromagnetics Society (BEMS). One distinguished author is the chairman of the Russian National Committee on Non-Ionizing Radiation. Another is a senior advisor to the European Environmental Agency.[27] Research Summaries in the BioInitiative Report are further updated in

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[26] *BioInitiative Report,* 2012, http://www.bioinitiative.org.

[27] Full titles and affiliations of authors are in Section 25 of the BioInitiative Report, www.bioinitiative.org.

2014, 2017 and 2019 and include several hundred more peer-reviewed scientific studies.[28]

- The 2015 International Scientists Appeal[29] to the UN/WHO by 247 scientists from 42 nations addressed grave concerns over rising ambient EMF/RFR. Their warnings include all RFR-emitting devices: cell phones, infrastructure, wifi, 'smart' meter/grid technology, devices like baby monitors, and commercial broadcast. The warning extends to 4 and 5G small cells, which may warrant specific exposure standards all of their own.
- The 2017 petition by Swedish scientist Lennart Hardell,[30] signed by over 235 scientists and medical doctors from 36 countries, calling for a EU moratorium on 5G roll-out until human and environmental hazards are investigated by non-industry scientists. Signatories noted 5G will substantially increase cumulative RFR effects on top of existing 2G, 3G, 4G,

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28 https://bioinitiative.org/research-summaries/

29 *The International EMF Scientist Appeal* (May, 11 2015), https://www.emfscientist.org/.

30 *5G Appeal* (updated May, 16, 2019), https://www.5gappeal.eu/about/.

wi-fi, and other exposures. They urged EU to halt 4 and 5G until non-industry scientists show total radiation levels from all sources are safe, especially to children, pregnant women, and the environment.

- The 2017 U.S. National Toxicology Program's (NTP)[31] release of a 16-year, $28-million study that found causal relationships between cell-phone RFR and DNA damage, malignant brain cancers (glioma), and malignant nerve tumors (schwannomas) of the heart in male rats. NTP, the largest long-term low-level RFR study ever conducted, used 2G-type radiation at non-thermal RFR where effects were considered impossible. Newer generation signaling characteristics are even more complex.
- The 2018 Ramazzini Institute study[32] in Italy verified NTP's findings at even lower non-thermal RFR intensities. They also

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31 *See* n.18.

32 L. Falcioni, et al., *Report of final results regarding brain and heart tumors in Sprague-Dawley rats exposed from prenatal life until natural death to mobile phone radiofrequency field representative of a 1.8 GHz GSM base station environmental emission,* ENVIRONMENTAL RESEARCH, Vol. 165, pp. 496-503 (Aug. 2018), https://www.sciencedirect.com/science/article/pii/S0013935118300367?via%3Dihub.

found increased brain tumors and schwannomas in both male and female rats though not statistically significant. Consistent with NTP, Ramazzini showed effects are reproducible. Yet FCC, FDA, and industry dismiss the data.

The question is: Why does FCC continue to adhere to an obsolete standard that takes none of the above concerns into consideration – a clear contraindication to public welfare – then misapply an erroneous presumption of safety to an entirely new technology never used before in civilian telecommunications?

III. The FCC Has Been Aware of the Adverse Health and Environmental Effects Caused By Radiofrequency Radiation.

The potential adverse health and environmental effects from nonionizing radiation have been known since the advent of radar used in WW2 aboard U.S. ships when cataracts, numerous cancers and infertility were observed in U.S. Navy midshipmen and radar technicians.[33] Since that time, and especially within the last 25 years, the use of wireless technologies has exploded – all without a clear

[33] B. Levitt, *Electromagnetic Fields, A Consumer's Guide to the Issues and How to Protect Ourselves*, pp.20-21 (Harcourt Brace/Harvest Books 1995).

understanding of the biological implications and without adequate regulatory controls. Ambient nonionizing radiation – a form of energetic air pollution – is the fastest growing environmental pollutant today.

Regulatory agencies – particularly the U.S. Environmental Protection Agency (EPA) which had statutory authority to set standards for ambient nonionizing radiation exposures from EMF/RFR infrastructure – began issuing reports/white papers/studies in the 1970's concerning civilian exposures. For a comprehensive timeline regarding what was known, when, and by whom, as well as actions recommended but never implemented, and how authority was taken away from EPA for the nonionizing bands of the electromagnetic spectrum at the very nexus of the civilian telecom buildout in 1996, see the Environmental Health Trust's website.[34] EPA retains control over

[34] Environmental Health Trust, *US Government Reports On Cell Phones, Radiofrequency And Electromagnetic Fields*, https://ehtrust.org/policy/us-government-reports-on-cell-phones-radiofrequency-electromagnetic-fields/; *Recent US Government Reports, Congressional Hearings On Wireless And Electromagnetic Radiation*, https://ehtrust.org/recent-us-government-reports-congressional-hearings-on-wireless-and-electromagnetic-radiation/; and *EPA Recommendations And Reports On Cell Phones, Radiofrequency And Electromagnetic Fields*, https://ehtrust.org/epa-recommendations-and-

environmental ionizing radiation for soil and water contamination.

IV. The FCC's Current Standards Cannot Adequately Measure the Effects of 5G Communications Technology.

All living cells function with complex electrical micro-current. The rise in ambient EMF/RFR levels is the single biggest environmental alteration within the last 25 years, speaking the same fundamental energetic language as living cells, leading many scientists today to think artificial EMF/RFR degrades the body's functional electrophysiology balance. 5G's infrastructure-intensive small-cell densification will increase that by orders of magnitude. FCC RFR exposure standards, over 20 years old, do not adequately cover these new exposures, leading even some industry scientists to call for new standards just for 5G.[35]

It is the long-term, low-level, chronic exposures that are rapidly increasing today from all types of wireless devices – cell phones, tablets, 'smart' homes, baby monitors, security cameras, wireless-enabled anti-collision vehicles, 'smart' grid/meters and others. Add to this ambient

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reports-on-cell-phones-radiofrequency-and-electromagnetic-fields/.

[35] Neufeld E., Kuster N., *Systematic Derivation of Safety Limits For Time-Varying 5G - Radiofrequency Exposure Based on Analytical Models and Thermal Dose*, HEALTH PHYSICS, Vol. 115, No. 6 (Dec. 2018).

exposures from all of the infrastructure – cell towers, small cells, and myriad antenna arrays to support 2G, 3G, 4G, 4G LTE (Long Term Evolution) and soon the 5G network creating ubiquitous machine-to-machine connectivity and it is easy to understand why many governments and health agencies outside the U.S. are calling for a precautionary approach before further buildout.

What's more, man-made radiation creates very different kinds of exposures with unusual signaling characteristics like digital pulsing, phased array, and saw-tooth waveforms, and at much higher power intensities than anything found in nature. A myriad of species are known to be exquisitely sensitive to low-level energy[36] and may be affected by these increasing background levels. No federal or state agency has standards to protect wildlife from RFR.[37] 5G could approach

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[36] S. Cucurachi, et al., *A review of the ecological effects of radiofrequency electromagnetic fields (RF-EMF)*, ENVIRONMENT INTERNATIONAL, Vol. 51, pp. 116-140 (Jan. 23, 2013). https://www.sciencedirect.com/science/article/pii/S0160412012002334?via%3Dihub (**Exhibit M**).

[37] Albert M. Manville, II, *What We Know, Can Infer, and Don't Yet Know about Impacts from Thermal and Non-thermal Non-ionizing Radiation to Birds and Other Wildlife* (Jul. 14, 2016), https://ecfsapi.fcc.gov/file/12270470130362/Manville%207-14-%202016%20Radiation%20Briefing%20Memo-Public.pdf (**Exhibit N**).

frequency bands that are actually visible to avian species. Yet FCC has instituted expedited review for environmental effects against NEPA laws.[38]

FCC RFR exposure standards are for acute short-term thermal effects (like a microwave oven cooks food) but today's exposures are long-term, low-level, chronic, and far below that threshold. Although a safety margin is built into the standards, any biological effects below that thermal threshold are simply unregulated for ambient, far-field exposures in particular that result from infrastructure. Complex signaling characteristics like waveform, pulsing, and modulation are not taken into consideration although each has been found to have detrimental biological effects as separate metrics. Cumulative effects from many different devices working simultaneously are also not taken into consideration. (RFR power density and categorical exclusion are considered one product at a time.) Nor does FCC monitor for compliance unless a complaint has been filed. The 5G network will add a whole new layer of ambient RFR exposure that does not now exist – mostly involuntary exposures when it comes to small cell placement near

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[38] *See* n.24.

people's homes.

FCC categorically excludes from review any device or application that falls below a certain power density threshold, which most wireless devices and some infrastructure (like small cells) do. That means there is no true regulatory oversight of nearly all the wireless products in use today with the exception of cell phones which have to meet a threshold for a specific absorption rate (SAR) of energy deposited in tissue.

FCC uses two categories of exposure for how RFR is assessed/regulated: the SAR, which is the rate of energy that is theoretically absorbed by a unit of tissue, and power density which is the intensity of energy in space. Power density is used for far-field exposures like cell towers while SARs are typically used for near-field exposures from devices like cell phones. SARs are generally expressed in watts per kilogram (W/kg) of tissue, while power density is expressed generally in microwatts per centimeter squared (μW/cm2). The SAR measurements are averaged either over the whole body, or over a small volume of tissue, typically between 1 and 10 grams of tissue. The SAR is used to quantify energy absorption to fields typically between 100 kHz and 10 GHz and encompasses RFR from devices such as cell phones up through diagnostic MRI (magnetic resonance imaging) under the purview of the FDA.

Both measurements have limitations, but power density is a preferable approach compared to SAR as it can be independently verified, measurement equipment is readily available, FCC Bulletin OET 65 has widely accepted calculation formulas, and the public can generally understand this information.

Although SARs may function as a biological model for electric shock, burns and electrocution, they are fundamentally meaningless for low-intensity RFR effects below those thresholds as they only measure heating effects. It is impossible to conduct SAR measurements in living organisms so all values are inferred from dead animal measurements or computer simulation.[39] (Living systems are far more complex than that, and certainly not all living tissue is alike.) SARs also fail to adequately address known effects from modulation, pulsing, and other signaling characteristics.

The scientific panel of the Seletun Report[40] in 2009 unanimously

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[39] *See* n.2.
[40] Fragopoulou, et al., *Scientific Panel on Electromagnetic Field Health Risks: Consensus Points, Recommendations, and Rationales*

agreed that SAR is a poor measurement approach and not suitable as the sole basis for testing/regulating public safety standards. SARs were exclusively used in many key studies reporting increased risk of DNA damage, brain cancer, acoustic neuroma, and reduced sperm quality parameters, among others. SAR measures only one aspect of exposure – heating – while excluding other critical characteristics inherent to biologically active exposures such as frequency and modulation, which provide essential information in understanding EMF biological responses over short and long-term exposures. These include, but are not limited to, effects on nervous system response and tissue/organ development, which are not predicated on tissue heating. Using exclusive SAR measurements may actually hinder the creation of biologically protective limits and therefore are not recommended for use in standards setting models.

The bottom line: The entire basis upon which FCC regulates is fundamentally an engineering model, not a true biological one.[41]

Scientific Meeting: Seletun, Norway, November 17-21, 2009 REVIEWS ON ENVIRONMENTAL HEALTH VOLUME 25 (Nov. 4, 2010).

[41] DEP'T OF HEALTH AND HUMAN SERVS., RF Guideline Issues Identified by Members of the Federal RF Interagency Work Group (Jun. 1999). http://www.emrpolicy.org/litigation/case_law/docs/exhibit_a.pdf

Power density may end up being a better determinant for 5G far-field infrastructure exposures since it can be measured at the generating source. At present, *FCC regulations do not use SAR values above 6 GHz and 5G licenses have already been granted far above 6 GHz with more to come. FCC plans to use power density as the measurement for 5G which is still inadequate in capturing true biological effects particular to 5G.* It is presumed that by controlling the field strength from the transmitting source that SARs will automatically be controlled too, but this may not be true, especially with exposures from small cells so close the population and 5G's unusual signaling characteristics.

Another primary criticism of FCC standards concerns the time-averaging of exposures rather than regulate for short-term peak exposures (typical when devices first transmit), which is the most important biological metric. During the duty cycle, transmitters put out a peak burst of RFR that has been found to exceed FCC limits by orders of magnitude. (Cell phone manufacturers tell consumers not to hold a functioning cell phone against the body or it too may exceed FCC limits.) Yet that peak is averaged away into the duty cycle's lower

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(**Exhibits O1** and **O2**).

exposures and essentially disappears into what is deemed "safe."

The proposed 5G network will contain high peak exposures[42] of its own that will also be lost in the background averaging of how FCC regulates. There is no reasonable basis for time-averaging and/or spatially averaging measured values as the sole basis for protection against chronic exposures. Pulsed RFR health effects require development of protective limits that control chronic exposure for *peak* values, not watered-down time-averaged exposures.

Of critical importance is the fact that because of the high peak exposure, *5G may even exceed FCC's thermal limits*.[43] Permanent tissue damage from heating may occur even after short exposures to 5G millimeter wave pulse trains (where repetitive pulses can cause rapid, localized heating). Even industry researchers are warning that there is an urgent need for new *thermal* safety standards to address the kind of health risks possible with this new technology. If 5G transmissions fail to meet even current short-term acute thermal exposure limits, then 5G's rollout is even more problematic than 5G's low-intensity effects for

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[42] *See* n.35.
[43] *Id*.

which no operative public safety standards yet exist. This alone will hopefully inspire the Court to ask FCC to hit the pause button until the issue of exposure standards is settled.

The biologically-relevant time period during which pulsed RFR causes disruption of key biological processes should be the basis for determining acceptable safety limits. For example, if biological systems register pulsed RFR as a continuous insult, e.g., by expression of stress proteins (or heat shock proteins), or by disruption of normal electrophysiology or neural synchrony, or by oxidative damage or mitochondrial cell function disruption, then the biologically relevant time period in which cells/cell membranes and tissue respond as a continuous insult must define the safety limit, not just where overt permanent damage is possible as is the case in thermal models.

V. 5G Communications Technology Leads to Negative Biological and Environmental Effects.

The research on EMF biological effects is legion. Research at non-thermal levels conducted over the last 20 years since FCC instituted its standards shows effects to: DNA, cell membranes, gene expression, neuronal function, the blood brain barrier, melatonin production, sperm damage, learning impairment, and immune system function. Known adverse effects to humans include infertility, neurogenerative changes, numerous cancers, and heart rate variability. For some this is not theoretical. Near towers and in classrooms with Wi-Fi, people have experienced headaches, increased noise sensitivity, rashes, nausea, exhaustion, muscle weakness, lower libido, premature bone aging, concentration and memory problems, and hyperactivity. Prenatal exposures have led to ADD and autism-like effects in test animals.

In 2012, in twenty-four technical chapters, the BioInitiative Working Group authors discussed the content and implications of about 1800 new studies since 2007.[44] Overall, these new studies report abnormal gene transcription (Section 5); genotoxicity and single and double strand DNA damage (Section 6); stress proteins because of the fractal RF-antenna like nature of DNA (Section 7); chromatin condensation and loss of DNA repair capacity in human stem cells (Sections 6 and 15); reduction in free-radical scavengers – particularly melatonin (Sections 5, 9, 13, 14, 15, 16,17); neurotoxicity in humans and animals (Section 9); carcinogenicity in humans (Sections 11, 12, 13, 14, 15, 16, 17); serious impacts on human and animal sperm

[44] *See* n.26.

morphology/function (Section 18); effects on the fetus, neonate and offspring (Sections 18,19); effects on brain and cranial bone development in the offspring of animals that are exposed to cell phone radiation during pregnancy (Sections 5, 18); and findings in autism spectrum disorders consistent with EMF/RFR exposure effects. Global precautionary actions that have been taken in countries around the world and recommended by medical/research experts are documented in Section 22. Use of the Precautionary Principal and its relevance are presented in Section 23. Key scientific evidence and public health policy recommendations are in Section 24.

Numerous effects to wildlife are also seen. Birds suffer disorientation near cell towers. European studies found adverse effects in avian breeding, nesting, and roosting, and documented nest and site abandonment, plumage deterioration, locomotion problems, plus deaths in house sparrow, white stork, rock dove, magpie, collared dove, and other avian species from microwave RFR. Under laboratory conditions, U.S. researchers found non-thermal radiation from standard cell phone frequencies were lethal to domestic chicken embryos. Other affected species include bats, amphibians, insects, and domestic animals - even plant/tree flora are susceptible. RFR created increased bacterial antibiotic resistance, and fruit flies showed morphological abnormalities and decreased survival.[45] The tiny millimeter waves used in 5G will be particularly devastating to insects and thin-skinned amphibians as they couple maximally with skin tissue. Exhibit P attached to the Appendix being filed concurrently herewith contains a chart compiled by Levitt and Lai[46] of biological effects at extremely low intensities comparable to 5G infrastructure. These exposures cannot be considered biologically inactive.

CONCLUSION

Given industry influence at all levels of government, only the courts can remedy this situation. We urge the Court to stop FCC from conducting business as a captured agency of the industry it is supposed to regulate.[47] There are safe ways to live with and encourage technology, but blind 5G technophoria at FCC is not it. The FCC is

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45 *See* n.37.

46 *See* n.2.

47 Norm Alster, *Captured Agency: How the FCC Is Dominated by the Industries It Presumably Regulates*, http://ethics.harvard.edu/files/center-for-ethics/files/capturedagency_alster.pdf.

supposed to manage the airwaves for the common good. They have also been given control over a critical public health issue that daily affects our lives, even as FCC has no health authority, and essential agencies with that expertise, like EPA, are no longer up to their advisory roles. FCC seeks FDA advice but historically FDA controls for devices, not ambient environmental exposures from infrastructure. FCC intentionally facilitating an unknown/untested technology that could essentially go unregulated other than via spectrum allocation, is not what the public wants from FCC, which has been given oversight for RFR *safety.* 5G's consequences must be much clearer before moving forward. In today's polarized political climate, this is not a public safety question that can be directed toward a legislative solution. Regulatory agencies like FCC are failing the public, or, like EPA, have been silenced. There is only a legal solution under these very specific circumstances.

In 2004, U.S. Senator Richard Blumenthal (D-CT), then the state's attorney for Connecticut, wrote an amicus brief that delineated many of the same questions now before this Court – questions all disregarded by

FCC then and now.[48] There is a longstanding FCC pattern of negligence regarding state/local rights and inadequate exposure standards that only the courts can remedy today. It is long past time to solve this problem, which is only getting worse as each new layer of technology appears.

In 2013, the FCC called for comments regarding their review of cell phone and RFR exposure limits to which they received over 900 responses. But there is intense pressure to make the current inadequate standards *even more lenient*.[49] Industry's goal is to "harmonize" U.S. standards with those from the International Council on Nonionizing Radiation Protection (ICNIRP) – a self-assigned group of industry engineers and physicists – with standards that are more lenient in key exposures than the current FCC standards. The ICNIRP

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48 *Amicus Curiae* Brief Of the State Of Connecticut In Support Of Petitioner EMR Network's Petition for Writ Of Certiorari, Richard Blumenthal, Attorney General of Connecticut, IN THE SUPREME COURT OF THE UNITED STATES, OCTOBER TERM, 2004, EMR NETWORK (*Petitioner)* v. FEDERAL COMMUNICATIONS COMMISSION and UNITED STATES OF AMERICA, No. 04-1515, 2004. (**Exhibit R**).

49 Personal communication of B. Blake Levitt and Robert F. Cleveland, Jr., Office of Engineering and Technology, Federal Communications Commission (2000).

standard is widely used throughout Europe and elsewhere. Conflicts of interest among members are currently being challenged in Europe.[50]

For these many reasons, *Amicus Curiae* requests that this Court:

- Direct FCC to develop standards based on true biological models, not on their current dosimetry models of how to make communications systems work with the least amount of transmitted power necessary.[51] Questions now are biological regarding consequences to living systems in the path of technology.
- Direct FCC to upgrade their standards to a biologically based model in power density measurements that specifically regulate for non-thermal, low-intensity effects, and chronic, cumulative exposures from myriad sources in child as well as adult models; *and under no circumstances allow standards to become more*

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[50] Sage C., et al., *Comment on SCENIHR: Opinion on Potential Health Effects of Exposure to Electromagnetic Fields*, Bioelectromagnetics 36:480-484, 2015: https://bioinitiative.org/rebuttal-emf-effects/ and https://bioinitiative.org/advisors-committee/.

[51] Sage, C., et al., *Public Health Implications of Wireless Technologies*, PATHOPHYSIOLOGY, Vol. 16, Issues 2–3, Pages 233-246 (Aug. 2009), https://doi.org/10.1016/j.pathophys.2009.01.011.

lenient.

- Direct FCC to include true signal propagation characteristics in their standards: modulation, pulsing, phasing, and especially non-averaged peak exposures, among others.
- Direct FCC to halt 5G buildout until exposure standards that truly apply to 5G are developed by unbiased sources and implemented.
- Direct FCC to abide by, and allow municipalities, to exercise their planning and zoning authorities in full, including National Environmental Policy Act (NEPA) and National Historic Preservation Act (NHPA) reviews for all small cells and 5G.
- Include a request for new research appropriations by unbiased, independent government agencies, as well as a recommendation to refund the agencies that FCC relies upon to help them make such determinations. EPA, NIH and the U.S. Fish & Wildlife Service should have funding for new research/labs permanently dedicated to EMF research that is arm's length from industry. A $1 per/year charge to cell phone

bills, overseen by FCC, would adequately fund those initiatives.

Dated: June 17, 2019

Respectfully submitted,

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STATEMENT OF RELATED CASES

This case (19-70147) has been consolidated with the following actions seeking judicial review of the Small Cell Order:

Sprint Corp. v. FCC, No. 19-70123
Verizon Commc'ns, Inc. v. FCC, No. 19-70124
Puerto Rico Telephone Co. v. FCC, No. 19-70125
City of Seattle v. FCC, No. 19-70136
City of San Jose v. FCC, No. 19-70144
City and County of San Francisco v. FCC, No. 19-70145
City of Huntington Beach v. FCC, No. 19-70146
AT&T Services, Inc. v. FCC, No. 19-70326
Am. Public Power Ass'n v. FCC, No. 19-70339
City of Austin v. FCC, No. 19-70341
City of Eugene v. FCC, No. 19-70344
AEPSC v. FCC, No. 19-70490

In addition, *United Keetoowah Band of Cherokee Indians, et al. v. FCC,* No. 18-1129 (D.C. Cir.) is currently pending before the United States Court of Appeals for the District of Columbia. This case seeks judicial review of a different FCC order (*In the Matter of Accelerating Wireless Broadband Deployment by Removing Barriers to Infrastructure Investment; see* 2018 FCC LEXIS 1008 (March 22, 2018)). However, Petitioners Natural Resources Defense Council and Edward B. Myers also raise issues related to RF and the FCC's RF standards.

UNITED STATES COURT OF APPEALS
FOR THE NINTH CIRCUIT

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CERTIFICATE OF SERVICE

I hereby certify that on June 17, 2019, I caused the foregoing Amicus Brief of The Berkshire-Litchfield Environmental Council (BLEC) to be electronically filed with the Clerk of Court for the United States Court of Appeals for the Ninth Circuit using the CM/ECF system. I further certify that all participants in the case are registered CM/ECF users and will be served electronically via the CM/ECF system.

/s/ Sblend A. Sblendorio
Sblend A. Sblendorio

Planetary electromagnetic pollution: it is time to assess its impact

As the Planetary Health Alliance moves forward after a productive second annual meeting, a discussion on the rapid global proliferation of artificial electromagnetic fields would now be apt. The most notable is the blanket of radiofrequency electromagnetic radiation, largely microwave radiation generated for wireless communication and surveillance technologies, as mounting scientific evidence suggests that prolonged exposure to radiofrequency electromagnetic radiation has serious biological and health effects. However, public exposure regulations in most countries continue to be based on the guidelines of the International Commission on Non-Ionizing Radiation Protection[1] and Institute of Electrical and Electronics Engineers,[2] which were established in the 1990s on the belief that only acute thermal effects are hazardous. Prevention of tissue heating by radiofrequency electromagnetic radiation is now proven to be ineffective in preventing biochemical and physiological interference. For example, acute non-thermal exposure has been shown to alter human brain metabolism by NIH scientists,[3] electrical activity in the brain,[4] and systemic immune responses.[5] Chronic exposure has been associated with increased oxidative stress and DNA damage[6,7] and cancer risk.[8] Laboratory studies, including large rodent studies by the US National Toxicology Program[9] and Ramazzini Institute of Italy,[10] confirm these biological and health effects in vivo. As we address the threats to human health from the changing environmental conditions due to human activity,[11] the increasing exposure to artificial electromagnetic radiation needs to be included in this discussion.

Due to the exponential increase in the use of wireless personal communication devices (eg, mobile or cordless phones and WiFi or Bluetooth-enabled devices) and the infrastructure facilitating them, levels of exposure to radiofrequency electromagnetic radiation around the 1 GHz frequency band, which is mostly used for modern wireless communications, have increased from extremely low natural levels by about 10^{18} times (figure). Radiofrequency electromagnetic radiation is also used for radar, security scanners, smart meters, and medical equipment (MRI, diathermy, and radiofrequency ablation). It is plausibly the most rapidly increasing anthropogenic environmental exposure since the mid-20th century, and levels will surge considerably again, as technologies like the Internet of Things and 5G add millions more radiofrequency transmitters around us.

Unprecedented human exposure to radiofrequency electromagnetic radiation from conception until death has been occurring in the past two decades. Evidence of its effects on the CNS, including altered neurodevelopment[14] and increased risk of some neurodegenerative diseases,[15] is a major concern considering the steady increase in their incidence. Evidence exists for an association between neurodevelopmental or

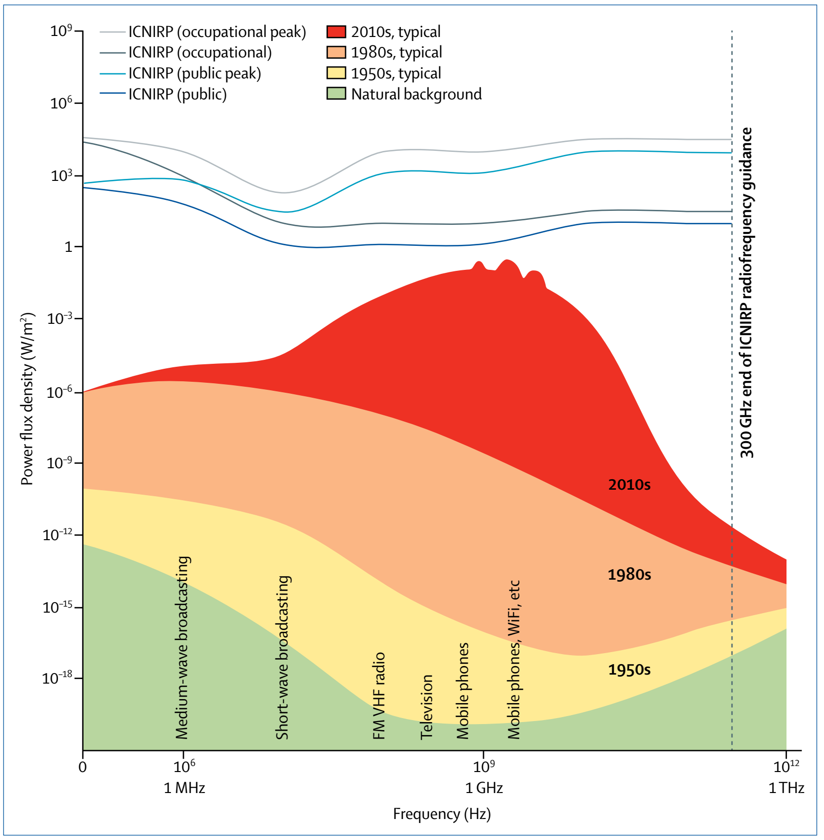

***Figure:* Typical maximum daily exposure to radiofrequency electromagnetic radiation from man-made and natural power flux densities in comparison with International Commission on Non-Ionizing Radiation Protection safety guidelines[1]**

Anthropogenic radiofrequency electromagnetic radiation levels are illustrated for different periods in the evolution of wireless communication technologies. These exposure levels are frequently experienced daily by people using various wireless devices. The levels are instantaneous and not time-averaged over 6 minutes as specified by International Commission on Non-Ionizing Radiation Protection for thermal reasons. Figure modified from Philips and Lamburn[12] with permission. Natural levels of radiofrequency electromagnetic radiation were based on the NASA review report CR-166661.[13]

behavioural disorders in children and exposure to wireless devices,[14] and experimental evidence, such as the Yale finding, shows that prenatal exposure could cause structural and functional changes in the brain associated with ADHD-like behaviour.[16] These findings deserve urgent attention.

For the **Oceania Radiofrequency Scientific Advisory Association** see www.orsaa.org

At the Oceania Radiofrequency Scientific Advisory Association, an independent scientific organisation, volunteering scientists have constructed the world's largest categorised online database of peer-reviewed studies on radiofrequency electromagnetic radiation and other man-made electromagnetic fields of lower frequencies. A recent evaluation of 2266 studies (including in-vitro and in-vivo studies in human, animal, and plant experimental systems and population studies) found that most studies (n=1546, 68·2%) have demonstrated significant biological or health effects associated with exposure to anthropogenic electromagnetic fields. We have published our preliminary data on radiofrequency electromagnetic radiation, which shows that 89% (216 of 242) of experimental studies that investigated oxidative stress endpoints showed significant effects.[7] This weight of scientific evidence refutes the prominent claim that the deployment of wireless technologies poses no health risks at the currently permitted non-thermal radiofrequency exposure levels. Instead, the evidence supports the International EMF Scientist Appeal by 244 scientists from 41 countries who have published on the subject in peer-reviewed literature and collectively petitioned the WHO and the UN for immediate measures to reduce public exposure to artificial electromagnetic fields and radiation.

For the **International EMF Scientist Appeal** see www.emfscientist.org

Evidence also exists of the effects of radiofrequency electromagnetic radiation on flora and fauna. For example, the reported global reduction in bees and other insects is plausibly linked to the increased radiofrequency electromagnetic radiation in the environment.[17] Honeybees are among the species that use magnetoreception, which is sensitive to anthropogenic electromagnetic fields, for navigation.

Man-made electromagnetic fields range from extremely low frequency (associated with electricity supplies and electrical appliances) to low, medium, high, and extremely high frequency (mostly associated with wireless communication). The potential effects of these anthropogenic electromagnetic fields on natural electromagnetic fields, such as the Schumann Resonance that controls the weather and climate, have not been properly studied. Similarly, we do not adequately understand the effects of anthropogenic radiofrequency electromagnetic radiation on other natural and man-made atmospheric components or the ionosphere. It has been widely claimed that radiofrequency electromagnetic radiation, being non-ionising radiation, does not possess enough photon energy to cause DNA damage. This has now been proven wrong experimentally.[18,19] Radiofrequency electromagnetic radiation causes DNA damage apparently through oxidative stress,[7] similar to near-UV radiation, which was also long thought to be harmless.

At a time when environmental health scientists tackle serious global issues such as climate change and chemical toxicants in public health, there is an urgent need to address so-called electrosmog. A genuine evidence-based approach to the risk assessment and regulation of anthropogenic electromagnetic fields will help the health of us all, as well as that of our planetary home. Some government health authorities have recently taken steps to reduce public exposure to radiofrequency electromagnetic radiation by regulating use of wireless devices by children and recommending preferential use of wired communication devices in general, but this ought to be a coordinated international effort.

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We declare no competing interests. We thank Alasdair Philips for assistance with the figure and Victor Leach and Steve Weller for assistance with the ORSAA Database, which has enabled our overview of the scientific evidence in this area of research.

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US POLICY

ENVIRONMENTAL HEALTH TRUST

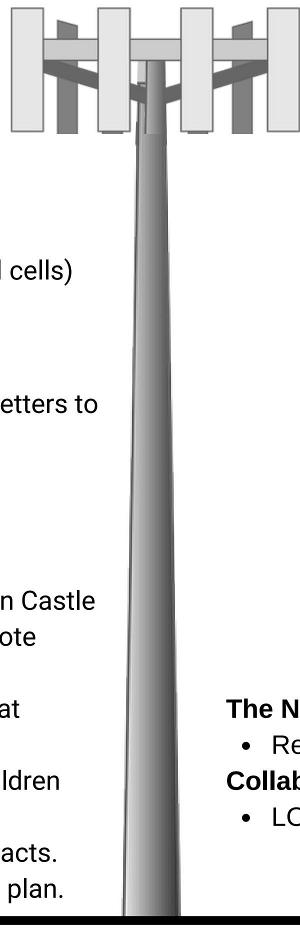
CELL TOWERS NEAR SCHOOLS

SCHOOL CELL TOWER SETBACKS

Many communities have policies, ordinances or zoning that ensures cellular antennas are restricted to a specific minimum distance from schools. Hempstead, New York requires a special use permit for cell towers near schools.

Examples of cell tower/school setbacks:

- **Palo Alto, California:** 1,500 feet
- **Los Altos , California**: 500 feet (small cells)
- **Walnut City, California**: 1,500 feet
- **Bar Harbor, Maine: 1**,500 feet
- **Sallisaw, Oklahoma:** 1,500 feet
- **Stockbridge, Massachusetts**: 1,500 feet
- **San Diego County California** 1,000 feet (small cells)
- **Ithaca, New York** - 250 feet (small cells)



The Greenbelt Maryland City Council

- Voted to oppose school cell towers and sent letters to the school board and County Executive.

CELL TOWERS REMOVED FROM SCHOOL GROUNDS

- **Milpitas California:** School Board asked Crown Castle and T-Mobile to relocate the cell tower to remote location.
- **Ripon California:** Sprint moved the cell tower at Weston Elementary after students and staff developed cancer and parents argued that children should not be guinea pigs.
- **Alameda California** cancelled cell tower contracts.
- **Dekalb County Georgia** dropped school tower plan.

SCHOOL BOARDS

- **Los Angeles California School District**: Resolutions opposing cell towers on school property and a cautionary level" for radiofrequency radiation 10,000 times lower than FCC limits.
- **Palo Alto Unified School District**: Resolution No. 2018-19.19 supports the City 1,500 setback and opposes cell tower "on or in close proximity to schools to ensure individuals, especially children, are protected from the potential negative effects associated with radiation exposure"
- **West Linn-Wilsonville Oregon School Board** prohibits cell towers on school property.
- **Vancouver School Board:** Resolution prohibiting cell antennas within 1,000 feet of school property.
- **Montgomery County Maryland Schools** policy does not allow cell towers on elementary schools.
- **Prince George's County Maryland** School Board decided not to renew a cell tower construction master leasing agreement that had allowed over 60 schools to be marketed as cell tower sites.
- **Portland Oregon Schools** ended leases for cell towers at schools .

The New Hampshire 5G Commission Report

- Recommends a setback of 1640 feet for schools.

Collaborative For High Performance Schools

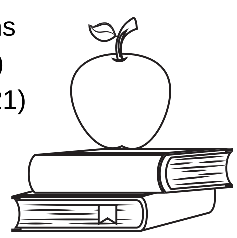
- LOW EMF Criteria- no cell towers on school property.

THE EPA SCHOOL SITING GUIDELINES

Lists exposure to electromagnetic fields and the fall distance as "potential hazards" from cell towers. The EPA guidelines recommend schools "identify and evaluate cell towers within ~200 feet of prospective school locations."

PUBLISHED RESEARCH

- 500 Meter buffer recommended for schools (Pearce 2019)
- A moratorium on 5G pending safety research (Frank 2020)
- A precautionary approach is better suited to State obligations under international human rights law (Roda and Perry 2014)
- Increased cancer deaths near cell antennas (Rodrigues 2021)
- Studies find: DNA Damage(Zothansiama 2017), Diabetes (Meo 2015), Cognitive effects (Meo 2018), sleep problems and headaches (Abdel-Rassoul 2007, Levitt & Lai 2010, Shahbazi-Gahrouei 2013)



THE AMERICAN ACADEMY OF PEDIATRICS says:

"An Egyptian study confirmed concerns that living nearby mobile phone base stations increased the risk for developing:

- Headaches
- Memory problems
- Dizziness
- Depression
- Sleep problems

"In large studies, an association has been observed between symptoms and exposure to these fields in the everyday environment."

UNITED STATES OF AMERICA

5G & CELL TOWERS

ENVIRONMENTAL HEALTH TRUST

HAWAI'I

- **Hawai'i County Council HI** passed a Resolution to halt 5G

NEW HAMPSHIRE

- Proposed State Bill - 1640 ft setbacks.
- **Keene NH Resolution** to halt 5G
- **Bedford NH** 750 ft. setback

MASSACHUSETTS

Randolph MA 500 ft setback. Yearly RFR measurements.
Lunenburg and Great Barrington MA 500 ft setback
Stockbridge MA prohibits a tower from being built 1000 feet from a school, park or athletic field and 600 ft from residence.

CALIFORNIA

Numerous CA cities restrict cell antennas near homes with setbacks and strict ordinances including: **Los Altos, Petaluma, Mill Valley, Malibu, Santa Barbara, Nevada City, Suisin, Calabasas, San Clemente, Westlake, Sonoma, Sebastopol, San Rafael, Ross Valley, Encinitas, Fairfax, Palo Alto, Walnut City** and **San Diego County.**

As an example of CA ordinances, the **Los Altos City ordinance:**

- prohibits installation of small cells on public utility easements in residential neighborhoods
- 500 foot setbacks for small cells for multi-family residences in commercial districts
- 500 ft separation from schools
- 1500 ft separation between nodes

San Diego County, California

- “SCWs shall not be located within 1,000 feet of schools, child care centers, hospitals, or churches.”

WISCONSIN

- **Greendale WI** passed Resolution R2018-20 referring to the FCC’s actions stripping local authority as “an unprecedented attack on local control.”

New York

- **Scarsdale NY: 500 foot setbacks to homes preferred.**
- **Copake NY**: Pre/post testing by RF engineer. No repeater closer than 200 ft to dwelling. No tower closer than 1500 ft to residence/church.

MAINE

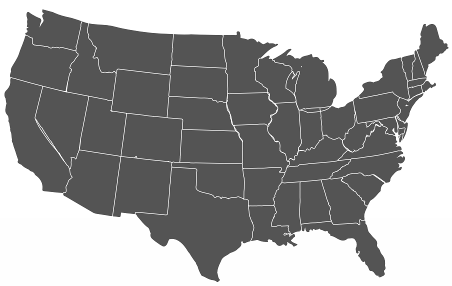
- Bar Harbor ME 1,500 ft setback - cell towers near schools/daycare .

CONNECTICUT

- **Easton CN City Council** passed a 5G cease and desist resolution
- **Warren, Connecticut** Policy defines "adequate coverage" and "adequate capacity." and was designed “to locate towers and/or antennas in a manner which protects property values, as well as the general safety, health, welfare and quality of life of the citizens.“ Coverage is considered to be “adequate” within that area surrounding a Base Station where the predicted or measured median field strength of the transmitted signal is such that the majority of the time, transceivers properly installed and operated will be able to communicate with the base station.

ILLINOIS

- **Oak Brook IL** Resolution calls for local control re small cels.



OHIO

- **Mason OH** Zoning Ordinance No small cells in residential areas or within 100 feet of residential prop; 2000 feet apart (unless colocated); equipment should be underground or wholly contained.

OKLAHOMA

- Sallisaw OK 1,500 feet setback

TENNESSEE

- **Farragut City** Resolution to halt 5G

NEW JERSEY

- **Little Silver, NJ** Carriers should provide notice to property owners within 500 feet of proposed facility.
- City of Jersey City, NJ Resolution 20-362 calls for local controls re small cells.

FLORIDA

- **Coconut Creek FL** Commission adopted a Resolution on 5G and radiofrequency radiation.
- **Hallandale Beach FL** Resolution urges the federal government to initiate independent health studies on 5G.
- **Lavallette FL** Resolution 2021-58: Applicant shall obtain certification from the Federal Aviation Administration and the United States Dept. of Defense demonstrating that the installation does not emit RF frequencies which may interfere with avionics of any approaching civil or military aircraft.” The City also requires the applicant to provide RF meters used by their technicians and train City employees. Verizon cannot install more than a total of 20 "small cell" nodes throughout the Borough to support 5G.

INDIANA

Carmel City IN Council resolution asks state lawmakers, FCC and Congress to limit 5G until health effects fully understood.

Links to ordinances at ehtrust.org

WORLDWIDE POLICY

5G & CELL TOWERS

ENVIRONMENTAL HEALTH TRUST

EUROPE

- Resolutions to halt 5G in numerous European cities including Trafford, UK, Lille, France, Ormidia, Cyprus, several Councils in Ireland and more.

SWITZERLAND

- Parliament refused to weaken radio frequency radiation (RFR) limits after 5G Report.

FRANCE

- 60 mayors/officials petition to halt 5G.
- Federal health agency investigating 5G
- 5G antenna RFR levels measured and publicly posted.

ITALY

- 600+ municipalities have passed resolution to halt 5G.

CANADA

- City of Toronto "Prudent Avoidance Policy" for Cell Towers.

BULGARIA

- Mezdra and Balchik have banned 5G.

ISRAEL

- Cell tower setback 100m from schools/ homes.

RUSSIA

No cell towers near schools.

NETHERLANDS

- Health Council recommends against 26 GHz for 5G due to lack of safety data.

UNITED STATES

- Resolutions to halt 5G passed in Hawaii County HI, Farragut TN, Keene NH & Easton CT.
- Numerous cities restrict cell antennas near homes including: Los Altos, Petaluma, Mill Valley, Malibu and San Diego County CA, Bedford NH and more.
- New Hampshire 5G Commission's 15 Recommendations include increasing transparency, reduce public exposure, research health effects and protect wildlife and trees.
- Oregon investigating health effects of wireless.
- Los Angeles CA Public Schools: RFR Limit 10,000x less than FCC.
- Palo Alto, Los Angeles LA Schools Greenbelt MD, Bar Harbor ME; No school cell towers

CYPRUS

- Cyprus National Committee on Environment and Child Health 5G Position Paper calls for 5G free zones.

AUSTRALIA

- New South Wales Dept. of Education policy objects to towers on/near schools.

LITHUANIA

- Cell antennas prohibited on kindergartens and hospitals.

CHILE

- Cell antennas prohibited in "sensitive areas" -kindergartens, hospitals and nursing homes.

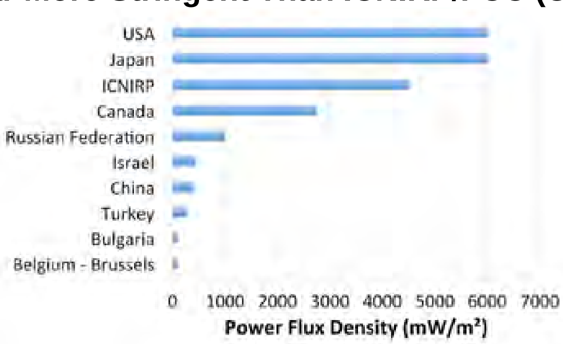
INDIA

- RFR limit tightened to 1/10 of CNIRP limits after Inter-Ministerial Report on impacts to wildlife.
- Mumbai, Zilla Parishad & Karnataka: Cell towers prohibited/removed near schools, colleges, orphanages and old age homes.
- Brihanmumbai Municipal: Cell towers banned at parks and playgrounds.
- State of Rajasthan: Supreme Court of India upheld removal of "hazardous to life" cell towers from vicinity of schools, hospitals/playgrounds.

BANGLADESH

- No cell towers on homes, schools, colleges, playing fields, populated areas and heritage areas.

Numerous Countries Have Cell Tower Network RFR Exposure Limits Far More Stringent Than ICNIRP/FCC (USA):



RFR power flux density exposure limits at 900 MHz (Clegg 2020)

China	Belarus	Turkey
Russia	Serbia	Greece
Italy	Slovenia	Liechtenstein
India	Montenegro	Tajikistan
Israel	Bulgaria	Kazakhstan
Chile		Uzbekistan
Switzerland		Kyrgyzstan
Brussels, Belgium		

These Governments Measure & Publish RFR Levels Online

France	Switzerland
Spain	Bulgaria
Austria	Tunisia
Greece	Malta
Turkey	Bhuton
India	Brazil
Israel	Bahrain
Gibraltar	Monaco
Brussels Belgium	French Polynesia

Text is hyperlinked to sources. More policy at ehtrust.org

Iranian Journal of Medical Physics

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Correlation between Base Transceiver Station and the Quality of Sleep and Life of Nearby Residents

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ARTICLE INFO

Article type:
Original Paper

Article history:
Received: Aug 28, 2019
Accepted: Jan 12, 2020

Keywords:
Electromagnetic Waves
BTS
Sleep Quality
Quality of Life

ABSTRACT

Introduction: Electromagnetic waves that are of higher energy than visible light transmit information between mobile phones and antennas BTS (Base Transceivers Station). The increasing use of mobile phones due to the proliferation of antennas is a matter of concern. The present study aimed to investigate the correlation between distance from the BTS antennas and the quality of sleep and life of nearby residents.

Material and Methods: For the assessment of the quality of sleep, the Pittsburgh Sleep Quality standard questionnaire (PSQI) was used. On the other hand, the 12-item Short -Form Health Survey (SF-12) was used to assess the quality of life. This questionnaire contains two parameters: Mental Health Composite Scores (MCS) and Physical Health Composite Scores (PCS).

Results: The analysis of the data obtained from 810 people indicated that the most sleep disturbance and the minimum average MCS score ($p<0.05$) were detected in the residents who were living within 50-100 meters from the antenna. Moreover, it was found that the average PCS score was lower among those residing within 100-200 meters from the antenna, as compared to other residents.

Conclusion: The present study demonstrates that exposure to electromagnetic waves can affect sleep quality, as well as the mental and physical life qualities of the residents depending on the distance from BTS. Antennas implant must be set in patterns that have the lowest intensity in terms of beam convergences for all residents.

► *Please cite this article as:*
Amraee A, Seif F, Bayatiani MR, Shakeri M, Zakeri F. Correlation between Base Transceiver Station and the Quality of Sleep and Life of Nearby Residents . Iran J Med Phys 2021; 18: 10-14. 10.22038/ijmp.2020.42808.1641.

Introduction

Radiofrequency radiation (RFR) emanating from base transceiver stations (BTS) (the antennas which communicate with the mobile phones) is one of the growing concerns about the possible effects of electromagnetic fields on the general health of people [1].

BTS consists of three parts, namely A, B, and C, each of which covers about 120 and totally 360 horizontal degrees [2]. Each BTS supports approximately 30 Kilometers (Km); nonetheless, their functional range varies in open areas. It is estimated at 20 Km with no building or obstacle nearby, whereas it is measured at 2-5 km in urban spaces with many tall buildings [2].

The exposure to these base stations is regarded as low-powered; however, their output is continuous (24 h/day for many years) [3]. This exposure is more powerful at close quarters, while the field intensities rapidly decline with increasing distance from the base of the antenna [1]. The impacts of acute exposure to electromagnetic fields are divided into two major groups: thermal effects generated by high-intensity exposure and non-thermal effects that deal with the low-intensity electromagnetic waves [4]. Waves used for mobile communications have non-thermal effects [4]. As a result of tremendous cell phone users worldwide, the impacts of electromagnetic waves emitted by BTSs on general health have come into the focus of researchers [5]. Jelder et al. have pointed to the effects of electromagnetic fields on oxidative stress indices [5]. In Poland, Bortkiewicz A et al. found a correlation between subjective symptoms and distance from BTSs in the people living in the vicinity of base stations [3]. They indicated that 57% of their study population reported headaches despite the fact that 36.4% of them were 100-150 meters away from the base stations. In addition, 24.4% of people living more than 150 meters away reported memory problems [3, 6].

In the same vein, in Germany, Blentner et al. reported that residents adjacent to a mobile base station (D <500 m), as well as those who are

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concerned about the risks of radiation emitted from mobile stations, made more health complaints, as compared to other participants [6, 7]. Austrian researchers have suggested that it is impossible to determine a threshold at which no effects occur. Moreover, they indicated that for assessing the effects on health, mobile base station power density must be greater than 0.5-1 mW/m2 to observe [6, 8]. Sorgucu and Develi stated that although the radio frequency level of mobile base stations does not exceed the international limit, the exposure to these low-intensity electromagnetic fields for a long time may pose serious risks to general health [6, 9].

In Iran, there are three mobile operators which are servicing their subscribers using their own BTS. With the overwhelming use of mobile phone telecommunication, BTSs antennas can be extensively observed near houses, hospitals, parks, and shopping centers. Although the waves used for mobile communications have non-thermal effects, long-term exposure sometimes over a lifetime can bring about effects that are cumulative with some thermal effects [4]. With this background in mind, the present study was performed to investigate the correlation between distance from the antennas and psychological effects (the quality of sleep and life) on people living near mobile phone BTS Antenna.

Materials and Methods

Study population

The current study was performed on 810 randomly selected inhabitants, including 411 women and 399 men) living near the mobile phone BTS antenna in Arak.

The participants were assigned to five groups according to their distance from the mobile phone BTS antenna (0-50 meters (m), 50-100 m, 100-200 m, 200-300 m, and > 300m). Furthermore, the duration of residence in the region was considered a physical variable to define the exposure condition of subjects (less than 1 year, 1-2 years, 2-5 years, and more than 5 years). To avoid the variability inherent in the study, the individuals with physical and mental illnesses which led to hospitalization and chronic physical and mental illness were excluded. Moreover, participants who continuously and excessively used mobile phones, phones, computers, and microwaves were ruled out.

Pittsburgh Sleep Quality index and SF-12 questionnaire

The sleep quality was measured using the Pittsburgh sleep quality index (PSQI) which is a self-assessed questionnaire evaluating sleep quality. 19 separate items generate seven component scores, namely sleep latency, subjective sleep quality, sleep duration, sleep disturbances, use of sleep medications, habitual sleep efficiency, and daytime functioning disorders. The final score is the summation of these seven components [10]. According to this questionnaire, there is a minimum and maximum possible score for sleep quality (within 0-39). The higher score of sleep quality signifies poor sleep quality. In other words, score 39 indicates the worst sleep quality, while zero shows the best [11]. On the other hand, the 12-item Short Form Health Survey (SF-12) was used to assess the quality of life. It is a multipurpose, generic 12-item questionnaire developed from the 36-Item Short Form Health Survey questionnaire (SF-36) which is widely used to evaluate health status [6, 7]. The SF-12 yields an eight-scale profile of scores, as well as physical and mental health summary measures: physical functioning (PF): two items, role limitations due to physical functioning (role-physical (RP)): two items, bodily pain (BP): one item), general health (GH): one item, vitality (VT): one item, social functioning (SF): one item, role limitations due to emotional problems (role emotional [RE]): two items, and mental health (MH0: two items)[12]. According to this questionnaire, the minimum and maximum possible scores for each dimension of quality of life and total quality of life fall within 0-100. In other words, score 100 indicates the best and zero signifies the worst quality of life [11].

In the present study, the quality of sleep was investigated using the PSQI standard questionnaire. On the other hand, in order to evaluate the quality of life, the SF-12 questionnaire was used which contain two parameters, namely Mental Health Composite Scores (MCS) and Physical Health Composite Scores (PCS). For both Pittsburgh and SF-12 questionnaires, the obtained data from completed questionnaires were converted to 0-39 and 0-100 metric, respectively, and compared between different groups of subjects, according to their distance from the BTS antennae and the length of time living in the vicinity of BTS.

Statistical analysis

Data were analyzed in IBM SPSS Statistics for Windows package (version 16) using Student's t-test and one-way ANOVA to evaluate the differences of sleep qualities among different groups of subjects. Furthermore, to analyze PCS and MCS scores in different groups, one-way ANOVA was performed. Statistical significance was defined at a p-value of <0.05 and the data were expressed as mean±SD.

Results

Out of 810 participants, 411(50.7%) were women and 399 (49.2) were men. The mean scores of PSQI for women and men were obtained at 7.37±3.54 and 6.5±3.20, respectively. No statistically significant difference was found between women and men in seven components of PSQI ($p\geq0.05$).

Figure 1 depicts the mean scores of different components of PSQI (subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction). The t-test revealed no statistically significant differences between women and men in terms of PSQI mean, according to the distance from the BTS antennae. The subjects who were living at the distance of 50-100 meters from BTSs demonstrated a significant increase in PSQI score (7.80±3.58; P<0.05). Based on the analysis of the SF-12 questionnaire, the average PCS score was lower among those who were living at 50-100 meters from the antennas (44.48±9.04). Moreover, the average MCS score was reported to be lower in subjects residing at the distance of 100-200 meters (42.04±9.13; Table 1).

Inhabitants who were living near the BTS antennae for 1-2 years had a high score of PSQI (7.41±3.88) and a lower score of MCS (42.68±7.56) among other groups. In addition, the average PCS score was lower in subjects living near BTSs for less than 1 year (45.28±8.01; Table 2).

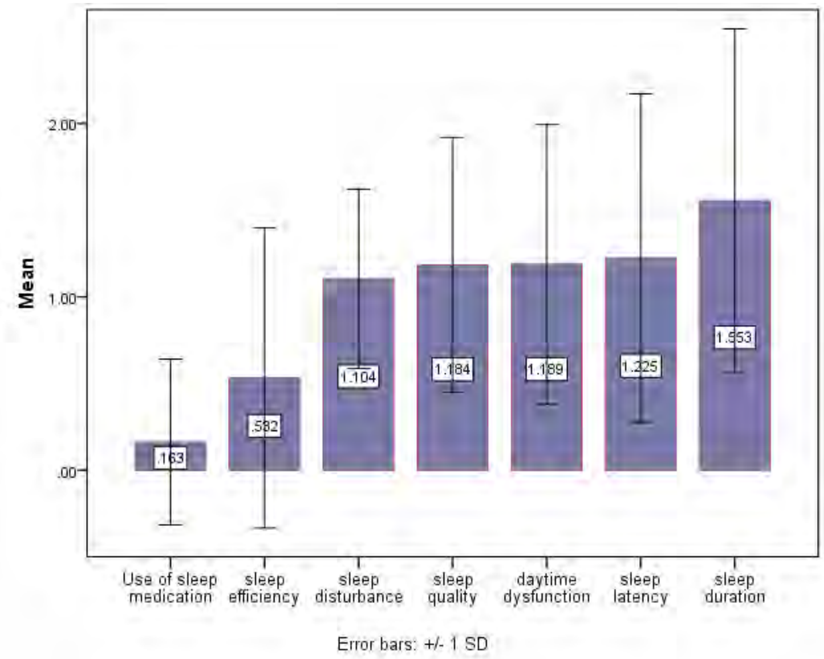

Figure 1. The mean scores of seven components of Pittsburgh sleep quality index (PSQI)

Table 1. Means of Pittsburgh sleep quality index, Mental Health Composite Scores, and Physical Health Composite Scores according to the distance from mobile phone BTS antennae

	Distances from BTS antennae (meter)					
	0-50	50-100	100-200	200-300	>300	P-value *
Total frequency	1621	64	163	143	177	
Pittsburgh sleep quality index (mean±SD)	6.69±3.26	7.80±3.58	7.53±3.30	6.91±3.38	6.87±3.49	P=0.012 F=3.23
Physical Health Composite Scores (mean±SD)	48.32±8.86	44.48±9.04	44.83±8.93	47.06±9.21	49.42±8.86	P=0.000 F=9.46
Mental Health Composite Scores (mean±SD)	46.85±8.23	42.98±9.20	42.04±9.13	45.37±9.13	46.06±8.9	P=0.000 F=8.45

* One-way ANOVA indicating differences between groups

Table 2. Means of Pittsburgh sleep quality index, Mental Health Composite Scores, and Physical Health Composite Scores according to a period of time of living near the mobile phone BTS antennae

	Period of time of living near the BTS antennae (year)			
	<1 year	1-2 years	2-5 years	>5 years
Pittsburgh sleep quality index (mean±SD)	7.21±3.21	7.41±3.88	7.19±3.32	7.23±3.48
Physical Health Composite Scores (mean±SD)	44.72±7.42	45.28±8.01	44.83±8.21	45.33±7.43
Mental Health Composite Scores (mean±SD)	43.28±7.02	42.68±7.56	42.33±8.11	42.83±7.98

Discussion

In recent years, the effects of electromagnetic fields emitted by the mobile stations, laptops, and magnetic resonance imaging (MRI) machines on animals and the general health of people have come into the focus of the researchers. The studies reported that the exposure of humans to high-frequency magnetic fields by mobile stations is two to four times lower than the current valid values [6]. The present study investigated the quality of sleep and life of people who are living near mobile phone BTS antennas. According to the PSQI means, most of sleep disorders were observed in people who were living at 50-100 meters from BTS antennas, while the least disorders were detected in those residing at less than 50 meters distance. Regarding sleep quality, the results indicated that residing within the distance of about 50-200 meters from the BTS antennas can affect sleep quality, as compared to living at less or more than this distance. Moreover, the results of the present study illustrated that the effect of distance of less than 50 m is approximately equal to that of detected in more than 300 m. According to the direction of radiation and spatial coverage of radiation, the highest intensity of waves is at intervals between 50 to 300 m. Nevertheless, the psychological and physiological effects may not obey the inverse square law that exists in radiation physics.

Some studies have demonstrated that the maximum intensity of BTS radiation occurs at 100-200 m distances from the antenna base, according to the direction and the radiation sector [13]. In the present research, the minimum value of the PCS score was related to those residing within this distance.

In addition, the obtained results showed that the length of time living near BTS exerted no effect on sleep quality. SF-12 questionnaire was used for the measurement of quality of life. The residents at the distance of 50-100 m had a minimum average of mental health. Moreover, people who were residing at the distance of 100-200 m had a minimum physical health average. Consistent with the results of a study conducted by H-P Hutter et al., the findings of the current study were indicative of the effects of these waves on such consequences as headache, level of consciousness, as well as factors associated with quality of life [14]. However, the present study did not provide any evidence for the impacts of the antenna on the physical components of quality of life []. In the same vein, Donker et al. stated that the short-term EMF emitted by mobile phone base stations has not any physiological effect on sleep quality[15]; nonetheless, these findings need to be confirmed in further studies.

The present findings in terms of effective factors on quality of life and sleep are in line with symptoms reported by Santini et al. The terms of effective factors on quality of life are including nausea, loss of appetite and visual disturbances for residents at the distance of 10-100 meters away and sleep disturbances for people residing with in the distance of 100-200 meters [16].

Shahabi et al. also reported that the residents in more than 300m from BTS had better health conditions, as compared to those living within less distances. Moreover, they found higher risks of headache and nausea among women residing at a distance of <300, as well as a decrease in libido among men who lived there [17]. In another study, the headache was detected in 57% of residents 36% of whom were living within a distance of 100-150 m [3].

In the present study, the maximum physical factor score of life quality was reported for people who were living in the region for more than 5 years, whereas the minimum score was reported for those who lived there less than 1 year. These findings need to be confirmed in further studies. The electromagnetic waves at the frequency range provided by the BTS antennas are non-ionizing waves. They can cause some biological effects through non-thermal pathways. These effects are more profound, as compared to the direct effects of these waves on clinical symptoms (including physical and mental symptoms). These symptoms reveal a psychological and sometimes non-scientific concern that generates a negative perception of the technology at the community level [7]. In compliance with a study carried out by Sabine et Al., such parameters as those presented in the present study, may not occur due to short-time radiation. Moreover, such effects as sleep disorders, neurological symptoms, nausea, fatigue, and quality of life-related parameters, may not be considered the early effects of exposure to electromagnetic beams of GSM or other modulation of telecommunication signals. Therefore, the occurrence of sleep disorders or psychological stress which was regarded as PCS in the present study is the long-term adverse consequence of residing in the vicinity of BTS [18]. Sorgucu and develi also reported the possibility of serious health problems in people who were exposed to very low levels of electromagnetic fields for very long periods of time [6].

Conclusion

In conclusion, the results of the present study indicated that exposure to electromagnetic waves caused by BTS antennas in terms of distance could affect the quality of sleep and life of individuals in both psychological and physical components. Therefore, it seems that convergence of the waves should be considered to the extent practicable in the setup of these antennas, and the waves should have the least possible intensity.

Acknowledgment

The authors' deepest appreciation goes to Arak University of Medical Sciences [Grant number: 990] for their valuable support.

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To Whom It May Concern:

Dear Sirs/Madams:

I am Scientist Emeritus and Former Director of the National Institute of Environmental Health Sciences and National Toxicology Program of the National Institutes of Health. I am currently a Scholar in Residence at the Nicholas School of the Environment at Duke University.

Wireless networks, cell towers and cell phones create radiofrequency radiation emissions. U.S. FCC limits for human exposure to radiofrequency were last reviewed in 1996 and based on the assumption that heating is the only harmful effect. Aware that the FCC's 1996 limits lacked the underpinning of solid scientific data regarding long term health effects, the FDA requested large-scale studies by the National Toxicology Program (NTP) and in 2018 the NTP studies found clear evidence of an association with cancer in male rats. Additionally, the NTP found heart damage and DNA damage, despite the fact that the animals were carefully exposed to non-heating RFR levels long assumed to be safe. The Ramazzini Institute animal studies used even lower RFR lower exposures to approximate cell tower emissions and also found increases of the same tumor type. The NTP studies were carefully controlled to ensure exposures did not significantly heat the animals. The animal study findings in combination with human studies indicate adverse effects from non heating levels of radiofrequency.

I document the importance of the NTP findings of effects from non thermal exposures in my declaration in an Amicus Brief for the case Environmental Health Trust et al v. the FCC. The August 13, 2021 judgment ordered the FCC to address several issues including the health implications of long term exposures.

A mounting body of published studies associates radiofrequency radiation with adverse negative health effects. FCC limits need to be strengthened to protect the public, especially children and vulnerable populations, from long term exposures.

Linda S. Birnbaum, PhD
Scientist Emeritus and Former Director
National Institute of Environmental Health Sciences and National Toxicology Program
Scholar in Residence, Duke University, Former President, Society of Toxicology
Adjunct Professor, Yale University and UNC, Chapel Hill, Visiting Professor, Queensland University (Australia)

National Toxicology Program Radiofrequency Radiation
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Massachusetts Joint Committee on Consumer Protection
Massachusetts Joint Committee on Advanced Information Technology, the Internet and Cybersecurity Committee
24 Beacon St. Room 506
Boston, MA 02133

Subject: In Support of Technology Safety Bills S. 186, S. 187, H. 115, H. 105-114

Dear Esteemed Legislators,

I am writing in support of legislation that which reduces RFR exposure, especially for children who are more vulnerable.

I am Professor Emeritus of Pediatrics and of Environmental & Occupational Health George Washington University School of Medicine and Health Sciences and George Washington University Milken Institute School of Public Health. I am also past chair of the Council on Environmental Health of the American Academy of Pediatrics, and also served on the Children's Health Protection Advisory Committee for the US EPA.

We assume that our federal health and environmental agencies regularly review the latest research and ensure that cell phones and wireless devices are safe. However, U.S. agencies which regulate cell phone radiation have not shown they have evaluated the research on children's unique vulnerability to ensure long term safety.

The reality is that US safety regulations for cell phone radiation were last set twenty-five years ago based on science that is now outdated. The Federal Communications Commission (FCC) is the primary agency responsible for regulating wireless radiation. The FCC has no expertise related to human health topics. Moreover, federal agencies like the Environmental Protection Agency or the National Cancer Institute or the Food and Drug Administration have not carried out up-to-date full scientific review of this growing technology. Just like the thousands of chemicals in our environment today, wireless radiation has not had appropriate oversight. It has slipped through the cracks.

The one agency which has carried out studies on the impact of long term exposure to electromagnetic fields and human health is the National Toxicology Program (NTP), a component of the National Institute of Environmental Health Sciences. The NTP found:

- **Clear evidence of an association with tumors in the hearts of male rats.** The tumors were malignant schwannomas.
- **Some evidence of an association with tumors in the brains of male rats.** The tumors were malignant gliomas.
- **Some evidence of an association with tumors in the adrenal glands of male rats.** The tumors were benign, malignant, or complex combined pheochromocytoma.

Pediatricians have long called for an update to this outdated cell phone radiation test method because research finds children can absorb up to 10 or more times higher wireless radiation than adults into their brain, eyes and bone marrow. Children are not little adults. As we sadly learned with early childhood lead exposures leaving long-lasting impairments, the developing brain is particularly susceptible. Unlike my generation, today's youth will be exposed for years and years.

Please support legislation that reduces children's radiofrequency radiation exposure and call on the federal government to strengthen human exposure limits to protect children. I am glad to answer any questions that you have.

Sincerely,

Jerome A Paulson, MD FAAP

Jerome Paulson MD FAAP

ENVIRONMENTAL HEALTH TRUST

January 28, 2021

Chairman Don Serotta
Town of Chester
1786 Kings Highway
Chester, NY 10918

Dear Chairman Don Serotta,

Cell antennas and cell towers should not be placed near schools and homes.

On August 13, 2021, the United States Court of Appeals for the District of Columbia Circuit ruled in our case against the FCC that the decision by the Federal Communications Commission (FCC) to retain its 1996 safety limits for human exposure to wireless radiation (which includes cell tower emissions) was "arbitrary and capricious." Once of the important aspects of the court decision was that the ruling found the FCC did not adequately explain why it ignored the impacts of long term wireless exposure, especially for children, who are more vulnerable to wireless radiation. This ruling highlights how no federal health agency has reviewed the full body of research to develop proper safety standards.

Extensive published scientific evidence indicates that radiofrequency radiation *at levels far below FCC limits* can cause cancer, increased oxidative stress, genetic damage, structural and functional changes of the reproductive system, memory deficits, behavioral problems, and neurological impacts. We consider radiofrequency radiation (RFR) to be a human carcinogen based on the current body of evidence.

At this time we have not identified a safe level of exposure. Although radiation levels decrease as you increase your distance from a particular antenna/tower, the reality is that adding a tower or base station to a community will definitely *increase* the radiation exposure in that area and at any distance within the surrounding coverage area.

We recommend policies to reduce human exposure to RFR, especially for children. Schools are where children spend the majority of their daytime hours. Therefore we strongly recommend against installing cell towers near schools, daycares, parks, homes, or hospitals.

Recent research on people living near cell antennas has found increases in molecular markers in the blood that predict cancer. This study evaluated effects in the human blood of individuals living near mobile phone base stations (for study purposes, they chose a distance of 80 meters) compared with healthy controls living more than 300 meters from a base station. The study measured higher RFR levels in the homes of people living in homes within 80 meters from the cell antennas (documenting the impact of increased RFR radiation from the antenna installations) and found statistically significant differences in their blood. The group living closer to the antennas had statistically significant higher frequency of micronuclei and a rise in lipid peroxidation in their blood; these changes are considered biomarkers predictive of cancer (Zothansiama et al, 2017).

Please note the following facts about cell towers and cell phone radiation:

- In 2011, radiofrequency radiation was classified as a Class 2B possible carcinogen by the World Health Organization's International Agency for Research on Cancer. Between then and now, the published peer-reviewed scientific evidence has significantly increased. Now, many scientists are of the opinion that the weight of current peer-reviewed evidence supports the conclusion that radiofrequency radiation should be regarded as a human carcinogen (Hardell and Carlberg 2017, Peleg et al, 2018, Miller et al 2018).
- The US National Toxicology Program $25 million animal study on long-term exposure to radiofrequency radiation found DNA Damage, heart damage, increased brain tumors, and increased heart tumors deemed "clear evidence of cancer." Importantly, this study was launched almost two decades ago by the FDA because the US government had not performed research on the long-term effects of RFR exposure and the FDA wanted data on long-term safety. In 1996, the EPA was defunded from developing proper safety standards, and since then there has been no systematic review of the science by any US agency.
- Researchers with the renowned Ramazzini Institute in Italy published findings that lab animals exposed to levels of RFR below FCC limits developed the same types of cancerous cancers as the US National Toxicology Program found in their large-scale animal study.
- An Australian study looked at RFR levels to which kindergarten children were exposed, depending on how close their school was to base stations/cell towers. Researchers equipped the children with RFR measuring devices. Researchers found that kindergartens located nearby base stations/cell towers (closer than 300 meters or approximately 330 yards) had total exposure to radiofrequency radiation (RFR or RF-EMF) more than 3 times higher than children at schools where base stations were further away than 300 meters.
- A 2018 study measured radiofrequency radiation exposures in the environment including emissions from cell phone towers, TV and FM radio broadcast antennas, cell phone

handsets, and Wi-Fi—in several countries including the United States. The researchers concluded that cell phone tower (base station) radiation emissions are the dominant contributor to RFR exposure in most outdoor areas.

- A 2015 review found that in 93 out of 100 studies, RFR exposure caused oxidative stress (Yakymenko 2015). A 2021 review again confirmed non ionizing radiation has oxidative effects (Schuermann 2021). Many well-known causes of cancer in humans (such as asbestos and arsenic) are understood to induce oxidative stress.
- Studies also show that when combined with lead or a known carcinogen, RFR has magnified the carcinogen's effects. For example, RFR at levels far below FCC limits more than doubled the numbers of liver and lung tumors in carcinogen-exposed mice (Lerchl 2015).
- The International Association of Firefighters has officially opposed cell towers on their stations since 2004 after a study found neurological damage in firefighters with antennas on their fire station. In 2017, when 5G "small cells" were coming to California via a 5G streamlining bill (SB 649), firefighter organizations came out in strong opposition to the bill and requested that towers not be installed on firehouses. They were successful and SB649 was amended to exempt their stations from the deployment due to their health concerns.
- Published research finds the frequencies impact wildlife. For example, studies have found that the radiation alters bird navigation and disturbs honeybee colonies. Research also shows adverse impacts on trees and plants. (Research on EMF and Bees, Research on Wildlife Research on Trees)
- A 2019 study of students in schools near cell towers found their higher RF exposure was associated with impacts on motor skills, memory, and attention (Meo 2019). Examples of other effects linked to cell towers in research studies include neuropsychiatric problems, elevated diabetes, headaches, sleep problems, and genetic damage. Such research continues to accumulate after the 2010 landmark review study on 56 studies that reported biological effects found at very low intensities of wireless radiation, including impacts on reproduction, permeability of the blood-brain barrier, behavior, cellular changes, and metabolic changes, and increases in cancer risk (Lai and Levitt 2010).

- The International EMF Scientist Appeal was submitted to the United Nations urging immediate protective policy action in light of the scientific evidence that has found adverse biological effects from electromagnetic radiation, including radiofrequency radiation, and, as of January 2019, this Appeal is signed by 247 scientists from 42 nations; these are scientists who have published peer-reviewed articles about electromagnetic fields. They state, "numerous recent scientific publications have shown that EMF affects living organisms at levels well below most international and national guidelines. Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being."

The exposure limits of the US Federal Communications Commission are totally outdated and do not protect the health of the public, especially not the health of children. The Los Angeles School District has banned cell towers on their District's school grounds.

Please note that in several countries, governments have set policies to protect children, pregnant women, and medically fragile persons by classifying areas with homes, hospitals, and schools as "sensitive areas." Some examples include:

- In India the government has set RFR limits to 1/10th of ICNIRP and the Brihanmumbai Municipal Corporation, Zilla Parishad, Rajasthan, and Mumbai have banned cell antenna/tower installations on schools.
- Greece has banned the installation of mobile phone base stations at the premises of schools, kindergartens, hospitals, or eldercare facilities.
- Chile's "Antenna Law" prohibits cell antennas/towers in "sensitive areas" (educational institutions, nurseries, kindergartens, hospitals, clinics, nursing homes).
- Several countries have lower allowable RFR limits in "sensitive" areas.

EHT's position is that children require special protections from radiofrequency radiation and their exposures should be reduced to as low as possible. We strongly recommend against cell tower/antenna placements at schools or near homes as this would increase daily RFR exposure.

Please feel free to contact us with more questions.

Sincerely,

Devra Davis, PhD, MPH
President and Founder, Environmental Health Trust
Visiting Professor, Hebrew University Hadassah Medical Center
https://ehtrust.org

Anthony B. Miller, MD
Professor Emeritus at the Dalla Lana School of Public Health, University of Toronto
Senior Advisor to Environmental Health Trust

Dr. Hugh Scully Testimony to the City of Toronto

(Past-President of Ontario Medical Association, Past-President of Canadian Medical Association, Past-President of Canadian Cardiovascular Society.)

As a physician leader in Canada with a great commitment to the health of Canadians, I am very concerned about the increasing evidence internationally that EMR is creating increasing health problems in our population as its use increases exponentially. This is particularly true among children and young Canadians, and teachers and nurses who are continuously exposed to WiFi routers in schools [and hospitals].

As a cardiac specialist, I am concerned that approximately 20% of people have detrimental cardiac rhythm sensitivity to EMR.

This issue is under active consideration by the Health and Public Policy Committee of the Royal College of Physicians and Surgeons of Canada, the Health Policy and Public Health Committees of the Canadian Medical Association and the Council of Family Physicians of Canada, the Canadian Pediatric Society and the Canadian Cardiovascular Society.

There is an abundance of evidence from around the world that EMR can be harmful to health. Many countries...not Canada or the United States...have initiated policies to mitigate the risks. We, in Canada, need to do the same or more.

It is imperative that City of Toronto does not install WiFi's in public parks and spaces. I ask you to vote against Councillor Matlow's proposal.

Sincerely,

Dr. Hugh Scully, BA,MD,MSc,FRSC[C],FACS

Professor of Surgery and Health Policy, University of Toronto, Past-President, OMA, CMA, CCS, Former Member of Council [Board], RCPSC and WMA, Member, Health Policy Advisory Council, American College of Surgeons.

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December 12, 2015

Montgomery County Schools
Carver Educational Services Center
850 Hungerford Drive
Rockville, MD 20850

cc Montgomery County City Council

Dear Montgomery County School District,

I am a pediatric neurologist and neuroscientist on the faculty of Harvard Medical School and on staff at the Massachusetts General Hospital. I am Board Certified in Neurology with Special Competency in Child Neurology, and Subspecialty Certification in Neurodevelopmental Disorders.

I have an extensive history of research and clinical practice in neurodevelopmental disorders, particularly autism spectrum disorders. I have published papers in brain imaging research, in physiological abnormalities in autism spectrum disorders, and in environmental influences on neurodevelopmental disorders such as autism and on brain development and function.

A few years ago I accepted an invitation to review literature pertinent to a potential link between Autism Spectrum Disorders and Electromagnetic Frequencies (EMF) and Radiofrequency Radiation(RFR). I set out to write a paper of modest length, but found much more literature than I had anticipated to review. I ended up producing a 60 page single spaced paper with over 550 citations. It is available at http://www.bioinitiative.org/report/wp-content/uploads/pdfs/sec20_2012_Findings_in_Autism.pdf and it was published in a revised and somewhat shortened form in two parts in the peer reviewed indexed journal *Pathophysiology (2013)*with the title: Áutism and EMF? Plausibility of a pathophysiological link." Please also see the appendix to this letter which contains a summary of this material and includes substantial scientific citations.

More recently I published an article entitled “Connections in Our Environment: Sizing up Electromagnetic Fields,” in *Autism Notebook Spring 2015* edition in which I summarized and personalized the information in the . In this article I describe how here is a whole series of problems at the cellular, sub-cellular and metabolic levels and immune levels that have been identified in autism. And interestingly, for every single one of those problems, there’s literature about how EMFs can create those kinds of problems.

The argument I made in these articles is not that EMF is proven to cause autism, but rather, that EMF can certainly contribute to degrading the physiological integrity of the system at the cellular and molecular level” – and this in turn appears to contribute to the pathogenesis/causation not only of autism but of many highly common chronic illnesses, including cancer, obesity, diabetes and heart disease.. Please see this article on page 24-25 at the link http://virtualpublications.soloprinting.com/publication/?i=252361

In fact, there are thousands of papers that have accumulated over decades –and are now accumulating at an accelerating pace, as our ability to measure impacts become more sensitive – that document adverse health and neurological impacts of EMF/RFR. Children are more vulnerable than adults, and children with chronic illnesses and/or neurodevelopmental disabilities are even more vulnerable. Elderly or chronically ill adults are more vulnerable than healthy adults.

Current technologies were designed and promulgated without taking account of biological impacts other than thermal impacts. We now know that there are a large array of impacts that have nothing to do with the heating of tissue. The claim from wifi proponents that the only concern is thermal impacts is now definitively outdated scientifically.

Radiofrequency electromagnetic radiation from wifi and cell towers can exert a disorganizing effect on the ability to learn and remember, and can also be destabilizing to immune and metabolic function. This will make it harder for some children to learn, particularly those who are already having learning or medical problems in the first place. And since half of the children in this country have some kind of chronic illness, this means that a lot of people are more vulnerable than you might expect to these issues.

Powerful industrial entities have a vested interest in leading the public to believe that EMF/RFR, which we cannot see, taste or touch, is harmless, but this is not true. Please do the right and precautionary thing for our children.

I urge you to opt for wired technologies in Montgomery County classrooms, particularly for those subpopulations that are most sensitive. It will be easier for you to make a healthier decision now than to undo misguided decisions later.

Thank you.

Martha Herbert, PhD, MD

Selected pertinent publications

Connections in our Environment: Sizing up Electromagnetic Fields by M.R. Herbert (published in Autism Notebook Spring 2015, pp.. 24-25) reviews in two pages key points of the more technical Herbert & Sage Autism-EMF paper

Herbert, M.R. and Sage, C. "Autism and EMF? Plausibility of a Pathophysiological Link". Part 1: *Pathophysiology* , 2013, Jun;20(3):191-209, epub Oct 4, PMID 24095003. Pubmed abstract for Part 1. Part II: *Pathophysiology,* 2013 Jun;20(3):211-34. Epub 2013 Oct 8, PMID 24113318. Pubmed abstract for Part II.

APPENDIX: MORE DETAILED SUMMARY OF THE PATHOPHYSIOLOGY

I became interested in the health and brain effects of electromagnetic frequency (EMF) and radiofrequency radiation (RFR) exposures in relation to my brain research because I was interested in how such exposures might alter brain function. In order to familiarize myself in more detail existing literature on the pathophysiological impacts of EMF/RFR, I coauthored a 40,000 word chapter in the 2012 update of the Bioinitiative, [1] and published an updated 30,000 word version of that paper ("Autism and EMF? Plausibility of a Pathophysiological Link") in 2013 in two parts in the peer reviewed journal *Pathophysiology.* [2, 3] My intention was to assess the plausibility of an association between increasing incidence of autism spectrum disorder and increasing EMF/RFR exposures. Rather than directly address the epidemiological issues, I looked at the parallels between the pathophysiological features documented in autism and the pathophysiological impacts of EMF/RFR documented in the peer-reviewed published scientific literature.

I will include here a brief summary of the paper (prepared for a lay audience) of the features of EMF/RFR that I reviewed (with citations at the end of this letter):

- EMF/RFR stresses cells. It lead to cellular stress, such as production of heat shock proteins, even when The EMF/RFR isn't intense enough to cause measurable heat increase. [4-6]
- EMF/RFR damages cell membranes, and make them leaky, which makes it hard for them to maintain important chemical and electrical differences between what is inside and outside the membrane. This degrades metabolism in many ways – makes it inefficient. [7-15]
- EMF/RFR damages mitochondria. Mitochondria are the energy factories of our cells. Mitochondria conduct their chemical reactions on their membranes. When those membranes get damaged, the mitochondria struggle to do their work and don't do it so well. Mitochondria can also be damaged through direct hits to steps in their chemical assembly line. When mitochondria get inefficient, so do we. This can hit our brains especially hard, since electrical communication and synapses in the brain demands huge amounts of energy.
- EMF/RFR creates "oxidative stress." Oxidative stress is something that occurs when the system can't keep up with the stress caused by utilizing oxygen, because the price we pay for using oxygen is that it generates free radicals. These are generated in the normal course of events, and they are "quenched" by antioxidants like we get

in fresh fruits and vegetables; but when the antioxidants can't keep up or the damage is too great, the free radicals start damaging things.
- EMF/RFR is genotoxic and damages proteins, with a major mechanism being EMF/RFR-created free radicals which damage cell membranes, DNA, proteins, anything they touch. When free radicals damage DNA they can cause mutations. This is one of the main ways that EMF/RFR is genotoxic – toxic to the genes. When they damage proteins they can cause them to fold up in peculiar ways. We are learning that diseases like Alzheimer's are related to the accumulation of mis-folded proteins, and the failure of the brain to clear out this biological trash from its tissues and fluids.
- EMF/RFR depletes glutathione, which is the body's premier antioxidant and detoxification substance. So on the one hand EMF/RFR creates damage that increases the need for antioxidants, and on the other hand they deplete those very antioxidants.[1, 16]
- EMF/RFR damages vital barriers in the body, particularly the blood-brain barrier, which protects the brain from things in the blood that might hurt the brain. When the blood-brain barrier gets leaky, cells inside the brain suffer, be damaged, and get killed. [1, 16, 17]
- EMF/RFR can alter the function of calcium channels, which are openings in the cell membranes that play a huge number of vital roles in brain and body. [18-27]
- EMF/RFR degrades the rich, complex integration of brainwaves, and increase the "entropy" or disorganization of signals in the brain – this means that they can become less synchronized or coordinated; such reduced brain coordination has been measured in autism. [28-40]
- EMF/RFR can interfere with sleep and the brain's production of melatonin. [41-43]
- EMF/RFR can contribute to immune problems. [44-50]
- EMF/RFR contribute to increasing stress at the chemical, immune and electrical levels, which we experience psychologically. [51-57] [17, 58-62] [63-68]

Please note that:

1. There are a lot of other things that can create similar damaging effects, such as thousands of "xenobiotic" substances that we call toxicants. Significantly, toxic chemicals (including those that contain naturally occurring toxic elements such as lead and mercury) cause damage through many of the same mechanisms outlined above.
2. In many of the experimental studies with EMF/RFR, damage could be diminished by improving nutrient status, particularly by adding antioxidants and melatonin. [69-72]

I understand that the concept of electromagnetic hypersensitivity is not always well understood in the medical and scientific communities. Indeed, the inter-individual variability is perplexing to those who would expect a more consistent set of features.

But given the range of challenges I have listed that EMF/RFR poses to core processes in biological systems, and given the inter-individually variable vulnerability across these symptoms, it is really not surprising that there would be subgroups with different combinations of symptom clusters.

It also appears to be the case that the onset and duration of symptoms or even brain response to EMR/RFR can be variable. This again is to be expected given the mediation of these symptoms through a variety of the above-listed pathophysiological processes, many of which differ in scale (ranging from molecular to cellular to tissue and organ) and time course of impact. The different parts of the body also absorb this energy differently, both because of their biophysical properties and as a function of their state of health or compromise thereof.

Here is a list of subgroups of symptom clusters identified by a group of German physicians, t exemplifies these variability issues:

Group 1 no symptoms
Group 2 sleep disturbance, tiredness, depressive mood
Group 3 headaches, restlessness, dazed state, irritability, disturbance of concentration, forgetfulness, learning difficulties, difficulty finding words
Group 4 frequent infections, sinusitis, lymph node swellings, joint and limb pains, nerve and soft tissue pains, numbness or tingling, allergies
Group 5 tinnitus, hearing loss, sudden hearing loss, giddiness, impaired balance, visual disturbances, eye inflammation, dry eyes
Group 6 tachycardia, episodic hypertension, collapse
Group 7 other symptoms: hormonal disturbances, thyroid disease, night sweats, frequent urge to urinate, weight increase, nausea, loss of appetite, nose bleeds, skin complaints, tumors, diabetes

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UNIVERSITY AT ALBANY
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Institute for Health and the Environment
WHO Collaborating Center in Environmental Health

3 August 2016

Petaluma City Schools
District Office
200 Douglas Street
Petaluma, California 94952

Dear Sirs/Madams:

I am a public health physician who served as the Co-Editor of the Bioinitiative Report, published in 2007 as a comprehensive review of the adverse health effects of radiofrequency electromagnetic fields.

There is strong and consistent evidence that excessive exposure to radiofrequency electromagnetic fields has adverse human health effects. Of particular concern is the clear evidence that children are more vulnerable than adults. The best-documented adverse effects are an increase in risk of cancer, but cancers do not appear immediately upon exposure but rather come years later. The National Toxicology Program has within the past couple of months reported that even rats exposed to radiofrequency radiation develop brain cancer! Within a school setting there is increasing evidence that excessive exposures reduce learning ability, which is the last thing one wants in a school. Some children will also develop a syndrome of electrohypersensitivity, where they get headaches and reduced ability to pay attention and learn. While these effects are not nearly as well documented as those relating to cancer, they are particularly important within a school. This is especially the case in a wireless computer classroom, where exposure can be very high. However there will be essentially no exposure in a wired computer classroom.

The exposure levels of the Federal Communications Commission are totally outdated and do not protect the health of the public, especially of children. I urge you to abandon any plans for wireless communication within schools. It is of course critical that all children have access to the Internet, but when this is done through wired connections they will not be exposed to excessive electromagnetic fields.

Yours sincerely,

David O. Carpenter

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District Office 4 August, 2016
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Dear Petaluma City Schools;
Superintendent Gary Callahan and Board of Trustees

Regarding: Wireless technology should not be used in schools or pre-schools due to health risks for children and employees

We have been asked to declare our opinion about wireless technology in schools by parents that are concerned about their children.

Based on current published scientific studies, we urge your administration to educate themselves on the potential risks from wireless technologies in schools, and to choose wired teaching technologies. The well-being and educational potential of children depends on it.

High-speed connectivity to schools is important but it can be a wired connection instead of Wi-Fi. Wireless classroom infrastructure and wireless devices for schoolchildren should be avoided for these reasons:

- Wireless radiofrequency (RF) radiation emissions were classified as a Possible Human Carcinogen (group 2B) by the World Health Organization International Agency for Research on Cancer (IARC) in May 2011. One of the signers, Dr Hardell, was part of the evaluation group.
- The IARC classification holds for *all forms of radio frequency radiation* including RF-EMF emissions from wireless transmitters (access points), tablets and laptops.
- Epidemiological studies show links between RF radiation exposure and cancer, neurological disorders, hormonal changes, symptoms of electrical hypersensitivity (EHS) and more. Laboratory studies show that RF radiation exposure increases risk of cancer, abnormal sperm, learning and memory deficits, and heart irregularities. Foetal exposures in both animal and human studies may result in altered brain development in the young offspring, with disruption in learning, memory and behaviour.
- Recently a report was released from The National Toxicology Program (NTP) under the National Institutes of Health (NIH) in USA on the largest ever animal study on cell phone RF radiation and cancer (http://biorxiv.org/content/biorxiv/early/2016/05/26/055699.full.pdf). An increased incidence of glioma and malignant schwannoma in the heart was found. Interestingly our research group and others have in epidemiological studies shown that persons using wireless phones (both mobile phones and cordless phones; DECT) have an increased risk for glioma and acoustic neuroma. Acoustic neuroma or vestibular schwannoma is the same type of tumour as the one found in the heart, although benign.
- The research showing increased brain cancer risk in humans *has strengthened* since the IARC 2011 classification as new research has been published which repeatedly shows a significant association after RF radiation exposure. In addition, tumour

promotion studies have now been replicated showing cancer promotion after exposures at low levels.
- It is our opinion and that of many colleagues that the current IARC cancer risk classification should move to an *even higher* risk group. The carcinogenic effect has been shown in human and animal studies. Several laboratory studies have shown mechanistic effects in carcinogenesis such as oxidative stress, down regulation of mRNA, DNA damage with single strand breaks.
- In summary RF radiation should be classified as Carcinogenic to Humans, Group 1 according to the IARC classification. This classification should have a major impact on prevention.

The evidence for these statements is based on hundreds of published, peer-reviewed scientific studies that report adverse health effects at levels much lower than current ICNIRP and FCC public safety limits. Compliance with government regulations does not mean that the school wireless environment is safe for children and staff (especially pregnant staff).

As researchers in cancer epidemiology and RF radiation exposures, we have published extensively in this area and it is our opinion that schools should choose wired Internet connections. Multiple epidemiological research studies show that exposures equivalent to 30 minutes a day of cell phone use over ten years results in a significantly increased brain cancer risk.

What will be the health effect for a child exposed all day long in school for 12 years? Wireless networks in schools result in full body low level RF radiation exposures that can have a cumulative effect on the developing body of a child. No safe level of this radiation has been determined by any health agency and therefore we have no safety assurances. Cancers can have long latency periods (time from first exposure until diagnosis) and it will take decades before we know the full extent of health impacts from this radiation. The statistics and effects will be borne by the children you serve.

Wi-Fi in schools, in contrast to wired Internet connections, will increase risk of neurologic impairment and long-term risk of cancer in students. Promoting wireless technology in schools disregards the current health warnings from international science and public health experts in this field.

We recommend that your school district install wired Internet connections and develop curriculum that teaches students at all ages safer ways to use their technology devices. If cell phones and other wireless devices are used in the school curriculum (as many schools are now doing with Bring your Own Device Policy) then there should be educational curriculum in place and well posted instructions in classrooms so that the students and staff use these devices in ways that reduce exposure to the radiation as much as possible.

Supporting wired educational technologies is the safe solution in contrast to potentially hazardous exposures from wireless radiation.

Respectfully submitted

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August 4, 2016

Petaluma City Schools
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Re: Adverse Effects of Radiofrequency fields

I am writing to express my concern over the increasing exposure of children in schools to Radiofrequency Fields (e.g. from wi-fi, as required for cell phones and iPads, and emitted by cell towers) and the lack of concern expressed by many councils, governments and School Boards on this issue. In particular, justification for the "safety" of radiofrequency fields is placed upon the use of outdated safety standards, based upon tissue heating, whereas it has now been well demonstrated that adverse biological effects occur at far lower levels of radiofrequency fields that do not induce tissue heating, including a recent animal study performed by the National Toxicology Program in the United States which found an increased incidence of brain cancers and other cancers in rats exposed to prolonged Radiofrequency fields.

I am a physician and epidemiologist specializing in cancer etiology, prevention, and screening, expert in epidemiology, and particularly causes of human cancer. I have performed research on ionizing radiation and cancer, electromagnetic fields and cancer, and have served on many committees assessing the carcinogenicity of various exposures, including working groups of the International Agency for Research on Cancer (IARC), widely regarded as providing unbiased assessment on the carcinogenicity of chemicals and other exposure to humans.

In 2011, an IARC working group designated radiofrequency fields as a class 2B carcinogen, a possible human carcinogen. Since that review a number of additional studies have been reported. One of the most important was a large case-control study in France, which found a doubling of risk of glioma, the most malignant form of brain cancer, after two years of exposure to cell phones. After five years exposure the risk was five-fold. They also found that in those who lived in urban environments the risk was even higher. In my view, and that of many colleagues who have written papers on this issue, these studies provide evidence that radiofrequency fields are not just a possible human carcinogen but a probable human carcinogen, i.e. IARC category 2A. It would be impossible to ignore such an assessment in regulatory approaches.

It is important to recognize that there are no safe levels of exposure to human carcinogens. Risk increases with increasing intensity of exposure, and for many carcinogens, even more with increasing duration of exposure. The only way to avoid the carcinogenic risk is to avoid exposure altogether. This is why we ban known carcinogens from the environment and why much effort is taken to get people, particularly young people, not to smoke. We now recognize that exposure to carcinogens in childhood can increase the risk of cancer in adulthood many years later. Further, people vary in their genetic makeup, and certain genes can make some people more susceptible than others to the effect of carcinogens. It is the young and those who are susceptible we should protect.

As an epidemiologist who has done a great deal of work on breast cancer, I have been concerned by a series of case reports from California and elsewhere of women who developed unusual breast cancers in the exact position where they kept cell phones in their bras. These are unusual cancers. They are multifocal, mirroring where the cell phone was kept. Thus in these relatively young women the radiofrequency radiation from very close contact with a cell phone has caused breast cancer.

Not only brain and breast cancers but parotid gland tumors, tumors of the salivary gland, have been associated with prolonged exposure to cell phones.

Given the long natural history of cancer and the fact that human populations have not been exposed for a sufficient length of time to reveal the full adverse effects of radiofrequency fields, it is extremely important to adopt a precautionary approach to the exposure of humans to such fields. An individual, if appropriately informed, can reduce her or his exposure to radiofrequency fields from devices that use wi-fi, but in the case of cell towers, smart meters and wi-fi in schools, the exposure they receive is outside their control. Then, with the people who manufacture these devices and those who promote wi-fi failing to issue adequate health warnings, we are reaching a situation where schools, work places and homes are being saturated with radiofrequency fields.

Thus to avoid a potential epidemic of cancer caused by radiofrequency fields from wi-fi and other devices, we should introduce means to reduce exposure as much as reasonably achievable, use hard wire connections to the internet and strengthen the codes that are meant to protect the public.

Yours sincerely

Anthony B. Miller, MD, FRCP(C), FRCP, FACE
Professor Emeritus
Dalla Lana School of Public Health, University of Toronto, Ontario, Canada

Karolinska Institutet
Department of Neuroscience
Experimental Dermatology Unit

Stockholm, December 8, 2015

To:
MCPS CEO Dr. Andrew Zuckerman [Andrew_Zuckerman@mcpsmd.org]
MCPS Superintendent Mr. Larry Bowers [Larry_Bowers@mcpsmd.org]
MCPS Chief Technology Officer Mr. Sherwin Collette [Sherwin_Collette@mcpsmd.org]
MCPS Board of Education [boe@mcpsmd.org]
840 Hungerford Drive
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cc:
Montgomery County Council [county.council@montgomerycountymd.gov]

Dear Madame or Sir,

My name is Olle Johansson, and I am an associate professor, heading the Experimental Dermatology Unit at Sweden's Karolinska Institute in the Department of Neuroscience. I understand you have recently made public pronouncements regarding the safety of Wi-Fi. As a neuroscientist who has been studying the biophysical and epidemiological effects of electromagnetic fields (EMFs) for over 30 years, I believe this designation is short-sighted.

Wireless communication is now being implemented in our daily life in a very fast way. At the same time, it is becoming more and more obvious that the exposure to electromagnetic fields not only may induce acute thermal effects to living organisms, but also non-thermal effects, the latter often after longer exposures. This has been demonstrated in a very large number of **non-ionizing radiation** studies and includes cellular DNA-damage, disruptions and alterations of cellular functions like increases in intracellular stimulatory pathways and calcium handling, disruption of tissue structures like the blood-brain barrier, impact on vessel and immune functions, and loss of fertility. Whereas scientists can observe and reproduce these effects in controlled laboratory experiments, epidemiological and ecological data derived from long-term exposures in well-designed case-control studies reflect this link all the way from molecular and cellular effects to the living organism up to the induction and proliferation of diseases observed in humans. It should be noted that we are not the only species at jeopardy; practically all animals, plants and bacteria may be at stake. Although epidemiological and ecological investigations as such never demonstrate causative effects, due to the vast number of confounders, they confirm the relevance of the controlled observations in the laboratories.

Many times since the early 1980s I have pointed out that the public's usage of cell phones has become the largest full-scale biological and medical experiment ever with mankind, and I was also the first person to firmly point out that this involuntary exposure violates the Nuremberg Code's principles for human experimentation, which clearly states that voluntary

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consent of human subjects is absolutely essential. Among many effects seen, the very serious one is the deterioration of the genome. Such an effect - if seen in a food item under development or in a potential pharmaceutical drug - immediately would completely ban it from further marketing and sale; genotoxic effects are not to be allowed or spread. For these reasons above, we, scientists, can not accept that children undergo an enormous health risk for their present and future, by being exposed to WI-FI in kindergardens or schools (even if the WI-FI masts/routers are not in the children's classroom). The precautionary principle has to be respected. Furthermore, when men place cell phones in their front pocket, or laptops on their laps, it should be noted that experimental studies have demonstrated that after similar exposures there is a decrease in sperm count as well as in the quality of sperm, which is a phenomenon that could affect society's overall ability to procreate in the future. Experiments in mice point to that it may be true already in 5 generations time.

Many other states including France, Russia, Israel and Germany, have employed various precautionary steps and their responses (including labelling cell phones and other transmitting devices with SAR ratings, discouraging the use of cell phones and other wireless gadgets by children, warning parents of the risks, and removing or restricting WiFi in schools and replacing it with hard-wired ethernet) as a result of the *WHO/IARC classification of radiofrequency electromagnetic radiation in 2011 as a Class 2B carcinogen as well as the earlier classification of power-frequent magnetic fields in 2001 also as a Class 2B carcinogen*, the information summarized in the Bioinitiative Reports of 2007 and 2012, and the other considerable international and independent research and reviews, that show adverse biological effects from electromagnetic fields, including heart palpitations, headaches, skin rashes, damage to DNA, mental health effects, impaired concentration, decreased problem-solving capacity, electrohypersensitivity, etc., are about to set a new standard for educational quality with due respect to children's and staff's health.

In the case of "protection from exposure to electromagnetic fields", it is thus of paramount importance to act from a prudence avoidance/precautionary principle point of view. Anything else would be highly hazardous. Total transparency of information is the key sentence here, as I believe the public does not appreciate having the complete truth revealed years after a certain catastrophe already has taken place. For instance, it shall be noted, that today's recommended values for wireless systems, such as the SAR-values, are just recommendations, and not safety levels. Since scientists observe biological effects at as low as 20 microWatts/kg, can it truly be stated that it is safe to allow irradiation of humans at SAR 2 W/kg, or at 100,000 times stronger levels of radiation?

IMBALANCED REPORTING

Another misunderstanding is the use of scientific publications (as the tobacco industry did for many years) as 'weights' to balance each other. But one can NEVER balance a report showing a negative health effect with one showing no effect. This is a misunderstanding which, unfortunately, is very often used both by the industrial representatives as well as official authorities to the detriment of the general public. True balance would be reports showing negative health effects against *exact replications* showing no or positive effects. However, this is not what the public has been led to believe.

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NEED FOR INDEPENDENT RESEARCH

In many commentaries, debate articles and public lectures - for the last 20-30 years – I have urged that completely independent research projects must be inaugurated immediately to ensure our public health. These projects must be entirely independent of all types of commercial interests; public health can not have a price-tag! It is also of paramount importance that scientists involved in such projects must be free of any carrier considerations and that the funding needed is covered to 100%, not 99% or less. This is the clear responsibility of the democratically elected body of every country.

WHO/INTERNATIONAL AGENCY FOR RESEARCH ON CANCER (IARC), 2011

Very recently (in Lyon, France, May 31, 2011) the WHO/International Agency for Research on Cancer (IARC) has classified radiofrequency electromagnetic fields as possibly carcinogenic to humans (Group 2B), based on an increased risk for glioma, a malignant type of brain cancer. This should be added to the previous (2001) 2B classification of power-frequent (ELF) electromagnetic fields – emitted at high levels from handheld gadgets, such as eReaders and mobile phones – as a risk factor for childhood leukemia. Given the 2001 very close votes (9 to 11) for moving it to 2A and all the new knowledge that has accumulated since 2001, today the association between childhood leukemia and power-frequent (ELF) electromagnetic fields would definitely be signed into the much more serious 2A ("probably carcinogenic") category. So, the 'red flag' is – unfortunately – flying very high.

INVOLUNTARY EXPOSURE

According to Article 24 of the UNICEF's Child Convention "children have the right to … a clean and safe environment, and information to help them stay healthy". We must all ensure that this article never is violated. This is about our social responsibility, and is very much a public health issue.

In summary, electromagnetic fields may be among the most serious and overlooked health issues today, and having these fields checked and reduced/removed from schools and kindergardens may be essential for health protection and restoration, and is a must for persons with the functional impairment electrohypersensitivity as for children who are more fragile (cf. Belyaev I, Dean A, Eger H, Hubmann G, Jandrisovits R, Johansson O, Kern M, Kundi M, Lercher P, Mosgöller W, Moshammer H, Müller K, Oberfeld G, Ohnsorge P, Pelzmann P, Scheingraber C, Thill R, "EUROPAEM EMF Guideline 2015 for the prevention, diagnosis and treatment of EMF-related health problems and illnesses", Rev Environ Health 2015; 30: 337–371). In addition, as recently discussed in a think-tank group here in Stockholm, it is very important to constantly educate oneself and participate in the general debate and public discussions to keep the information build-up active. Thus, it is of paramount importance to keep the "kettle boiling", never blindly trusting or accepting given 'facts', but only read and think for yourself and for your loved ones. Only so you can arrive at a genuinely working precautionary principle.

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CONCLUSION

In conclusion, wireless systems, such as Wi-Fi routers or cell towers, and their electromagnetic fields, can not be regarded as safe in schools, but must be deemed highly hazardous and unsafe for the children as well as for the staff.

I encourage governments and local health and educational bodies to adopt a framework of guidelines for public and occupational EMF exposure that reflect the Precautionary Principle. As noted, the Precautionary Principle states when there are indications of possible adverse effects, though they remain uncertain, the risks from doing nothing may be far greater than the risks of taking action to control these exposures. The Precautionary Principle shifts the burden of proof from those suspecting a risk to those who discount it — as some nations have already done. Precautionary strategies should be based on design and performance standards and may not necessarily define numerical thresholds because such thresholds may erroneously be interpreted as levels below which no adverse effect can occur.

Some 100 years back, we learned the hard lessons of ionizing radiation and the need for strict health protections – now we must openly face the possibility that we must take a seat in life's school and learn again. This time it is about non-ionizing radiation.

Based on all of the above, I strongly urge you to reconsider your public stance on the safety of Wi-Fi, cell towers, and similar systems in schools as their non-ionizing radiation emissions very likely are hazardous and unsafe for students, staff and teachers.

With my very best regards
Yours sincerely
Olle Johansson

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MCPS COO Dr. Andrew Zuckerman
MCPS Interim Superintendent Larry Bowers
MCPS Board of Education
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January 3, 2016

Dear Montgomery County COO Dr. Andrew Zuckerman, Interim Superintendent Larry Bowers, Board of Education and Office of Technology;

I have been asked to comment on the MCPS Statement Concerning Deployment of Wireless Computing Technologies. I am happy to do so.

The first paragraph in that statement is not relevant to the issue at hand because it is perfectly possible to use wired communication for such education. This document is being produced on a computer on which I only use wired communication, connecting to the internet, connecting to my printer and for other purposes, as well.

The 2nd and 3rd paragraphs of your statement may well be technically correct. However these give us no assurance whatsoever of safety of Wi-Fi fields. The FCC guidelines as are many other such guidelines, are based on the assumption that only heating effects of microwave/lower frequency EMFs can have biological effects. However that assumption has been falsified by thousands of studies published from the 1950s to the present, each showing that non-thermal levels of exposure often produce biological effects. For example, in 1971, the U.S. Office of Naval Medical Research produced a document reporting over 100 different non-thermal effects [1], listing 40 apparent neuropsychiatric changes produced by non-thermal microwave frequency exposures, including 5 central/peripheral nervous system (NS) changes, 9 central NS effects, 4 autonomic system effects, 17 psychological disorders, 4 behavioral changes and 2 misc. effects [1]. It also listed cardiac effects including ECG changes and cardiac necrosis as well as both hypotension and hypertension, and also 8 different endocrine effects.

Changes affecting fertility included tubular degeneration in the testis, decreased spermatogenesis, altered sex ratio, altered menstrual activity, altered fetal development, programmed cell death (what is now known as apoptosis) and decreased lactation. Many other non-thermal changes were also listed for a total of over 100 non-thermal effects. They also provided [1] approximately 2000 citations documenting these various health effects. That was almost 45 years ago and is only the beginning of the evidence for the existence of non-thermal effects. My own recent paper [2] shows that widespread neuropsychiatric effects are caused by non-thermal exposures to many different microwave frequency electromagnetic fields (EMFs).

Tolgskaya and Gordon [3] in 1973 published a long and detailed review of effects of microwave and lower frequency EMFs on experimental animals, mostly rodents. They report that non-thermal exposures impact many tissues, with the nervous system being the most sensitive organ in the body, based on histological studies, followed by the heart and the testis. They also report effects of non-thermal exposures on liver, kidney, endocrine and many other organs. The nervous system effects are very extensive and include changes many changes in cell structure, disfunction of synaptic connections between neurons and programmed cell death and are discussed in Refs. [2,3] and more modern studies reporting extensive effects of such non-thermal EMF exposures on the brain are also cited in [2]. There are also many modern studies showing effects of non-thermal exposures on fertility in animals.

The Raines 1981 National Aeronautics and Space Administration (NASA) report [4] reviewed an extensive literature based on occupational exposures to non-thermal microwave EMFs. Based on multiple studies, Raines [4] reports that 19 neuropsychiatric effects are associated with occupational microwave/ radiofrequency EMFs, as well as cardiac effects, endocrine including neuroendocrine effects and several other effects.

I reviewed many other scientific reviews on this topic, each of which clearly supports the view that there are various non-thermal health impacts of these EMFs [5]. In 2015, 206 international scientists signed a statement sent to the United Nations Secretary General and to member states, stating that international safety guidelines and standards are inadequate to protect human health [6]. Each of these 206 scientists from 40 countries had scientific publications on biological effects of such EMFs and therefore each is well qualified to judge this. ***It can be seen from this statement to the UN, that there is a strong scientific consensus that current safety guidelines and standards are inadequate because they do not take into consideration all of the non-thermal health effects produced by various EMF exposures.***

That scientific consensus also rejects, therefore, the FCC EMF guidelines, guidelines that cannot be defended despite your own attempt to do so in MCPS Statement Concerning Deployment of Wireless Computing Technologies.

It can be seen from the previous paragraphs, that the following non-thermal effects of EMF exposures are well documented:

Ø Widespread neuropsychiatric effects
Ø Several types of endocrine (that is hormonal) effects
Ø Cardiac effects impacting the electrocardiogram (Note: these are often associated with occurrence of sudden cardiac death)
Ø Male infertility
However, there are many additional types of biological changes produced by non-thermal EMF exposures (reviewed in 5,7] including:
Ø Oxidative stress
Ø Changes in calcium fluxes and calcium signaling
Ø Several types of DNA damage to the cells of the body, including single strand and double strand DNA breaks and 8-OH-guanine in DNA
Ø Cancer (which is undoubtedly caused, in part, by such DNA damage)
Ø Female infertility
Ø Lowered melatonin; sleep disruption
Ø Therapeutic effects of EMFs when they are highly controlled and focused on a specific part of the body

It can be seen from the above, that each of the things that we most value as individuals and as a species are being attacked by non-thermal microwave frequency EMFs [5.7]:
§ **Our Health**
§ **Our brain function**
§ **The integrity of our genomes**
§ **Our ability to produce healthy offspring**

I want to emphasize that the specific health effects listed above are **not** the only things that are likely to be impacted by non-thermal EMF exposures, they are however the best documented such effects.

While it has been clear for many years that there are many non-thermal health effects of microwave frequency EMFs, it has not been clear until about 2 ½ years ago, how these effects are produced by such exposures. I stumbled onto the mechanism in 2012 and published on it in mid-2013. This 2013 paper [8] was honored by being placed on the Global Medical Discovery web site as one of the most important medical papers of 2013. At this writing, it has been cited 61 times according to the Google Scholar database, with over 2/3rds of those citations during 2015. So clearly it is having a substantial and rapidly increasing impact on the scientific literature. I have given 26 professional talks, in part or in whole on EMF effects in 10 different countries over the last 2 1/4 years. So it is clear that there has been a tremendous amount of interest in this research.

What the 2013 study showed [8], was that in 24 different studies (and there are now 2 more that can now be added [2]), effects of low-intensity EMFs, both microwave frequency and lower frequency EMFs could be blocked by calcium channel blockers, drugs that block what are called voltage-gated calcium channels (VGCCs). There were a total of 5 different types of calcium channel blocker drugs used in these studies, with each type acting on a different site on the VGCCs and each thought to be highly specific for blocking VGCCs. What these studies tell us is that these EMFs act to produce non-thermal effects by activating the VGCCs. Where several effects were studied, when one of them was blocked or greatly lowered, each other effect studied was also blocked or greatly lowered. This tells us that the role of VGCC activation is quite wide – many effects go through that mechanism, possibly even all non-thermal effects in mammals. There are a number of other types of evidence confirming this mechanism of action of microwave frequency EMFs [2,]. Each of the 11 health impacts caused by non-thermal EMF exposures can be explained as being produced by indirect effects of VGCC activation [5,7].

It is now apparent [7] that these EMFs act directly on the voltage sensor of the VGCCs, the part of the VGCC protein that detects electrical changes and can open the channel in response to electrical changes. The voltage sensor (and this is shown on pp. 102-104 in [7]) is predicted, because of its structure and its location in the plasma membrane of the cell, to be extraordinarily sensitive to activation by these EMFs, about 7.2 million times more sensitive than are single charged groups elsewhere in the cell. What this means is that arguments that EMFs produced by particular devices are too weak to produce biological effects, are immediately highly suspect because the actual target, the voltage sensor of the VGCCs is extremely sensitive to these EMFs. **Because heating is mostly produced by forces on these singly charged groups elsewhere in the cell, limiting safety guidelines to heating effects means that these guideline allow exposures that are something like 7.2 million times too high**.

Why then does the FCC stick with these totally unscientific safety guidelines? That is the 64 billion dollar question. The FCC has been shown, in a long detailed document published by Harvard University Center for Ethics, to be a “captured agency”, that is captured by the telecommunications industry that the FCC is supposed to be regulating [9; can be obtained full text from web site listed in 9]. So perhaps the failure of the FCC to follow the extensive science in this important area, can be understood. Of course, what that means is that the FCC is completely failing in its role of protecting the public and it is a major blunder, therefore for either you or any other organization to depend on the FCC guideline as a reliable predictor of impacts of EMFs in humans.

So what is known about health impacts of Wi-Fi EMFs?

Table 1. The following Table summarizes various health impacts of Wi-Fi EMF exposures:

Citation(s)	**Health Effects**
[10,11,12,13,14,15,16]	Sperm/testicular damage, male infertility
[10,15,17,18,19,20]	Oxidative stress
[20]	Calcium overload

[11,12,20]	Apoptosis (programmed cell death)
[17]	Melatonin lowering; sleep disruption
[10,13]	Cellular DNA damage
[21]	MicroRNA expression (brain)
[18]	Disrupts development of teeth
[22]	Cardiac changes, blood pressure disruption; erythrocyte damage; catecholamine elevation
[23,24]	Neuropsych changes including EEG
[25]	Growth stimulation of adipose stem cells (role in obesity?)

Each of the effects reported above in 2 to 7 studies have an extensive literature for their occurring in response to various other microwave frequency EMFs so it should be clear that these observations on Wi-Fi exposures are highly probable to be correct. These include (see Table 1) findings that Wi-Fi exposures produce impacts on the testes leading to lowered male fertility; oxidative stress; intracellular calcium overload; apoptosis (a process that has an important causal role in neurodegenerative diseases); cellular DNA damage; neuropsychiatric changes including EEG changes. Each of these are very serious and oxidative stress has causal roles in many different human diseases; intracellular calcium overload has many different consequences – for example, it has a central role in causing neurodegenerative diseases; cellular DNA damage can cause cancer and produce mutations that impact future generations (if there are any). Other Wi-Fi effects each only documented by a single study are also effects where a variety of other non-thermal microwave EMFs also cause these, as shown by extensive literature on each of them. These include: melatonin lowering and sleep disruption; and the effects reported by Saili et al [22] cardiac changes, blood pressure disruption; erythrocyte damage; catecholamine elevation. So these may well be correct observations as well despite having only a single Wi-Fi specific study for each.

Summary:

1. The EMF safety guidelines supported by the FCC and others assume that only heating effects need be of concern. These assumptions have been known to be false for at least 45 years and there is a scientific consensus on this, that has lead to the petition by 206 highly qualified international scientists to the UN stating that current safety guidelines are inadequate.
2. We now know that low intensity non-thermal exposures work via VGCC activation and that indirect effects of such VGCC activation can produce each of the health effects that have been widely reported to occur in response to such EMF exposures for something like 60 years. These attack:
    a. **Our health**

b. Our brain function
c. The integrity of our genomes
d. Our ability to produce healthy offspring

3. The voltage sensor of the VGCCs is stunningly sensitive to such low intensity EMFs, about 7.2 million times more sensitive than are singly charge groups elsewhere in our cells. The consequence of this is that safety guidelines allow exposures that are very roughly 7.2 million times too high.
4. The FCC has been shown, in a detailed Harvard University study, to be a Captured Agency, captured by the industry that it is supposed to be regulating. This provides an additional reason to be very highly skeptical about all FCC safety guidelines.
5. 15 studies have each shown health effects of Wi-Fi, most of which have also been shown to occur in response to low intensity exposures to other types of microwave frequency EMFs. These are likely to have massive health effects by producing male infertility (female infertility has not been studied in response to Wi-Fi), oxidative stress (involved in dozens of human diseases), cellular DNA damage (possibly leading to both cancer and mutations in future generations), life threatening cardiac effects, cellular apoptosis and also intracellular calcium overload (with both of these possibly leading to neurodegenerative diseases), various neuropsychiatric changes and many others.

It is my view that it is sheer insanity to fail to see the threat to our and to all human civilization by continuing to ignore the threats from such EMFs, starting with Wi-Fi.

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Board Member
Los Angeles Unified School District,
Board of Education

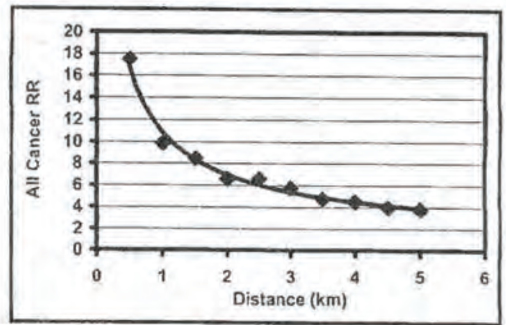
Re: Health effects of cell tower radiation

As an active researcher on biological effects of electromagnetic fields (EMF) for over twenty five years at Columbia University, as well as one of the organizers of the 2007 online Bioinitiative Report on the subject, I am writing in support of a limit on the construction of cell towers in the vicinity of schools.

There is now sufficient scientific data about the biological effects of EMF, and in particular about radiofrequency (RF) radiation, to argue for adoption of precautionary measures. We can state unequivocally that EMF can cause single and double strand DNA breakage at exposure levels that are considered safe under the FCC guidelines in the USA. As I shall illustrate below, there are also epidemiology studies that show an increased risk of cancers associated with exposure to RF. Since we know that an accumulation of changes or mutations in DNA is associated with cancer, there is good reason to believe that the elevated rates of cancers among persons living near RF towers are probably linked to DNA damage caused by EMF. Because of the nature of EMF exposure and the length of time it takes for most cancers to develop, one cannot expect 'conclusive proof' such as the link between helicobacter pylori and gastric ulcer. (That link was recently demonstrated by the Australian doctor who proved a link conclusively by swallowing the bacteria and getting the disease.) However, there is enough evidence of a plausible mechanism to link EMF exposure to increased risk of cancer, and therefore of a need to limit exposure, especially of children.

EMF have been shown to cause other potentially harmful biological effects, such as leakage of the blood brain barrier that can lead to damage of neurons in the brain, increased micronuclei (DNA fragments) in human blood lymphocytes, all at EMF exposures well below the limits in the current FCC guidelines. Probably the most convincing evidence of potential harm comes from living cells themselves when they start to manufacture stress proteins upon exposure to EMF. The stress response occurs with a number of potentially harmful environmental factors, such as elevated temperature, changes in pH, toxic metals, etc. This means that ***when stress protein synthesis is stimulated by radiofrequency or power frequency EMF, the body is telling us in its own language that RF exposure is potentially harmful.***

There have been several attempts to measure the health risks associated with exposure to RF, and I can best summarize the findings with a graph from the study by Dr. Neil Cherry of all childhood cancers around the Sutro Tower in San Francisco between the years 1937 and 1988. Similar studies with similar results were done around broadcasting antennas in Sydney, Australia and Rome, Italy, and there are now studies of effects of cellphones on brain cancer. The Sutro tower contains antennas for broadcasting FM (54.7 kW), TV (616 kW) and UHF (18.3 MW) signals over a fairly wide area, and while the fields are not uniform, and also vary during the day, the fields were measured and average values estimated, so that one could associate the cancer risk with the degree of EMF exposure.



The data in the figure are the risk ratios (RR) for a total of 123 cases of childhood cancer from a population of 50,686 children, and include a 51 cases of leukaemia, 35 cases of brain cancer and 37 cases of lymphatic cancer. It is clear from the results that the risk ratio for all childhood cancers is elevated in the area studied, and while the risk falls off with radial distance from the antennas, as expected, it is still above a risk ratio of 5 even at a distance of 3km where the field was $1\mu W/cm^2$. This figure is what we can expect from prolonged RF exposure. In the Bioinitiative Report, we recommended $0.1\mu W/cm^2$ as a desirable precautionary level based on this and related studies, including recent studies of brain cancer and cellphone exposure.

As I mentioned above, many potentially harmful effects, such as the stress response and DNA strand breaks, occur at nonthermal levels (field strengths that do not cause a temperature increase) and are therefore considered safe. It is obvious that the safety standards must be revised downward to take into account the nonthermal as well as thermal biological responses that occur at much lower intensities. Since we cannot rely on the current standards, it is best to act according to the precautionary principle, the approach advocated by the European Union and the scientists involved in the Bioinitiative report. In light of the current evidence, the precautionary approach appears to be the most reasonable for those who must protect the health and welfare of the public and especially its most vulnerable members, children of school-age.

Sincerely yours,

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Associate Professor of Physiology and Cellular Biophysics

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MCPS COO Dr. Andrew Zuckerman
MCPS Interim Superintendent Larry Bowers
MCPS Board of Education
MCPS Office of Technology
Montgomery County Schools
Carver Educational Services Center
850 Hungerford Drive
Rockville, MD 20850

December 13, 2015

Dear Montgomery County COO Dr. Andrew Zuckerman, Interim Superintendent Larry Bowers, Board of Education and Office of Technology;

In my capacity as a pediatric occupational therapist, biologist, international speaker, and author on the subject of the impact of technology on child development and learning, I'm writing to you on behalf of students, teachers, and parents requesting you reconsider the use of devices which operate using wireless radiation.

Please find below guiding principles regarding managed balance between technology and healthy activity, as well as information on wireless radiation. More judicious use of educational based technologies is a safe manner, will serve to ensure sustainable futures for all children. Reversion to Ethernet or fiber optic cable devices, until such time as the World Health Organization deems wireless to not be harmful to young children, is recommended.

Guiding principles for the use of educational based technology in school environments.

Minimize Risk and Maximize Safety.

- Wireless radiation has not been proven safe (WHO 2011).
- Recent research indicates wireless radiation causes harmful effects to adult humans (Avendano 2012, Hardell 2013).
- Long term effects of wireless radiation on children are unknown at this time (AAP 2013).
- Children have thinner skulls, more aqueous bodies, and have rapidly developing cells, indicating they are exceedingly more vulnerable to harmful effects from wireless radiation than adults (AAP 2013, C4ST 2015).
- The American Academy of Pediatrics and the Canadian Pediatric Society recommends no more than 1-2 hours total technology use per day, including

educational technology. Many schools exceed these expert guidelines (AAP 2014).

Weigh Risk vs. Benefit.

- Education technology is not evidence based and is laden with conflict of interest e.g. manufacturers claims are financially motivated, and are not substantiated by university level research.
- Traditional and standardized teaching methods have substantive research support and evidence, yet are being rapidly replaced with education technology.

Ensure adequate foundational skills prior to use of technology.

Children need to balance the following 4 critical factors with technology, to optimize development and learning. Time spent with technology adversely affects these factors.

- *Movement:* stimulates vestibular, proprioceptive and cardiovascular systems.
- *Touch:* stimulates parasympathetic system for lowered cortisol and adrenalin.
- *Human Connection:* activates parasympathetic system; a life sustaining force.
- *Nature:* attention restorative, improves learning, erases effects of technology.
- *See video:* Message to Schools on EdTech

Risks associated with the use of technology by children are as follows:

- *Sedentary nature* of technology use is causally related to the recent rise in obesity/diabetes, developmental delay and learning difficulties (Tremblay 2011, HELP EDI Mapping 2009/13, Ratey 2008, PISA 2012).
- *Isolating factor* of technology use is associated with escalation in social impairments, mental illnesses (including adhd and autism), and self-regulation difficulties (Houtrow 2014).
- *Overstimulation* from technology use is a causal factor in rise in attention deficit, aggression, sleep disturbance, and chronic stress from hyper-arousal of the sympathetic nervous system (Christakis 2004, Gentile 2009, Markman 2010, Bristol University 2010).
- *Neglect* of students by teachers and support staff who are engaged in their own personal technology, is unfortunately common.
- Consequently, the risks associated with using education technology far outweigh the dubious benefits.

When In Doubt, Act With Caution.

- Existing research on harmful effects of wireless radiation on *adults*, indicates taking a cautionary approach when considering same radiation exposure to *children* (AAP 2014).

- Rapid cell turnover in children creates particular concern regarding potential DNA damage from wireless radiation, and consequent susceptibility to cancer. While rise in cancer incidence is becoming more apparent, rise in rates of cancer in children will not be observable until adulthood.
- Removal of wireless radiation and reversion to Ethernet cabled devices, will ensure immediate and long term safety to all students, teachers, and support staff.
- Defaulting to a remote authority regarding removing wireless radiation from schools, is not acting in the best interests of students and staff, and may not be defensible in a court of law.

Montgomery County's statement that the radiofrequency levels in schools "is compliant" with federal regulations *does not* assure safety to the students in your care. The current proposed technology plan to further increase the use of screens in classrooms on a daily basis, clearly does not support children's healthy development.

The implications of failure of schools to act with caution now regarding wireless radiation and technology, could potentially be horrific in both scope and magnitude, and may constitute neglect of children. Please act now to safeguard your children's future.

Respectfully,

CRowan

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Montgomery County Board of Education
Montgomery County Schools
Carver Educational Services Center
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January 20, 2016

Dear Montgomery County Board of Education,

Concerned parents in your school district have asked me to write to you regarding the health risks of wireless radiofrequency radiation exposure in the classroom. Based on what I have been told, I want to urge you to halt programs that currently have students use their own phones in ways that expose their eyes and brains to levels of radiation that have never been tested for safety.

I was Founding Director of the Board on Environmental Studies and Toxicology of the U.S. National Research Council, and Founding Director of the Center for Environmental Oncology at the University of Pittsburgh Cancer Institute. President Clinton appointed me to the Chemical Safety and Hazard Investigation Board, and I am former Senior Advisor to the Assistant Secretary for Health in the Department of Health and Human Services. I founded the non-profit Environmental Health Trust in 2007 to provide basic research and education about environmental health hazards. Our scientific team is currently focusing on the health risks of radiofrequency radiation as an important public health issue.

Many people are unaware that cell phones and wireless laptops and tablets function as two-way microwave radios. A typical classroom might have the following scenario: every student has a laptop--which is typically tested for use 8 inches from an adult male body--a cell phone in the pocket--which is also tested at a minimum distance from an adult male body-- and a network transmitter on the ceiling and possibly a cell tower outside next to the sports field. All these devices emit microwave radiation which can be readily absorbed into children's bodies and brains.

Manufacturers specifically recommend that cell phones be used “as tested”—at this little-known minimum distance from the body. Recently, *Consumer Reports* in November advised that people should not keep phones in the pocket—advice that few children or adults appreciate. *These devices have never been tested for safety with children.* Accumulating research indicates that long-term exposure to low levels over long lifetimes could pose a serious risk to our health.

Regarding tested distances for using laptops, the Federal Communications Commission (FCC) states that laptops and computers are "mobile devices are transmitters designed to be used in such a way that a separation distance of at least 20 centimeters is normally maintained between the transmitter's radiating structure(s) and the body of the user or nearby persons." The body in this instance refers to a large male weighing more than 200 pounds and standing six feet tall.

As the county is preparing to increase student use of Chromebooks, please be aware that the Samsung Chromebook manual states:
"United States of America USA and Canada Safety Requirements and Notices

- Do not touch or move antenna while the unit is transmitting or receiving.
- Do not hold any component containing the radio such that the antenna is very close or touching any exposed parts of the body, especially the face or eyes, while transmitting.
- Regardless of the power levels, care should be taken to minimize human contact during normal operation.
- This device should be used more than 20 cm (8 inches) from the body when wireless devices are on and transmitting.
- FCC Statement for Wireless LAN use: *"While installing and operating this transmitter and antenna combination the radio frequency exposure limit of 1mW/cm2 may be exceeded at distances close to the antenna installed. Therefore, the user must maintain a minimum distance of 20cm from the antenna at all times."*

As one of the leaders in educational policy of this nation, your school district has an opportunity to set an example for school districts nationwide by installing safer technology in classrooms and educating students, teachers and staff about tested distances that devices should be used to reduce radiation. A number of public and private schools have already implemented such policies. Just as we provide children with seat belts and bike helmets, a precautionary approach to wireless is recommended by many scientists and governments worldwide.

For more information about all of these issues, please read cell phone instructions for various models at http://showthefineprint.org. Our newly posted Ebook also details fine print safety instructions in wireless device user manuals.

When children use these devices close to their bodies, they are exceeding these safety instructions, and exposing themselves to radiofrequency (RF) radiation levels which can exceed our government FCC RF radiation exposure limits. The FCC RF exposure limit was designed to protect the public from the thermal (heating) effects of acute exposure to RF energy. The FCC states, "Tissue damage in humans could occur during exposure to high RF levels because of the body's inability to cope with or dissipate the excessive heat that could be generated. Two areas of the body, the eyes and the testes, are particularly vulnerable to RF heating because of the relative lack of available blood flow to dissipate the excess heat load."

CHILDREN ABSORB MORE RADIATION THAN ADULTS

Our recently published research in the IEEE *Spectrum* with investigators at the Federal Universities of Brazil provides new state-of-the-art radiation exposure brain modeling which confirms that substantially higher radiofrequency radiation doses occur in younger children as compared to adults even where products comply with tested guidelines developed for adults.

FCC REGULATIONS ARE OUTDATED

FCC exposure limits were set more than 19 years ago and were based on decades-old research. The Government Accountability Office published a 2012 Report that calls on the FCC to formally reassess their current RF energy (microwave) exposure limits, stating that the "FCC RF energy exposure limit *may not* reflect the latest research." I encourage you to read scientific submissions to FCC Proceeding Number 13-84 at http://bit.ly/1aGxQiq. It is unknown when the FCC will make a ruling, however, *until that time* the current outdated FCC limits are *not reflective* of the current state of science.

FCC REGULATIONS DO NOT PROTECT THE PUBLIC FROM BIOLOGICAL EFFECTS

As the California Medical Association states in their 2014 Resolution calling for updated FCC Regulations, "peer reviewed research has demonstrated adverse biological effects of wireless EMF [electromagnetic fields] including single and double stranded DNA breaks, creation of reactive oxygen species, immune dysfunction, cognitive processing effects, stress protein synthesis in the brain, altered brain development, sleep and memory disturbances, ADHD, abnormal behavior, sperm dysfunction, and brain tumors."

In May 2015, over 200 scientists who have authored more than 2,000 articles on this topic appealed to the United Nations to address "the emerging public health crisis" related to cellphones and other wireless devices, urging that the United Nations Environmental Programme (UNEP) initiate an assessment of alternatives to current exposure standards and practices that could substantially lower human exposures to non-ionizing radiation. These scientists state that "the ICNIRP guidelines do not cover long-term exposure and low-intensity effects, " and are " insufficient to protect public health." They also state that "the various agencies setting safety standards have failed to impose sufficient guidelines to protect the general public, particularly children who are more vulnerable to the effects of EMF." Please see their website at https://emfscientist.org.

INCREASED CANCER RISK

Wireless radiofrequency radiation was classified as a Class 2B "Possible Human Carcinogen" by the World Health Organization's International Agency for Research on Cancer in 2011. According to many scientists, evidence *has increased* since 2011, indicating that cell phone and wireless radiation should be classified as a "probable carcinogen." Those exposed at younger ages show four to eight times increased cancer risk. Replicated research just published in Biochemical and Biophysical Research Communications indicates that radiofrequency acts as a *tumor promoter* at low to moderate levels.

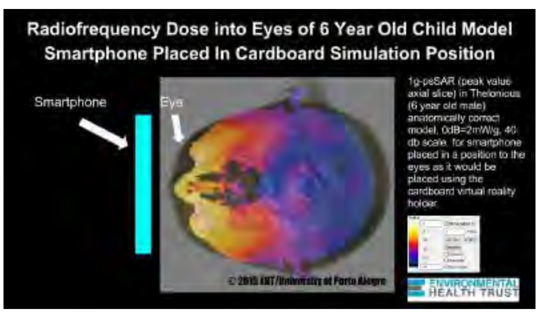
CONCERN FOR PREGNANT STUDENTS AND STAFF

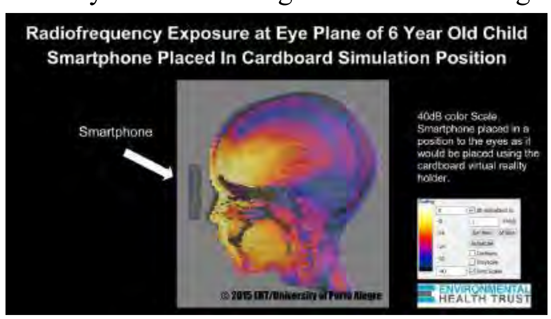
Pregnant students and staff are especially at risk from wireless because the fetus is the most vulnerable to toxic exposures. Several experimental studies are showing irreversible changes after prenatal exposure to cell phone and wireless radiation such as altered brain functioning, decreased brain cells and altered reproductive organ development. More than 100 physicians, scientists and public health professionals joined together to express their concern about the risk that wireless radiation poses to pregnancy and now *urge pregnant women to limit their exposures*. Please read these scientists BabySafe Joint Statement

VIRTUAL TECHNOLOGY RESULTS IN HIGHER EXPOSURES TO THE EYE AND BRAIN

Most recently, I was contacted by a parent in your district about the virtual reality devices now used in MCPS classrooms to go on a virtual "field trip." As indicated by online instructions, this experience involves using smartphones placed directly in front of the child's eyes so that they can directly watch a fascinating video of faraway lands. The smartphone is streaming radiation throughout the classroom from the teacher's iPad for the entire "field trip."

Please be aware that FCC regulations set decades ago did not utilize science that looks at the effects from cell phones on different body tissues such as the eyes. Upon hearing about this issue, I contacted EHT-associated scientists at federal universities of Brazil who do state-of-the-art computer modeling. I asked them to position the phone as it would be in the virtual reality cardboard for use in front of the child's eyes and assess the microwave radiation. The yellow and orange color show the highest exposures.





My colleagues and I are sharing this work with you today because we believe you should have more information about microwave radiation exposures that will take place through this system.

This research image above utilizes a sophisticated computer system that the U.S. Food and Drug Administration (FDA) currently applies to evaluate medical devices. It simulates the radiation absorption into *anatomically correct models*--something that currently used systems for testing phones and devices cannot do. In a study from Memorial Sloan-Kettering Cancer Center, radiation physicist David Gultekin, working with Bell Labs electrical engineer Lothar Moeller, reported that normal working cell phones can create tiny hotspots within brain tissue. Unlike other organs, eyes do not have circulation to effectively carry away heat.

In addition to the impact from the microwave radiation, there could also be impacts to a child's retina from the blue light emitted by the screen. Youths under the age of 20, and especially very young children, have little or no yellowing of the lens (which helps protect the adult eye). Therefore, blue light (or UV) which enters the eye is unfiltered in children and strikes the retina at full‑strength exposing not only the retina, but the lens to possible damage over the long time. Such injury may not be evident until later in time.

In 2010, Andreas Christ and team reported that children's hippocampus and hypothalamus absorbs 1.6–3.1 times higher and the cerebellum absorbs 2.5 times higher microwave radiation compared to adults; children's bone marrow of the skull absorbs 10 times higher microwave radiation than in adults, *and children's eyes absorb much higher microwave radiation than adults.* A recent Deans' Lecture I delivered to University of Melbourne provides an overview on this research.

SIMPLE STEPS WILL PROTECT CHILDREN

Compelling research raises the possibility of very serious harm to children from radiofrequency radiation exposures well below "FCC compliant" levels. Legal does not mean safe. Based on the preliminary work that I share with you here, I urge you to forgo the use of such devices such as virtual reality cardboard as there is no research that has considered their impact on children's eyes. At this time, the smart choice for school decision makers is to act now and reduce radiofrequency wireless exposures. In fact, many countries (over 20) and health authorities worldwide recommend reducing radiofrequency radiation to children.

More recently, the Cyprus Government's National Committee on Environment and Children's Health released a video about reducing wireless and I invite you to watch this excellent example of responsible action at this link https://www.youtube.com/watch?v=H43IKNjTvRM .

I understand that your county has a Bring Your Own Device policy whereby cell phones are not only allowed *in* the classroom but are actively used in the curriculum. As I have been told, students in film class might use their cell phones to take footage to create a movie, and in some math classes they use their cell phones as a calculator. Advice should be routinely provided to any student using a wireless device at school about *how to reduce exposures*. For example, if phones are used on airplane mode, and wireless is turned off on computers then these devices will neither send nor receive microwave radiation.

When powered on, phones undergo short bursts of microwave radiation up to 900 times per minute, *whether or not the phone is being used for talking.* Once teachers and students are educated on how they can simply turn their phone onto airplane mode, then they can use the phone in the classroom *without* being exposed to unnecessary radiofrequency radiation.

Likewise, laptops such as Chromebooks are also emitting constant radiation and at much higher levels when a student is streaming video or using cloud based applications. Laptops can easily be hardwired to ethernet so that students can safely use the internet without radiation emissions. Please review the Best Practices for Low EMF in Schools developed by the Northeast Collaborative For High Performing Schools which details how schools can reduce exposure to radiofrequency fields and still have full internet connectivity.

Along with the recommendation of over 200 scientists (see https://emfscientist.org) and health authorities worldwide, I recommend that the best course of action is to take simple precautions—as many nations already currently advise. *Children's exposures to wireless radiation should be reduced as much as possible.* We have a responsibility to act now to reduce children's exposure to radiofrequency radiation. Children's nervous, immune and reproductive systems are rapidly developing and, along with pregnant women, children deserve an abundance of caution.

As several colleagues and I wrote in a letter to the U.S. Secretary of Education just a few months ago, we recommend your school district do the following:

1. **Raise school community awareness through new educational curriculum:** Students, teachers and their families should be given information on wireless health risks and simple precautionary steps they can take to protect their health. It is important to teach children how to use technology both safely and more responsibly in order to protect their health and wellbeing.

2. **Install a safe communication and information technology infrastructure in schools to meet educational needs:** Solutions exist to reduce exposures to wireless emissions and mitigate the health risk. Low-EMF Best Practices have been developed, allowing educational needs to be met with safer, hard-wired Internet connections, which are also faster and more secure.

Low-EMF Best Practices are the solution that allows for full communication, information access and learning tools use in the classroom while minimizing unnecessary health risks. Your district can thoughtfully integrate safe technology into every classroom while responsibly safeguarding the health of every generation.

I fully understand that this information has not been widely understood. I would be happy to provide or develop an online technical briefing to your senior staff to assist you as you make decisions today that will affect the health of students for the rest of their lives.

Yours respectfully,

Devra Davis, PhD MPH
President and Founder
Environmental Health Trust
Visiting Professor of Medicine
The Hebrew University, Hadassah Medical Center
Associate Editor, Frontiers in Radiation and Health
ehtrust.org

July 28, 2014

Board of Trustees
Fay School
48 Main Street
Southborough, MA 01772

Re: Advisability of WiFi in schools

Dear Sirs/Madams:

This is concerning potential adverse health effects associated with exposure to radiofrequency/microwave (RF/MW) radiation, specifically that from wireless routers and wireless computers. I am writing to express concern that students at your school are experiencing electrosensitivity symptoms from these technologies.

I am a public health physician who has been involved in issues related to electromagnetic fields (EMFs) for several decades. I served as the Executive Secretary for the New York Powerline Project in the 1980s, a program of research that showed that children living in homes with elevated magnetic fields coming from powerlines suffered from an elevated risk of developing leukemia. I served as Director of the Wadsworth Laboratory of the New York State Department of Health, as well as Dean of the School of Public Health at the University at Albany/SUNY. I have edited two books on effects of EMFs, ranging from low frequency fields to radiofrequency/ microwave radiation, or the kind emitted by WiFi routers, cell phones, neighborhood antennas and wireless computer equipment. I served as the co-editor of the BioInitiative Report 2012 (Bioinitiatve.org), a comprehensive review of the literature showing biological effects at non-thermal levels of exposure, much of which has since been published in the peer-reviewed journal, *Pathophysiology* (attached). Also, I served on the President's Cancer Panel that examined radiation exposures as they relate to cancer risk, in 2009, and a report from that testimony is also attached. Thus, this is a subject which I know well, and one on which I take a public health approach rooted in the fundamental principle of the need to protect against risk of disease, even when one may not have all the information that would be desirable.

There is clear and strong evidence that intensive use of cell phones increases the risk of brain cancer, tumors of the auditory nerve and cancer of the parotid gland, the salivary gland in the cheek by the ear. The evidence for this conclusion is detailed in the attached publications. The WHO's International Agency for Research on Cancer has also classified the radiation from both cell phones and WiFi as a Class 2B "Possible Carcinogen" (2011). WiFi uses similar radio-frequency radiation as cell phones (in the 1.8 to 5.0 GHz range). The difference between a cell phone and a WiFi environment, however, is that while the cell phone is used only intermittently, and at higher power, a WiFi environment is continuous, and transmitting even when not being used. In addition, WiFi transmitters are indoors, where people (and in this case, children) may be very close by, or certainly close to devices using the WiFi, such as wireless computers, iPads and smart boards, the radiation from which can be intolerable to sensitive people.

Furthermore, commercial routers, like those in schools, operate at much higher wattage than consumer routers. They are designed to penetrate through materials like cement, wood and brick, to handle dozens to hundreds of users, and to reach into outdoor areas, so industrial grade routers are of much greater concern.

An additional consideration to appreciate is that it is not only the power of wireless radiation that causes biological dysregulation, but the frequencies, pulsing, amplitude, and the quantity and kind of information being transmitted that can have effects as well. These 'non-thermal effects' have been shown in thousands of studies to be biologically active, and may be more important than the effects from the power. Thus, while a router may be in the ceiling, or not right next to a student, teacher or administrator, the known biological and health effects, particularly the non-thermal ones, are still very much occurring.

Finally, while acute electrosensitivity symptoms, like the ones I understand your students are experiencing, are of course of great concern (such as cognitive effects impairing attention, memory, energy levels, and concentration; cardiac irregularities, including in children; or, headaches or other symptoms in students wearing braces), the full effects for society from chronic and cumulative exposures are not known at this time. Given what we do know, however, including the DNA effects, I must, as a public health physician, advise minimizing these exposures as much as possible. Indications are that cell phones and wireless technologies may turn out to be a serious public health issue, comparable to tobacco, asbestos, DDT, PCBs, pesticides and lead paint, or possibly worse given the ubiquitous nature of the exposures. While unfortunately we must wait for federal regulation to catch up with the science, the prudent thing to do in the interim would be to exercise precaution at every opportunity.

Computers and the world-wide web have tremendous value in education, but the value also depends on how these are used in numerous respects. As wired internet connections do not pose radiation risk, are readily available, are faster and more secure than WiFi, and are now even available for certain tablets, I highly recommend you factor the risks I have described into your technology planning. At the same time, I would urge you to take the complaints of your students very seriously, and potentially involve the school nurse and teachers in helping to assess the extent of the electrosensitivity problem among students at the school.

An excellent reference on the EMF and electrosensitivity science is "Electrosensitivity and Electrohypersensitivity—A Summary" (2013) authored by M.J. Bevington and available through Electrosensitivy-U.K. (www.es-uk.info/)

If I can be of further help, please do not hesitate to call.

Yours sincerely,

David O. Carpenter

David O. Carpenter, M.D.
Director, Institute for Health and the Environment
University at Albany

Enclosures

Martin Blank, PhD
Department of Physiology and Cellular Biophysics
Columbia University
New York, NY 10032

July 25, 2014

Mr. Thomas McKean, President, Board of Trustees
Mr. James Shay, President-Elect, Board of Trustees
Fay School
48 Main Street
Southborough, MA01772

To the Board of Trustees,

It has been brought to my attention that school children have become symptomatic at your school after installation of WiFi. I am writing to express my concern and to encourage you to review the independent science on this matter.

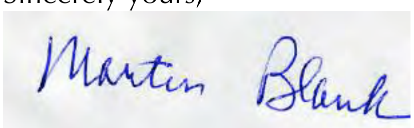
I can say with conviction, in light of the science, and in particular in light of the cellular and DNA science, which has been my focus at Columbia University for several decades, putting radiating antennas in schools (and in close proximity to developing children) is an uninformed choice. Assurances that the antennas are within 'FCC guidelines' is meaningless today, given that it is now widely understood that the methodology used to assess exposure levels only accounts for one type of risk from antennas, the thermal effect from the power, not the other known risks, such as non-thermal frequencies, pulsing, signal characteristics, etc. They fail also to consider multiple simultaneous exposures from a variety of sources in the environment, and cumulative exposures over a lifetime. Compliance with FCC guidelines, thus, unfortunately, is not in any way an assurance of safety today, as the guidelines are fundamentally flawed. Until the guidelines and advisories in the U.S. are updated, the intelligent thing for your Board of Trustees to do is to exercise the Precautionary Principle and hard wire all internet connections.

I know this might be disappointing to hear, as I understand you have invested in the WiFi. But there is no amount of money that could justify the added physiological stress from wireless antenna radiation and its many consequences, most in particular for children. Our research has shown that the cellular stress response, a protective reaction that is indicative of cellular damage, occurs at levels that are deemed 'safe'. Many other harmful reactions have been reported, such as the impairment of DNA processes that can account for the observed increased risk of cancer, as well as the potential cognitive decline, and sleep effects that may be due to impairment of the blood brain barrier. The DNA effects are of particular concern for future generations, an area of research that is just beginning to raise alarms. As with other environmental toxic exposures, children are far more vulnerable than adults, and they will have longer lifetimes of exposure.

The science showing reasons for concern about the microwave radiation emitted by antennas is abundant and there will be a day of reckoning. As I explain in my recent book, *Overpowered*, The Precautionary Principle instructs us that in the face of serious threats, a lack of scientific 'certainty' never justifies inaction. The changes occurring at the molecular level, and known associations with many diseases, are sufficient at this time to give us pause and to recommend minimizing exposures to these fields, in our homes, schools, neighborhoods and workplaces. There is significant potential for risk, and to very large numbers of people, and the effects are occurring nonetheless whether or not we are noticing them.

I recommend you hardwire the internet connections at your school, and also encourage students to use hard wired connections at home for internet access, as well as for all computer equipment connections and voice communications.

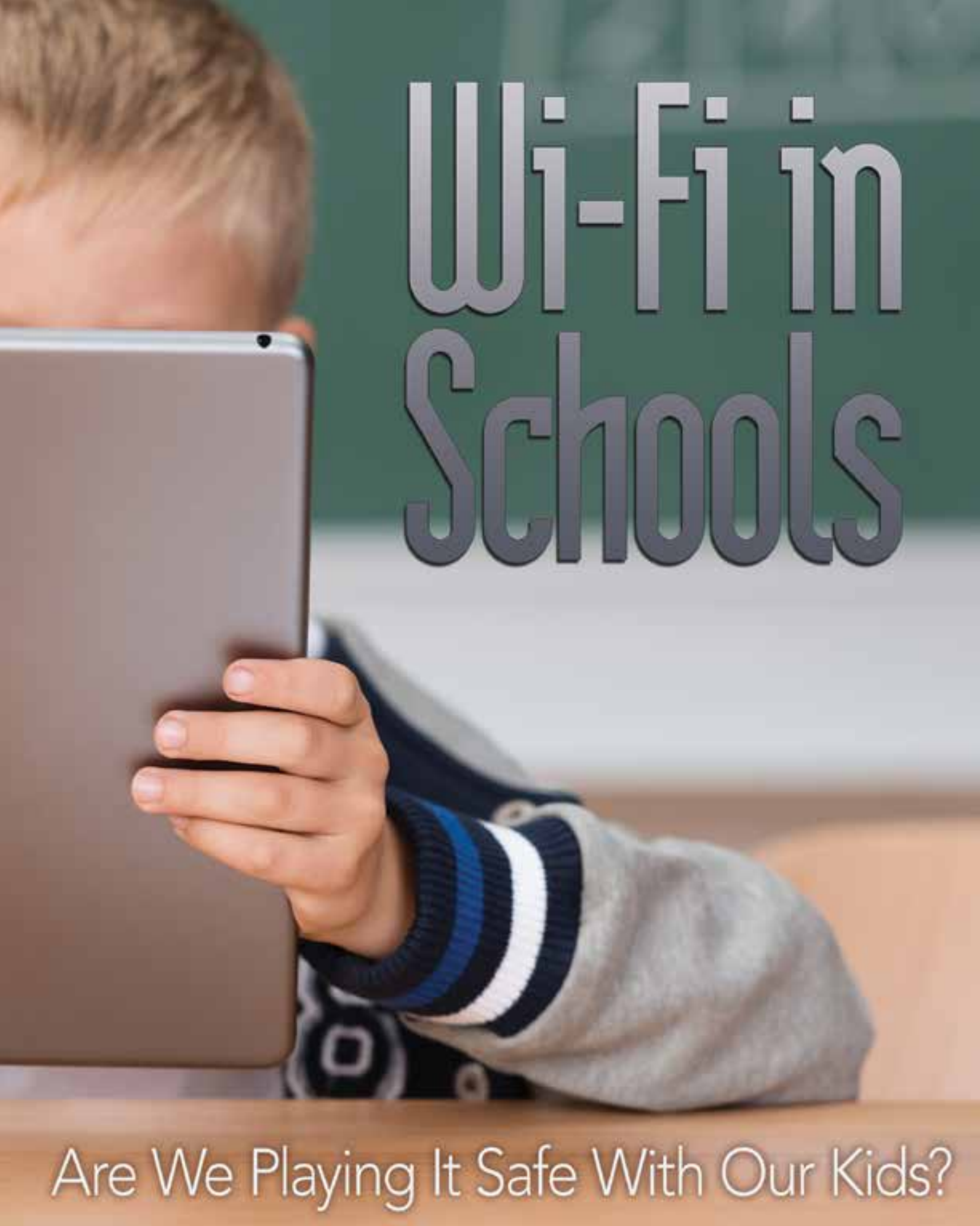
Sincerely yours,



Martin Blank, PhD
mb32@columbia.edu,

Martin Blank, PhD, Special Lecturer and (ret.) Associate Professor, Columbia University, Department of Physiology and Cellular Biophysics. Dr. Blank is a leading expert in the effects of electromagnetic fields on DNA and biology, and Past President of the Bioelectromagnetics Society. He holds two PhDs, in physical chemistry and in colloid science, an interdisciplinary field involving chemistry, physics and nanoscience. Dr. Blank was author of the BioInitiative Report's section on the impact of electromagnetic fields on Stress Proteins; Editor of the journal *Pathophysiology*'s special issue on Electromagnetic Fields (2009); and co-author of "Electromagnetic fields and health: DNA based dosimetry" (2012), which recommends a new way of assessing the biological impact of electromagnetic fields across the spectrum, using DNA. Dr. Blank's book, *"Overpowered—What Science Tells Us About the Dangers of Cell Phones and Other WiFi-Age Devices",* was published in 2014.

Wi-Fi in Schools



Are We Playing It Safe With Our Kids?

“Current FCC standards do not account for the unique vulnerability and use patterns specific to pregnant women and children. It is essential that any new standard for cell phones or other wireless devices be based on protecting the youngest and most vulnerable populations to ensure they are safeguarded throughout their lifetimes.” American Academy of Pediatrics Letter to FCC August 29, 2013 (20)

By Cindy Russell, MD
VP of Community Health, SCCMA

Industry has been quite successful in creating magically useful wireless technologies such as cell phones, Ipads, Wi-Fi, and now wearable tech devices such as Google glasses, we all love. Many of these handy gadgets have now reached the typical classroom across the globe. It has become apparent, however, that there are substantial downsides to being too connected to technology and as safety concerns mount, governments such as France and Israel are backing away from the blind adoption of wireless technology in schools, especially for young children.

These devices are cool and convenient, however there remains nagging questions of overuse and safety as the application of these devices has increased to the point we are literally exposed 24 hours a day to this radiation. Wireless microwaves come from many sources both at work and at home.

An increasing number of physicians, scientists, and parents are concerned about long term health effects from Wi-Fi in schools. (42)(43)(44)(49) As any parent knows, computers now are as ubiquitous in schools as they are at work. From kindergarteners on up kids are required to learn computer skills in order to take core testing online. There is a push to enable students to be connected to the internet 24/7 to take photos, email documents, and research a topic. In schools, wired connections for computers have been rapidly being eliminated to install wireless systems that connect students both indoors and outdoors on campus.

Europe and some schools in the U.S. are taking a different more precautionary approach and going back to the future with wired plug in computers. Studies have also cast doubt on some of the benefits of classroom computers and warned of the new age of “Digital Dementia” which has now crept into Korean youth due to the heavy use of electronic gadgets. (17)(48)

Professors in college are banning computers during lectures and finding students learn more. (38) (39)

CHILDREN ARE MORE VULNERABLE THUS NEED MORE PROTECTION

Children have several organ systems that are immature at birth and are thus much more sensitive to toxic exposures. The human brain, one of the top vital organs, is far from being a finished product in youth. Long-term structural maturation of the nervous system is required for successful development of cognitive, motor, and sensory functions. Neuronal axons – long thin projections from the nerve cell – act as electronic transmission lines. Axons in major pathways of the brain continue to develop throughout childhood and adolescence. Myelin is the insulation surrounding individual nerves protecting it from outside electrical charges. The process of myelination is much faster the first two years but continues into adulthood. (16) Children have thinner skulls (29), their immune systems are undeveloped, their cells are dividing more rapidly, thus, they are more vulnerable to EMF radiation and other carcinogens. They also have a longer cumulative exposure to all toxins including EMF radiation.

CURRENT WIRELESS SAFETY STANDARDS AND MICROWAVING POTATOES

Wireless devices work on high frequency microwaves similar to the microwave you use to cook food with. It is with less power but substantial research (1)(2)(3)(4) demonstrates that even at low power within the current safety standards these microwaves can cause biologic harm to plants, animals, and cellular structures. Current Federal Communications Commission (FCC) standards are based only on heat generated by the device, not on adverse biological effects seen in hundreds of studies and at much lower levels.

Our own CMA supports reassessment of EMF standards. The California Medical Association, in 2014, passed a resolution as follows:

> “Resolved 1:That CMA supports efforts to re-evaluate microwave safety exposure levels associated with wireless communication devices, including consideration

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of adverse nonthermal biologic and health effects from non-ionizing electromagnetic radiation used in wireless communications and be it further

Resolved 2: That CMA support efforts to implement new safety limits for wireless devices to levels that do not cause human or environmental harm based on scientific research.

ADVERSE EFFECTS DEMONSTRATED IN PEER REVIEWED PUBLISHED RESEARCH (2)

- DNA with single and double stranded breaks
- Leakage of the blood brain barrier (two hours of cell phone exposure causes 7+ days of albumin leakage)
- Stress protein production in the body indicating injury
- Infertility/reproductive harm
- Neurologic harm with direct damage to brain cells
- Lowering of melatonin levels
- Immune dysfunction
- Inflammation/oxidation.

PLAUSIBLE MECHANISM FOUND FOR EMF MICROWAVE EFFECTS

Dr. Martin Pall, Professor Emeritus of Biochemistry, Washington State University has studied how electromagnetic fields impact the cells of our bodies. His 2013 paper on this subject highlights a major biological mechanism of action of EMF microwave radiation on cell structure. His work, along with two dozen prior studies, demonstrated that EMF microwave radiation effects cellular calcium channels and this can be inhibited with calcium channel blockers. "A whole series of biological changes reportedly produced by microwave exposures can now be explained in terms of this new paradigm of EMF actions via Voltage Gated Calcium Channels (VGCC) activation." (14)(15)

In May 2011, the International Agency for Research on Cancer (IARC) classified radiofrequency electromagnetic fields as possibly carcinogenic to humans (Group 2B).(30)

EMF AFFECTS ON WILDLIFE: BIRDS, BEES, AND TOMATO PLANTS

Bird researchers in Germany found that their migratory European Robins lost their sense of navigation when in the city. (5) This was found to be due to the EMF radiation interfering with the bird's special internal magnetic compass. They replicated the experiment over seven years before publishing the results in the prestigious journal *Nature*.

John Phillips and others have found that newts, sea turtles, and migratory birds use a magnetic compass to navigate long distances and this can be interrupted by low levels of EMF. (6)(7) A review of effects on cell towers and wireless devices showed that beehives can have rapid colony collapse with exposure to cell phone radiation. (8)

Plants have been shown to have stress response to EMF from wireless devices. (9)(10) (22) In tomatoes exposed for short duration, the stress response seen by exposure to EMF was prevented by administration of calcium counteracting drugs. (11) Even simple high school science experiments document abnormal seed growth near Wi-Fi routers. (19) There appear to be adverse biological effects of this seemingly harmless radiation.

HUMAN ELECTROSENSITIVITY: IS IT REAL?

There is varied opinion about those who state they are sensitive to EMF. Scientific research has not given a definitive answer, nevertheless, many seem to suffer from vague and often disabling symptoms they feel in the presence of EMF. Exposure to EMF radiation in some people reportedly causes headaches, memory problems, fatigue, sleep disorders, depression. This is so significant for some people that they have to live in a very low EMF environment to feel normal. (25)

Sweden recognizes electro-sensitivity as a functional impairment and estimates that about 3% of the population suffers from this. (23)(24) Dr. Magda Havas found in replicated studies that some EMF sensitive individuals heart rates increased with wireless devices turned on in double blind study. (12)(26) Researchers at Louisiana State University, in 2011, studied a self reported EMF sensitive physician and found "In a double-blinded EMF provocation procedure specifically designed to minimize unintentional sensory cues, the subject developed temporal pain, headache, muscle twitching, and skipped heartbeats within 100 s after initiation of EMF exposure ($p < .05$)." They concluded that "EMF hypersensitivity can occur as a bona fide environmentally inducible neurological syndrome." (27)

Genius and Lipp reviewed the current literature on EHS, in 2011, and point to several explanations for this multisystem phenomenon, including toxicant induced loss of tolerance as many with EHS symptoms had high levels of PCB's possibly causing immune dysfunction. Scientific research also identifies an inflammatory response with cytokine production. Another aspect of research points to catecholamine and adrenal gland dysfunction. In addition, heavy metal toxicity has also been proposed as contributing to EHS. (28)

The Austrian Medical Association feels Electrohypersensitivity is a real phenomenon and in 2012 published Guidelines for EMF and Electro-hypersensitivity. They state the primary method of treatment should consist in the prevention or reduction of EMF exposure, taking care to reduce or eliminate all sources of EMF if possible. (32)

GOVERNMENT ACTIONS ON WI-FI IN SCHOOLS

While much of the U.S. is marching forward with Wi-Fi in schools, Europe is changing direction, as indicated by the policies listed below. (45) Internationally there is wide disagreement in standards. The U.S. and Canadian limits are 1000 microwatts/cm2. China and Russia are 10 microwatts/cm2. Belgium is 2.4 microwatts/cm2, and Austria is 0.001 microwatts/cm2. The Bioinitiative Report 2012 recommendation for "No Observable Effect" is 0.0003 microwatts/cm2. Cosmic background EMF we evolved with is <0.00000000001 microwatts/cm2. (2)

COUNCIL OF EUROPE PARLIAMENT ASSEMBLY 2011 EMF MICROWAVE POLICY : "THE POTENTIAL DANGERS OF ELECTROMAGNETIC FIELDS AND THEIR EFFECT ON THE ENVIRONMENT"

The report notes "other non-ionizing frequencies, whether from extremely low frequencies, power lines or certain high frequency waves used in the fields of radar, telecommunications, and mobile telephony, appear to have more or less potentially harmful, non-thermal, biological effects on plants, insects, and animals, as well as the human body, even when exposed to levels that are below the official threshold values."

The Council calls for a number of measures to protect humans and the environment, especially from high-frequency electromagnetic fields. One of the recommendations is to "take all reasonable measures to reduce exposure to electromagnetic fields, especially to radio frequencies from mobile phones, and particularly the exposure to children and young people who seem to be most at risk from head tumors". (37)

IN FRANCE: A NEW NATIONAL LAW BANS WI-FI IN NURSERY SCHOOLS

In January 2015, France passed a landmark law that calls for precaution with wireless devices for children and the general public. (34)(35) It calls for:

1. Wi-Fi banned in nursery schools.
2. Wi-Fi routers should be turned off in school when not in use.
3. Schools are informed when new tech equipment is installed.
4. Citizens will have access to environmental cell tower radiation measurements near homes.
5. There will be continued research conducted into health effects of wireless communications.
6. Information on reducing exposure to EMF radiation is mandatory in the contents of the cell phone package.
7. Wi-Fi hotspots are labeled.

ISRAELI MINISTRY OF EDUCATION ISSUE GUIDELINES TO LIMIT WI-FI IN SCHOOLS

On August 27, 2013, the Israeli Ministry of Education issued new guidelines regarding Wi-Fi use in schools. (33) The guidelines will:

1. Stop the installation of wireless networks in classrooms in kindergarten.
2. Limit the use of Wi-Fi between first and third grades. In the first grade, students will be limited to use Wi-Fi to study for one hour per day and no more than three days per week. Between the first and third grades, students will be limited to use Wi-Fi up to two hours per day for no more than four days per week.
3. To limit unnecessary exposure teachers will be required to turn off mobile phones and Wi-Fi routers when they are not in use for educational purposes.
4. All Wi-Fi equipment be tested for compliance with safety limits before and after installation in an Israeli school.
5. Desktop computers and power supplies be kept at least 20 cm from students.

2012 THE RUSSIAN COMMITTEE ON NON-IONIZING RADIATION PROTECTION OFFICIALLY RECOMMENDED THAT WI-FI NOT BE USED IN SCHOOLS.

2011 THE RUSSIAN COMMITTEE ON NON-IONIZING RADIATION PROTECTION (RNCNIRP) RELEASED THEIR RESOLUTION ENTITLED "ELECTROMAGNETIC FIELDS FROM MOBILE PHONES: HEALTH EFFECTS ON CHILDREN AND TEENAGERS."

According to the opinion of the Russian National Committee on Non-Ionizing Radiation Protection, the following health hazards are likely to be faced by the children mobile phone users in the nearest future: disruption of memory, decline of attention, diminishing learning and cognitive abilities, increased irritability, sleep problems, increase in sensitivity to the stress, increased epileptic readiness. (36)

Expected (possible) remote health risks: brain tumors, tumors of acoustical and vestibular nerves (in the age of 25-30 years), Alzheimer's

Continued on page 20

disease, "got dementia", depressive syndrome, and the other types of degeneration of the nervous structures of the brain (in the age of 50 to 60).

PLAYING IT SAFE FOR OUR KIDS

A healthy and safe learning environment is a cornerstone of education. Current FCC standards are obsolete and inappropriate as they are based only on heat effects, not biological effects. They give us a false sense of security. There may be higher EMF levels at school than at home as routers are more powerful. Cumulative Effects on DNA or cell structures are not taken into consideration in any safety standard. Because of the long-term exposure to EMF microwave radiation this generation is experiencing, they will be at higher risk for potential health problems. We will not know what happens to our progeny's DNA until our grandchildren are born.

Considering there has been a more precautionary approach internationally to microwave radiation exposure and the trend is toward less exposure in schools, especially to vulnerable populations such as children, it makes sense to re-evaluate our wireless schools. We buckle our seat belts and wear a helmet when we ride bikes even though we don't know if we will get in an accident. Although not all the issues of wireless microwaves are understood, there is enough science to understand it acts as a toxicant at even low levels that fall within current safety standards. We also know that decades of research precedes meaningful regulation in the area of toxins, thus the only reasonable approach is precautionary.

In addition, we need to be thoughtful about how much our kids should use computers and what this is doing not only to them, but to our society as a whole. We get starry eyed with every new wireless gadget, however, in "Alone Together" Sherry Turkle expertly addresses the rise in isolation, loneliness, lack of privacy, and increasing pressure on students in this age of invasive technology. Her thorough and non-judgmental scientific investigation of the psychological effects of computers makes us aware that we need to take care that we do not replace real human connection with a "virtual reality" that will redirect us in an unhealthy direction.

As physicians and parents, we understand that decisions we make today may have far reaching consequences in the future for our kids. Let's play it safe for them right now.

> *"Certain high frequency waves used in the fields of radar, telecommunications, and mobile telephony, appear to have more or less potentially harmful, non-thermal, biological effects on plants, insects, and animals, as well as the human body, even when exposed to levels that are below the official threshold values."*

RECOMMENDATIONS FOR SCHOOLS

1. **Wired internet connections** like we used to have are the safest and possibly cheapest option – all the benefits of the internet without the risk.
2. **Wireless devices**, but with an on/off switch in each room so teachers can use only when needed for educational purposes.
3. **Limit Wi-Fi** use, especially in younger grades.
4. **Cell phones stay off and in the backpacks during class** and on the campus during school hours.
5. **Have EMF and electrical measurements done by one or more qualified, experienced consultants before and after any installation**. Understand you may need to increase your knowledge of low and high frequency electromagnetic fields and limits to accurately interpret the reports. The Bioinitiative Report is a very useful compendium that has recommendations for safer levels.
6. **Support efforts by governments to provide independent standardized transparent research to define safe limits in all the different wireless frequencies used commercially.** This could lead to less EMF emissions and safer wireless devices.

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F.A.C.N., C.N.S., C.B.T.,
Integrative Metabolic Cardiology

July 16, 2014

Chairman and Trustees
Fay School
48 Main Street
Southborough, MA 01772

RE: Wi-Fi in Schools

Dear Chairman and Trustees:

I am writing this letter on behalf of concerned parents of children who are attending schools with Wi-Fi technology. I'm a cardiologist and co-founder of Doctors for Safer Schools, an organization dedicated to informing teachers, parents and superintendents about the uncertainty and possible environmental health hazards of Wi-Fi technologies.

The heart is a delicate and complex electromagnetic organ that can be adversely affected by exogenous signals from wireless technology and microwave radiation. For this reason it is unwise to expose students and teachers to Wi-Fi radiation for internet access, especially when safer alternative wired options are available. Children are particularly vulnerable to this radiation and the incidents of cardiovascular events including sudden cardiac arrest, seems to be increasing, especially among young athletes (up to the age of 19). In some cases this is due to undetected heart defects, blunt trauma to the heart in contact sports, and heat stress during strenuous exercise, but in instances these irregularities may be exacerbated by or due to microwave signals interfering with the autonomic nervous system that regulates the heart.

I know this because I am a board certified cardiologist and have been a Fellow of the American College of Cardiology since 1977. At the Manchester Memorial Hospital in Connecticut, I served in several roles, including Chief of Cardiology, Director of Cardiac Rehabilitation, and Director of Medical Education.

In both Canada and the United States a large number of students are complaining that they feel unwell in classrooms that have Wi-Fi technology. These complaints have been investigated and what emerges is the following:

1. Symptoms common among these students include headaches, dizziness, nausea, feeling faint, pulsing sensations or pressure in the head, chest pain or pressure, difficulty

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concentrating, weakness, fatigue, and a racing or irregular heart accompanied by feelings of anxiety. These symptoms may seem diverse but they indicate autonomic dystonia or dysfunction of the autonomic nervous system.

2. Symptoms do not appear in parts of the school that do not have this technology (Wi-Fi-free portables) and they do not appear in homes that do not have wireless technology.

3. We know that the heart is sensitive to and can be adversely affected by the same frequency used for Wi-Fi (2.4 GHz) at levels a fraction of federal guidelines (less than 1%) and at levels that have been recorded in two Ontario schools with Wi-Fi technology.

4. The incidence of sudden cardiac arrests (SCA) among young athletes is increasing and doctors don't know why. In one small Ontario community, the number of students experiencing SCA is disturbingly high. Whether WiFi and nearby cell phone antennas exacerbate SCA needs to be investigated further before students are subjected to these fields.

In conclusion it is unwise to install wireless technology (WiFi) in schools. We do not know what the long-term effects of low-level microwave radiation are on students and teachers. The safety of this technology on children has not been tested and I would advise that you follow the precautionary principle that states the following:
"*In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.*"
(Rio Conference 1992).

The principle implies that we have a social responsibility to protect the public from exposure to harm, when scientific investigations have found a plausible risk. That "plausible risk" exists for microwave radiation at very low levels. These protections can be relaxed only if further scientific findings emerge that provide sound evidence that no harm will result. In some legal systems the application of the precautionary principle has been made a statutory requirement.

Sincerely,

Stephen T. Sinatra

Stephen T. Sinatra, M.D., F.A.C.C., F.A.C.N., C.N.S

Karolinska Institutet
Department of Neuroscience
Experimental Dermatology Unit

Stockholm, July 24, 2014

Mr. Thomas McKean, President, Board of Trustees
Mr. James Shay, President-Elect, Board of Trustees
Fay School
48 Main Street
Southborough, MA 01772

Ladies and Gentlemen,

It has been brought to my attention that children in your school are physically being impacted by radiation from WiFi antennas, and that some of the student's reactions have been severe. I was concerned to learn this. It is unwise to chronically expose children to this type of radiation, as their bodies are more sensitive than adults and the radiation has been shown to impair not just physiological functioning but cognitive function and learning.

Radiation of the kind emitted by WiFi transmitters impacts attention, memory, perception, learning capacity, energy, emotions and social skills. There is also diminished reaction time, decreased motor function, increased distraction, hyperactivity, and inability to focus on complex and long-term tasks. In some situations, children experience cardiac difficulties. In one Canadian school district, incidence of cardiac arrest in children was 40x the expected rate, and defibrillators have had to be placed at each school. Online time, particularly multi-tasking in young children, has been linked with a chronically distracted view of the world preventing learning critical social, emotional and relational skills. There is a physiological as well as psychological addiction taking place. I am sure, that as stewards of the lives of the children in your charge, you would not wish any of these outcomes.

Given the large and growing body of science indicating biological and health effects from the radiation emitted by antennas, it would be most imprudent at this time to permit wireless antennas on—or inside—your property. Understand the FCC exposure guidelines only protect against the acute power density, or acute thermal, effects, and they do nothing to protect against the other aspects of the radiation's risk, such the frequencies, amplitude, pulsing, intensity, polarity and biologically disruptive information content. Thus, until the FCC establishes guidelines for the non-thermal effects, any reliance by your school on current FCC guidelines, based solely on *thermal effects* would necessarily be incomplete. I urge a school of your caliber to be a leader on this issue, and appreciate that two wrongs do not make a right.

I enclose for your review the transcript of the Seletun Scientific Statement laying out the key concerns on this topic. If I can be of further help, please, do not hesitate to be in touch.

Yours truly,

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CC: cheemf@lists.healthandenvironment.org
Sent: 2/8/2013 2:21:54 P.M. Pacific Standard Time
Subj: [cheemf] Adoption of Wi-Fi in Los Angeles USD classrooms

TO: Los Angeles Unified School District (LAUSD)

FROM: Joel M. Moskowitz, Ph.D.
Director, Center for Family and Community Health
School of Public Health
University of California, Berkeley

RE: Adoption of Wi-Fi in Classrooms

DATE: February 8, 2013

Based upon my review of the research of the health effects associated with exposure to radiofrequency (RF) electromagnetic radiation (EMR), especially microwave radiation, I feel compelled to register my concern that adoption of Wi-Fi in LAUSD classrooms is likely to put at risk the health of many students and employees in the District.

In December, Dr. Gayle Nicoll of URS Corporation asked me to serve as an expert reviewer for a report that URS prepared for the LAUSD regarding the adoption of Wi-Fi in classrooms. Since Ms. Nicoll could not assure me that URS has no conflicts of interest, I turned down her request and sent her references to recent studies about Wi-Fi radiation. I cc:ed Board members and key staff as I was concerned about the health risks of unnecessarily subjecting 660,000 children to 13,000 hours of Wi-Fi microwave radiation during their K-12 school years.

Although I have not seen the URS report, I imagine it is based on the FCC's outmoded 1996 safety standards which only protect the public from the **thermal risk of RF EMR exposure** (i.e., from heating of tissue). For the past three years, in numerous media interviews I have been calling on the FCC to strengthen its standards and testing procedures to protect the public and workers from the low-intensity, **non-thermal risks of RF EMR exposure** that have been reported in hundreds, if not thousands, of research studies. These include increased risk of neurological and cardiovascular problems, sperm damage and male infertility, reproductive health risks, and cancer.

The **precautionary principle** should be applied to this critical policy decision. This principle, developed at a U.N. environmental conference in 1992 states that in the absence of scientific consensus if an action has a suspected risk of causing harm, the burden of proof it is not harmful falls on those taking the action, and all reasonable measures to reduce the risk must be taken.

Internet access can be provided to students through wires or optical fiber without installing Wi-Fi in the classrooms.

For further information, please see my **Electromagnetic Radiation Safety web site** at http://saferemr.blogspot.com where I have archived news releases and links to recent reports by major scientific groups and political agencies.

Sincerely,

Joel M. Moskowitz, Ph.D.

===

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December 1, 2015

Montgomery County Schools
Carver Educational Services Center
850 Hungerford Drive
Rockville, MD 20850

Attention: Dr. Andrew Zuckerman, Chief Operating Officer
MCPS Board of Education Members

This letter of comment has been prepared after reviewing the *Montgomery County Public Schools Radiofrequency (RF) Summary Monitoring Report* dated July 2015 produced by AECOM Environment.

1) The instrument cited as being used for the peak measurements in section 7, a Narda SRM-3006, is not suitable to measure the very short (1 millisecond) spikes typically found in WiFi 802.11n communication. As stated on page 7-1, each data sweep takes 550 milliseconds, making the instrument unsuitable for reliably logging the short bursts typical in 802.11n WiFi communications. Palit et al conclude that 50% of the uplink traffic will be in bursts shorter than 2 milliseconds. The peak levels of those packets will not be reliably logged by a device with a 550 millisecond sweep time.

Palit et al, 2012. Anatomy of WiFi Access Traffic of Smartphones and Implications for Energy Saving Techniques. International Journal of Energy, Information and Communications, Vol. 3, Issue 1.

2) Even the average-level tests seem inconsistent with engineering reality. Figure 7.1 shows a background noise level mostly flat between 2.4GHz and 5.8Ghz. That noise (typically -70dBm) is generally consistent with the internal thermal noise in a quality wide-band measuring instrument. Two tiny peaks out of that noise are represented to be the "*average electric field generated at one foot away from an AP in use at Beverly Farms Elementary School*." Even with just the 802.11n beacon-frame idling, the peak field a foot away from an access point should be a million times higher than the levels of figure 7.1. Why do we just see a blip on the chart? Clearly some unusual 'averaging' has occurred, yet the parameters of that averaging, and the potential clinical implications of that averaging, are not noted in the annotation to the Figures. Further, Figure 7.2 shows a background noise level some 10dB higher than figure 7.1, something that would be very unusual in measurements at these Gigahertz frequencies.

3) The RF exposure estimates are additionally inadequate because, in reality, there is no way to meet the distancing that AECOM's report bases it's measurements on for an individual student. In normal use, kids hover over devices. They hug them to the body. They put them in their laps at lunchtime, on the couch and in bed doing homework. It is entirely unrealistic to expect teachers and parents to guarantee that students always keep their Chromebooks at some arbitrary distance during use.

4) The report concludes with classroom RF measurement comparisons to an outdated 2007 BioInitiative Report recommendation of 0.1 uW/cm2. (Section 7). Graphics need to be re-drawn with comparisons to the 2012 recommended BioInitiative level, and do so not only for a 12" spacing, but also for the one-inch distance measured from the Chromebook (Figure 7-3 and 7-4). Using an arbitrary 12" distance to report and compare to either the 2007 or 2012 BioInitiative recommendations will seriously underestimate RF exposures since students don't always (or even typically) maintain a foot of distance. Their 'leaning in' and having to place their faces close to the device is common usage, and is unavoidable.

5) The methodology is not specific as to the number of operating devices and clustering of students at work – which is necessary to characterize exposures from a room full of operational wireless devices. Figure 2.1 shows multiple wireless devices connected to one wireless router. Measuring one or several Chromebooks rather than one Chromebook for each of the 25-35 students plus router isn't how a normal classroom operates. It **does not** produce RF measurements of a typical class using many wireless devices at once, so this is a fundamental flaw. It will underestimate RF exposures.

6) There is also a comment to be made here about the setup – how does this methodology reasonably reflect how smaller or younger children with short arms and torsos actually use tablets? What RF exposures they can expect to receive? The likely consequence to the measurements is greater exposure. Unless the students are using chopsticks instead of their fingers, or are using wired keyboards that increase the distance to the wireless device, RF exposures will be worse for the younger or smaller-stature students.

7) This Report appears to legitimize MCSD's use of wireless in the classroom by asserting compliance with the 2007 BioInitiative Report recommendation, yet the report does not mention the significant revision of that threshold in the years between 2007 and 2012. Both BioInitiative Reports clearly state that their recommendations are interim and 'that they may have to go lower.' Recent studies of students reporting headache, irritability, concentration and behavior problems at levels as low as 0.003-0.006 uW/cm2, indicate that neither BioInitiative Report threshold may be low enough to assure safety. As the co-editor of the BioInitiative Reports, and a founding member of the BioInitiative Working Group, the way in which our work has been invoked is not consistent with the findings of the BioInitiative Reports overall. The conclusions of this report cannot be said to give a positive assertion of safety because of the degree of uncertainty over whether the testing equipment was adequate (we believe it was not); the lack of comparison data; and the failure to measure RF exposures at realistic distances from the student(s).

8) Correct BioInitiative citations are:

BioInitiative Working Group, Cindy Sage and David O. Carpenter, Editors. BioInitiative Report: A Rationale for Biologically-based Public Exposure Standards for Electromagnetic Radiation at www.bioinitiative.org, December 31, 2012.

BioInitiative Working Group, Cindy Sage and David O. Carpenter, Editors. BioInitiative Report: A Rationale for a Biologically-based Public Exposure Standard for Electromagnetic Fields (ELF and RF) at www.bioinitiative.org, August 31, 2007

CONCLUSION

The data in this report cannot therefore be used to infer safety, or lack of safety, of children in any of the tested locations.

Respectfully submitted,

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September 22, 2014

On behalf of the BioInitative Working Group, we are writing to express our concern about the views expressed by CEOs from Google, Dell, Apple, Adobe, eBay, Facebook, the George Lucas Educational Foundation and others to the FCC supporting wireless technologies in schools.

Your letter to the FCC dated July 7, 2014 titled Education Superhighway, states:

> *"Today, we are writing to you to urge swift bi-partisan action at your July 11, 2014 meeting to adopt the E-Rate modernization proposal set forth by Chairman Wheeler."*
> *"By responsibly investing $2 billion of unused funds and providing predictable ongoing support for Wi-Fi, the plan will make dramatic progress in bringing high-speed connectivity to our classrooms."*

No one denies that bringing high-speed connectivity to our classrooms is important. But it can be a wired connection and does not have to be WiFi. It does not reflect well on the ethics of your corporations to encourage the FCC to provide $2 billion dollars for new wireless classroom infrastructure and devices for school children, knowing that wireless emissions have been classified as a Possible Human Carcinogen by the World Health Organization's International Agency for Research on Cancer (2011). To promote wireless technologies in schools is to deliberately and knowingly disregard current health warnings from international science and public health experts.

Saturating schools with wireless technology will likely create unnecessary liability for municipalities and result in a loss of public trust and confidence in the corporations that push their wireless products with a blind eye toward health concerns.

Epidemiological studies show links between radiofrequency radiation (RFR) exposure and cancers, neurological disorders, hormonal changes, symptoms of electrical hypersensitivity (EHS) and more. Laboratory studies show that RFR exposure increases risk of cancer, abnormal sperm, learning and memory deficits, and heart irregularities. Fetal exposures in both animal and human studies result in altered brain development in the young offspring, with disruption in learning, memory and behavior. The brain development of a fetus can be impaired by in-utero exposure to a pregnant woman. The evidence for these statements is based on hundreds of published, peer-reviewed scientific studies that report adverse effects at levels much lower than current FCC public safety limits. WiFi is schools, in contrast to wired internet connections, will increase risk of neurologic impairment and long-term risk of cancer in students. Corporations cannot avoid responsibility simply by asserting compliance with existing legal, but outdated and inadequate FCC public safety limits.

Today, corporations that deal with educational technology should be looking forward and helping school administrators and municipal leaders to access safe, wired solutions. Your corporations can reasonably foresee and offer alternatives to potentially hazardous exposures to wireless radiation by choosing to support wired educational technologies.

Thank you for your attention to this letter.

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David O. Carpenter, MD, Tel: 518-525-2660 Email: dcarpenter@albany.edu
Co-Editors, BioInitiative 2012 Report
For the BioInitiative Working Group

Copies: CEOs signing Education Superhighway letter to the FCC
Federal Communications Commission
The White House, President Obama
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Michael Kundi, PhD, Austria
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Ying Li, PhD, Canada
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Iole Pinto, PhD, Italy
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American Academy of Environmental Medicine

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www.aaemonline.org

May 13, 2013

Open Letter to the Superintendents
of the School Districts of the United States

The American Academy of Environmental Medicine (AAEM) strongly supports the use of wired Internet connections.

The AAEM comprises Medical Doctors, Osteopaths, and PhD researchers focusing on the effects of environmental agents on human health. For forty years the Academy has trained Physicians to treat the most difficult patients who are often overlooked by our medical system, because the cause of their illness, rather than being caused by an infection or traditionally understood cause, is related to more basic underlying causes such as chemical, toxic metal, food or radiation exposures.

In May 2011 the World Health Organization elevated exposure to wireless radiation, including WiFi, into the Class 2b list of Carcinogens.

There is consistent emerging science that shows people, especially children who are more vulnerable due to developing brains, and thinner skulls, are affected by the increasing exposure to wireless radiation. In September 2010, the Journal of the American Society for Reproductive Medicine-Fertility and Sterility, reported that only four hours of exposure to a standard laptop using WiFi caused DNA damage to human sperm.

In December 2012 the American Academy of Pediatrics- representing 60,000 pediatricians, wrote to Congress requesting it update the safety levels of microwave radiation exposure especially for children and pregnant women.

In a school setting, children are exposed to WiFi for an unprecedented period of time, for their entire childhood. Some of these signals will be much more powerful than is received at home, due to the need for the signals to go through walls, and serve multiple computers simultaneously. The school signals are dozens of times more powerful than the café and restaurant systems.

To install this system in your school district risks a widespread public health hazard that the medical system is not yet prepared to address. Statistics show that you can expect to see an immediate reaction in 3% and delayed effects in 30%, including teachers.

It is better to exercise caution and substitute with a safe alternate such as a wired connection, which is not classified as a possible Carcinogen. While more research is being conducted children must be protected. Wired technology is not only safer, it also stronger and more secure.

While the debate ensues about the dangers of WiFi, cell phone towers and cell phones, it is the doctors who must deal with the after affects. Until we can determine why some get sick and others do not, and some are debilitated for indeterminate amounts of time, we implore you to not take the risk, with the health of so many children who have entrusted you to keep them safe while at school.

Respectfully,

The Executive Committee of the American Academy of Environmental Medicine

Message to Schools and Colleges about Wireless Devices and Health

If wireless devices, such as Wi-Fi, are used in your schools and colleges, then the health of your students, your faculty, and your staff can be at risk. This is a difficult problem but an addressable one if you act.

Background: Wireless devices transmit information using radiofrequency/microwave radiation. The international biomedical research community has been studying the biological impact of such radiation for decades, but more intensely in recent years. Thousands of peer-reviewed studies published in biomedical research journals have contributed to our understanding of this impact. So many serious biological effects have been found that immediate responsive action is warranted. Further, these biological effects are occurring at levels of radiation far lower than earlier understood. Simply stated, a worldwide health crisis is emerging and is becoming a hallmark of the 21st Century. The international biomedical research community is trying to warn us; but we, in the USA, are not yet listening. I hope this message will help to change that.

As a scientist, I urge you to look into the **health impact of the radiofrequency/microwave radiation** produced by wireless devices. Examples of wireless devices of concern in our environment are Wi-Fi in all of its forms; cell phones and cell towers (especially those located on school grounds); cordless phones; wireless computers, whether desktop, laptop, or tablet versions; wireless baby monitors; wireless smart electricity meters; emerging wireless smart appliances; and microwave ovens (because they always leak radiation).

This crisis is the consequence of many factors. Here are some of them:

- All living things are bioelectrical in nature. That is why electrocardiograms and electroencephalograms work. They, of course, measure the tiny electrical signals that operate the heart and the brain. The critical tasks performed by these tiny electrical signals, and so many other electrical signals in all living things, can be disrupted by radiofrequency/microwave radiation.

- The levels of manmade radiofrequency/microwave radiation in our environment are increasing exponentially and already exceed, by many orders of magnitude, the levels at which all life on Earth evolved. Simply stated, we are drowning in a rising sea of manmade radiofrequency/microwave radiation.

- The invisible nature of radiofrequency/microwave radiation leaves the public and the decision-makers unaware of the rising levels of radiation around them.

- The genuine usefulness of wireless devices promotes denial of the risks.

- The intense advertising, the economic power, and the political power of profitable wireless industries enable them to dominate the public dialogue and to hold sway over government regulators and legislators.

- Current Federal standards for limiting the exposure of the public to radiofrequency/microwave radiation are outdated and overly permissive. Those standards are based on thermal heating alone. In effect, the Government claims that if you are not cooked too much by the radiation, then you are fine. Those Federal standards ignore the many biological effects that occur at much lower levels of radiation, leaving the public unprotected.

- Federal and state governments are advocating unlimited expansion of wireless technology, and are even co-funding such expansion and mandating the acceptance of wireless technology by the public. Such actions reflect a widespread lack of understanding of, or willful blindness to, the underlying science and its consequences for public health.

- Some of the more serious consequences of exposure to radiofrequency/microwave radiation (such as DNA damage, cancer, and infertility) are especially nefarious because they give no early warning signs.

- Other consequences of exposure do give early warning signs (such as sleep disruption, headaches, fatigue, ringing in the ears, memory loss, dizziness, heart arrhythmia, and many others); but those signs are too often dismissed because they can have other causes as well, complicating identification of the true cause.

- The absence of routine training of physicians in the biological effects of radiofrequency/microwave radiation makes it difficult for physicians to identify the causes and to provide responsive guidance.

- Even aware individuals cannot control their exposure in any environment shared with others, because the radiation around them, much like second-hand smoke, is forced on them by unaware individuals. Only governments can fully solve this problem, but they are currently part of the problem. For now the public will have to protect itself, and that will require public education and action.

Fortunately, many of the services that wireless devices offer can be realized with much safer wired devices. The wired devices achieve connectivity with fiber-optic, coaxial, or Ethernet cables. The wired devices are faster, more reliable, and more cyber secure. They are, however, less mobile, often less convenient, and somewhat more expensive to install. But those drawbacks pale in comparison to the benefits of good health.

Simply stated, schools and colleges can protect their students, staff, and faculty from the health risks posed by wireless devices, including Wi-Fi, by converting to safe wired connectivity. If your institution lacks the resources to convert now, do consider shutting down your wireless devices anyway and converting as soon as you can. You can advance learning without leaving a trail of illness behind you, some of which can be lifelong.

As a suggested starting place for exploring the concerns about the radiation from wireless devices, I have appended an "Annotated List of References" and an "Annotated List of Videos". Please view, especially, video (1) called "Wi-Fi in Schools, the Facts", made in Australia, on page 6.

Regards,

Ronald M. Powell, Ph.D.
20316 Highland Hall Drive
Montgomery Village, MD 20886-4007
Telephone: 301-926-7568
Email: ronpowell@verizon.net

My background

I am a retired U.S. Government scientist (Ph.D., Applied Physics, Harvard University, 1975). During my Government career, I worked for the Executive Office of the President, the National Science Foundation, and the National Institute of Standards and Technology. For those organizations, respectively, I addressed Federal research and development program evaluation, energy policy research, and measurement development in support of the electronics and electrical-equipment industries and the biomedical research community. I currently interact with other scientists and with physicians around the world on the impact of the environment – including the radiofrequency/microwave environment – on human health.

ANNOTATED LIST OF REFERENCES

The international biomedical research community has conducted thousands of studies seeking to identify the biological effects of exposure to both low frequency and radiofrequency electromagnetic fields, extending into the microwave region. So many serious biological effects have been found from such fields, at levels earlier thought to be low enough to be safe, that immediate action is needed to alert and protect the public.

The most massive review of this biomedical literature is the 1479-page BioInitiative 2012 Report which considered about ***1800*** biomedical research publications, most issued in the previous five years. The BioInitiative 2012 Report was prepared by an international body of 29 experts, heavy in Ph.D.s and M.D.s, from 10 countries, including the USA which contributed the most experts (10). The review concludes that "The continued rollout of wireless technologies and devices puts global public health at risk from unrestricted wireless commerce unless new, and far lower*[,]* exposure limits and strong precautionary warnings for their use are implemented."

> BioInitiative Working Group, Cindy Sage, M.A. and David O. Carpenter, M.D., Editors, BioInitiative Report: A Rationale for Biologically-based Public Exposure Standards for Electromagnetic Radiation, December 31, 2012
> http://www.bioinitiative.org

A group of six doctors in Oregon, led by Paul Dart, M.D., released, in June 2013, a 74-page review of ***279*** biomedical research publications. This review makes the health case against "cell phones, base stations, Wi-Fi, Smart Meters and other RF *[radiofrequency]* or ELF *[extremely low frequency]* -emitting devices". The review notes that "The current levels of exposure need to be reduced rather than increased further. The FCC *[Federal Communications Commission]* must especially protect vulnerable groups in the population including children and teenagers, pregnant women, men of reproductive age, individuals with compromised immune systems, seniors, and workers." This review is posted on the website of the FCC at the link entitled "Health Effects of RF - Research Review (87)".

> Biological and Health Effects of Microwave Radio Frequency Transmissions, A Review of the Research Literature, A Report to the Staff and Directors of the Eugene Water and Electric Board, June 4, 2013
> http://apps.fcc.gov/ecfs/comment/view?id=6017465430

Michael Bevington, in 2013, published a book that summarizes the findings of ***1828*** international biomedical research publications. The book describes the symptoms caused by exposure to electromagnetic radiation, the many diseases associated with such exposure, and the relative risk levels associated with specific sources of electromagnetic radiation. The citations of papers include the PMID index numbers for easy location on the PubMed.gov website of the National Institutes of Health. This website provides the largest index to the biomedical research literature in the world.

> Electromagnetic Sensitivity and Electromagnetic Hypersensitivity: A Summary by Michael Bevington
> NEW EDITION: March 2013
> http://www.es-uk.info

About 200 scientists from 39 countries around the world submitted an international appeal to the United Nations and to the World Health Organization in May 2015. These scientists seek improved protection of the public from harm from the radiation produced by many wireless sources, including "cellular and cordless phones and their base stations, Wi-Fi, broadcast antennas, smart meters, and baby monitors" among others.

Together, these scientists have published over 2000 peer-reviewed research papers on this subject.

https://www.emfscientist.org/index.php/emf-scientist-appeal

The International Agency for Research on Cancer, of the World Health Organization, has already classified radiofrequency electromagnetic fields as a Class 2B carcinogen ("possible carcinogen"), based primarily on the increased risk of brain cancer. That decision was made in 2011. Since then, the research supporting a higher classification of risk ("probable carcinogen", or even "known carcinogen") has continued to build.

http://www.iarc.fr/en/media-centre/pr/2011/pdfs/pr208_E.pdf

The American Academy of Environmental Medicine (AAEM), which trains physicians in preparation for Board Certification in Environmental Medicine, states: "The AAEM strongly supports the use of wired Internet connections, and encourages avoidance of radiofrequency such as from WiFi, cellular and mobile phones and towers, and 'smart meters'." AAEM further states that "The peer reviewed, scientific literature demonstrates the correlation between RF *[radiofrequency]* exposure and neurological, cardiac, and pulmonary disease as well as reproductive and developmental disorders, immune dysfunction, cancer and other health conditions. The evidence is irrefutable." The AAEM concludes: "To install WiFi in schools plus public spaces risks a widespread public health hazard that the medical system is not yet prepared to address."

AAEM, Wireless Radiofrequency Radiation in Schools, November 14, 2013
http://www.aaemonline.org/pdf/WiredSchools.pdf

The American Academy of Pediatrics (AAP), whose 60,000 doctors care for our children, supports the development of more restrictive standards for radiofrequency radiation exposure that would better protect the public, particularly the children. The AAP, in a letter to the Federal Communications Commission (FCC) and the Food and Drug Administration (FDA), dated August 29, 2013, states that "Children are not little adults and are disproportionately impacted by all environmental exposures, including cell phone radiation. Current FCC standards do not account for the unique vulnerability and use patterns specific to pregnant women and children. It is essential that any new standard for cell phones or other wireless devices be based on protecting the youngest and most vulnerable populations to ensure they are safeguarded throughout their lifetimes."

http://apps.fcc.gov/ecfs/document/view?id=7520941318

The U.S. Government bears a major responsibility for the exponential growth in the levels of radiation from wireless devices in the environment. In 1996, the U.S. Congress passed, and the President signed, the Telecommunications Act of 1996. Under pressure from the cell phone industries, this law included this provision: "No State or local government or instrumentality thereof may regulate the placement, construction, and modification of personal wireless service facilities *[cell towers]* on the basis of the environmental effects of radio frequency emissions to the extent that such facilities comply with the *[Federal Communications]* Commission's regulations concerning such emissions." Because the Federal Communications Commission's regulations on radiation exposure are so permissive, this provision prevents state and local governments from protecting their people from radiation from cell towers, based on health concerns.

Telecommunications Act of 1996
https://transition.fcc.gov/Reports/tcom1996.pdf

The Federal Communications Commission (FCC) has acted in partnership with the wireless industries by permitting wireless radiation levels far higher than the biomedical research literature indicates are necessary to protect human health. The success of the wireless industries in capturing the FCC, the committees in the U.S. Congress that oversee the FCC, and the Executive Branch is detailed in a new monograph from the Center for Ethics at Harvard University. As an example of that capture, the President recently appointed, as head of the FCC, the former head of the CTIA – The Wireless Association, which is the major lobbying organization for the wireless industry. This, of course, is the infamous "revolving door".

Norm Alster, Captured Agency: How the Federal Communications Commission is Dominated by the Industries It Presumably Regulates (2015)
http://ethics.harvard.edu/news/new-e-books-edmond-j-safra-research-lab

Further, the U.S. Government's "American Recovery and Investment Act of 2009" provided funding that was used to motivate the installation of wireless smart meters (also called the "Advanced Metering Infrastructure" or "AMI") by offering cost sharing, in the form of grants, to the utilities that would adopt such meters.

https://www.smartgrid.gov/recovery_act/overview/smart_grid_investment_grant_program.html

Many states then extended the impact of the above Act by *mandating* the acceptance of wireless smart meters by the public. These meters contain microwave transmitters/receivers and are placed either on, or inside, every home and many businesses. A California court-ordered document indicates that each smart meter broadcasts bursts of radiation, on average about 10,000 times per day and up to a maximum of about 190,000 times per day. Such bursts flood neighborhoods with radiation, day and night, throughout the year.

http://emfsafetynetwork.org/wp-content/uploads/2011/11/PGERFDataOpt-outalternatives_11-1-11-3pm.pdf

Increasingly, the public is becoming aware of the threat that wireless radiation poses to health. The initial opposition focuses primarily on *mandated* sources of exposure, especially when the individuals exposed include the unborn and young children as they are among the most vulnerable. Thus, the strongest initial opposition is surfacing for cell towers, especially on school grounds; for Wi-Fi in schools and colleges; and for wireless smart meters placed on, or inside, homes and businesses. Most states now have opposition groups, and some states have even 10 or 20 such groups. These groups are pursuing relief through state regulatory bodies, through state legislatures, and through the courts. Below is a sampling of the hundreds of U.S. websites that reflect the nature and scope of the opposition to the unbridled expansion of wireless technology. Such websites seek to educate the public and decision-makers, and thus to promote responsive action, based on the underlying science.

The BabySafe Project
http://www.babysafeproject.org/the-science/

National Association for Children and Safe Technology
http://www.nacst.org/

Stop Smart Meter's listing of groups in the USA and other countries opposed to wireless smart meters
http://stopsmartmeters.org/frequently-asked-questions/contacts-database/

Smart Grid Awareness, a Website by SkyVision Solutions, Consumer Protection Advocate
http://smartgridawareness.org

ANNOTATED LIST OF VIDEOS

There are hundreds of videos on the Internet that address the impact of wireless radiation on health. Here are just a few that provide an especially good introduction to this topic. An Internet search will surface many more.

(1) An introduction to the health risks posed by Wi-Fi in schools

Wi-Fi in Schools, the Facts (September 9, 2013) (18 minutes)
Produced by Wi-Fi in Schools Australia.
https://www.youtube.com/watch?v=QQryZbxlqXI&feature=youtu.be

(2) Wide ranging overview of the impact of electromagnetic radiation on human health, particularly at microwave frequencies, with a special emphasis on children and the school environment

Electromagnetic Radiation Health for Children 2014 (70 minutes)
Presented by Dr. Erica Mallery-Blythe, a UK physician.
https://www.youtube.com/watch?v=sNFdZVeXw7M

(3) Documentary on the wireless industry's efforts to suppress public awareness of the health effects of wireless radiation

Microwaves, Science & Lies (2014) (90 minutes)
Produced by Jean Heches and Nancy de Meritens of France.
https://vimeo.com/ondemand/17755/89417454

(4) Samples of video testimony by individuals harmed by the radiation from wireless devices

Cell Phones Cause Cancer (October 17, 2012) (9 minutes)
Presented by Jimmy Gonzalez, Esq.
https://www.youtube.com/watch?v=DIlOVJd0lA8

Woman suffers acute radiation exposure from a bank of smart meters (January 21, 2015) (3 minutes).
Produced by Maryland Smart Meter Awareness.
https://www.youtube.com/watch?v=F9QZuWPw6Y0&feature=youtu.be

Man experiences adverse health effects from exposure to a smart meter (March 7, 2013) (3 minutes).
Presented by Garic Schoen of Gaithersburg, MD.
Produced by Maryland Smart Meter Awareness.
http://marylandsmartmeterawareness.org/smart-meter-news/maryland-ms-resident-testimony-to-economic-matters-committee-re-hb1038-on-march-14-2013/

Individuals with high sensitivity to the radiation from wireless devices search for increasingly rare safe electromagnetic environments.
Searching for a Golden Cage (May 8, 2014) (13 minutes)
Produced by Nadav Neuhaus.
http://time.com/golden-cage/

IDEA

IRISH DOCTORS' ENVIRONMENTAL ASSOCIATION
CUMANN COMHSHAOIL DHOCTÚIRÍ NA HEIREANN

Patrons:
Prof. Declan Kennedy
Prof. Vyvyan Howard
Prof. Risteard Mulcahy

Chairperson:
Juliet Duff
Glenville, Co. Cork

Hon. Secretary:
Dr. Philip Michael
Bandon, Co. Cork

Treasurer:
Dr. Elizabeth Cullen
Thomastown,
Kilcullen,
Co. Kildare
Tel: 045-485215

Website: www.ideaireland.org

Affiliated to: ISDE - International Society of Doctors for the Environment. www.isde.org
and members of HEAL - Health and Environment Alliance www.env-health.org
and HCWH - Health Care Without Harm. www.noharm.org

Linked officially with WHO - World Health Organisation

Affiliated to International Physicians for the Prevention of Nuclear War - IPPNW (Nobel Prize Winner 1985)

Charity No. 14368

7th January, 2013

Dear Principal,

The Irish Doctors Environmental Association (IDEA) has very serious concerns in relation to the ubiquitous use of Wi-Fi in Irish schools, and alerts you to the warnings of many leading international scientists and medical doctors who believe Wi-Fi is harmful to health, especially children's health.
http://wifiinschools.org.uk/resources/safeschools2012.pdf
Wi-Fi is an unregulated technology and there is absolutely no evidence that it is safe.

Since May 31st, 2011, radiofrequency electromagnetic fields (as in Wi-Fi) have been classified by the World Health Organisation as 'possibly carcinogenic' to humans. The IDEA unequivocally supports the Council of Europe, The European Environmental Agency and The International Commission for Electromagnetic Safety (ICEMS) in urging the adoption of the Precautionary Principle to protect human health.
Warnings by Scientists and Doctors:
http://www.iemfa.org/index.php/appeals

The Precautionary Principal has already been adopted by a number of Governments and agencies internationally.
Governments & organisations banning and warning against Wi-Fi:
http://www.cellphonetaskforce.org/?page_id128

While we fully support the promotion of technology in education we urge you to use wired technologies for your own safety and that of your pupils and staff. The tragedy of avoidable illness is only superseded by the knowledge that it could have been avoided.

Yours sincerely

Elizabeth Cullen

Elizabeth Cullen M.B. B.Ch. B.A.O. M.Sc. Ph. D 045-485215

pp. Philip Michael

Philip Michael M.B. B.Ch. B.A.O. D.C.H. MICGP 023 8844697

Komitéen for Strålebeskyttelse
c/o Advokatfirma Christian Harlang
Nytorv 5, 1.sal
DK-1450 København K
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C4ST
CANADIANS FOR SAFE TECHNOLOGY
CANADIENS POUR UNE TECHNOLOGIE SÉCURITAIRE

PO Box 33
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Oakville, ON
Canada
L6J 7P5

April 9, 2014

Via email: rec@harlanglaw.dk

Dear members of The Committee on Radiation Protection/Komitéen for Strålebeskyttelse:

My name is Frank Clegg and I am the CEO of Canadians for Safe Technology, C4ST, a volunteer based, national organization which promotes the safe use of wireless technology.

In my previous role as President of Microsoft Canada, I witnessed the incredible benefits that technology can provide. I also witnessed the potential harmful effects if technology is not implemented safely. Though wireless technologies afford schools various advantages, this solution cannot overshadow the evidence which demonstrates cause for concern. I request that you consider the following important facts.

The Canadian Teachers' Federation (CTF) is a national alliance of provincial and territorial teacher organizations that represent nearly 200,000 elementary and secondary school teachers across Canada. In their submission to the public consultation of the Royal Society of Canada, Oct. 28, 2013, they submitted the following recommendations. (Safety Code 6 is Health Canada's guideline regarding the limits of radiation from wireless devices).
Recommendations...
... That Safety Code 6 include a recommendation for prudent use of Wi-Fi whenever possible including the recommendation to limit consistent exposure in schools by turning off wireless access points when not in use. ...
That Safety Code 6 exposure thresholds be based upon both thermal and biological effects of exposure to Wi-Fi.
... That the Expert Panel recommend an education program regarding the relative safety of Wi-Fi exposure and that appropriate resources be developed to educate the public regarding ways to avoid potential exposure risks of Wi-Fi access points and devices.

As reported by CBC News on Aug. 17, 2013, http://www.cbc.ca/news/canada/toronto/story/2013/08/17/toronto-cell-phone-ban.html "The Elementary Teachers' Federation of Ontario has updated its policy position on the student use of personal electronic devices, preferring for them to be turned off and put away unless a teacher says otherwise. That policy, which was amended at the union's annual general meeting, informs ETFO in its discussions with the government and school boards on related issues. A portion of that policy now states that such devices, which include cellphones, should "be stored and turned off during the instructional day unless their use is directly authorized by staff." In a separate resolution, ETFO voted to study the effects of non-ionizing electromagnetic radiation, the potentially harmful radiation emitted by cellphones. A report is due on the matter in February."

In a letter to the Peel Region, April 22, 2013, The American Academy of Environmental Medicine stated "To install this widespread wireless internet access system in Peel District schools risks a widespread public health hazard that the medical system is not yet prepared to address. Statistics show that you can expect to see an immediate reaction in 3% and delayed effects in 30%, including teachers."

In 2012, the BC Confederation of Parent Advisory Councils passed resolution 18 which states: "BCCPAC call on Boards of Education to cease to install Wi-Fi and other wireless networks in schools where other networking technology is feasible."
http://www.bccpac.bc.ca/resolutions/wi-fi-classrooms-committee-report

In May 2011, the World Health Organization (WHO) announced that the radiation emitted from wireless devices, including Wi-Fi, is a Class 2B carcinogen, which falls into the same category as lead and DDT.

You may already be aware that some schools and libraries in France and Switzerland have already removed Wi-Fi due to the suspected harmful health effects.

The Council of Europe, which includes 47 countries, adopted resolution 1815 which suggests in member countries "give preference to wired Internet connections, and strictly regulate(s) the use of mobile phones by schoolchildren on school premises."

The European Parliament (EU) resolutions 2008/2211(INI) & 2007/2252(INI,) state: "wireless technology (mobile phones, Wi-Fi / WiMAX, Bluetooth, DECT landline telephones) emits EMFs that may have adverse effects on human health... particularly to young people whose brains are still developing... **the limits on exposure to electromagnetic fields which have been set for the general public are obsolete."** (emphasis in original)

Other countries such as Israel, Russia, Switzerland, Frankfurt, Bavaria, and Salzburg have followed suit making the difficult decision to use hard wired connections as well. Recently, France passed a law recommending hard wired technology in schools.

The Austrian Medical Chamber shares that “WiFi may lead to concentration difficulties and memory problems in certain individuals.” The Austrian Medical Association recommends Wi-Fi free school environments.

The International Society of Doctors for the Environment (ISDE) and Irish Doctors Environmental Association (IDEA) advises to “Avoid Wi-Fi in home or work if possible, particularly in schools or hospitals. Use wired technology whenever possible” sharing that: “Because of the potentially increased risks for the fetus, infants and young children due to their thinner more permeable skulls and developing systems, particularly the immune and neurological systems, based on the precautionary principal and on the mounting evidence for harm at the sub-cellular level, we recommend that EMR exposure should be kept to a minimum.”

The American Academy of Pediatrics (AAP) - 60,000 Pediatricians and Pediatric Surgeons calls for caution as well stating that "The differences in bone density and the amount of fluid in a child’s brain compared to an adult’s brain could allow children to absorb greater quantities of RF energy deeper into their brains than adults... the current exposure limits may not reflect the latest research on RF energy" and lends support to removing Wi-Fi from schools as well.

As stewards of the public trust, I urge you to ensure the safest possible learning environment for the students in your care and to set an example for school districts by removing Wi-Fi and adopting “Best Practices” which limit the use of other wireless technologies.

Sincerely,

Frank Clegg
CEO,
Canadians for Safe Technology (C4ST)
frank@c4st.org

cc: Susanne Hansen, sh.klodskov@gmail.com

UNIVERSITY AT ALBANY
State University of New York

Institute for Health and the Environment
and
Department of Environmental Health Sciences
School of Public Health

28 February 2011

Chairman and Trustees
Kawartha Pine Ridge District School Board
Education Centre
1994 Fisher Drive
Peterborough, Ontario K9J7A1

Dear Sirs/Madams:

This is concerning potential adverse health effects associated with exposure to radiofrequency (RF) radiation, specifically that from wireless routers. I am a public health physician who has been involved in issues related to electromagnetic fields (EMFs) for a number of years. I served as the Executive Secretary for the New York Powerline Project in the 1980s, a program of research which showed that children living in homes with elevated magnetic fields coming from powerlines suffered from an elevated risk of developing leukemia. I have edited two books on effects of EMFs, including RF radiation. I served as the co-editor of the Bioinitiative Report (www.bioinitiative.org), a comprehensive review of the literature on this subject. The public health chapter from this report was subsequently published in a peer reviewed journal, and that is attached. Also I testified before the President's Cancer Panel on this subject in 2009, and a publication coming from that testimony is also attached. Thus this is a subject which I know well, and one on which I take a public health approach that has as a fundamental principle the need to protect against risk of disease even when one does not have all the information that would be desirable.

There is clear and strong evidence that intensive use of cell phones increases the risk of brain cancer, tumors of the auditory nerve and cancer of the parotid gland, the salivary gland in the cheek by the ear. The evidence for this conclusion is detailed in the attached publications. WiFi uses similar radiofrequency radiation (1.8 to 5.0 GHz), although the intensity of exposure in the immediate environment is much lower than what one gets from holding a cell phone close to your head. The difference between a cell phone and a WiFi environment, however, is that while the cell phone is used only intermittently a WiFi environment is continuous. In addition WiFi transmitters are indoors, where people (and in this case, children) may be very close to them. There is evidence from Scandinavian studies of cell phone usage that children who use cell phones are about five times more likely to develop brain cancer than if use starts as an adult. Thus it is especially important to protect children.

To my knowledge there has not been any health investigation of individuals living or working in WiFi environments as compared to others who are not. However, because the radiation is the same as those for cell phones, there is every reason to assume that the health effects would be the same, varying only in relation to the total dose of radiation. Wired facilities do not generate any RF radiation. While there is not specific proof that WiFi increases risk of cancer, there is certainly no evidence that it is safe. I urge you to not put WiFi in any school. Children should not be put at increased risk of developing cancer.

Yours sincerely,

David O. Carpenter

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Director, Institute for Health and the Environment
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U.S.A

13th December 2015

PhD Mikko Ahonen, Tampere, Finland
MD Lena Hedendal, Luleå, Sweden
MSc. Tarmo Koppel, Tallinn, Estonia

1. Regarding: Measurements related problems in the MCPS Wi-Fi Report

We have analysed the measurement report and would like to note the following:

- In the **Comparison-table 2.2.** the MCPS provides only average values, no peak values. In cell phone technologies (like GSM) the difference between average and peak value is 2-fold. **In Wireless local area technologies like Wi-Fi, the difference between average value and peak value is up to 100-fold** (Ferro & Potorti, 2005). Note that in the table 2.2. by the MCPS only average values are presented. Later you provide **in the chapter 7.2.2 Maximum, Instantaneous Power Density, which needs attention since these levels occasionally exceeded in your school measurements allowable EMC-levels (EN60601-1 → 3 V/m) for medical instruments** (Robinson *et al*., 2003).

- **Almost all MCPS measurements were done in the near field of the devices under 3 wavelengths.** The wavelength for 2,4 GHz is 12,5 cm and for 5 GHz is 6 cm. That means that the near field will be <37,5 cm for 2,4 GHz and <18 cm for 5 GHz. In order to assess power density exposure in near field one needs to measure both electric and magnetic field components.

- The MCPS has not provided **information about Wi-Fi technology, namely it's beacon signal**. This signal, officially **SSID (Service Set IDentifier), is created by the access point (AP) by sending constantly SSID 10 times in a second , at 10 Hz** (Ferro and Poporti, 2005). **Mobile industry has patented technology to avoid this constant SSID sending for health reasons** (Swisscom, 2004). This SSID sending at 10 Hz is an additional risk-factor and it should be mentioned. Our brain operates in alpha, beta and gamma bands. This Wi-Fi beacon overlaps the alpha band. Low-frequency EMFs (including low-frequency pulses) have an effect on evoked potentials of the brain (Carrubba *et al*., 2008).

- **Because of the risk of this 10 Hz Beacon signal of Wi-Fi, The European Academy for Environmental Medicine has assigned very strict precautionary RF-levels for Wi-Fi** (Belyaev et al., 2015). Please, pay attention to Wi-Fi RF power density peak-levels in the next picture.

RF source Max Peak/Peak Hold	Daytime exposure	Nighttime exposure	Sensitive populations[1)]
Radio broadcast (FM)	10,000 μW/m²	1000 μW/m²	100 μW/m²
TETRA	1000 μW/m²	100 μW/m²	10 μW/m²
DVBT	1000 μW/m²	100 μW/m²	10 μW/m²
GSM (2G) 900/1800 MHz	100 μW/m²	10 μW/m²	1 μW/m²
DECT (cordless phone)	100 μW/m²	10 μW/m²	1 μW/m²
UMTS (3G)	100 μW/m²	10 μW/m²	1 μW/m²
LTE (4G)	100 μW/m²	10 μW/m²	1 μW/m²
GPRS (2.5G) with PTCCH* (8.33 Hz pulsing)	10 μW/m²	1 μW/m²	0.1 μW/m²
DAB+ (10.4 Hz pulsing)	10 μW/m²	1 μW/m²	0.1 μW/m²
Wi-Fi 2.4/5.6 GHz (10 Hz pulsing)	10 μW/m²	1 μW/m²	0.1 μW/m²

Picture. Precautionary levels for RF-radiation. **For Wi-Fi less than 10 μW/m² (peak value), which is 0,001 μW/cm² (peak value).** By the **European Academy for Environmental Medicine** (Belyaev *et al*., 2015, p. 356)

- **We would like to draw attention to** long-term exposure related health risks.

Radiofrequency radiation from Wi-Fi devices causes fertility problems as shown by several in vivo and in vitro studies (see for example Atasoy *et al.,* 2013, Avendaño *et al,.* 2012, Dasdag *et al.,* 2015a, Shokri *et al*., 2015).

Additionally, **RF-radiation from Wi-Fi access points (AP) causes oxidative stress in cells which leads to several disorders** (see for example Nazıroğlu *et al*., 2012, Aynali *et al.,* 2013, Salah *et al.,* 2013). The overall detrimental impact of RF radiation induced oxidative stress is summarised in the review of Yakymenko *et al*. (2015).

2. Regarding: The IARC classification of RF-EMF as Group 2B, i.e., 'possibly' carcinogenic to humans and the MCPS Report's inaccurate interpretation

The classification of radiofrequency electromagnetic fields (RF-EMF) as Group 2B, i.e., 'possibly' carcinogenic to humans,was made by 30 scientists from 14 countries at a meeting 2011 for the International Agency for Research on Cancer (IARC), World Health Organization (IARC 2011, Baan et al. 2012). **The working group mainly based their classification on one cohort study** (Schüz et al., 2006) **and five case-control studies** (Muscat et al., 2000, Inskip et al., 2001, Auvinen et al.,2002, The Interphone study group, 2010, Hardell et al., 2011).

They also reviewed more than 40 studies that assessed the carcinogenicity of RF-EMF in rodents, including seven 2-year cancer bioassays and also many studies with endpoints relevant to mechanisms of carcinogenesis, including genotoxicity, effects on immune function, gene and protein expression, cell signaling, oxidative stress, and apoptosis (Baan et al., 2011).

The referred INTERPHONE study (The Interphone study group, 2010), in the MCPS radiation report, was one of the case-control studies. **The Interphone study was a multicentre study of mobile phone use and brain tumours, including malignant tumours in the brain as glioma and benign tumours as acoustic neuroma and meningioma**. The pooled analysis included 2708 glioma cases and 2972 controls (participation rates 64% and 53%, respectively). In the Interphone study a regular user of mobile phones had an average of at least one call per week for a period of ≥6 months. **This very low user group was compared to several other groups of low users compared to nowadays more extensive use of mobile phones.** The highest group of users, ≥1640 hours was divided in three sub groups depending on how many years they had used a mobile phone. For the shortest time span on 1-4 years only 23 of the glioma cases and 8 of the controls had used their mobile phones for more than 1640 hours. If any of these 23 persons with a brain cancer or any of the 8 controls had used their mobile phones for only one year they would have used it at least in average for four and a half hours a day during a year. If they instead had talked in their mobile phones during four years it would be for an average of a little more than an hour a day.
For the group of users between 5 and 9 years, 84 cases and 73 controls, the use per day would be at least between 54 minutes and 30 minutes. **For the long user group of 10 years or more, 93 cases and 73 controls, they talked in their mobile phones for 27 minutes a day or less for more than 10 years of use.**
For the main part of cases their use of mobile phones had been for a lot less than four hours a day. Today when most people use only their mobile phone and landline phones both at home and at work are becoming scarce, an amount of 4 hours or more wireless telephone use / day for salesman, telephone operators and so on is not uncommon.
In the Interphone study there was an statistical significant increased risk for a malignant brain tumour of 1.4 times (odds ratio, OR, 1.4, 95% CI 1.03-1.89) only for the highest user group of a total on more than 1640 hours.
Hardell et al. (2011) in Sweden found that **cases who had used a mobile phone for more than 1 year had an increased risk for glioma of 1.3** (OR 1.3, 95% Cl 1.1-1.6).

The **risk increased with increasing time since first use and with total call time, reaching 3.2 times** (OR 3,2, Cl 2.0-5.1) **for more than 2000 hours of use**. Use of the mobile phone on the same side of the head as the tumour was associated with higher risk.

Since 2011 several other studies have been published which are strengthening the possible association between RF-EMF and cancer. Using the **Bradford Hill viewpoints for evaluating strengths of evidence of the risk for brain tumours associated with use of mobile and cordless phones the classification <u>should be upgraded to group 1 carcinogen, i.e., "the agent is carcinogenic to humans"</u>** (Hardell & Carlberg, 2013).

New case-control studies have verified Hardell's studies (Coureau et al., 2014) and up to 20 years of mobile phone use have found even higher risk for brain tumours (Hardell & Carlberg, 2015).

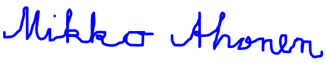
A newly published study has found a tumor promotion effect on mice from exposure to radiofrequency electromagnetic fields below exposure limits for humans (Lerchl *et al*., 2015). RF-EMFs do not cause direct DNA damage. On the contrary **numerous studies have shown generation of reactive oxygen species (ROS) that can cause oxidative damage of DNA. This is a well-known mechanism in carcinogenesis for many agents.** The broad biological potential of ROS and other free radicals makes radiofrequency radiation a potentially hazardous factor for human health, not only cancer risk but also other health effects (Yakymenko *et al*., 2015).

The IARC classification of RF-EMF as Group 2B, possibly carcinogenic to humans, doesn't only include exposure from mobile phones near the ear. **The classification includes all sources of RF-EMFs.** The exposure from mobile phone base stations, Wi-Fi access points, smart phones, laptops and tablets can be long term, sometimes around the clock both at home and at school. **This constant exposure to lower levels of exposure may be as deleterious to health as higher exposure during short time** (Fragopoulou et al., 2012, Dasdag et al., 2015b). This **risk may be accentuated for children because their probable longer use of wireless devices** (Morgan et al., 2014). **Children are also growing and have more immature cells which can be more sensible to RF-EMF** (Markova et al., 2010)

In conclusion, long term health effects from RF EMFs are still under investigation and a significant amount of troublesome scientific evidence has surfaced. By using wireless technologies at close range, long term health risks cannot be excluded. Therefore, we recommend schools to use wired technologies.

Respectfully submitted

Sincerely,



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24 March 2014

Open letter by British medical doctors: Health and safety of Wi-Fi and mobile phones

We wish to highlight our concern over the safety of exposure to microwave radiation from wireless technology, particularly for vulnerable groups like children, pregnant women, the elderly and those with compromised health.

There is growing concern that chronic (long-term) exposure to radiofrequency/microwave radiation from wireless technologies causes damage, particularly genetic damage, cognitive damage, cancer and decreased fertility. There is now substantial evidence of a link between mobile phone use and brain cancer. This was recognised by the International Agency for Research on Cancer (IARC)'s 30-strong panel of scientists, which in 2011 classed radiofrequency radiation as "possibly carcinogenic".

Additionally, doctors are encountering a significant and growing number of people presenting with **a range of acute (short-term) symptoms from wireless radiation, including headaches, palpitations, rashes, fatigue, sleep disturbance, allergies and memory and concentration problems.**

International medical agencies have recognised the evidence of harm (see appended list) but these rulings may take many years to be reflected in public health policy. This controversy is a common characteristic of scientific understanding when environmental exposures are new.

New technologies and substances often come with scientific conflict, which can continue for several decades before consensus is achieved. Commercial pressures often delay the acceptance of health risks, even when scientific evidence is compelling. In the case of tobacco, asbestos, x-rays and leaded petrol, for example, it took many decades before damage was established and accepted by health agencies and, during those decades, millions of people suffered ill health and death as a result of the delay. Now, despite evidence of harm, wireless technology is being rolled out widely.

We urge health agencies and the public to act immediately to reduce exposure to radiofrequency/ microwave radiation. This is especially important for children, who are physiologically more vulnerable to this exposure, and for whom adults have a safeguarding responsibility. **Children's health should be put ahead of convenience and commercial benefits. Children should not use mobile phones except in an emergency, and WiFi should be replaced with wired alternatives in schools and other settings where children spend considerable time.**

Yours faithfully,

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Dr Andrew Tresidder MRCGP (1989), MBBS (Lond) – Medical Doctor
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Dr Elizabeth Cullen MBBCh BAO MSc PhD – Medical Doctor
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Appendix – International Rulings

1. In 2011 the **World Health Organization's scientific panel, the International Agency for Research on Cancer (IARC),** reviewed all the evidence on carcinogenesis (cancer-causing) and categorised electromagnetic radiation from mobile phones and Wi-Fi as **Possibly Carcinogenic (Class 2B).**

See http://www.iarc.fr/en/media-centre/pr/2011/pdfs/pr208_E.pdf

2. **The Council of Europe has called for member states to take measures to reduce exposure to electromagnetic fields and give preference to wired internet connections for children, particularly in schools and classrooms.**

The Parliamentary Assembly stated that "the Assembly regrets that, despite calls for the respect of the precautionary principle and despite all the recommendations, declarations and a number of statutory and legislative advances, there is still a lack of reaction to known or emerging environmental and health risks and virtually systematic delays in adopting and implementing effective preventive measures. Waiting for high levels of scientific and clinical proof before taking action to prevent well-known risks can lead to very high health and economic costs, as was the case with asbestos, leaded petrol and tobacco."

See http://assembly.coe.int/mainf.asp?link=/documents/adoptedtext/ta11/eres1815.htm

3. **The BioInitiative Report**, updated in 2012 by 29 scientists, states that **biological effects are clearly established and occur at very low levels of exposure to electromagnetic fields and radiofrequency radiation** from just minutes of exposure to mobile phone masts (cell towers), WI-FI, and wireless utility 'smart' meters.

See http://www.bioinitiative.org/conclusions

4. **The American Academy of Environmental Medicine** stated in a 2012 Position Paper that "**Multiple studies correlate RF exposure with diseases such as cancer, neurological disease, reproductive disorders, immune dysfunction, and electromagnetic hypersensitivity."**

See http://aaemonline.org/emf_rf_position.html

6. **International Society of Doctors for the environment (ISDE) and Irish Doctors' Environmental Association (IDEA)** state that "**there is sufficient scientific evidence to warrant more stringent controls** on the level and distribution of electromagnetic radiation [EMR]. The joint statement and recommendations are part of a call by medical and scientific experts for safe technologies in schools."

See http://www.env-health.org/news/members-news/article/isde-idea-statement-on

5. The Safe Schools Report 2012 lists statements by **other doctors and medical associations** raising concerns over children's exposure to electromagnetic fields from Wi-Fi and other wireless technology.

See http://wifiinschools.org.uk/resources/safeschools2012.pdf

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July 10, 2009.

Open Letter to Parents, Teachers, & School Boards Regarding Wi-Fi Networks in Schools and Cell Phone Antennas near School Property

I am a scientist who does research on the health effects of electromagnetic radiation and I am becoming increasingly concerned that a growing number of schools are installing WiFi networks and are making their school grounds available for cell phone antennas.

You will be told by both the federal government (Federal Communication Commission in the US; Health Canada and Industry Canada in Canada) as well as by the Wi-Fi provider that this technology is **safe** provided that exposures to radio frequency radiation remain below federal guidelines.

This information is **outdated** and **incorrect** based on the growing number of scientific publications that are reporting adverse health and biological effects below our "short-term, thermal-based" guidelines (see www.bioiniative.org) and the growing number of scientific and medical organizations that are asking for stricter guidelines to be enforced.

For these reasons it is irresponsible to introduce Wi-Fi microwave radiation into a school environment where young children and school employees spend hours each day.

FACT:

1. **GUIDELINES: Guidelines for microwave radiation (which is what is used in Wi-Fi) range 5 orders of magnitude in countries around the world.** The lowest guidelines are in Salzburg Austria and now in Liechtenstein. The guideline in these countries is 0.1 microW/cm^2. See short video (http://videos.next-up.org/SfTv/Liechtenstein/AdoptsTheStandardOf06VmBioInitiative/09112008.html). In Switzerland the guideline is 1 and in both Canada and the US it is 1000 microW/cm^2!

   Why do Canada and the US have guidelines that are so much higher than other countries? Our guidelines are based on a short-term (6-minute in Canada and 30-minute in US) heating effect. It is assumed that if this radiation does not heat your tissue it is "safe". This is NOT correct. Effects are documented at intensities well below those that are able to heat body tissue. See attached report: *Analysis of Health and Environmental Effects of Proposed San Francisco Earthlink Wi-Fi Network* (2007). These biological effects include increased permeability of the blood brain barrier, increased calcium flux, increase in cancer and DNA breaks, induced stress proteins, and nerve damage. Exposure to this energy is associated with altered white blood cells in school children; childhood leukemia; impaired motor function, reaction time, and memory; headaches, dizziness, fatigue, weakness, and insomnia.

2. **ELECTRO-HYPER-SENSITIVITY:** A growing population is adversely affected by these electromagnetic frequencies. The illness is referred to as "electro-hyper-sensitivity" (EHS) and is recognized as a disability in Sweden. The World Health Organization defines EHS as:

   ". . . a phenomenon where individuals experience adverse health effects while using or being in the vicinity of devices emanating electric, magnetic, or electromagnetic fields (EMFs). . . EHS is a real and sometimes a debilitating problem for the affected persons, while the level of EMF in their neighborhood is no greater than is encountered in normal living environments. Their exposures are generally several orders of magnitude under the limits in internationally accepted standards. "

   Health Canada acknowledges in their Safety Code 6 guideline that some people are more sensitive to this form of energy but they have yet to address this by revising their guidelines.

Symptoms of EHS include sleep disturbance, fatigue, pain, nausea, skin disorders, problems with eyes and ears (tinnitus), dizziness, etc. It is estimated that 3% of the population are severely affected and another 35% have moderate symptoms. Prolonged exposure may be related to sensitivity and for this reason it is imperative that children's exposure to microwave radiation (Wi-Fi and mobile phones) be minimized as much as possible.

3. **CHILDREN'S SENSITIVITY:** Children are more sensitive to environmental contaminants and that includes microwave radiation. The Stewart Report (2000) recommended that children not use cell phones except for emergencies. The cell phone exposes your head to microwave radiation. A wireless computer (Wi-Fi) exposes your entire upper body and if you have the computer on your lap it exposes your reproductive organs as well. Certainly this is not desirable, especially for younger children and teenagers. For this reason we need to discourage the use of wireless technology by children, especially in elementary schools. That does not mean that students cannot go on the Internet. It simply means that access to the Internet needs to be through wires rather than through the air (wireless, Wi-Fi).

4. **REMOVAL OF WI-FI:** Most people do not want to live near either cell phone antennas or Wi-Fi antennas because of health concerns. Yet when Wi-Fi (wireless routers) are used inside buildings it is similar to the antenna being inside the building rather than outside and is potentially much worse with respect to exposure since you are closer to the source of emission.

   Libraries in France are removing Wi-Fi because of concern from both the scientific community and their employees and patrons.

   The Vancouver School Board (VSB) passed a resolution in January 2005 that prohibits construction of cellular antennas within 1000 feet (305 m) from school property.

   Palm Beach, Florida, Los Angeles, California, and New Zealand have all prohibited cell phone base stations and antennas near schools due to safety concerns. The decision not to place cell antennas near schools is based on the likelihood that children are more susceptible to this form of radiation. **Clearly if we do not want antennas "near" schools", we certainly do not want antennas "inside" schools!** The safest route is to have wired internet access rather than wireless. While this is the more costly alternative in the short-term it is the least costly alternative in the long run if we factor in the cost of ill health of both teachers and students.

5. **ADVISORIES:** Advisories to limit cell phone use have been issued by the various countries and organizations including the UK (2000), Germany (2007), France, Russia, India, Belgium (2008) as well as the Toronto Board of Health and the Pittsburgh Cancer Institute (July 2008). While these advisories relate to cell phone use, they apply to Wi-Fi exposure as well since both use microwave radiation. If anything, Wi-Fi computers expose more of the body to this radiation than do cell phones.

6. **PRECAUTIONARY PRINCIPLE**: Even those who do not "accept" the science showing adverse biological effects of microwave exposure should recognize the need to be careful with the health of children. For this reason we have the Precautionary Principle, which states:

   In order to protect the environment, the precautionary approach shall be widely applied by States according to their capability. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost effective measures to prevent environmental degradation.

   In this case "States" refers to the School Board and those who make decisions about the health of children.

The two most important environments in a child's life are the home (especially the bedroom) and the school. For this reason it is imperative that these environments remain as safe as possible. **If we are to err, please let us err on the side of caution.**

Respectfully submitted,
Dr. Magda Havas,
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July 10, 2009

Shallow Minds:
How the Internet and Wi–Fi in Schools Can Affect Learning

By Cindy Lee Russell, MD
VP-Community Health, Santa Clara County Medical Association

Most of us cannot live without our computers, text messaging, e-mail, and immediate access to the vast cloud of information, especially kids and teenagers who have grown up in the age of the Internet. In fact, more schools are integrating computers at younger ages, even in kindergarten. Forty-nine states are phasing out cursive handwriting altogether. What effects does it have, however, on learning, brain development, cognition, and brain health? Studies have shown some interesting ways that technology is rewiring and shaping our brain, which may not be "all good."

A growing body of scientific evidence suggests that the Internet, with its distractions and interruptions, is turning us into scattered, superficial thinkers. What does that portend for our kids?

Multitasking and Internet Addiction

Nicholas Carr explains, in his book "The Shallows," that we are changing the way we process information. "Dozens of studies by psychologists, neurobiologists, educators, and Web designers point to the same conclusion: When we go online, we enter an environment that promotes cursory reading, hurried and distracted thinking, and superficial learning….The Net delivers precisely the kind of sensory and cognitive stimuli-repetitive, intensive, interactive, addictive, that have been shown to result in strong and rapid alterations in brain circuits and functions."

Researchers from Stanford, in 2009, gave a battery of cognitive tests to a group of heavy and light media Internet multitaskers. They found that the heavy multitaskers were much more easily distracted by "irrelevant environmental stimuli" and had less control over their working memory. In addition, they were much less able to focus on a particular task. Professor Clifford Nass, who led the research, stated intensive multitaskers are "suckers for irrelevancy. Everything distracts them." (5)

"Teaching is a human experience. Technology is a distraction when we need literacy, numeracy, and critical thinking." Paul Thomas, author and associate professor of education at Furman University

Law School Professors Ban Laptops in Classrooms

Several years ago, professors who were irritated with students surfing the Web and hiding behind laptop screens began banning the use of the Internet or laptops in the classroom. Laptops have been banned in classes at Harvard Law School, Yale, George Washington University, University of Virginia, and South Texas College of Law, to mention a few. (4)(15) A 2006 study by Carrie Fried backed up the policies, demonstrating that students who used laptops in class spent considerable time multitasking. They more importantly found that the level of laptop use was negatively related to several measures of student learning. (3)

A 2012 survey by Elon University, the Pew Internet, and American Life Project asked over 1,000 leaders in the U.S. their thoughts about cognition in our millennial generation. They were asked to consider how the Internet and its environment are changing, for better or worse. Overall, the survey found that multitasking is the new norm and that hyper-connectivity may be leading to a lack of patience and concentration. The "always on" ethos may be encouraging a culture of expectation and instant gratification.

Brain Maturation, Learning, Memory, and Intelligence

The maturation of intelligence requires quiet, deep thought, and time. Established research findings in cognitive science leads to the conclusion that laptop use, especially with Wi-Fi access, could interfere with learning.

The hippocampus, which lies under the cortex, is intimately involved in long-term memory storage. Initial experiences are stored and stabilized in the hippocampus and then later transferred to the cortex. Removal of the hippocampus does not affect long-term memories, but prevents new memories from forming.

Learning depends on the ability to transfer information from our working memory to long-term memory and weave this into other acquired knowledge. There is a bottleneck in the passage of working memory to long-term memory. We have a limited ability as humans to capture and process information. The Internet provides too many choices and too much information at once. Excess distracting information creates "overload," preventing long-term memorization and important information is lost. No one disagrees that we need to protect our memories. As author Nicholas Carr highlights, personal memory is not just for the individual to function, but it shapes and sustains our collective cultural memory.

Brain Drain:

Adverse Neurologic and Health Effects of Wireless Microwave Communications

A growing body of peer reviewed research is showing neurologic damage to fetal brain and other systems from Wi-Fi and other microwave wireless sources. In a prior article, "Why-Fi: Is Wireless Communication Hazardous to Your Health?" in the Sept/Oct 2010 SCCMA *Bulletin*, the full range of effects of EMF from our cell phones and wireless devices was discussed. New basic science research in the last three years is confirming these findings. Initially, the Bioinitiative report of 2007 reviewed the biological effects of low level EMF. It found that there was clear evidence of adverse effects to living systems at current environmental exposures and at doses well below the threshold of the International Commission of Non-Ionizing Radiation Protection (ICNIRP) safety guidelines. Current microwave safety limits are based solely on the heating of tissue and do not take into account research showing negative biological effects on DNA, cancer, protein synthesis, skin tissue changes, sperm motility and viability, cognitive functioning, and disruption of the blood brain barrier.

Current Research on Cognition and Wireless Communication

Fetal Radiofrequency Radiation Exposure From 800-1900 MHz-Rated Cellular Telephones Affects Neurodevelopment and Behavior in Mice. *Scientific Reports*. March 2012.

Aldad et al noted that neurobehavioral disorders are increasingly prevalent in children with 3%-7% of school-aged children diagnosed with attention deficit hyperactivity disorder (ADHD). The etiology is unclear, however, an association between prenatal cellular telephone use and hyperactivity in children has been postulated by others. To test this, he exposed pregnant mice to cell phone radiation throughout gestation (days 1-17), with a sham cell phone control group. He found that the exposed group had dose responsive impaired neurologic transmission in the prefrontal cortex and that the mice exposed in utero were hyperactive and had impaired memory. He concluded "that these behavioral changes were due to altered neuronal developmental programming."(3)

Microwave Radiation Induced Oxidative Stress, Cognitive Impairment, and Inflammation in Brain of Fischer Rats. Megha. 2012.

Megha evaluated the intensity of oxidative stress, cognitive impairment, and brain inflammation in rats exposed to typical cell phone microwave radiation. They were subjected to 900 and 1,800 MHz EMF for two hours a day, for 30 days. They state, "Significant impairment in cognitive function and induction of oxidative stress in brain tissues of microwave exposed rats were observed, in comparison with sham exposed groups… Results of the present study indicated that increased oxidative stress due to microwave exposure may contribute to cognitive impairment and inflammation in brain."

Effect of Low Level Microwave Radiation Exposure on Cognitive Function and Oxidative Stress in Rats. Deshmukh. 2013.

The author highlights the exponential increase in wireless communication devices we are exposed to. He evaluated the effects of cell phone radiation on oxidation in tissues, in addition to cognition in rats. They subjected rats to 900 MHz EMF for two hours per day, five days a week, for 30 days, with an unexposed control group. "Results showed significant impairment in cognitive function and increase in oxidative stress, as evidenced by the increase in levels of MDA (a marker of lipid peroxidation) and protein carbonyl (a marker of protein oxidation) and unaltered GSH content in blood. Thus, the study demonstrated that low level MW radiation had significant effect on cognitive function and was also capable of leading to oxidative stress."

The Internet Can Damage Teenage Brains

A large radiologic study from China, published July 2011, looked at structural brain changes in Internet-addicted teenagers. It is estimated that 24 million teenagers are addicted to the Internet in China. The researchers found a consistent atrophy of grey matter in parts of the brain and shrinkage of the surface of the brain in those addicted to the Internet. The effects were worse the longer the addiction. In addition, the study revealed changes in white matter of the brain, which function to transmit messages in the brain to the grey matter. They concluded these structural abnormalities were most likely associated with functional impairments in cognitive control.

"It strikes me as a terrible shame that our society requires photos of brains shrinking in order to take seriously the common-sense assumption that long hours in front of screens is not good for our children's health. Dr Aric Sigman, Fellow of the Royal Society of Medicine

WHO Classifies EMF as a Carcinogen

In 2011, The WHO/International Agency for Research on Cancer (IARC) classified radiofrequency electromagnetic fields as "possibly carcinogenic to humans (Group 2B), based on an increased risk for glioma, a malignant type of brain cancer1, associated with wireless phone use."

France Bans Wi-Fi in Schools, But Replaces With Ethernet

The French National Assembly, March 2013, passed an amendment to ban Wi-Fi in their schools until it's proven "safe for human consumption." They instead agreed to install far safer, wired Ethernet cable connections.

The Council of Europe has called for a ban on Wi-Fi use in schools and also recommends a wired alternative.

In Austria, the Austrian Medical Society has also issued a policy statement asking for a ban of Wi-Fi in schools.

The U.K. has a useful frequently-updated website on Wi-Fi in schools, which provides much scientific research. http://www.wifiinschools.org.uk/ Still the controversy persists.

The Cost of a Virtual World

There are a host of concerns with classroom technology, and the virtual world it creates, that have not been explored in the rush to "modernize" education and prevent our kids from becoming "computer illiterate," despite the fact that computers are designed for ease of use. These issues range from distraction in the classroom, impairment of cognitive development and long-term memory, deficiency in learning social skills, Internet addiction, cyber bullying, access to inappropriate content, eye fatigue, and security risks to online learning networks. In addition, the sheer cost of computers and continuous upgrades is likely to break many school budgets. We have not mentioned the issue of toxic e-waste, another growing public health problem.

Common Sense

We will not get rid of the Internet or computers. We should not ignore, however, the enlarging body of science that points to real threats to public health and, especially, our children's safety and well-being. The best approach is precautionary. Reduce the risk by reducing the microwave emissions. It is our obligation as physicians and parents to protect our children. They are the future and our legacy.

1. Remove wireless devices (white boards and routers) in schools in favor of wired connections and fiberoptic.
2. If there is Wi-Fi, then give teachers the authority to turn it off when not in use or if they feel it is not necessary.
3. Ban cell towers near or on schools.
4. Limit screen time on computers.
5. Limit or ban cell phone use in the class.
6. Limit or ban cell phone use at home.
7. Do not allow laptops to be placed on laps.
8. Undertake independent scientific studies on Wi-Fi and computer use that look at acute and long-term health effects.
9. Train teachers how to recognize symptoms of EMF reactions.
10. Conduct meetings with parents and teachers to address this issue in each school.

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Minimize health risks from electronic devices

Published in the September 2016 NJEA Review
by Adrienne Markowitz and Eileen Senn

Desktops, laptops, tablets, eBook readers, printers, projectors, smart boards, smart TVs, cellphones, cordless phones and wireless networks (WiFi) have become ubiquitous in schools. At their best, they are powerful tools for education. At their worst, they threaten the physical and mental health of teachers, paraeducators, secretaries, librarians and other school staff members and students who spend numerous hours using the devices.

Physical health risks from electronic devices include pain and tingling from repetitive strain injuries to the hands and wrists; pain in the neck, shoulders and back; dry, burning, itchy eyes, blurred vision and headaches; altered sleep patterns and next-day fatigue from exposure to blue screen light; distracted driving; and various health problems from exposure to radiation.

Mental health risks arise from stress due to raised expectations for multitasking, productivity and proficiency with devices; dealing with malfunctioning devices; student and colleague distraction from and addiction to devices; and intrusion of devices into nonwork time.

WiFi devices emit radiation

Radio frequency (RF) electromagnetic frequency (EMF) radiation is sent and/or received by the antennae of phones, routers and other wireless devices. RF radiation is capable of causing cancer, reproductive, neurological and ocular effects. The amount of radiation exposure received depends on the amount of time exposed and distance from the source. Radiation levels fall off exponentially with distance from antennae. If you double the distance, the radiation is four times less. If you triple the distance, it is nine times less, and so on. Children and developing fetuses are particularly at risk because their bodies are still growing. People with implanted medical devices are at risk for device interference.

Hazards and solutions

The most straightforward ways to minimize health risks are to use electronic devices in moderation and to maximize your distance from them. There are also specific solutions to specific hazards listed below.

Local associations should work with their UniServ field representative to negotiate solutions that are in the control of district administrators such as providing training and ergonomic equipment and hard-wiring devices. Individuals should take steps within their control, such as:

For repetitive strain injuries

- Use voice control/speech recognition.
- Use ergonomic alternatives to traditional mice and keyboards.
- Use as many fingers as possible when typing and both thumbs when texting.

For neck, shoulder and back pain

- Ensure an ergonomic workstation.
- When using a hand-held device, support it and the forearms.
- Avoid bending the head down or jutting it forward.
- Take frequent, short breaks from the device.
- Ensure good posture and change positions frequently.
- Stand and do stretching exercises.

For eye pain, blurred vision and headaches

- Use sufficient, but not excessive, lighting.
- Use assistive technology built into Apple, Android and Windows devices.
- Enlarge and darken the cursor and pointer.
- Enlarge the font; magnify the text.
- Use text-to-speech instead of reading.
- Use special computer glasses.
- Relax the eyes on a minibreak.

For altered sleep patterns and next-day fatigue

- Stop using devices at least one hour before bedtime.

For distracted driving

- Use hands-free devices, preferably speakerphones.
- Pull over and park.
- Let someone else drive.

For radiation exposure

- Keep devices away from the body and bedroom.
- Carry phones in briefcases, etc., not on the body.
- Put devices on desks, not laps.
- Hard wire all devices that connect to the internet.
- Hard wire all fixed devices such as printers, projectors and boards.
- Use hard-wired phones instead of cell or cordless phones.
- Text rather than call.
- Keep conversations short or talk in person.
- Put devices in airplane mode, which suspends EMF transmission by the device, thereby disabling Bluetooth, GPS, phone calls, and WiFi.
- Use speaker phone or ear buds instead of holding the phone next your head.
- Take off Bluetooth devices when not using them.

For stress

- Training in device use, assistive technology.
- Easy access to user manuals.
- Easily available technical support.

Cell phones and cancer

The National Toxicology Program (NTP) is conducting the largest set of laboratory rodent studies to date on cellphone RF radiation. The studies cost $25 million and are designed to mimic human exposure. They are based on the cellphone frequencies and modulations currently in use in the United States. The NTP studies are designed to look at effects in all parts of the body.

On May 27, 2016, NTP released a report with partial results of the studies. They found increased occurrence of rare brain tumors called gliomas and increases in nerve tumors called schwannoma of the heart in male rats. The released results are partial because more rat studies and all of the mouse studies will be forthcoming by 2017. The cells that became cancerous in the rats were the same types of cells as those that have been reported to develop into tumors in human cellphone users.

The EMF produced by cellphones was classified as possibly carcinogenic to humans by the World Health Organization in 2011. They found that long-term use of a cell phone might lead to two different types of tumors, gliomas and acoustic neuroma, a tumor of the auditory nerve.

For more information

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Adrienne Markowitz holds a Master of Science in Industrial Hygiene from Hunter College, City University of New York. Eileen Senn holds a Master of Science in Occupational Health from Temple University in Philadelphia. They are consultants with the New Jersey Work Environment Council, which is a frequent partner with NJEA on school health and safety concerns.

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Resolution 1815 (2011)[1]
Final version

The potential dangers of electromagnetic fields and their effect on the environment

Parliamentary Assembly

1. The Parliamentary Assembly has repeatedly stressed the importance of states' commitment to preserving the environment and environmental health, as set out in many charters, conventions, declarations and protocols since the United Nations Conference on the Human Environment and the Stockholm Declaration (Stockholm, 1972). The Assembly refers to its past work in this field, namely Recommendation 1863 (2009) on environment and health: better prevention of environment-related health hazards, Recommendation 1947 (2010) on noise and light pollution, and more generally, Recommendation 1885 (2009) on drafting an additional protocol to the European Convention on Human Rights concerning the right to a healthy environment and Recommendation 1430 (1999) on access to information, public participation in environmental decision-making and access to justice – implementation of the Århus Convention.

2. The potential health effects of the very low frequency of electromagnetic fields surrounding power lines and electrical devices are the subject of ongoing research and a significant amount of public debate. According to the World Health Organization, electromagnetic fields of all frequencies represent one of the most common and fastest growing environmental influences, about which anxiety and speculation are spreading. All populations are now exposed in varying degrees to electromagnetic fields, the levels of which will continue to increase as technology advances.

3. Mobile telephony has become commonplace around the world. This wireless technology relies upon an extensive network of fixed antennae, or base stations, relaying information with radio-frequency signals. Over 1.4 million base stations exist worldwide and the number is increasing significantly with the introduction of third generation technology. Other wireless networks that allow high-speed Internet access and services, such as wireless local area networks, are also increasingly common in homes, offices and many public areas (airports, schools, residential and urban areas). As the number of base stations and local wireless networks increases, so does the radio-frequency exposure of the population.

4. While electrical and electromagnetic fields in certain frequency bands have wholly beneficial effects which are applied in medicine, other non-ionising frequencies, whether from extremely low frequencies, power lines or certain high frequency waves used in the fields of radar, telecommunications and mobile telephony, appear to have more or less potentially harmful, non-thermal, biological effects on plants, insects and animals as well as the human body, even when exposed to levels that are below the official threshold values.

5. As regards standards or threshold values for emissions of electromagnetic fields of all types and frequencies, the Assembly strongly recommends that the ALARA (as low as reasonably achievable) principle is applied, covering both the so-called thermal effects and the athermic or biological effects of electromagnetic emissions or radiation. Moreover, the precautionary principle should be applied when scientific evaluation does not allow the risk to be determined with sufficient certainty. Given the context of growing exposure of the population, in particular that of vulnerable groups such as young people and children, there could be extremely high human and economic costs if early warnings are neglected.

1. Text adopted by the Standing Committee, acting on behalf of the Assembly, on 27 May 2011 (see Doc. 12608, report of the Committee on the Environment, Agriculture and Local and Regional Affairs, rapporteur: Mr Huss).

6. The Assembly regrets that, despite calls for the respect of the precautionary principle and despite all the recommendations, declarations and a number of statutory and legislative advances, there is still a lack of reaction to known or emerging environmental and health risks and virtually systematic delays in adopting and implementing effective preventive measures. Waiting for high levels of scientific and clinical proof before taking action to prevent well-known risks can lead to very high health and economic costs, as was the case with asbestos, leaded petrol and tobacco.

7. Moreover, the Assembly notes that the problem of electromagnetic fields or waves and their potential consequences for the environment and health has clear parallels with other current issues, such as the licensing of medication, chemicals, pesticides, heavy metals or genetically modified organisms. It therefore highlights that the issue of independence and credibility of scientific expertise is crucial to accomplish a transparent and balanced assessment of potential negative impacts on the environment and human health.

8. In light of the above considerations, the Assembly recommends that the member states of the Council of Europe:

8.1. in general terms:

8.1.1. take all reasonable measures to reduce exposure to electromagnetic fields, especially to radio frequencies from mobile phones, and particularly the exposure to children and young people who seem to be most at risk from head tumours;

8.1.2. reconsider the scientific basis for the present standards on exposure to electromagnetic fields set by the International Commission on Non-Ionising Radiation Protection, which have serious limitations, and apply ALARA principles, covering both thermal effects and the athermic or biological effects of electromagnetic emissions or radiation;

8.1.3. put in place information and awareness-raising campaigns on the risks of potentially harmful long-term biological effects on the environment and on human health, especially targeting children, teenagers and young people of reproductive age;

8.1.4. pay particular attention to "electrosensitive" people who suffer from a syndrome of intolerance to electromagnetic fields and introduce special measures to protect them, including the creation of wave-free areas not covered by the wireless network;

8.1.5. in order to reduce costs, save energy, and protect the environment and human health, step up research on new types of antenna, mobile phone and DECT-type device, and encourage research to develop telecommunication based on other technologies which are just as efficient but whose effects are less negative on the environment and health;

8.2. concerning the private use of mobile phones, DECT wireless phones, WiFi, WLAN and WIMAX for computers and other wireless devices such as baby monitors:

8.2.1. set preventive thresholds for levels of long-term exposure to microwaves in all indoor areas, in accordance with the precautionary principle, not exceeding 0.6 volts per metre, and in the medium term to reduce it to 0.2 volts per metre;

8.2.2. undertake appropriate risk-assessment procedures for all new types of device prior to licensing;

8.2.3. introduce clear labelling indicating the presence of microwaves or electromagnetic fields, the transmitting power or the specific absorption rate (SAR) of the device and any health risks connected with its use;

8.2.4. raise awareness on potential health risks of DECT wireless telephones, baby monitors and other domestic appliances which emit continuous pulse waves, if all electrical equipment is left permanently on standby, and recommend the use of wired, fixed telephones at home or, failing that, models which do not permanently emit pulse waves;

8.3. concerning the protection of children:

8.3.1. develop within different ministries (education, environment and health) targeted information campaigns aimed at teachers, parents and children to alert them to the specific risks of early, ill-considered and prolonged use of mobiles and other devices emitting microwaves;

8.3.2. for children in general, and particularly in schools and classrooms, give preference to wired Internet connections, and strictly regulate the use of mobile phones by schoolchildren on school premises;

8.4. concerning the planning of electric power lines and relay antenna base stations:

8.4.1. introduce town planning measures to keep high-voltage power lines and other electric installations at a safe distance from dwellings;

8.4.2. apply strict safety standards for the health impact of electrical systems in new dwellings;

8.4.3. reduce threshold values for relay antennae in accordance with the ALARA principle and install systems for comprehensive and continuous monitoring of all antennae;

8.4.4. determine the sites of any new GSM, UMTS, WiFi or WIMAX antennae not solely according to the operators' interests but in consultation with local and regional government authorities, local residents and associations of concerned citizens;

8.5. concerning risk assessment and precautions:

8.5.1. make risk assessment more prevention oriented;

8.5.2. improve risk-assessment standards and quality by creating a standard risk scale, making the indication of the risk level mandatory, commissioning several risk hypotheses to be studied and considering compatibility with real-life conditions;

8.5.3. pay heed to and protect "early warning" scientists;

8.5.4. formulate a human-rights-oriented definition of the precautionary and ALARA principles;

8.5.5. increase public funding of independent research, in particular through grants from industry and taxation of products that are the subject of public research studies to evaluate health risks;

8.5.6. create independent commissions for the allocation of public funds;

8.5.7. make the transparency of lobby groups mandatory;

8.5.8. promote pluralist and contradictory debates between all stakeholders, including civil society (Århus Convention).

February 26, 2017 Ronald M. Powell, Ph.D.[1]

The Health Argument against Cell Phones and Cell Towers

The biomedical evidence showing that the radiofrequency radiation emitted by cell phones and cell towers is harmful to health continues to grow. This document summarizes the health argument against cellular technology, whatever the benefits of that technology may be. You may wish to inform yourself about these arguments for any of several reasons:

- You use a cell phone.
- You encourage, or do not discourage, the use of cell phones by family members.
- You live in, or are contemplating moving into, a community close to a cell tower.
- Your school, college, fire station, or police station is considering permitting the installation of a cell tower on its property.
- Your community is considering permitting the installation of cellular repeaters, small-cell towers, or even full cell towers within its jurisdiction.

Below, I introduce myself, provide evidence of the harmfulness of cellular radiation, and show that U.S. Government is not protecting us from harm and is unlikely to do so in the near future. That means that we must protect ourselves and our families at the individual and the community levels while working toward protective action by governments at the local, state, and Federal levels.

Who am I?

I am a retired U.S. Government career scientist (Ph.D., Applied Physics, Harvard University, 1975). During my Government career, I worked for the Executive Office of the President of the United States, the National Science Foundation, and the National Institute of Standards and Technology. For those organizations, respectively, I addressed Federal research and development program evaluation, energy policy research, and measurement development in support of the electronics and electrical-equipment industries and the biomedical research community. I currently interact with other scientists and with physicians around the world on the impact of electromagnetic fields on human health.

Evidence of harm

I present below key evidence, and associated references, that the exposure of humans to radiofrequency radiation, and specifically cellular radiation, is harmful to health.

In 2016, the National Toxicology Program, at the National Institutes of Health, linked cellular radiation to brain and heart tumors.

The National Toxicology Program (NTP), at the National Institutes of Health (NIH), just published the "Partial Findings" of a $25 million multi-year study of the impact of cellular radiation on health. The U.S. Food and Drug Administration "nominated" this NTP study. The NTP indicated that this is the largest and most complex study ever conducted by the NTP.

[1] Ronald M. Powell, Ph.D., USA, email ronpowell@verizon.net, web site https://www.scribd.com/document/291507610/.

The NTP study exposed each of six separate groups of male rats to one of the six possible combinations of three different levels of cellular radiation and two different modulation formats. The modulation format is the method used to impress information on the cellular signal. A separate seventh group of male rats was used as a "control", that is, for comparison, and was protected from exposure to any cellular radiation.

The NTP study found a "likely" causal relationship between exposure to cellular radiation and the occurrence of malignant brain cancer (glioma) and malignant nerve tumors (schwannomas) of the heart in the male rats:

> The rates of occurrence of brain glioma in the male rats ranged from 0 to 3.3 percent for the six groups exposed to radiation. The mean rate of occurrence was 2.0 percent across all six groups.[2]
>
> The rates of occurrence of heart schwannoma in the male rats ranged from 1.1 to 6.6 percent for the six groups exposed to radiation. The mean rate of occurrence was 3.5 percent across all six groups.[3]
>
> The seventh group of male rats, which was used as a control and which was protected from exposure to any cellular radiation, experienced no instances of brain glioma or heart schwannoma.

The NTP considered its findings so important to public health that it issued the "Partial Findings" (May 2016) prior to completing the full study. The NTP then presented those findings at an international conference (BioEM2016, June 2016) attended by 300 scientists from 41 countries. The NTP characterized the motivation for the early release of the "Partial Findings" this way:

> "Given the widespread global usage of mobile communications among users of all ages, even a very small increase in the incidence of disease resulting from exposure to RFR [radiofrequency radiation] could have broad implications for public health. There is a high level of public and media interest regarding the safety of cell phone RFR and the specific results of these NTP studies."

The NTP promised further findings from its study for publication through 2017. Included in those further findings will be test results on mice. You can learn more about this study from the following references:

> **Reference:** NTP's brief description of its study. National Toxicology Program: Cell Phones. (http://ntp.niehs.nih.gov/results/areas/cellphones/index.html)
>
> **Reference:** NTP's published "Partial Findings" of the study. Michael Wyde, Mark Cesta, Chad Blystone, Susan Elmore, Paul Foster, Michelle Hooth, Grace Kissling, David Malarkey, Robert Sills, Matthew Stout, Nigel Walker, Kristine Witt, Mary Wolfe, and John Bucher, Report of Partial Findings from the National Toxicology Program Carcinogenesis Studies of Cell Phone Radiofrequency Radiation in Hsd: Sprague Dawley® SD rats (Whole Body Exposure), posted June 23, 2016. (http://biorxiv.org/content/biorxiv/early/2016/06/23/055699.full.pdf)
>
> **Reference:** Informative discussion of the NTP study. Environmental Health Trust, Frequently Asked Questions about the U.S. National Toxicology Program Radiofrequency Rodent Carcinogenicity Research Study. (http://ehtrust.org/science/facts-national-toxicology-program-cellphone-rat-cancer-study)

[2] In the "Partial Findings" reference cited above, the mean (average) rate of occurrence for malignant glioma in male rats was determined from Table 1 on page 13 as follows: (3 + 3 + 2 + 0 + 0 + 3)/(90 + 90 + 90 + 90 + 90 + 90) = 2.0 percent.

[3] In the "Partial Findings" reference cited above, the mean (average) rate of occurrence for malignant heart schwannoma in male rats was determined from Table 3 on page 15 as follows: (2 + 1 + 5 + 2 + 3 + 6)/(90 + 90 + 90 + 90 + 90 + 90) = 3.5 percent.

Reference: Announcement of the BioEM2016 presentation. Results of NIEHS' National Toxicology Program GSM/CDMA phone radiation study to be presented at BioEM2016 Meeting in Ghent, 05 June 2016 — 10 June 2016 Ghent University, Belgium. (http://www.alphagalileo.org/ViewItem.aspx?ItemId=164837&CultureCode=en)

Reference: Viewgraphs presented by Michael Wyde, Ph.D., NTP study scientist, at BioEM2016 Meeting, Ghent, Belgium, June 8, 2016. NTP Toxicology and Carcinogenicity Studies of Cell Phone Radiofrequency Radiation. (http://ntp.niehs.nih.gov/ntp/research/areas/cellphone/slides_bioem_wyde.pdf)

The NTP study reinforces the classification of radiofrequency radiation, including cellular radiation, as a possible human carcinogen, made by the International Agency for Research on Cancer of the World Health Organization in 2011.

In its "Partial Findings" the NTP noted that its study reinforces a decision made by the International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) in 2011. That decision classified radiofrequency radiation, including specifically cellular radiation, as a Group 2B carcinogen (possible carcinogen for humans). This classification was based on the increased risk of malignant brain cancer (glioma) and acoustic neuroma (a benign tumor of the auditory nerve), which is a form of schwannoma (vestibular schwannoma).[4]

Reference: Announcement of the IARC classification. International Agency for Research on Cancer**,** IARC Classifies Radiofrequency Electromagnetic Fields as Possibly Carcinogenic To Humans, Press Release No. 208, 31 May 2011. (http://www.iarc.fr/en/media-centre/pr/2011/pdfs/pr208_E.pdf)

Reference: Full report on the IARC classification. IARC Monographs: Non-Ionizing Radiation, Part 2: Radiofrequency Electromagnetic Fields, Volume 102, 2013. (http://monographs.iarc.fr/ENG/Monographs/vol102/mono102.pdf)

The findings of the NTP study, in combination with the findings of other studies conducted since 2011, have greatly increased the likelihood that the IARC will raise its classification of radiofrequency radiation to Group 2A (probable carcinogen for humans) or even to Group 1 (known carcinogen for humans) in the near future.

In 2015, hundreds of international scientists appealed to the United Nations and the World Health Organization to warn the public about the health risks caused by electromagnetic fields (EMF), including radiofrequency radiation and, specifically, cellular radiation.

As of January 29, 2017, 224 scientists from 41 nations have signed an international appeal first submitted to the United Nations and to the World Health Organization in May 2015. These scientists seek improved protection of the public from harm caused by the radiation produced by many wireless sources, including "cellular and cordless phones and their base stations, Wi-Fi, broadcast antennas, smart meters, and baby monitors" among others. Together, these scientists "have published more than 2000 research papers and studies on EMF." They state the following:

[4] The Mayo Clinic describes acoustic neuroma here: http://www.mayoclinic.org/diseases-conditions/acoustic-neuroma/basics/definition/CON-20023851.

"Numerous recent scientific publications have shown that EMF affects living organisms at levels well below most international and national guidelines. Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being in humans. Damage goes well beyond the human race, as there is growing evidence of harmful effects to both plant and animal life."

Reference: Welcome to EMFscientist.org.
(https://www.emfscientist.org)

Reference: International EMF Scientist Appeal: Scientists call for Protection from Non-ionizing Electromagnetic Field Exposure, May 15, 2015 (updated October 10, 2016).
(https://www.emfscientist.org/index.php/emf-scientist-appeal)

Reference: International Scientists Petition U.N. to Protect Humans and Wildlife from Electromagnetic Fields and Wireless Technology.
(https://www.emfscientist.org/images/docs/International_EMF_Scientist_Appeal_Description.pdf)

In 2012, the BioInitiative Working Group published the most comprehensive of the recent analyses of the international biomedical research, showing a multitude of biological effects from exposure to radiofrequency radiation, including cellular radiation, at levels below the current exposure guidelines set by the Federal Communications Commission (FCC).

The health risks posed by the expanding use of radiofrequency radiation in wireless devices are not limited to cancer, as devastating as that consequence is. The broad range of health effects was extensively reviewed in the BioInitiative Report 2012. This 1479-page review considered about 1800 peer-reviewed biomedical research publications, most issued in the previous five years. The BioInitiative Report 2012 was prepared by an international body of 29 experts, heavy in Ph.D.s and M.D.s, from 10 countries, including the USA which contributed the greatest number of experts (10). The report concluded the following:

"The continued rollout of wireless technologies and devices puts global public health at risk from unrestricted wireless commerce unless new, and far lower exposure limits and strong precautionary warnings for their use are implemented."

Reference: BioInitiative Working Group, Cindy Sage, M.A. and David O. Carpenter, M.D., Editors, BioInitiative Report: A Rationale for Biologically-based Public Exposure Standards for Electromagnetic Radiation, December 31, 2012.
(http://www.bioinitiative.org)

The BioInitiative Report 2012 documented, in its "RF Color Charts", examples of eight categories of biological effects that occurred at levels below the current exposure guidelines set by the FCC:

- stress proteins, heat shock proteins, and disrupted immune function
- reproduction and fertility effects
- oxidative damage, reactive ion species (ROS), DNA damage, and DNA repair failure
- disrupted calcium metabolism
- brain tumors and blood-brain barrier
- cancer (other than brain) and cell proliferation

- sleep, neuron firing rate, electroencephalogram (EEG), memory, learning, and behavior
- cardiac, heart muscle, blood-pressure, and vascular effects.

These biological effects were attributed to "Radiofrequency Radiation at Low Intensity Exposure" from "cell towers, Wi-Fi, wireless laptops, and smart meters".

> **Reference:** See the "RF Color Charts", accessed from the left column of the web page below. (http://www.bioinitiative.org)

The U.S. Government is not protecting us.

The radiation exposure guidelines of the FCC do not protect us because they are outdated and based on a false assumption.

The current radiation exposure guidelines of the FCC were adopted in 1996, 20 years ago. Those guidelines are based primarily on an analysis by the National Council on Radiation Protection and Measurements (NCRP) which was published in 1986, 30 years ago. That was many years before the emergence of nearly all of the digital wireless devices in use today.

> "The FCC-adopted limits for Maximum Permissible Exposure (MPE) are generally based on recommended exposure guidelines published by the National Council on Radiation Protection and Measurements (NCRP) in 'Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields,' NCRP Report No. 86, Sections 17.4.1, 17.4.1.1, 17.4.2 and 17.4.3. Copyright NCRP, 1986, Bethesda, Maryland 20814...."
>
> **Reference:** Federal Communications Commission, Office of Engineering & Technology, Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields, OET Bulletin 65, Edition 97-01 (August 1997). See the last paragraph on page 64. (http://transition.fcc.gov/Bureaus/Engineering_Technology/Documents/bulletins/oet65/oet65.pdf)

Those exposure guidelines have not been substantially changed since that analysis in 1986. They are based on the *thermal assumption* that the only harm that radiofrequency radiation can cause is due to tissue heating. This thermal assumption has been thoroughly disproved since, as biological effects have been found to occur at levels of radiation below, and even far below, those that cause significant tissue heating. Such lower levels are commonly referred to as *nonthermal* levels. The result is that many authorities now consider the FCC's current exposure guidelines as entirely outdated and much too high (that is, much too permissive) to protect the public.

The evidence disproving the thermal assumption is based on the broadened understanding of the biological effects of radiofrequency radiation made possible by thousands of peer-reviewed papers published by international biomedical scientists since 1986. The BioInitiative Report 2012 is the most recent comprehensive review of that research and provides many examples of bioeffects occurring at nonthermal radiation levels, as described above. Further, the new study by the National Toxicology Program, also described above, added to the evidence disproving the thermal assumption. That study exposed rats to levels of radiation below those that cause significant heating, and both above and below the FCC's current exposure guidelines as well. Yet, even below the FCC's current exposure guidelines, the male rats still developed malignant brain cancer (glioma) and malignant tumors (schwannomas) of the nerves of the heart.

The shortcomings of the FCC's exposure guidelines are described in detail in the following reference:

> **Reference:** Outdated FCC "Safety" Standards: The Five Fallacies of the Electromagnetic Radiation Exposure Limits.
> (http://ehtrust.org/policy/fcc-safety-standards/)

The FCC is not a credible source for exposure guidelines because it lacks health expertise and because it is too heavily influenced by the wireless industries that it is supposed to regulate.

The FCC lacks the health expertise required for developing health-related radiation exposure guidelines. Further, the FCC seems more interested in assuring compatibility among electronic systems than in assuring the compatibility of electronic systems with human, animal, and plant life. Since the exposure guidelines relate to health, it would make more sense for them to be developed by an agency with health expertise, such as the Environmental Protection Agency (EPA).

In addition, the FCC lacks the impartiality required to be a source of credible guidelines. The FCC is too heavily influenced by the wireless industries that the FCC is supposed to regulate. The FCC has acted in partnership with the wireless industries by permitting wireless radiation levels far higher than the biomedical research literature indicates are necessary to protect human health. The success of the wireless industries in capturing the FCC, the committees in the U.S. Congress that oversee the FCC, and the Executive Branch is detailed in a recent monograph from the Center for Ethics at Harvard University.

> **Reference:** Norm Alster, Captured Agency: How the Federal Communications Commission is Dominated by the Industries It Presumably Regulates (2015).
> http://ethics.harvard.edu/news/new-e-books-edmond-j-safra-research-lab

As an example of that capture, President Obama, in 2013, appointed Thomas Wheeler, as the Chairman of the FCC. At that time, Mr. Wheeler was the head of the CTIA – The Wireless Association, which is the major lobbying organization for the wireless industries. This is the infamous "revolving door".

The FCC's decision to fast-track Fifth Generation (5G) cellular technology without prior study of its health impact demonstrates the FCC's disinterest in the public health.

On July 14, 2016, the FCC adopted new rules that would promote fast-tracking the expansion of cellular service to new and higher frequencies as part of the Fifth Generation (5G) of cellular technology. This decision will open selected frequency bands above 24 gigahertz (GHz) and up to 71 GHz. At the same time, the FCC has requested comment on opening even higher frequencies, possibly above 95 GHz.

> **Reference:** FCC Takes Steps to Facilitate Mobile Broadband and Next Generation Wireless Technologies in Spectrum above 24 GHz: New rules will enable rapid development and deployment of next generation 5G technologies and services.
> (http://transition.fcc.gov/Daily_Releases/Daily_Business/2016/db0714/DOC-340301A1.pdf)

> **Reference:** Fact Sheet: Spectrum Frontiers Rules Identify, Open Up Vast Amounts of New High-Band Spectrum for Next Generation (5G) Wireless Broadband.
> (http://transition.fcc.gov/Daily_Releases/Daily_Business/2016/db0714/DOC-340310A1.pdf)

All five commissioners of the FCC, including Chairman Thomas Wheeler, approved this expedited move to 5G. No commissioner called for evaluating the health impact before proceeding with 5G, despite the recent findings of the National Toxicology Program at NIH that cellular radiation likely causes tumors. Nor did even one commissioner express any interest in, or concern about, the impact of this new technology on public health. Rather, the FCC's emphasis was on the billions of dollars to be made by proceeding to implement 5G as rapidly as possible, with a minimum of regulatory interference, to assure an international competitive position.

In contrast to the FCC's disinterest in the impact of 5G on the public health, extensive written comments from individual members of the public and from many interested organizations raised a host of health concerns that were totally ignored in the FCC's presentations.

> **Reference:** July 2016 Open Commission Meeting addressing "Spectrum Frontiers" and "Advancing Technology Transitions".
> (https://www.fcc.gov/news-events/events/2016/07/july-2016-open-commission-meeting)

> **Reference:** The FCC Approves 5G Millimeter Wave Spectrum Frontiers. Includes excerpts from selected comments provided to the FCC by individuals and organizations that expressed concern about the health impact of the FCC's plan for 5G.
> (http://ehtrust.org/policy/fcc-approves-5g-millimeter-wave-spectrum-frontiers/)

> **Reference:** Comments on FCC Docket 14-177, Spectrum Bands above 24 GHz. All of the comments submitted to the FCC about the key docket leading to the implementation of 5G.
> (https://www.fcc.gov/ecfs/search/filings?proceedings_name=14-177&sort=date_disseminated,DESC)

U.S. Government agencies, and U.S. medical organizations, have disputed the validity of the FCC's exposure guidelines.

U.S. Government agencies, as well as U.S. medical organizations, have disputed the validity of the FCC's thermal exposure guidelines, maintaining that they are outdated and need to be updated to provide adequate protection of human beings, including children and seniors as well as other vulnerable groups.

U.S. Environmental Protection Agency

The Environmental Protection Agency (EPA) would be a better agency than the FCC to entrust with setting radiofrequency radiation exposure guidelines because the EPA has both health expertise and environmental responsibilities. The EPA is often cited by the FCC, and by the wireless industries, as one of the agencies that the FCC has *consulted* about the FCC's exposure guidelines, as if to increase the credibility of those guidelines. However, the fact that the EPA has *explicitly disputed* the validity of those guidelines is consistently omitted from those FCC citations.

Specifically, in 2002, the EPA addressed the limitations of the thermal exposure guidelines of the FCC, and the similar guidelines of private organizations, including the Institute of Electrical and Electronics Engineers and the International Commission on Non-Ionizing Radiation Protection:

> "The FCC's current exposure guidelines, as well as those of the Institute of Electrical and Electronics Engineers (IEEE) and the International Commission on Non-ionizing Radiation Protection, are thermally based, and do not apply to chronic, nonthermal exposure situations…. The FCC's exposure guideline is

considered protective of effects arising from a thermal mechanism but not from all possible mechanisms. Therefore, the generalization by many that the guidelines protect human beings from harm by any or all mechanisms is not justified."

"Federal health and safety agencies have not yet developed policies concerning possible risk from long-term, nonthermal exposures. When developing exposure standards for other physical agents such as toxic substances, health risk uncertainties, with emphasis given to sensitive populations, are often considered. Incorporating information on exposure scenarios involving repeated short duration/nonthermal exposures that may continue over very long periods of time (years), with an exposed population that includes children, the elderly, and people with various debilitating physical and medical conditions, could be beneficial in delineating appropriate protective exposure guidelines."

Reference: Letters from Frank Marcinowski, Director, Radiation Protection Division, EPA, and Norbert Hankin, Center for Science and Risk Assessment, Radiation Protection Division, EPA, to Janet Newton, President, the EMR Network, with copies to the FCC and the IEEE, dated July 16, 2002. (http://www.emrpolicy.org/litigation/case_law/docs/noi_epa_response.pdf)

In summary, the EPA makes the following points: (1) the FCC 's thermal exposure guidelines do *not* protect against all harm, only the harm caused by too much heating; (2) the FCC's thermal exposure guidelines do *not* apply to "chronic, nonthermal exposure", which is the type of exposure generated by cell towers and many other wireless devices; and (3) when new FCC guidelines are developed for chronic nonthermal exposures, they must accommodate "children, the elderly, and people with various debilitating physical and medical conditions" because those groups are not accommodated now.

U.S. Food and Drug Administration

The Food and Drug Administration (FDA) is also often cited by the FCC, and by the wireless industries, as one of the agencies that the FCC has consulted about exposure guidelines. But the FDA is the agency that "nominated" the NTP study of the possible health effects of cellular radiation, in part because of the FDA's uncertainty about the validity of the FCC's exposure guidelines:

"Currently cellular phones and other wireless communication devices are required to meet the radio frequency radiation (RFR) exposure guidelines of the Federal Communications Commission (FCC), which were most recently revised in August 1996. The existing exposure guidelines are based on protection from acute injury from thermal effects of RFR exposure, and may not be protective against any non-thermal effects of chronic exposures."

Reference: Nominations from FDA's Center from [for] Device[s] and Radiological Health, Radio Frequency Radiation Emissions of Wireless Communication Devices (CDRH), Executive Summary, as attached to transmittal letter from William T. Allaben, Ph.D., FDA Liaison, to Dr. Errol Zeiger, Coordinator, Chemical Nomination and Selection, National Toxicology Program, May 19, 1999,[5] (http://ntp.niehs.nih.gov/ntp/htdocs/chem_background/exsumpdf/wireless051999_508.pdf)

The FDA's wisdom in nominating the NTP study was well justified by the NTP's publication of the "Partial Findings" described above. Those findings demonstrated both that the FCC's exposure guidelines are not protective and that the thermal assumption on which those guidelines are based is invalid.

[5] This date and the referenced URL were changed when this superior reference was posted, at my request, by the NTP/NIEHS/NIH.

U.S. Department of the Interior

In 2014 the Department of the Interior (Fish and Wildlife Service) also addressed the limitations of the FCC's thermal exposure guidelines. The Department of the Interior was motivated by the multiple adverse effects of electromagnetic radiation on the health, and the life, of birds, particularly in connection with cell towers. The Department of the Interior stated the following:

> "However, the electromagnetic radiation standards used by the Federal Communications Commission (FCC) continue to be based on thermal heating, a criterion now nearly 30 years out of date and inapplicable today."
>
> **Reference:** Letter from Willie R. Taylor, Director, Office of Environmental Policy and Compliance, Office of the Secretary, United States Department of the Interior, to Mr. Eli Veenendaal, National Telecommunications and Information Administration, U.S. Department of Commerce, dated February 7, 2014.
> (https://www.ntia.doc.gov/files/ntia/us_doi_comments.pdf)

American Academy of Environmental Medicine

The American Academy of Environmental Medicine (AAEM), which trains physicians in preparation for Board Certification in Environmental Medicine, states the following:

> "The AAEM strongly supports the use of wired Internet connections, and encourages avoidance of radiofrequency such as from WiFi, cellular and mobile phones and towers, and 'smart meters'."
>
> "The peer reviewed, scientific literature demonstrates the correlation between RF [radiofrequency] exposure and neurological, cardiac, and pulmonary disease as well as reproductive and developmental disorders, immune dysfunction, cancer and other health conditions. The evidence is irrefutable."
>
> "To install WiFi in schools plus public spaces risks a widespread public health hazard that the medical system is not yet prepared to address."
>
> **Reference:** American Academy of Environmental Medicine, Wireless Radiofrequency Radiation in Schools, November 14, 2013.
> (http://www.aaemonline.org/pdf/WiredSchools.pdf)

American Academy of Pediatrics

The American Academy of Pediatrics (AAP), whose 60,000 doctors care for our children, supports the development of more restrictive standards for radiofrequency radiation exposure in order to better protect the public, particularly the children. In a letter to the Federal Communications Commission (FCC) and the Food and Drug Administration (FDA), dated August 29, 2013, the AAP states the following:

> "Children are not little adults and are disproportionately impacted by all environmental exposures, including cell phone radiation. Current FCC standards do not account for the unique vulnerability and use patterns specific to pregnant women and children. It is essential that any new standard for cell phones or other wireless devices be based on protecting the youngest and most vulnerable populations to ensure they are safeguarded throughout their lifetimes."

Reference: American Academy of Pediatrics, letter dated August 29, 2013 addressed to The Honorable Mignon L. Clyburn, Acting Commissioner, Federal Communications Commission, and The Honorable Dr. Margaret A. Hamburg, Commissioner, U.S. Food and Drug Administration. (http://apps.fcc.gov/ecfs/document/view?id=7520941318)

After reviewing the "Partial Findings" from the new study by the National Toxicology Program at the National Institutes of Health, described above, the American Academy of Pediatrics cautioned parents about the use of cell phones by their children:

"In light of the findings, the Academy continues to reinforce its recommendation that parents should limit use of cell phones by children and teens."

Reference: American Academy of Pediatrics, AAP responds to study showing link between cell phone radiation, tumors in rats, May 27, 2016. (http://www.aappublications.org/news/2016/05/27/Cancer052716)

The Telecommunications Act of 1996, in combination with the FCC's exposure guidelines, empowers the wireless industries to mandate the exposure of the public to levels of radiofrequency radiation already found harmful to health.

The Telecommunications Act of 1996 bars state and local governments from objecting to the placement of cell towers on environmental/health grounds unless the FCC's exposure guidelines would be exceeded. Specifically, the Act states the following:

"No State or local government or instrumentality thereof may regulate the placement, construction, and modification of personal wireless service facilities on the basis of the environmental effects of radio frequency emissions to the extent that such facilities comply with the Commission's [FCC's] regulations concerning such emissions."

Reference: Telecommunications Act of 1996, Section 704 Facilities Siting; Radio Frequency Emission Standards, page 117. (http://transition.fcc.gov/Reports/tcom1996.pdf)

This Act, in combination with the FCC's permissive exposure guidelines, strips state and local governments of the right to protect their own residents from levels of radiofrequency radiation already shown to be harmful to health. In effect, this Act transfers to the wireless industries the right to ***mandate*** the exposure of the public, including those most vulnerable to harm, to radiofrequency radiation without the need for further governmental action. State and local governments can still resist, but to do so they must confront this Act which is designed to frustrate their success. Even so, some governments do heroically resist and some do succeed.

Protecting ourselves and our families

We can act on our own to protect ourselves and our families, but only partially.

Instead of increasing our exposure to cellular radiation, and to the radiation from other digital wireless devices, we can decrease our exposure and improve our chances for good health. Desirable steps in this direction include the following:

- Reduce or stop the use of cell phones. Reserve them for emergencies or other essential uses.
- Replace cordless telephones with corded telephones.
- Establish wired (Ethernet) interconnections between routers and the wireless devices that the routers support. Then turn off the wireless capabilities, such as Wi-Fi and Bluetooth, of them all.
- "Opt out" of the wireless smart meter on your residence, if your state or local electric power company permits. Many states, but not all, have an opt-out provision.
- Alert family members about the health risks posed by wireless devices, particularly for vulnerable groups such as pregnant mothers, unborn children, young and teenage children, adult males of reproductive age, seniors, the disabled, and anyone with a chronic health condition. Everyone is vulnerable, but these groups are more so.

  Reference: For more information on reducing radiation at home, please see Ronald M. Powell, Ph.D., How to Reduce the Electromagnetic Radiation in Your Home, which is document (10) on the following list.
  (https://www.scribd.com/document/291507610/)

We can obtain better protection if we work together.

We can contribute our efforts to the hundreds of new organizations that are emerging nationwide to raise awareness about the health risks posed by the radiation exposure from wireless devices in homes, in the workplace, in schools, and in public places, especially where children are present. Through the Internet, look for organizations that address the intersection of health with cell phones, cordless phones, Wi-Fi, smart meters, and wireless desktop computers, laptops, and tablets. These wireless devices are the principal sources of radiofrequency radiation in the home.

Take care for our children. Today's adults grew up in an environment with much less radiofrequency radiation than exists today. Today's children are not so lucky. To have the same chance at a healthy life, they need a lot of help. Unfortunately, the levels of radiofrequency radiation in our environment are rising exponentially as governments and wireless industries continue to promote, and even mandate, the exposure of the public to ever higher levels of radiofrequency radiation, with no limit in sight. That means that many of our children will become chronically ill, and many will die, while still young adults. This is a tragedy in the making. To stop it will require greatly increased awareness of the problem and serious political action at multiple levels of government. That is no small task, but we all can help. We can join with others to become a part of the solution for ourselves and our families, but especially for our children and our grandchildren.

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Pathophysiology xxx (2009) xxx–xxx

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Preface

There is an old joke with a well-known punch line about a man who has just fallen from the 86th floor of the Empire State Building in New York. As he passes the 30th floor, he is heard saying to himself 'so far, so good'...

Most of us laugh because we know where the man is headed, and that he must know too. But, our laughter usually has a guilty edge. We know that many of us are guilty of occasionally displaying a 'so far, so good' attitude in our own lives. We think of the smoker who says that about the possibility of getting lung cancer or heart disease and who counts on beating the odds because he feels healthy at the moment. That smoker will not find out if he won the bet until many years later, and by then it is often too late. The 'so far, so good' attitude to health is so common that people even kid themselves about it. One smoker told me that smoking would only cut a few years off his life, and that he did not mind losing the last few years because they are usually not much fun anyway.

Unlike the optimist in the joke, whose end is virtually certain, many of us live like the smoker, playing the odds and reassuring ourselves 'so far, so good'. Diseases like cancer usually take many years to develop, and we try not to think how some of the things we do casually can affect the long-term odds by compromising the natural processes that protect us. We rely on our bodies to be strong and resilient all the time. Yet, we know there are limits to the body's natural ability to reverse damage to cells. We also know that there may be gaps in the ability of our genetic endowment to cope with damage. At some level, we all know it is just common sense to try to minimize damage to our bodies and maximize the ability to repair.

These opening paragraphs provide a quick introduction to the theme of this issue of Pathophysiology and a summary of the point of view of its authors. The public is currently interested in possible hazards from radio frequency (RF) due to cellphones, towers, WiFi, etc. The concern is certainly warranted, but we are surrounded by electromagnetic fields (EMFs) of many frequencies, and there are also significant biological effects and known risks from low frequency EMF. The scientific problem is to determine the nature of EMF interaction with biological systems and develop ways of coping with harmful effects in all frequency ranges, as well as their cumulative effects. The practical problem is to minimize the harmful biological effects of all EMF.

The technical papers in this issue are devoted to an examination and an evaluation of evidence gathered by scientists regarding the effects of EMF, especially RF radiation, on living cells and on the health of human populations. The laboratory studies point to significant interactions of both power frequency and RF with cellular components, especially DNA. The epidemiological studies point to increased risk of developing certain cancers associated with long-term exposure to RF. Overall, the scientific evidence shows that the risk to health is significant, and that to deny it is like being in free-fall and thinking 'so far, so good'. We must recognize that there is a potential health problem, and that we must begin to deal with it responsibly as individuals and as a society.

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EMF effects on DNA

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Exhibit A

Abbreviations: EMF, electromagnetic fields; Hz, hertz (cycles/s the unit of frequency); ELF, extremely low frequency (3–3×10^3 Hz) power frequency is 50–60 Hz; RF, radio frequency (band width 3×10^3 to 3×10^{11} Hz); UHF, ultrahigh frequency band the RF sub-division used for cell phones (3×10^8 to 3×10^9 Hz).

0928-4680/$ – see front matter © 2009 Published by Elsevier Ireland Ltd.
doi:10.1016/j.pathophys.2009.02.002

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Special Issue on EMF

Bioelectromagnetics, the study of biological effects of electromagnetic fields (EMF), is an interdisciplinary science with a technical literature that is not easily accessible to the non-specialist. To increase access of the public to the technical literature and to the health implications of the scientific findings, the Bioinitiative Report was organized by an international group of scientists and published online at www.bioinitiative.org on August 31, 2007. The report has been widely read, and was cited in September 2008 by the European Parliament when it voted overwhelmingly that the current EMF safety standards were obsolete and needed to be reviewed.

This special issue of Pathophysiology includes scientific papers on the EMF issue by contributors to the Bioiniative Report, as well as others, and is prepared for scientists who are not specialists in bioelectromagnetics. Each paper is independent and self-contained. To help the reader appreciate how the different subjects contribute to an understanding of the EMF issue, the papers are arranged in groups that emphasize key areas, and the role of science in analyzing the problem and evaluating possible solutions. The subject headings are:

- DNA to show biological effects at the sub-cellular level that occur at very low EMF thresholds and across frequency ranges of the EM spectrum. Interactions with DNA may account for many of the effects of EMF, and they raise the possibility that genetic damage due to EMF can lead to cancer.
- The Brain is exposed to radiation from mobile phone antennas, and laboratory studies show that the radiation causes leakage of the protective blood–brain barrier, as well as the death of neurons in the brain. Radiation emitted from base stations can affect all who are in the vicinity. Epidemiological studies have shown a relation between exposure to mobile phones, base-stations and the development of brain tumors. Some epidemiological studies have significant flaws in design, and the risk of brain cancer may be greater than reported in the published results.
- In addition to the risk of brain cancer, EMF in the environment may contribute to diseases like Alzheimer's dementia and breast cancer in humans, as well as reproductive and developmental effects in animals in the wild. EMF affect the biochemical pathways and immunological mechanisms that link the different organ systems in our bodies and those of animals. The human body can act as an antenna for RF signals, and a small percentage of the population appears to be so sensitive to EMF that it interferes with their daily lives. In addition to the growing presence of EMF signals in the environment, the complexity of the signals may be important in altering biological responses. These are among the many factors that must be considered in approaching EMF safety issues.
- Science as a guide to public policy

Four centuries ago, when Francis Bacon envisioned a course for modern science, he expressed the idea that *knowledge is power that should be applied for the benefit of mankind*. It is in keeping with that ethical standard that the last two papers in this issue show how knowledge gained from scientific research can help solve problems arising from EMF in our environment. The first of these papers discusses the Precautionary Principle, its growing acceptance as a rational approach to environmental issues, and how past experience can help us deal with the EMF issue. The second paper, by the editors of the original BioInitiative Report, is an update on how best to deal with the challenge of EMF in the environment and, specifically, the problems accompanying wireless technologies.

We trust that the reviews and original research papers will increase awareness of the growing impact of EMF in the environment, and the need for modern society to deal expeditiously with the potential health problems brought to light by EMF research.

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22 January 2009

Please cite this article in press as: M. Blank, Preface, Pathophysiology (2009), doi:10.1016/j.pathophys.2009.02.002

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Pathophysiology xxx (2009) xxx–xxx

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Electromagnetic fields stress living cells

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Received 30 January 2009; accepted 30 January 2009

Abstract

Electromagnetic fields (EMF), in both ELF (extremely low frequency) and radio frequency (RF) ranges, activate the cellular stress response, a protective mechanism that induces the expression of stress response genes, e.g., HSP70, and increased levels of stress proteins, e.g., hsp70. The 20 different stress protein families are evolutionarily conserved and act as 'chaperones' in the cell when they 'help' repair and refold damaged proteins and transport them across cell membranes. Induction of the stress response involves activation of DNA, and despite the large difference in energy between ELF and RF, the same cellular pathways respond in both frequency ranges. Specific DNA sequences on the promoter of the HSP70 stress gene are responsive to EMF, and studies with model biochemical systems suggest that EMF could interact directly with electrons in DNA. While low energy EMF interacts with DNA to induce the stress response, increasing EMF energy in the RF range can lead to breaks in DNA strands. It is clear that in order to protect living cells, EMF safety limits must be changed from the current thermal standard, based on energy, to one based on biological responses that occur long before the threshold for thermal changes.

Keywords: DNA; Biosynthesis; Electromagnetic fields; ELF; RF

1. Electromagnetic fields (EMF) alter protein synthesis

Until recently, genetic information stored in DNA was considered essentially invulnerable to change as it was passed on from parent to progeny. Mutations, such as those caused by cosmic radiation at the most energetic end of the EM spectrum, were thought to be relatively infrequent. The model of gene regulation was believed to be that the negatively charged DNA was tightly wrapped up in the nucleus with positively charged histones, and that most genes were 'turned off' most of the time. Of course, different regions of the DNA code are being read more or less all the time to replenish essential proteins that have broken down and those needed during cell division.

New insights into the structure and function of DNA have resulted from numerous, well-done laboratory studies. The demonstration that EMF induces gene expression and the synthesis of specific proteins [1,2] generated considerable controversy from power companies, government agencies, physicists, and most recently, cell phone companies. Physicists have insisted that the reported results were not possible because there was not enough energy in the power frequency range (ELF) to activate DNA. They were thinking solely of mechanical interaction with a large molecule and not of the large hydration energy tied up in protein and DNA structures that could be released by small changes in charge [3]. Of the biologists who accepted such results [4], most thought that the EMF interaction originated at, and was amplified by, the cell membrane and not with DNA.

It is now generally accepted that weak EMF in the power frequency range can activate DNA to synthesize proteins. An EMF reactive sequence in the DNA has been identified [5] and shown to be transferable to other gene promoters [6]. This DNA sequence acts as an EMF sensitive antenna

Abbreviations: EMF, electromagnetic fields; Hz, hertz; ELF, extremely low frequency; RF, radio frequency; MAPK, mitogen activated protein kinase; ERK1\2, extracellular signal regulated kinase; JNK, c-Jun-terminal kinase p38MAPK; SAPK, stress activated protein kinase; NADH, nicotinamide adenine dinucleotide dehydrogenase; ROS, reactive oxygen species.

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0928-4680/$ – see front matter © 2009 Published by Elsevier Ireland Ltd.
doi:10.1016/j.pathophys.2009.01.006

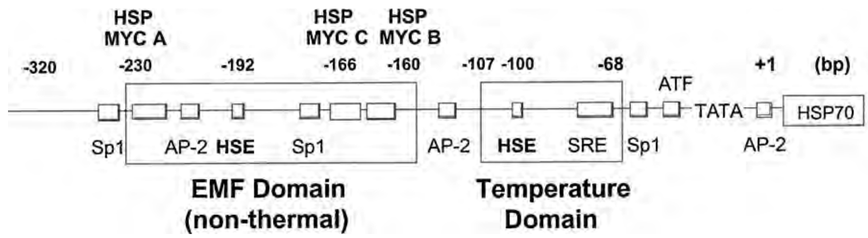

Fig. 1. Diagram of the HSP70 promoter showing the two different DNA sequences that have been identified as activated by EMF (non-thermal) and by thermal stimuli, respectively. The EMF domain contains three nCTCTn consensus sequences (electromagnetic response elements; EMRE), and differs from the consensus sequence (nGAAn) in the temperature or thermal domain.

that responds to EMF when transfected into reporter genes. Research at the more energetic levels of power frequency [7] and in the RF [8] ranges has shown that exposure to EMF can lead to breaks in the DNA strands. Therefore, DNA can no longer be considered unaffected by environmental EMF levels. It can be activated and damaged by EMF at levels that are considered safe [9]. The vulnerability of DNA to environmental influences and the possible dangers associated with EMF, had been underscored by discovery of EMF activation of the cellular stress response in the ELF range [10,11]. The cellular stress response is an unambiguous signal by the cell that EMF is potentially harmful.

2. Physiological stress and cellular stress

Discussions of physiological stress mechanisms usually describe responses of the body to pain, fear, ‘oxygen debt’ from muscle overexertion. These responses are mediated by organ systems. For example, the nervous system transmits action potentials along a network of nerves to cells, such as adrenal glands, that release rapidly acting agents such as epinephrine and norepinephrine and slower acting mineralocorticoids. These hormones are transported throughout the body by the circulatory system. They mobilize the defenses to cope with the adverse conditions and enable the body to ‘fight or flee’ from the noxious stimuli. The defensive actions include changes in heart rate, breathing rate, muscle activity, etc.

In addition to the responses of organ systems, there are protective mechanisms at the cellular level known as the cellular stress response. These mechanisms are activated by damage to cellular components such as DNA and protein [12], and the responses are characterized by increased levels of stress proteins [13] indicating that stress response genes have been upregulated in response to the stress.

The first stress response mechanism identified was the cellular reaction to sharp increases in temperature [14] and was referred to as ‘heat shock’, a term that is still retained in the nomenclature of the protective proteins, the hsps, heat shock proteins. Stress proteins are designated by the prefix ‘hsp’ followed by a number that gives the molecular weight in kilodaltons. There are about 20 different protein families ranging in molecular weight from a few kilodaltons to over 100 kD, with major groups of proteins around 30 kD, 70 kD and 90 kD.

Research on the ‘heat shock’ response has shown that hsp synthesis is activated by a variety of stresses that are potentially harmful to cells, including physical stimuli like pH and osmotic pressure changes, as well as chemicals such as alcohol and toxic metal ions like Cd^{2+}. EMF is a recent addition to the list of physical stimuli. It was initially shown in the power frequency (extremely low frequency, ELF) range [13], but shortly afterwards, radio frequency (RF) fields [15] and amplitude modulated RF fields [16] were shown to activate the same stress response.

Studies of stress protein stimulation by low frequency EMF have focused on a specific DNA sequence in the gene promoter that codes for hsp70, a major stress protein. Synthesis of this stress protein is initiated in a region of the promoter (see Fig. 1) where a transcription factor known as heat shock factor 1 (HSF-1) binds to a heat shock element (HSE). This EMF sensitive region on the HSP70 promoter is upstream from the thermal domain of the promoter and is not sensitive to increased temperature. The binding of HSF-1 to HSE occurs at −192 in the HSP70 promoter relative to the transcription initiation site. The EMF domain contains three nCTCTn myc-binding sites −230, −166 and −160 relative to the transcription initiation site and upstream of the binding sites for the heat shock (nGAAn) and serum responsive elements [5,6,17,18]. The electromagnetic response elements (EMREs) have also been identified on the c-*myc* promoter and are also responsive to EMF. The sensitivity of the DNA sequences, nCTCTn, to EMF exposures has been demonstrated by transfecting these sequences into CAT and Luciferase reporter genes [6]. Thus, the HSP70 promoter contains different DNA regions that are specifically sensitive to different stressors, thermal and non-thermal.

Induction of increased levels of the major stress protein, hsp70, by EMF is rapid, within 5 min. Also it occurs at extremely low levels of energy input, 14 orders of magnitude lower than with a thermal stimulus [10]. The far greater sensitivity to EMF than to temperature change in elevating the protective protein, hsp70, has been demonstrated to have potential clinical application, preventing injury from ischemia reperfusion [19–21]. George et al. [22] have shown the non-invasive use of EMF-induced stress proteins improved hemodynamic parameters during reperfusion

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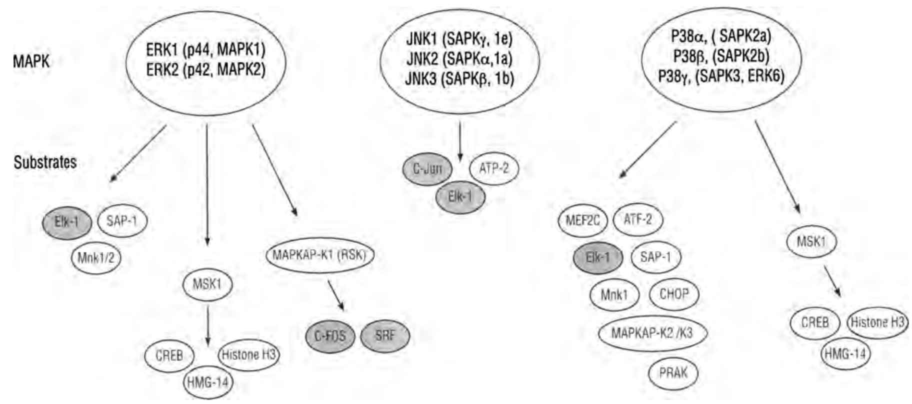

Fig. 2. The four mitogen activated protein kinase (MAPK) signaling cascades identified to date are: extracellular signal regulated kinase 1/2 (ERK), c-Jun-terminal kinase (JNK), p38MAPK and stress activated protein kinase (SAPK). Elements of the three MAPkinase pathways that have been identified as activated by EMF are shown as the shaded circles.

following ischemia. This effect occurred in the absence of measurable increased temperature.

3. EMF interaction with signaling pathways

EMF penetrate cells unattenuated and so can interact directly with the DNA in the cell nucleus, as well as other cell constituents. However, biological agents are impeded by membranes and require special mechanisms to gain access to the cell interior. Friedman et al. [23] have demonstrated that the initial step in transmitting extracellular information from the plasma membrane to the nucleus of the cell occurs when NADH oxidase rapidly generates reactive oxygen species (ROS). These ROS stimulate matrix metalloproteinases that allow them to cleave and release heparin binding epidermal growth factor. This secreted factor activates the epidermal growth receptor, which in turn activates the extracellular signal regulated kinase 1\2 (ERK) cascade. The ERK cascade is one of the four mitogen-activated protein kinase (MAPK) signaling cascades that regulate transcriptional activity in response to extracellular stimuli. The elements of the three

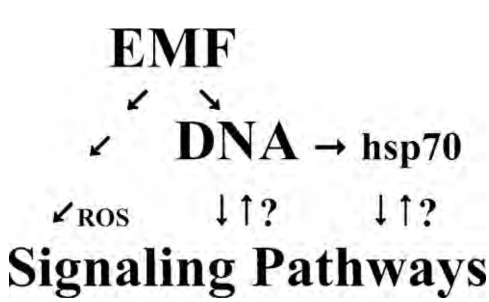

Fig. 3. The signaling pathways and the stress response are activated by EMF. The activation mechanisms discussed in the text are indicated by arrows. In the stress response, DNA activation leads to hsp synthesis and may be due to direct EMF interaction with DNA. The signaling pathways are activated by reactive oxygen species (ROS) that are probably generated by EMF. Possible interactions between the pathways, DNA and hsp are indicated with question marks. In any case, EMF leads to activation of all the processes shown.

MAPK signaling cascades implicated in exposures to ELF and RF are highlighted in Fig. 2.

The four MAPK cascades are: (1) ERK, (2) c-Jun-terminal kinase (JNK), (3) stress activated protein kinase (SAPK) and (4) p38SAPK. Each of the cascades is composed of three to six tiers of protein kinases, and their signals are transmitted by sequential phosphorylation and activation of the protein kinases in each of the tiers. The result is activation of a large number of regulatory proteins, which include a set of transcription factors, e.g., c-Jun, c-Fos, hsp27 and hsp70. Activation of the stress response is accompanied by activation of specific signal transduction cascades involved in regulating cell proliferation, differentiation and metabolism [24–26]. The MAPK pathways have been characterized in several cell types [24,27–30]. Exposure to non-thermal ELF as well as thermal RF affects the expression of many cellular proteins [23–25] (Fig. 3).

The elevated expression of these protein transcription factors participate in the induction of various cellular processes, including several that are affected by cell phones, e.g., replication and cell-cycle progression [25,31] and apoptosis [32]. RF fields have been shown to activate specific transcription factor binding that stimulate cell proliferation and induce stress proteins [25,33]. It has been reported [31] that within 10 min of cell phone exposures, two MAPKinase cascades, p38 and ERK1\2, are activated. Both ELF and RF activate the upregulation of the HSP70 gene and induction of elevated levels of the hsp70 protein. This effect on RNA transcription and protein stability is controlled by specific protein transcription factors that are elements of the mitogen MAPK cascade.

EMF also stimulate serum response factor which binds to the serum response element (SRE) through ERK MAPK activation and is associated with injury and repair *in vivo* and *in vitro*. The SRE site is on the promoter of an early response gene, c-fos, which under specific cellular circumstances has oncogenic properties. The c-fos promoter is EMF-sensitive; a 20 min exposure to 60 Hz 80mG fields significantly increases c-*fos* gene expression [34]. The SRE accessory protein,

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Elk-1, contains a growth-regulated transcriptional activation domain. ERK phosphorylation potentiates Elk-1 and transactivation at the c-*fos* SRE [29].

During the past twenty years, the growing use of cellular phones has aroused great concern regarding the health effects of exposure of the brain to 900 MHz RF waves. Despite claims that the energy level is too low to induce changes in DNA and that the devices are safe, the non-thermal effects that have been demonstrated at both ELF and RF exposure levels can cause physiological changes in cells and tissues even at the level of DNA. Finally, it should be mentioned that some of the pathways described in this section also have roles in protein synthesis via RNA polymerase III, an enzyme in oncogenic pathways [35] and could, therefore, provide a mechanistic link between cancer and EMF exposure.

4. Cells affected by the stress response

Reviews on EMF and the stress response have appeared for the ELF range [13] and for the RF range [36]. The most recent review was published online in section 7 of the Bioinitiative Report [9], and it summarized both ELF and RF studies, mainly at frequencies 50 Hz, 60 Hz, 900 MHz and 1.8 GHz. The citations in that review were not exhaustive, but the different frequencies and biological systems represent the diversity of results on stimulation of DNA and stress protein synthesis in many different cells. It is clear that the stress response does not occur in reaction to EMF in all types of cells, and sometimes because of the use of tissue cultured cell lines, even the same cell line can give opposite results in the same laboratory [37].

Many different types of cells have been shown to respond to EMF, both *in vivo* and *in vitro*, including epithelial, endothelial and epidermal cells, cardiac muscle cells, fibroblasts, yeast, *E. coli*, developing chick eggs, and dipteran cells (see Bioinitiative Report [9], section 7). Tissue cultured cells are less likely to show an effect of EMF, probably because immortalized cells have been changed significantly to enable them to live indefinitely in unnatural laboratory conditions. This may also be true of cancer cells, although some (e.g., MCF7 breast cancer cells) have responded to EMF [38,39], and in HL60 cells, one cell line responds to EMF while another does not [24]. Czyz et al. [16] found that p53-deficient embryonic stem cells showed an increased EMF response, but the wild type did not.

A broad study of genotoxic effects (i.e., DNA damage) in different kinds of cells [40] found no effects with lymphocytes, monocytes and skeletal muscle cells, but did find effects with fibroblasts, melanocytes and rat granulosa cells. Other studies [41,42] have also found that the blood elements, such as lymphocytes and monocytes are natural cells that have not responded. Since mobile cells can easily move away from a stress, there would be little selective advantage and evolutionary pressure for developing the stress response. The lack of response by skeletal muscle cells is related to the need to desensitize the cells to excessive heating during activity. Unlike slow muscle fibers that do synthesize hsp70, cells containing fast muscle fibers do not synthesize hsp70 to protect them from over-reacting to the high temperatures reached a during activity.

Table 1
Biological thresholds in the ELF range.

Biological system	Threshold (μT)[a]	Reference
Acceleration of reaction rates		
Na,K-ATPase	0.2–0.3	Blank and Soo [49]
cytochrome oxidase	0.5–0.6	Blank and Soo [43]
ornithine decarboxylase	~2	Mullins et al. [58]
malonic acid oxidation	<0.5	Blank and Soo [59]
Biosynthesis of stress proteins		
HL60, Sciara, yeast,	<0.8	Goodman et al. [11]
breast (HTB124, MCF7)	<0.8	Lin et al. [39]
chick embryo (anoxia)	~2	DiCarlo et al. [60]
Breast cancer (MCF7) cell growth		
block melatonin inhibition	0.2 < 1.2	Liburdy et al. [38]
Leukemia epidemiology	0.3–4	Ahlbom et al. [61] Greenland et al. [62]

[a] The estimated values are for departures from the baseline, although Mullins et al. (1999) and DiCarlo et al. (2000) generally give inflection points in the dose–response curves. The leukemia epidemiology values are not experimental and are listed for comparison.

5. EMF–DNA interaction mechanisms: electron transfer

The biochemical compounds in living cells are composed of charges and dipoles that can interact with electric and magnetic fields by various mechanisms. An example discussed earlier is the generation of reactive oxygen species (ROS) in activation of the ERK signaling cascade. The cellular stress response leading to the synthesis of stress proteins is also activated by EMF. However, the specific reaction is not known, except that it is stimulated by very weak EMF. For this reason, our focus has been on molecular processes that are most sensitive to EMF and that could cause the DNA to come apart to initiate biosynthesis. We have suggested that direct EMF interaction with electrons in DNA is likely for the following reasons:

- The largest effects of EMF would be expected on electrons because of their high charge to mass ratio. At the sub-atomic level, one assumes that electrons respond instantaneously compared to protons and heavier atomic nuclei, as in the Born-Oppenheimer Approximation. The very low field strengths and durations that activate the stress response and other reactions (Table 1) suggest interaction with electrons, and make ion-based mechanisms unlikely.
- Weak ELF fields have been shown to affect the rates of electron transfer reactions [43,44]. A 10 μT magnetic field exerts a very small force of only $\sim 10^{-20}$ N on a unit charange,

but this force can move an isolated electron more than a bond length, ~1 nm, in ~1 nanosecond.

- There is a specific EMF responsive DNA sequence that is associated with the response to EMF (Fig. 1), and that retains this property when transfected
- Displacement of electrons in DNA would cause local charging that has been shown to lead to disaggregation of biopolymers [45].
- As the energy in an EMF stimulus increases, there is an increase in single strand breaks, followed by double strand breaks, suggesting an interaction with EMF at all energy levels [46].

Effects of EMF on electrons in chemical reactions were detected indirectly in studies on the Na,K-ATPase [47], a ubiquitous enzyme that establishes the normal Na and K ion gradients across cell membranes. Electric and magnetic fields, each accelerated the reaction only when the enzyme was relatively inactive. It is reasonable to assume that the threshold response occurs when the same charge is affected by the two fields, so the velocity (v) of the charge (q) could be calculated from these measurements and its nature determined. Assuming both fields exert the same force at the threshold, the electric (E) and the magnetic (B) forces should be equal.

$$F = qE = qvB. \quad (1)$$

From this $v = E/B$, the ratio of the threshold fields, and by substituting the measured thresholds [48,49], $E = 5 \times 10^{-4}$ V/m and $B = 5 \times 10^{-7}$T (0.5 μT), we obtain $v = 10^3 m/s$. This very rapid velocity, similar to that of electrons in DNA [50], indicated that electrons were probably involved in the ion transport mechanism of the Na,K-ATPase [47]. An electron moving at a velocity of 10^3 m/s crosses the enzyme (~10^{-8} m) before the ELF field has had a chance to change. This means that a low frequency sine wave signal is effectively a repeated DC pulse. This is true of all low frequency effects on fast moving electrons.

Studies of effects of EMF on electron transfer in cytochrome oxidase, ATP hydrolysis by the Na,K-ATPase, and the Belousov–Zhabotinski (BZ) redox reaction, have led to certain generalizations:

- EMF can accelerate reaction rates, including electron transfer rates
- EMF acts as a force that competes with the chemical forces in a reaction. The effect of EMF varies inversely with the intrinsic reaction rate, so EMF effects are only seen when intrinsic rates are low. (This is in keeping with the therapeutic efficacy of EMF on injured tissue, while there is usually little or no effect on normal tissue.)
- Experimentally determined thresholds are low (~0.5 μT) and comparable to levels found by epidemiology. See Table 1.
- Effects vary with frequency, with different optima for the reactions studied: The two enzymes showed broad frequency optima close to the reaction turnover numbers for Na,K-ATPase (60 Hz) and cytochrome oxidase (800 Hz), suggesting that EMF interacted optimally when in synchrony with the molecular kinetics. This is not true for EMF interactions with DNA, which are stimulated in both ELF and RF ranges and do not appear to involve electron transfer reactions with well-defined kinetics.

Probably the most convincing evidence for a frequency sensitive mechanism that involves stimulation of DNA is activation of protein synthesis in striated muscle. In this natural process, specific muscle proteins are synthesized by varying the rate of the (electrical) action potentials in the attached nerves [51]. The ionic currents of the action potentials that flow along and through the muscle membranes, also pass through the muscle cell nuclei that contain the DNA codes for the muscle proteins. Two frequencies were studied in muscle, high (100 Hz) and low (10 Hz) frequency, corresponding to the frequencies of the fast muscles and slow muscles that have different contraction rates and different muscle proteins. In the experiments, either the fast or slow muscle proteins were synthesized at the high or low frequency stimulation rates corresponding to the frequency of the action potentials. The clear dependence of the protein composition on the frequency of the action potentials indicates a relation between stimulation and activation of DNA in muscle physiology. The process is undoubtedly far more complicated and unlikely to be a simple electron transfer reaction as with cytochrome oxidase. It is more probable that an entire region of DNA coding for a group of related proteins is activated simultaneously.

A mechanism based on electron movement is in keeping with the mV/m electric field and μT magnetic field thresholds that affect the Na,K-ATPase. The very small force on a charge (~10^{-20} N) can affect an electron, but is unlikely to have a direct effect on much more massive ions and molecules, especially if they are hydrated. Ions are affected by the much larger DC electric fields of physiological membrane processes. The low EMF energy can move electrons, cause small changes in charge distribution and release the large hydration energy tied up in protein and DNA structures [3]. Electrons have been shown to move in DNA at great speed [50], and we have suggested that RF and ELF fields initiate the stress response by directly interacting and accelerating electrons moving within DNA [52,53].

A mechanism based on electron movement also provides insight into why the same stress response is stimulated by both ELF and RF even though the energies of the two stimuli differ by orders of magnitude. A typical ELF cycle at 10^2Hz lasts 10^{-2} s and a typical RF cycle at 10^{11} Hz lasts 10^{-11} s. Because the energy is spread over a different number of cycles/second in the two ranges, the energy/cycle is the same in both ELF and RF ranges. Since electron movement occurs much faster than the change of field, both frequencies are seen by rapidly moving electrons as essentially DC pulses. Each cycle contributes to electron movement at both

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frequencies, but more rapidly at the higher frequency. The fluctuation of protons between water molecules in solution at a frequency of about 10^{12} Hz [54] gives an indication of the speed of electron movement, and may suggest an upper limit of the frequency in which sine wave EMF act as DC pulses.

6. DNA biology and the EM spectrum

Research on DNA and the stress response has shown that the same biology occurs across divisions of the EM spectrum, and that EMF safety standards based on cellular measures of potential harm should be much stricter. These data also raise questions about the utility of spectrum sub-divisions as the basis for properly assessing biological effects and setting separate safety standards for the different sub-divisions. The frequencies of the EM spectrum form a continuum, and division into frequency bands is only a convenience that makes it easier to assign and regulate different portions of the spectrum for practical uses, such as the different design requirements of devices for EMF generation and measurement. Except for the special case of the visual range, the frequency bands are not based on biology, and the separate bands now appear to be a poor way of dealing with biological responses needed for evaluating safety. The DNA studies indicate the need for an EMF safety standard rooted in biology and a rational basis for assessing health implications.

DNA responses to EMF can be used to create a single scale for evaluation of EMF dose because:

- The same biological responses are stimulated in ELF and RF ranges.
- The intensity of EMF interactions with DNA leads to greater effects on DNA as the energy increases with frequency. In the ELF range, the DNA is only activated to initiate protein synthesis, while single and double strand breaks occur in the more energetic RF and ionizing ranges.

A scale based on DNA biology also makes possible an approach to a quantitative relation between EMF dose and disease. This can be done by utilizing the data banks that have been kept for A-bomb exposure and victims of nuclear accidents, data that link exposure to ionizing radiation and subsequent development of cancer. Utilizing experimental studies of DNA breaks with ionizing radiation, it is possible in principle to relate cancer incidence to EMF exposures. It should be possible to determine single and double strand breaks in a standard preparation of DNA, caused by exposure to EMF for a specified duration, under standard conditions. Although many studies of DNA damage and repair rates under different conditions would be needed, this appears to be a possible experimental approach to assessing the relation between EMF exposure and disease.

7. The stress response and safety standards

Most scientists believe that basic research eventually pays off in practical ways. This has certainly been true of EMF research on the stress response, where EMF stimulated stress proteins have been used to minimize damage to ischemic tissues on reperfusion. However, more importantly, biological effects stimulated by both ELF and RF have shown that the standards used for developing safety guidelines are not protective of cells.

First and foremost, it is important to realize that the stress response occurs in reaction to a potentially harmful environmental influence. The stress response is an unambiguous indication that cells react to EMF as potentially harmful. It is therefore an indication of compromised cell safety, given by the cell, in the language of the cell. The low threshold level of the stress response shows that the current safety standards are much too high to be considered safe.

In general, cellular processes are unusually sensitive to fields in the environment. The biological thresholds in the ELF range (Table 1) are in the range of 0.5–1.0 μT—not very much higher than the ELF backgrounds of ∼0.1 μT. The relatively low field strengths that can affect biochemical reactions is a further indication that cells are able to sense potential danger long before there is an increase in temperature.

EMF research has also shown that exposure durations do not have to be prolonged to have an effect. Litovitz et al. [55,56], working with the enzyme ornithine decarboxylase, showed an EMF response when cells were exposed for only 10 s to ELF or ELF modulated 915 MHz, providing that the exposure was continuous. Gaps in the sine wave resulted in a reduced response, and interference with the sine wave in the form of superimposed ELF noise also reduced the response [57]. The interfering effect of noise has been shown in the RF range by Lai and Singh [46], who reported that noise interferes with the ability of an RF signal to cause breaks in DNA strands. The decreased effect when noise is added to a signal is yet another indication that EMF energy is not the critical factor in causing a response. In fact, EMF noise appears to offer a technology for mitigating potentially harmful effects of EMF in the environment.

EMF research has shown that the thermal standard used by agencies to measure safety is at best incomplete, and in reality not protective of potentially harmful non-thermal fields. Non-thermal ELF mechanisms are as effective as thermal RF mechanisms in stimulating the stress response and other protective mechanisms. The current safety standard based on thermal response is fundamentally flawed, and not protective.

Finally, since both ELF and RF activate the same biology, simultaneous exposure to both is probably additive and total EMF exposure is important. Safety standards must consider total EMF exposure and not separate standards for ELF and RF ranges.

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Pathophysiology xxx (2009) xxx–xxx

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Electromagnetic fields and DNA damage

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Received 24 October 2008; received in revised form 16 November 2008; accepted 16 November 2008

Abstract

A major concern of the adverse effects of exposure to non-ionizing electromagnetic field (EMF) is cancer induction. Since the majority of cancers are initiated by damage to a cell's genome, studies have been carried out to investigate the effects of electromagnetic fields on DNA and chromosomal structure. Additionally, DNA damage can lead to changes in cellular functions and cell death. Single cell gel electrophoresis, also known as the 'comet assay', has been widely used in EMF research to determine DNA damage, reflected as single-strand breaks, double-strand breaks, and crosslinks. Studies have also been carried out to investigate chromosomal conformational changes and micronucleus formation in cells after exposure to EMF. This review describes the comet assay and its utility to qualitatively and quantitatively assess DNA damage, reviews studies that have investigated DNA strand breaks and other changes in DNA structure, and then discusses important lessons learned from our work in this area.

Keywords: Electromagnetic field; DNA damage; Comet assay; Radiofrequency radiation; Cellular telephone

1. The comet assay for measurement of DNA strand breaks

DNA is continuously damaged by endogenous and exogenous factors and then repaired by DNA repair enzymes. Any imbalance in damage and repair and mistakes in repair result in accumulation of DNA damage. Eventually, this will lead to cell death, aging, or cancer. There are several types of DNA lesions. The common ones that can be detected easily are DNA strand breaks and DNA crosslinks. Strand breaks in DNA are produced by endogenous factors, such as free radicals generated by mitochondrial respiration and metabolism, and by exogenous agents, including UV, ionizing and non-ionizing radiation, and chemicals.

There are two types of DNA strand breaks: single- and double-strand breaks. DNA single-strand breaks include frank breaks and alkali labile sites, such as base modification, deamination, depurination, and alkylation. These are the most commonly assessed lesions of DNA. DNA double-strand breaks are very critical for cells and usually they are lethal. DNA strand breaks have been correlated with cell death [1–5], aging [6–8] and cancer [9–13].

Several techniques have been developed to analyze single- and double-strand breaks. Most commonly used is microgel electrophoresis, also called the 'comet assay' or 'single cell gel electrophoresis'. This technique involves mixing cells with agarose, making microgels on a microscope slide, lysing cells in the microgels with salts and detergents, removing proteins from DNA by using proteinase K, unwinding/equilibrating and electrophoresing DNA (under highly alkaline condition for assessment of single-strand breaks or under neutral condition for assessment of DNA double-strand breaks), fixing the DNA, visualizing the DNA with a fluorescent dye, and then analyzing migration patterns of DNA from individual cells with an image analysis system.

The comet assay is a very sensitive method of detecting single- and double-strand breaks if specific criteria are met. Critical criteria include the following. Cells from tissue culture or laboratory animals should be handled with care to minimize DNA damage, for instance, by avoiding light and high temperature. When working with animals exposed to EMF *in vivo*, it is better to anesthetize the animals with CO_2 before harvesting tissues for assay. Antioxidants

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0928-4680/$ – see front matter © 2009 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.pathophys.2008.11.005

such as albumin and sucrose, or spin-trap molecules such as α-phenyl-*tert*-butyl nitrone (PBN), should be added during dispersion of tissues into single cells. Cells should be lysed at 0–4 °C to minimize DNA damage by endonucleases. Additionally, antioxidants such as tris and glutathione, and chelators such as EDTA, should be used in the lysing solution. High concentrations of dimethylsulfoxide (DMSO) should be avoided due to its chromatin condensing effect. Treatment with proteinase K (PK; lyophilized DNAse-free proteinase-K from Amresco is ideal) at a concentration of 0.5–1 mg/ml (depending upon cell type and number of cells in the microgel) should be used for 1–2 h at 37 °C to reveal all possible strand breaks which otherwise may go undetected due to DNA–protein crosslinks. Longer times in PK will lead to loss of smaller pieces of DNA by diffusion. Glass slides should be chosen based on which high resolution agarose (3:1 high resolution agarose from Amresco is ideal) will stick well to the slide and on the ability of the specimen to be visualized without excessive fluorescence background. Choice of an electrophoresis unit is important to minimize slide-to-slide variation in DNA migration pattern. A unit with uniform electric field and buffer recirculation should be used. Electrophoresis buffers should have antioxidants and chelators such as DMSO and EDTA. DNA diffusion should be minimized during the neutralization step by rapidly precipitating the DNA. Staining should employ a sensitive fluorescent dye, such as the intercalating fluorescent labeling dye YOYO-1. A cell-selection criteria for analysis should be set before the experiment, such as not analyzing cells with too much damage, although, the number of such cells should be recorded.

There are different versions of the comet assay that have been modified to meet the needs of specific applications and to improve sensitivity. Using the most basic form of the assay, one should be able to detect DNA strand breaks in human lymphocytes that were induced by 5 rad of gamma-ray [14,15].

2. Radiofrequency radiation (RFR) and DNA damage

In a series of publications, Lai and Singh [16–19] reported increases in single- and double-strand DNA breaks, as measured by the comet assay, in brain cells of rats exposed for 2 h to a 2450-MHz RFR at whole body specific absorption rate (SAR) between 0.6 and 1.2 W/kg. The effects were blocked by antioxidants, which suggested involvement of free radicals. At the same time, Sarkar et al. [20] exposed mice to 2450-MHz microwaves at a power density of 1 mW/cm^2 for 2 h/day over a period of 120, 150, and 200 days. Rearrangement of DNA segments were observed in testis and brain of exposed animals. Their data also suggested breakage of DNA strands after RFR exposure. Phillips et al. [21] were the first to study the effects of two forms of cell cellular phone signals, known as TDMA and iDEN, on DNA damage in Molt-4 human lymphoblastoid cells using the comet assay. These cells were exposed to relatively low intensities of the fields (2.4–26 μW/g) for 2–21 h. They reported both increased and decreased DNA damage, depending on the type of signal studied, as well as the intensity and duration of exposure. They speculated that the fields may affect DNA repair in cells. Subsequently, different groups of researchers have also reported DNA damage in various types of cells after exposure to cell phone frequency fields. Diem et al. [22] exposed human fibroblasts and rat granulosa cells to cell phone signal (1800 MHz; SAR 1.2 or 2 W/kg; different modulations; for 4, 16 and 24 h; intermittent 5 min on/10 min off or continuous). RFR exposure induced DNA single- and double-strand breaks as measured by the comet assay. Effects occurred after 16 h of exposure to different cell phone modulations in both cell types. The intermittent exposure schedule caused a significantly stronger effect than continuous exposure. Gandhi and Anita [23] reported increases in DNA strand breaks and micronucleation in lymphocytes obtained from cell phone users. Markova et al. [24] reported that GSM signals affected chromatin conformation and γ-H2AX foci that co-localized in distinct foci with DNA double-strand breaks in human lymphocytes. The effect was found to be dependent on carrier frequency. Nikolova et al. [25] reported a low and transient increase in DNA double-strand breaks in mouse embryonic stem cells after acute exposure to a 1.7-GHz field. Lixia et al. [26] reported an increase in DNA damage in human lens epithelial cells at 0 and 30 min after 2 h of exposure to a 1.8-GHz field at 3 W/kg. Sun et al. [27] reported an increase in DNA single-strand breaks in human lens epithelial cells after 2 h of exposure to a 1.8-GHz field at SARs of 3 and 4 W/kg. DNA damage caused by the field at 4 W/kg was irreversible. Zhang et al. [28] reported that an 1800-MHz field at 3.0 W/kg induced DNA damage in Chinese hamster lung cells after 24 h of exposure. Aitken et al. [29] exposed mice to a 900-MHz RFR at a SAR of 0.09 W/kg for 7 days at 12 h per day. DNA damage in caudal epididymal spermatozoa was assessed by quantitative PCR (QPCR) as well as by alkaline and pulsed-field gel electrophoresis. Gel electrophoresis revealed no significant change in single- or double-strand breaks in spermatozoa. However, QPCR revealed statistically significant damage to both the mitochondrial genome and the nuclear β-globin locus. Changes in sperm cell genome after exposure to 2450-MHz microwaves have also been reported previously by Sarkar et al. [20]. Related to this are several publications that have reported decreased motility and changes in morphology in isolated sperm cells exposed to cell phone radiation [30], sperm cells from animals exposed to cell phone radiation [31], and cell phone users [32–34]. Some of these *in vivo* effects could be caused by hormonal changes [35,36].

There also are studies reporting no significant effect of cell phone RFR exposure on DNA damage. After RFR-induced DNA damage was reported by Lai and Singh [16] using 2450-MHz microwaves and after the report of Phillips et al. [21] on cell phone radiation was published, Motorola funded a series of studies by Roti Roti and colleagues [37] at

Washington University to investigate DNA strand breaks in cells and animals exposed to RFR. None of the studies reported by this group found significant effects of RFR exposure on DNA damage [38–40]. However, a different version of the comet assay was used in these studies. More recently, four additional studies from the Roti-Roti laboratories also reported no significant effects on DNA damage in cells exposed to RFR. Li et al. [41] reported no significant change in DNA strand breaks in murine C3H10T1/2 fibroblasts after 2 h of exposure to 847.74- and 835.02-MHz fields at 3–5 W/kg. Hook et al. [42] showed that a 24-h exposure of Molt-4 cells to CDMA, FDMA, iDEN or TDMA-modulated RFR did not significantly alter the level of DNA damage. Lagroye et al. [43,44] also reported no significant change in DNA strand breaks, protein–DNA crosslinks, and DNA–DNA crosslinks in cells exposed to 2450-MHz RFR.

From other laboratories, Vijayalaxmi et al. [45] reported no increase in DNA stand breaks in human lymphocytes exposed *in vitro* to 2450-MHz RFR at 2.135 W/kg for 2 h. Tice et al. [46] measured DNA single-strand breaks in human leukocytes using the comet assay after exposure to various forms of cell phone signals. Cells were exposed for 3 or 24 h at average SARs of 1.0–10.0 W/kg. Exposure for either 3 or 24 h did not induce a significant increase in DNA damage in leukocytes. McNamee et al. [47–49] found no significant increase in DNA breaks and micronucleus formation in human leukocytes exposed for 2 h to a 1.9-GHz field at SAR up to 10 W/kg. Zeni et al. [50] reported that a 2-h exposure to 900-MHz GSM signal at 0.3 and 1 W/kg did not significantly affect levels of DNA strand breaks in human leukocytes. Sakuma et al. [51] exposed human glioblastoma A172 cells and normal human IMR-90 fibroblasts from fetal lungs to cell phone radiation for 2 and 24 h. No significant changes in DNA strand breaks were observed up to a SAR of 800 mW/kg. Stronati et al. [52] showed that 24 h of exposure to 935-MHz GSM basic signal at 1 or 2 W/Kg did not cause DNA strand breaks in human blood cells. Verschaeve et al. [53] reported that long-term exposure (2 h/day, 5 days/week for 2 years) of rats to 900-MHz GSM signal at 0.3 and 0.9 W/kg did not significantly affect levels of DNA strand breaks in cells.

3. Extremely low frequency electromagnetic fields (ELF EMF) and DNA damage

To complete the picture, a few words on the effects of ELF EMF are required, since cell phones also emit these fields and they are another common form of non-ionizing EMF in our environment. Quite a number of studies have indicated that exposure to ELF EMF could lead to DNA damage [54–69]. In addition, two studies [70,71] have reported effects of ELF fields on DNA repair mechanisms. Free radicals and interaction with transitional metals (e.g., iron) [60,62,63,69] have also been implicated to play a role in the genotoxic effects observed after exposure to these fields.

4. Some considerations on the effects of EMF on DNA

From this brief literature survey, no consistent pattern of RFR exposure inducing changes in or damage to DNA in cells and organisms emerges. However, one can conclude that under certain conditions of exposure, RFR is genotoxic. Data available are mainly applicable only to radiation exposure that would be typical during cell phone use. Other than the study of Phillips et al. [21], there is no indication that RFR at levels that one can experience in the vicinity of base stations and RF-transmission towers could cause DNA damage.

Differences in experimental outcomes are expected since many factors could influence the outcome of experiments in EMF research. Any effect of EMF has to depend on the energy absorbed by a biological organism and on how the energy is delivered in space and time. Frequency, intensity, exposure duration, and the number of exposure episodes can affect the response, and these factors can interact with each other to produce different effects. In addition, in order to understand the biological consequence of EMF exposure, one must know whether the effect is cumulative, whether compensatory responses result, and when homeostasis will break down. The contributions of these factors have been discussed in a talk given by one us (HL) in Vienna, Austria in 1998 [72].

Radiation from cell phone transmission has very complex patterns, and signals vary with the type of transmission. Moreover, the technology is constantly changing. Research results from one types of transmission pattern may not be applicable to other types. Thus, differences in outcomes of the research on genotoxic effects of RFR could be explained by the many different exposure conditions used in the studies. An example is the study of Phillips et al. [21], which demonstrated that different cell phone signals could cause different effects on DNA (i.e., an increase in strand breaks after exposure to one type of signal and a decrease with another). This is further complicated by the fact that some of the studies listed above used poor exposure procedures with very limited documentation of exposure parameters, e.g., using an actual cell phone to expose cells and animals, thus rendering the data from these experiments as questionable.

Another source of influence on experimental outcome is the cell or organism studied. Many different biological systems were used in the genotoxicity studies. Different cell types [73] and organisms [74,75] may not all respond similarly to EMF.

Comment about the comet assay also is required, since it was used in many of the EMF studies to determine DNA damage. Different versions of the assay have been developed. These versions have different detection sensitivities and can be used to measure different aspects of DNA strand breaks. A comparison of data from experiments using different versions of the assay could be misleading. Another concern is that most of the comet assay studies were carried out by experimenters who had no prior experience with this technique and mistakes

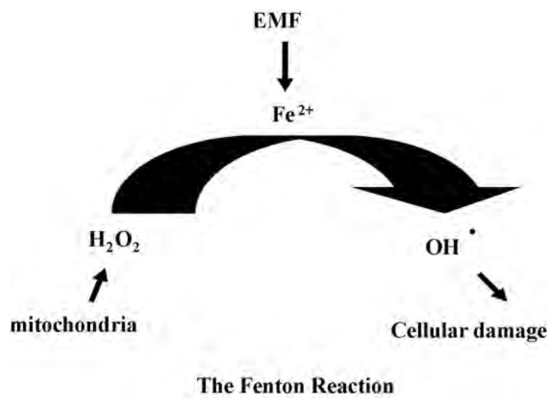

Fig. 1. A representation of the Fenton reaction and its role as a mediator in EMF-induced bioeffects.

were made. For example, in the study by Lagroye et al. [43] to investigate the effect of PK digestion on DNA migration after RFR exposure, PK was added to a lysing solution containing the detergent Triton X-100, which would inactivate the enzyme. Our experience indicates that the comet assay is a very sensitive and requires great care to perform. Thus, different detection sensitivities could result in different laboratories, even if the same procedures are followed. One way to solve this problem of experimental variation is for each research team to report the sensitivity of their comet assay, e.g., the threshold of detecting strand breaks in human lymphocytes exposed to X-rays. This information has generally not been provided for EMF-genotoxicity studies. Interestingly, when such information was provided, a large range of sensitivities have been reported. Malyapa et al. [40] reported a detection level of 0.6 cGy of gamma radiation in human lymphocytes, whereas McNamee et al. [76] reported 10–50 cGy of X-irradiation in lymphocytes, which is much higher than the generally acceptable detection level of the comet assay [15].

A drawback in the interpretation and understanding of experimental data from bioelectromagnetics research is that there is no general acceptable mechanism on how EMF affects biological systems. The mechanism by which EMF produces changes in DNA is unknown. Since the energy level associated with EMF exposure is not sufficient to cause direct breakage of chemical bonds within molecules, the effects are probably indirect and secondary to other induced biochemical changes in cells.

One possibility is that DNA is damaged by free radicals that are formed inside cells. Free radicals affect cells by damaging macromolecules, such as DNA, protein, and membrane lipids. Several reports have indicated that EMF enhances free radical activity in cells [18,19,61,62,77,78], particularly via the Fenton reaction [62]. The Fenton reaction is a process catalyzed by iron in which hydrogen peroxide, a product of oxidative respiration in the mitochondria, is converted into hydroxyl free radicals, which are very potent and cytotoxic molecules (Fig. 1).

It is interesting that ELF EMF has also been shown to cause DNA damage. Furthermore, free radicals have been implicated in this effect of ELF EMF. This further supports the view that EMF affects DNA via an indirect secondary process, since the energy content of ELF EMF is much lower than that of RFR. Effects via the Fenton reaction predict how a cell would respond to EMF. For instance:

(1) Cells that are metabolically active would be more susceptible to EMF, because more hydrogen peroxide is generated by mitochondria to fuel the reaction.
(2) Cells that have high level of intracellular free iron would be more vulnerable to EMF. Cancer cells and cells undergoing abnormal proliferation have higher concentrations of free iron because they uptake more iron and have less efficient iron storage regulation. Thus, these cells could be selectively damaged by EMF. Consequently, this suggests that EMF could potentially be used for the treatment of cancer and hyperplastic diseases. The effect could be further enhanced if one could shift anaerobic glycolysis of cancer cells to oxidative glycolysis. There is quite a large database of information on the effects of EMF (mostly in the ELF range) on cancer cells and tumors. The data tend to indicate that EMF could retard tumor growth and kill cancer cells. One consequence of this consideration is that epidemiological studies of cancer incidence in cell phone users may not show a risk at all or even a protection effect.
(3) Since the brain is exposed to rather high levels of EMF during cell phone use, the consequences of EMF-induced genetic damage in brain cells are of particular importance. Brain cells have high levels of iron. Special molecular pumps are present on nerve cell nuclear membranes to pump iron into the nucleus. Iron atoms have been found to intercalate within DNA molecules. In addition, nerve cells have a low capacity for DNA repair, and DNA breaks could easily accumulate. Another concern is the presence of superparamagnetic iron-particles (magnetites) in body tissues, particularly in the brain. These particles could enhance free radical activity in cells and thus increase the cellular-damaging effects of EMF. These factors make nerve cells more vulnerable to EMF. Thus, the effect of EMF on DNA could conceivably be more significant on nerve cells than on other cell types of the body. Since nerve cells do not divide and are not likely to become cancerous, the more likely consequences of DNA damage in nerve cells include changes in cellular functions and in cell death, which could either lead to or accelerate the development of neurodegenerative diseases. Double-strand breaks, if not properly repaired, are known to lead to cell death. Cumulative DNA damage in nerve cells of the brain has been associated with neurodegenerative diseases, such as Alzheimer's, Huntington's, and Parkinson's diseases. However, another type of brain cell, the glial cell, can become cancerous as a result of DNA damage. The question is whether the damaged cells

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would develop into tumors before they are killed by EMF due to over accumulation of genetic damages. The outcome depends on the interplay of these different physical and biological factors—an increase, decrease, or no significant change in cancer risk could result from EMF exposure.

(4) On the other hand, cells with high amounts of antioxidants and antioxidative enzymes would be less susceptible to EMF. Furthermore, the effect of free radicals could depend on the nutritional status of an individual, e.g., availability of dietary antioxidants, consumption of alcohol, and amount of food consumption. Various life conditions, such as psychological stress and strenuous physical exercise, have been shown to increase oxidative stress and enhance the effect of free radicals in the body. Thus, one can also speculate that some individuals may be more susceptible to the effects of EMF exposure.

Additionally, the work of Blank and Soo [79] and Blank and Goodman [80] support the possibility that EMF exposure at low levels has a direct effect on electron transfer processes. Although the authors do not discuss their work in the context of EMF-induced DNA damage, the possibility exists that EMF exposure could produce oxidative damage to DNA.

5. Lessons learned

Whether or not EMF causes biological effects, let alone effects that are detrimental to human health and development, is a contentious issue. The literature in this area abounds with apparently contradictory studies, and as presented in this review, the literature specific to the effects of RFR exposure on DNA damage and repair in various biological systems is no exception. As a consequence of this controversy, there are several key issues that must be addressed—contrary data, weight of evidence, and data interpretation consistent with known science.

Consider that EMF does not share the familiar and comforting physical properties of chemical agents. EMF cannot be seen, tasted, smelled, or felt (except at high intensities). It is relevant, therefore, to ask, in what ways do scientists respond to data, especially if that data are contrary to their scientific beliefs or inconsistent with long-held hypotheses? Often such data are ignored, simply because it contradict what is accepted as conventional wisdom. Careful evaluation and interpretation of data may be difficult, because technologies used to expose biological systems to EMF and methodologies used to assess dosimetry generally are outside the experience of most biomedical scientists. Additionally, it is often difficult to assess differences in methodologies between studies, one or more of which were intended to replicate an original investigation. For instance, Malyapa et al. [40] reported what they claimed to be a replication of the work of Lai and Singh [16]. There were, however, significant differences in the comet analyses used by each group. Lai and Singh precipitated DNA in agarose so that low levels of DNA damage could be detected. Malyapa et al. did not. Lai and Singh treated their samples with PK to digest proteins bound to DNA, thus allowing DNA to move toward the positive pole during electrophoresis (unlike DNA, most proteins are negatively charged, and if they are not removed they will drag the DNA toward the negative pole). The Malyapa et al. study did not use PK. There were other methodological differences as well. Such is also the case in the study of Hook et al. [42], which attempted to replicate the work of Phillips et al. [21]. The latter group used a PK treatment in their comet assay, while the former group did not.

While credibility is enhanced when one can relate data to personal knowledge and scientific beliefs, it has not yet been determined how RFR couples with biological systems or by what mechanisms effects are produced. Even carefully designed and well executed RFR exposure studies may be summarily dismissed as methodologically unsound, or the data may be interpreted as invalid because of inconsistencies with what one believes to be correct. The quintessential example is the belief that exposure to RFR can produce no effects that are not related to the ability of RFR to produce heat, that is, to raise the temperature of biological systems [81,82]. Nonetheless, there are many examples of biological effects resulting from low-level (athermal) RFR exposure [83,84]. Consider here the work of Mashevich et al. [85]. This group exposed human peripheral blood lymphocytes to an 830-MHz signal for 72 h and at different average SARs (SAR, 1.6–8.8 W/kg). Temperatures ranged from 34.5 to 38.5 °C. This group observed an increase in chromosome 17 aneuploidy that varied linearly with SAR. Temperature elevation alone in the range of 34.5–38.5 °C did not produce this genotoxic effect, although significant aneuploidy was observed at higher temperatures of 40–41 °C. The authors conclude that the genotoxic effect of the radiofrequency signal used is elicited through a non-thermal pathway.

Also consider one aspect of the work of Phillips et al. [21]. In that study, DNA damage was found to vary in direction; that is, under some conditions of signal characteristics, signal intensity, and time of exposure, DNA damage increased as compared with concurrent unexposed controls, while under other conditions DNA damage decreased as compared with controls. The dual nature of Phillips et al.'s [21] results will be discussed later. For now consider the relationship of these results to other investigations. Adey et al. [86] performed an *in vivo* study to determine if rats treated *in utero* with the carcinogen ethylnitrosourea (ENU) and exposed to an 836.55-MHz field with North American Digital Cellular modulation (referred to as a TDMA field) would develop increased numbers of central system tumors. This group reported that rather than seeing an increase in tumor incidence in RFR-exposed rats, there was instead a decrease in tumor incidence. Moreover, rats that received no ENU but which were exposed to the TDMA signal also showed a decrease in the number of spontaneous tumors as compared

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with animals exposed to neither ENU nor the TDMA signal. This group postulated that their results may be mechanistically similar to the work of another group. Stammberger et al. [87] had previously reported that rats treated *in utero* with ENU and then exposed to low doses of X-irradiation exhibited significantly reduced incidences of brain tumors in adult life. Stammberger and colleagues [87] hypothesized that low-level X-irradiation produced DNA damage that then induced the repair enzyme 0^6-alkylguanine-DNA alkyltransferase (AT). Numerous groups have since reported that X-irradiation does indeed induce AT activity (e.g., [88,89]). In this context, it is significant that Phillips et al. [21] found that cells exposed *in vitro* to a TDMA signal identical to that used in the study of Adey et al. [86] produced a decrease in DNA damage under specific conditions of intensity and time of exposure (lower intensity, longer time; higher intensity, shorter time). These results raise the intriguing possibility that the decrease in tumor incidence in the study of Adey et al. [86] and the decrease in DNA damage in the study of Phillips et al. [21] both may have been the result of induction of AT activity resulting from DNA damage produced by exposure to the TDMA signal. This remains to be investigated.

Because the issue of RFR-induced bioeffects is contentious, and because the issue is tried in courtrooms and various public forums, a term heard frequently is weight of evidence. This term generally is used to describe a method by which all scientific evidence related to a causal hypothesis is considered and evaluated. This process is used extensively in matters of regulation, policy, and the law, and it provides a means of weighing results across different modalities of evidence. When considering the effects of RFR exposure on DNA damage and repair, modalities of evidence include studies of cells and tissues from laboratory animals exposed *in vivo* to RFR, studies of cells from humans exposed to RFR *in vivo*, and studies of cells exposed *in vitro* to RFR. While weight of evidence is gaining favor with regulators [90], its application by scientists to decide matters of science is often of questionable value. One of the reasons for this is that there generally is no discussion or characterization of what weight of evidence actually means in the context in which it is used. Additionally, the distinction between weight of evidence and strength of evidence often is lacking or not defined, and differences in methodologies between investigators are not considered. Consequently, weight of evidence generally amounts to what Krimsky [90] refers to as a "seat-of-the-pants qualitative assessment." Krimsky points out that according to this view, weight of evidence is "a vague term that scientists use when they apply implicit, qualitative, and/or subjective criteria to evaluate a body of evidence." Such is the case in the reviews by Juutilainen and Lang [91] and Verschaeve and Maes [92]. There is little emphasis on a critical analysis of similarities and differences in biological systems used, exposure regimens, data produced, and investigator's interpretations and conclusions. Rather, there is greater emphasis on the number of publications either finding or not finding an effect of RFR exposure on some endpoint. To some investigators, weight of evidence does indeed refer to the balance (or imbalance) between the number of studies producing apparently opposing results, without regard to critical experimental variables. While understanding the role these variables play in determining experimental outcome could provide remarkable insights into defining mechanisms by which RFR produced biological effects, few seem interested in or willing to delve deeply into the science.

A final lesson can be derived from a statement made by Gos et al. [93] referring to the work of Phillips et al. [21]. Gos and colleagues state, "The results in the latter study (Phillips et al., 1998) are puzzling and difficult to interpret, as no consistent increase or decrease in signal in the comet assay at various SARs or times of exposure was identified." This statement is pointed out because studies of the biological effects of exposure to electromagnetic fields at any frequency are often viewed as outside of or distinct from what many refer to as *mainstream science*. However, what has been perceived as an inconsistent effect is indeed consistent with the observations of bimodal effects reported in hundreds of peer-reviewed publications. These bimodal effects may be dependent on concentration of an agent, time of incubation with an agent, or some other parameter relating to the state of the system under investigation. For instance, treatment of B cells for a short time (30 min) with the protein kinase C activator phorbol 12,13-dibutyrate increased proliferative responses to anti-immunoglobulin antibody, whereas treatment for a longer period of time (≥3 h) suppressed proliferation [94]. In a study of κ-opioid agonists on locomotor activity in mice, Kuzmin et al. [95] reported that higher, analgesic doses of κ-agonists reduced rearing, motility, and locomotion in non-habituated mice. In contrast, lower, subanalgesic doses increased motor activity in a time-dependent manner. Dierov et al. [96] observed a bimodal effect of all-trans-retinoic acid (RA) on cell cycle progression in lymphoid cells that was temporally related to the length of exposure to RA. A final example is found in the work of Rosenstein et al. [97]. This group found that the activity of melatonin on depolarization-induced calcium influx by hypothalamic synaptosomes from rats sacrificed late evening (2000 h) depended on melatonin preincubation time. A short preincubation time (10 min) stimulated uptake, while a longer preincubation (30 min) inhibited calcium uptake. These effects were also dependent on the time of day when the rats were sacrificed. Effects were maximal at 2000 h, minimal at 2400 h, and intermediate at 400 h. At 1000 h, only inhibitory effects of melatonin on calcium uptake were observed. These examples point out that what appears to be inconsistency may instead be real events related to and determined by the agents involved and the state of the biological system under investigation. The results of Phillips et al. [21] may be the result of signal modulation, signal intensity, time of exposure, or state of the cells. The results may indicate a bimodal effect, or they may, as the investigators suggest, represent time- and signal-dependant changes in the balance between damage and repair because of direct or indirect effects of RFR exposure on repair mechanisms.

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6. Summary

Exposure of laboratory animals *in vivo* and of cultured cells *in vitro* to various radiofrequency signals has produced changes in DNA damage in some investigations and not in others. That many of the studies on both sides of this issue have been done well is encouraging from a scientific perspective. RFR exposure does indeed appear to affect DNA damage and repair, and the total body of available data contains clues as to conditions producing effects and methodologies to detect them. This view is in contrast to that of those who believe that studies unable to replicate the work of others are more credible than the original studies, that studies showing no effects cancel studies showing an effect, or that studies showing effects are not credible simply because we do not understand how those effects might occur. Some may be tempted to apply incorrectly the teachings of Sir Karl Popper, one of the great science philosophers of the 20th century. Popper proposed that many examples may lend support to an hypothesis, while only one negative instance is required to refute it [98]. While this holds most strongly for logical subjects, such as mathematics, it does not hold well for more complex biological phenomena that are influenced by stochastic factors. Each study to investigate RFR-induced DNA damage must be evaluated on its own merits, and then studies that both show effects and do not show effects must be carefully evaluated to define the relationship of experimental variables to experimental outcomes and to assess the value of experimental methodologies to detect and measure these outcomes (see Section 2).

The lack of a causal or proven mechanism(s) to explain RFR-induced effects on DNA damage and repair does not decrease the credibility of studies in the scientific literature that report effects of RFR exposure, because there are several plausible mechanisms of action that can account for the observed effects. The relationship between cigarette smoking and lung cancer was accepted long before a mechanism was established. This, however, occurred on the strength of epidemiologic data [99]. Fortunately, relevant epidemiologic data relating long-term cell phone use (>10 years) to central nervous system tumors are beginning to appear [84,100–102], and these data point to an increased risk of acoustic neuroma, glioma and parotid gland tumors.

One plausible mechanism for RFR-induced DNA damage is free radical damage. After finding that two free radical scavengers (melatonin and N-tert-butyl-α-phenylnitrone) prevent RFR-induced DNA damage in rat brain cells, Lai and Singh [62] hypothesized that this damage resulted from free radical generation. Subsequently, other reports appeared that also suggested free radical formation as a result of RFR exposure [103–105]. Additionally, some investigators have reported that non-thermal exposure to RFR alters protein structure and function [106–109]. Scientists are familiar with molecules interacting with proteins through lock-and-key or induced-fit mechanisms. It is accepted that such interactions provide energy to change protein conformation and protein function. Indeed, discussions of these principles are presented in introductory biology and biochemistry courses. Perhaps then it is possible that RFR exposure, in a manner similar to that of chemical agents, provides sufficient energy to alter the structure of proteins involved in DNA repair mechanisms to the extent that their function also is changed. This has not yet been investigated.

When scientists maintain their beliefs in the face of contrary data, two diametrically opposed situations may result. On the one hand, data are seen as either right or wrong and there is no discussion to resolve disparities. On the other hand, and as Francis Crick [110] has pointed out, scientists who hold theoretically opposed positions may engage in fruitful debate to enhance understanding of underlying principles and advance science in general. While the latter certainly is preferable, there are external factors involving economics and politics that keep this from happening. It is time to acknowledge this and embark on the path of fruitful discussion. Great scientific discoveries await.

Acknowledgment

We thank Khushbu Komal and Ji-Sun Park for assistance in the preparation of the manuscript.

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Pathophysiology xxx (2009) xxx–xxx

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Genotoxic effects of radiofrequency electromagnetic fields

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Received 24 October 2008; received in revised form 16 November 2008; accepted 16 November 2008

Abstract

101 publications are exploited which have studied genotoxicity of radiofrequency electromagnetic fields (RF-EMF) *in vivo* and *in vitro*. Of these 49 report a genotoxic effect and 42 do not. In addition, 8 studies failed to detect an influence on the genetic material, but showed that RF-EMF enhanced the genotoxic action of other chemical or physical agents. The controversial results may in part be explained by the different cellular systems. Moreover, inconsistencies may depend from the variety of analytical methods being used, which differ considerably with respect to sensitivity and specificity. Taking altogether there is ample evidence that RF-EMF can alter the genetic material of exposed cells i*n vivo* and *in vitro* and in more than one way. This genotoxic action may be mediated by microthermal effects in cellular structures, formation of free radicals, or an interaction with DNA-repair mechanisms.

Keywords: Gene mutations; Cytogenetic effects; DNA fragmentation; Mechanisms of genotoxicity

1. Introduction

Alterations of genetic information in somatic cells are the key event in the process of carcinogenesis [1,2]. Consequently any agent, which has a genotoxic attribute is suspected also to be cancerogenic. This is the driving force behind the multitude of studies on genotoxicity of radiofrequency electromagnetic fields (RF-EMF), conducted so far. A total of 101 publications on genotoxicity studies of RF-EMF are exploited here, of which 49 report genotoxic effects, subsequently marked as GT(+) (Table 1), 43 do not (Table 2), and 9 find, that RF-EMF do not induce genotoxic events by itself but enhance the genotoxic action of other physical or chemical agents (Table 3). Thus, in contrast to several reviews in the past [3–6], it now became evident that non-thermal genotoxic effects of RF-EMF is convincingly demonstrated by a substantial number of published studies. The studies have been performed with a variety of different test systems – some studies used more than one test system – which will be assigned here to the three principle endpoints of a genotoxic action: (1) effect on chromosomes, (2) DNA fragmentation, and (3) gene mutations.

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2. Effect on chromosomes

This group comprises the analysis of numerical or structural anomalies of metaphase chromosomes (CA), sister-chromatid-exchanges (SCEs), and formation of micronuclei (MN). Of the 21 studies using CA, 9 are CA-positive, 11 CA-negative, and 1 reports an RF-induced enhancement of genotoxicity by X-rays. In general proliferating cells are required for the study of chromosomal effects, however, micronuclei have also been analysed in polychromatic erythrocytes and in exfoliated cells, for instance from buccal smears [7,8]. Moreover, aneuploidy rates of distinct chromosomes as well as chromosomal translocations can also be studied in interphase nuclei using fluorescence in situ hybridization (FISH). While structural aberrations detected by conventional CA are mainly lethal to the cell, translocations are persistent and may be passed to the cellular progeny. Using FISH increased levels of aneuploidy of chromosome 1, 10, 11, and 17 have been reported in human blood lymphocytes after RF-EMF exposure [9]. In metaphase chromosomes FISH may increase the sensitivity of chromosomal analysis [10] but this has only once been used for RF-EMF studies [11].

CA brings about to detect a variety of chromosomal aberrations. In contrast, micronuclei originate only from acentric

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doi:10.1016/j.pathophys.2008.11.004

Please cite this article in press as: H.W. Ruediger, Genotoxic effects of radiofrequency electromagnetic fields, Pathophysiology (2009), doi:10.1016/j.pathophys.2008.11.004

Table 1
Publications which report RF-EMF related genotoxic effects.

Reference	Biological system	Genotoxic endpoint	Results and comments
Aitken et al. [45]	Mouse sperm	QPCR and comet assay	Gel electrophoresis revealed no gross evidence of increased single- or double-DNA strand breakage in spermatozoa. However, a detailed analysis of DNA integrity using QPCR revealed damage to both the mitochondrial genome ($p < 0.05$) and the nuclear-globin locus ($p < 0.01$).
Balode [46]	Cow erythrocytes	Micronuclei (MN)	The counting of micronuclei in peripheral erythrocytes gave low average incidences, 0.6 per 1000 in the exposed group and 0.1 per 1000 in the control, but statistically significant ($p < 0.01$) differences were found in the frequency distribution between the control and exposed groups.
Belyaev et al. [47]	Human blood lymphocytes	Chromatin condensation and 53BP1 foci	Decrease in background levels of 53BP1 foci and may indicate decrease in accessibility of 53BP1 to antibodies because of stress-induced chromatin condensation.
Busljeta et al. [48]	Rat hematopoietic tissues	MN	Erythrocyte count, haemoglobin and haematocrit were increased in peripheral blood (days 8 and 15). Concurrently, anuclear cells and erythropoietic precursor cells were decreased ($p < 0.05$) in the bone marrow on day 15, but micronucleated cells' (MNCs) frequency was increased.
d'Ambrosio et al. [49]	Human blood lymphocytes	MN	The micronucleus frequency was not affected by CW exposure; however, a statistically significant micronucleus effect was found following exposure to phase modulated field.
Diem et al. [23]	Human cultured fibroblasts and rat granulosa cells	Alkaline and neutral comet assay	The intermittent exposure showed a stronger effect in the comet assay than continuous exposure.
Ferreira et al. [50]	Rat hematopoietic tissues exposed during embryogenesis	MN	The irradiated group showed a significant increase in MN occurrence.
Fucic et al. [15]	Human blood lymphocytes	MN	X-rays and microwaves were preferentially clastogens while vinyl chloride monomer showed aneugenic activity as well. Microwaves possess some mutagenic characteristics typical of chemical mutagens.
Gadhia et al. [51]	Human blood lymphocytes	Chromosomal aberrations and SCE	There was a significant increase ($p < 0.05$) in dicentric chromosomes among mobile users who were smoker–alcoholic as compared to nonsmoker–nonalcoholic. Synergistic action with MMC, SCEs showed a significant increase among mobile users.
Gandhi and Singh [7]	Human blood lymphocytes and buccal mucosa cells	Chromosomal aberrations and MN	Increased number of micronucleated buccal cells and cytological abnormalities in cultured lymphocytes.
Gandhi, 2005 [52]	Human blood lymphocytes	Comet assay, *in vivo* capillary MN	Mean comet tail length (26.76 ± 0.054 mm; 39.75% of cells damaged) in mobile phone users was highly significant from that in the control group. The *in vivo* capillary blood MNT also revealed highly significant (0.25) frequency of micronucleated cells.
Garaj-Vrhovac et al [53]	Human blood lymphocytes	Chromosomal aberrations and MN	In all experimental conditions, the frequency of all types of chromosomal aberrations was significantly higher than in the control samples. In the irradiated samples the presence of dicentric and ring chromosomes was established. The incidence of micronuclei was also higher in the exposed samples.
Garaj-Vrhovac et al. [54]	Chinese hamster cells V79	DNA synthesis by [3H]thymidine uptake, and chromosomal aberrations	In comparison with the control samples there was a higher frequency of specific chromosome lesions in cells that had been irradiated.
Garaj-Vrhovac et al. [55]	Chinese hamster cells V79	Chromosomal aberrations and MN	Significantly higher frequency of specific chromosome aberrations such as dicentric and ring chromosomes in irradiated cells. The presence of micronuclei in irradiated cells confirmed the changes that had occurred in chromosome structure.
Garaj-Vrhovac et al. [56]	Human blood lymphocytes	MN	Increase in frequency of micronuclei as well as disturbances in the distribution of cells over the first, second and third mitotic division in exposed subjects compared to controls.
Haider et al. [57]	*Tradescantia* flower buds	MN	The results at all exposure sites except one were statistically significant.
Koyama et al. [12]	CHO-K1 cells	MN + kinetochore determination	RF at SAR of 78 W/kg and higher form MN with a particular increase of kinetochore-positive MN and potentiate MN formation induced by bleomycine treatment.
Lai et al. [58]	Rat brain cells	Comet assay	RFR exposure significantly increased DNA double strand breaks in brain cells of the rat, and the effect was partially blocked by treatment with naltrexone.
Lai and Singh [59]	Rat brain cells	Alkaline comet assay	No effects immediately after 2 h of exposure to pulsed microwaves, whereas a dose rate-dependent increase in DNA single strand breaks was found in brain cells of rats at 4 h post-exposure with CW and pulsed waves.

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Lai and Singh [60]	Rat brain cells	Comet assay	Significantly higher levels of DNA single and double strand breaks. Exposure to ‘noise’ alone did not significantly affect the levels, however, simultaneous ‘noise’ exposure blocked microwave-induced increases in DNA strand breaks.
Lai and Singh [61]	Rat brain cells	Comet assay	An increase in DNA strand breaks was observed after exposure to either the pulsed or continuous-wave radiation, no significant difference was observed between the effects of the two forms of radiation.
Lai and Singh [35]	Rat brain cells	Comet assay	Treatment immediately before and after RFR exposure with either melatonin or *N*-tert-butyl-alpha-phenylnitrone (PBN) blocks induction of DSB by RFR. It is hypothesized that free radicals are involved in RFR-induced DNA damage in the brain cells of rats.
Lixia et al. [62]	Human lens epithelial cells	Comet assay and BudR incorporation	No DNA breaks at 1 and 2 W/kg but increase 0 and 30 min after exposure to 3 W/kg. Exposure at 2 and 3 W/kg for 2 h significantly increased HsP 70 protein but not mRNA expression.
Maes et al. [63]	Human blood lymphocytes	Chromosome aberrations	Some cytogenetic damage was obtained *in vitro* when blood samples were very close to the antenna. The questionable *in vivo* results (six maintenance workers) are not considered here.
Maes et al. [64]	Human blood lymphocytes	Chromosomal aberrations, SCE, and MN	Marked increase in the frequency of chromosome aberrations (including dicentric chromosomes and acentric fragments) and 19 micronuclei. On the other hand, the microwave exposure did not influence the cell kinetics nor the sister-chromatid-exchange (SCE) frequency.
Markova et al. [65]	Human blood lymphocytes	p53 binding protein and γH2AX foci	MWs from GSM mobile telephones affect chromatin conformation and 53BP1/gamma-H2AX foci similar to heat shock.
Mashevich et al. [66]	Human blood lymphocytes	Chromosomal aberrations	A linear increase in chromosome 17 aneuploidy was observed as a function of the SAR value.
Mazor et al. [9]	Human blood lymphocytes	Aneuploidy rate of Chr. # 1, 10, 11, 17 determined by interphase FISH	Increased levels of aneuploidy in chromosomes 1 and 10 at higher SAR, while for chromosomes 11 and 17 the increases were observed only for the lower SAR.
Nikolova et al. [67]	Mouse nestin-positive neural progenitor cells	Transcript of specific genes and proteins, proliferation, apoptosis, DNA DSB	Down-regulation of neural-specific Nurr1and up-regulation of bax and GADD45 mRNA levels. Short-term RF-EMF exposure for 6 h, but not for 48 h, resulted in a low and transient increase of DNA double strand breaks.
Paulraj and Behari [68]	Rat brain cells	Comet assay	Statistically significant ($p < 0.001$) increase in DNA single strand breaks in brain cells of rat.
Pavicic and Trosic [13]	V79 cells	Alteration of microtubule proteins	The microtubule structure altered after 3 h of irritation.
Phillips et al. [69]	Molt-4 T-lymphoblastoid cells	Comet assay	DNA damage decreased by (1) exposure to the iDEN signal (2.4 μW/g for 2 h or 21 h), (2) exposure to the TDMA signal (2.6 μW/g for 2 h and 21 h), (3) exposure to the TDMA signal (26 μW/g for 2 h), exposure to the iDEN signal (24 μW/g for 2 h) and 21 h significantly increased DNA damage.
Sarimov et al. [70]	Human blood lymphocytes	Chromatin condensation by anomalous viscosity	Analysis of pooled data from all donors showed statistically significant effect of 1-h exposure to MW. Effects differ at various GSM frequencies and vary between donors.
Sarkar et al. [71]	Mouse testis and brain cells	Restriction pattern after Hinfl treatment	As compared to control animals, band patterns in exposed animals were found to be distinctly altered in the range of 7–8 kb which was also substantiated by densitometric analysis.
Schwarz et al. [33]	Human cultured fibroblasts and lymphocytes	Alkaline comet assay and MN	UMTS exposure increased the CTF and induced centromere-negative micronuclei in human cultured fibroblasts in a dose- and time-dependent way. No UMTS effect was obtained with lymphocytes, either unstimulated or stimulated with phytohemagglutinin.
Sykes et al. [22]	pKZ1 mice	lacZ transgene inversion	No difference between the control and treated groups in the 1- and 5-day exposure groups, but a reduction in inversions below the spontaneous frequency in the 25-day exposure group. This suggests that RF radiation can lead to a perturbation in recombination frequency.
Tice et al. [72]	Human blood lymphocytes	Alkaline comet assay and MN	Exposure for either 3 or 24 h with the unmodulated signal did not induce a significant increase in DNA DSB or MN in lymphocytes. However, with the modulated signal there was a significant and reproducible increase in the frequency of micronucleated lymphocytes.
Tkalec et al. [14]	*Allium cepa* seeds	Germination, mitotic index, mitotic abnormalities	Increased mitotic aberrations in root meristematic cells of *A. cepa*. Effects were markedly dependent on the field frequencies applied as well as on field strength and modulation. Findings also indicate that mitotic effects of RF-EMF could be due to impairment of the mitotic spindle.
Trosic et al. [73]	Rat hematopoietic tissues	MN and polychromatic erythrocytes (PCEs)	The incidence of micronuclei/1000 PCEs in peripheral blood was significantly increased ($p < 0.05$) in the subgroup exposed to fro/MW radiation after eight irradiation treatments of 2 h each in comparison with the sham-exposed control group.

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Table 1 (*Continued*)

Reference	Biological system	Genotoxic endpoint	Results and comments
Trosic et al. [74]	Rat hematopoietic tissues	MN and polychromatic erythrocytes	In polychromatic erythrocytes significant differences ($p < 0.05$) for experimental days 8 and 15. The frequency of micronucleated PCEs was also significantly increased on experimental day 15 ($p < 0.05$).
Trosic and Busljeta [75]	Rat hematopoietic tissues and peripheral blood	MN and polychromatic erythrocytes	BMPCEs were increased on days 8 and 15, and PBPCEs were elevated on days 2 and 8 ($p < 0.05$).
Vijayalaxmi et al. [76]	C3H/HeJ cancer prone mice, peripheral blood and bone marrow	MN	No observed RF effects. A correction was published, stating that there was actually a significant MN increase in peripheral blood and bone marrow cells after chronic exposure to RF [Vijayalaxmi, M.R. Frei, S.J. Dusch, V. Guel, M.L. Meltz, J.R. Jauchem, Radiat. Res. 149 (3) (1998) 308].
Wu et al. [39]	Human epithelial lens cells	Comet assay and intracellular ROS	RF at 4 W/kg for 24 h significantly increased intracellular ROS and DNA damage. Both can be blocked completely by electromagnetic noise.
Yadav and Sharma [8]	Exfoliated buccal cells	MN in buccal cells	In exposed subjects 9.84 ± 0.745 micronucleated cells and 10.72 ± 0.889 total micronuclei (TMN) as compared to zero duration of exposure along with average 3.75 ± 0.774 MNC and 4.00 ± 0.808 TMN in controls. Correlation between 0–1, 1–2, 2–3 and 3–4 years of exposure and the frequency of MNC and TMN.
Yao et al. [40]	Human lens epithelial cells	Alkaline comet assay, gamma-H2AX foci, ROS level	SAR of 3 and 4 W/kg induced significant DNA damage in the comet assay, while no statistical difference in double strand breaks was found by γH2AX foci. Electromagnetic noise could block RF-induced ROS formation and DNA damage.
Yao et al. [41]	Human lens epithelial cells	Alkaline comet assay, γH2AX foci, ROS level	DNA damage was significantly increased by comet assay at 3 and 4 W/kg, whereas double strand breaks by γH2AX foci were significantly increased only at 4 W/kg. Significantly increased ROS levels were detected in the 3 and 4 W/kg groups.
Zhang et al. [77]	Chinese hamster lung cells (CHL)	γH2AX foci	Increased percentage of γH2AX foci positive cell of 1800 MHz RF EMF exposure for 24 h ($37.9 \pm 8.6\%$) or 2-acetylaminofluorene exposure ($50.9 \pm 9.4\%$). However, there was no significant difference between the sham-exposure and RF EMF exposure for 1 h ($31.8 \pm 8.7\%$).
Zotti-Martelli et al. [78]	Human blood lymphocytes	MN	Both spontaneous and induced MN frequencies varied in a highly significant way among donors ($p < 0.009$) and between experiments ($p < 0.002$), and a statistically significant increase of MN, although rather low, was observed dependent on exposure time ($p = 0.0004$) and applied power density ($p = 0.0166$).
Zotti-Martelli et al. [79]	Human blood lymphocytes	MN	The results showed for both radiation frequencies an induction of micronuclei as compared to the control cultures at a power density of 30 mW/cm^2 and after an exposure of 30 and 60 min.

Abbreviations: Mitomycin C (MMC), bleomycin (BLM), methylmethansulfonate (MMS), 4-nitroquinoline-1-oxide (4-NQ1O), ethylmethansulfonate (EMS), chromosomal aberration analysis (CA), micronucleus assay (MN), reactive oxygen species (ROS), and fluorescence *in vitro* hybridization (FISH).

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Table 2
Publications which do not report RF-EMF related genotoxic effects.

Reference	Biological system	Genotoxic endpoint	Results and comments
Antonopouloset al. [80]	Human blood lymphocytes	SCE	No increase in SCE or cell cycle progression found.
Belyaev et al. [81]	Rat brain, spleen, and thymus	Comet assay	GSM MWs at 915 MHz did not induce PFGE-detectable DNA double stranded breaks or changes in chromatin conformation, but affected expression of genes in rat brain cells.
Bisht et al. [82]	Mouse C3H 10T cells	MN	CDMA (3.2 or 4.8 W/kg) or FDMA (3.2 or 5.1 W/kg) RF-EMF radiation for 3, 8, 16 or 24 h did not result in a significant increase either in the percentage of binucleated cells with micronuclei or in the number of micronuclei per 100 binucleated cells.
Chang et al. [83]	*Escherichia coli* tester strain	Bacterial mutagenicity (Ames test)	No mutagenic or co-mutagenic effect with 4-NQ1O.
Ciaravino et al. [84]	CHO cells	SCE	Radiofrequency electromagnetic radiation (RF-EMF) did not change the number of SCEs that were induced by adriamycin.
Garson et al. [85]	Human blood lymphocytes	CA	No RF-EMF effect observed.
Gorlitz et al. [86]	B6C3F1 mice lymphocytes, erythrocytes, and keratinocytes	MN	No visible effect.
Gos et al. [87]	*Saccharomyces cerevisiae*	Mutation rates	No effects in fluctuation tests on forward mutation rates at CAN1, on the frequency of petite formation, on rates of intra-chromosomal deletion formation, or on rates of intra-genic recombination in the absence or presence of MMS.
Hook et al. [88]	Molt-4 T lymphoblastoid cells	Comet assay	No RF-EMF effects observed.
Juutilainen et al. [89]	Female CBA/S mice and K2 female transgenic mice	MN in erythrocytes	No effect on MN frequency.
Kerbacher et al. [90]	CHO cells	CA	No alteration was observed in the extent of chromosome aberrations induced by either simultaneous fro radiation exposure or convection heating to equivalent temperatures.
Komatsubara et al. [91]	Mouse m5S cells	CA	No effect on CA; temperature increase up to 41 °C at 100 W/kg.
Koyama et al. [92]	CHO cells	MN	No MN increase in cells exposed to HFEMF at a SAR of lower than 50 W/kg, while those at SARs of 100 and 200 W/kg were significantly higher when compared with the sham-exposed controls (temperature effect).
Lagroye et al. [93]	Rat brain cells	Alkaline comet assay	No observed effect.
Lagroye et al. [94]	C3H 10T1/2 cells	Comet assay, DNA–protein crosslinks	No observed effect.
Li et al. [95]	Murine C3H 10T cells	Comet assay	No observed effect.
Maes et al. [96]	Human blood lymphocytes	CA, SCE	Combined exposure of RF-EMF and to MMC and X-rays. Overall, no indication was found of a mutagenic, and/or co-mutagenic/synergistic effect.
Maes et al. [97]	Human blood lymphocytes	CA, SCE	Combined treatments with X-rays or MMC did not provide any indication of a synergistic action between the RF-EMF fields and X-rays or MMC.
Maes et al. [98]	Human blood lymphocytes	CA, SCE, Comet assay	The alkaline comet assay, SCE, and CA tests revealed no evidence of RF-EMF-induced genetic effects. No cooperative action was found between the electromagnetic field exposure and MMC using either the comet assay or SCE test.
Malyapa et al. [99]	Rat brain cells	Comet assay	No significant differences observed.
Malyapa et al. [100]	U87MG and C3H 10T1/2 cells	Comet assay	No significant differences observed.
Malyapa et al. [101]	U87MG and C3H 10T1/2 cells	Comet assay	No significant differences observed.
McNamee et al. [102]	Human blood lymphocytes	Comet assay and MN	No significant differences observed.
McNamee et al. [103]	Human blood lymphocytes	Comet assay and MN	No significant differences observed.
McNamee et al. [104]	Human blood lymphocytes	Comet assay	No significant differences observed.
Meltz et al. [105]	L5178Y mouse leukemic cells	Mutation in TK locus	No effect of RF-EMF alone or in the induced mutant frequency due to the simultaneous exposure to RF-EMF and proclaim, as compared with the proflavin exposures alone.
Ono et al. [106]	lacZ-transgenic mice	Mutations at the lac gene in spleen, liver, brain and testis	Mutation frequencies at the lacZ gene in spleen, liver, brain, and testis were similar to those observed in non-exposed mice.

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Table 2 (*Continued*)

Reference	Biological system	Genotoxic endpoint	Results and comments
Roti Roti et al. [107]	C3H 10T1/2 cells	Transformed foci	No statistically significant differences observed.
Sakuma et al. [108]	Human glioblastoma A172 cells and fetal lung fibroblasts	DNA strand breaks (comet assay?)	No statistically significant differences.
Scarfi et al. [109]	Human blood lymphocytes	MN	No statistically significant differences observed.
Speit et al. [24]	Human cultured fibroblasts	Comet assay and MN	No statistically significant differences observed.
Stronati et al. [110]	Human blood lymphocytes	Comet assay, CA, SCE, MN	By comparison with appropriate sham-exposed and control samples, no effect of RF-EMF alone could be found for any of the assay endpoints. In addition RF-EMF did not modify any measured effects of the X-radiation.
Takahashi et al. [111]	Big Blue mice brain tissues	lacZ transgene inversion	No statistically significant differences observed.
Verschaeve et al. [112]	Rat brain and liver tissues, erythrocytes	MN (erythrocytes) and comet assay	No genotoxic effect of RF-EMF alone. Co-exposures to MX and RF-EMF radiation did not significantly increase the response of blood, liver and brain cells compared to MX exposure only.
Vijayalaxmi et al. [113]	Human blood lymphocytes	CA and MN	No observed RF-EMF effects.
Vijayalaxmi et al. [114]	Human blood lymphocytes	CA and MN	No observed RF-EMF effects.
Vijayalaxmi et al. [115]	Human blood lymphocytes	Comet assay	No observed RF-EMF effects.
Vijayalaxmi et al. [116]	Human blood lymphocytes	CA, MN	No observed RF-EMF effects.
Vijayalaxmi et al. [117]	Rat hematopoietic tissues and erythrocytes	MN	No observed RF-EMF effects.
Vijayalaxmi et al. [118]	Rat whole body and head only exposures. BM erythrocytes	MN	No observed RF-EMF effects.
Vijayalaxmi et al. [119]	CF-1 male mice, peripheral blood and bone marrow	MN	No observed RF-EMF effects.
Zeni et al. [120]	Human blood lymphocytes	Comet assay, CA, SCE	No observed RF-EMF effects.
Zeni et al. [121]	Human blood lymphocytes	MN	No observed RF-EMF effects.

Abbreviations: Chromosomal aberration analysis (CA), methotrexat (MX), mitomycin C (MMC), 4-nitroqinoline-1-oxide (4-NQ1O), methylmethansulfonate (MMS), code division multiple access (CDMA), frequency division multiple access (FDMA), and time division multiple access (TDMA).

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Table 3
Publications which report synergistic RF-EMF effects in combination with other genotoxicants.

Reference	Genotoxic agents	Biological system	Genotoxic endpoint	Results and comments
Baohong et al. [122]	MMC, BLM, MMS, 4-NQ1O	Human blood lymphocytes	Alkaline comet assay	1.8 GHz RFR (SAR, 3 W/kg) for 2 h did not induce DSB, but could enhance the human lymphocyte DNA damage effects induced by MMC and 4-NQ1O. The synergistic DNA damage effects with BLM or MMS were not obvious.
Baohong et al. [123]	254 nm UVC	Human blood lymphocytes	Alkaline comet assay	RF exposure for 1.5 and 4 h did not enhance significantly human lymphocyte DNA damage, but could reduce and increase DNA damage of human lymphocytes induced by UVC at 1.5 and 4 h incubation respectively.
Kim et al. [124]	Cyclophosphamide, 4-NQ1O, EMS	L5178Y mouse lymphoma cells (comet assay) and CHL cells (CA)	Alkaline comet assay and CA	No direct cytogenetic effect of RF alone or in combination with cyclophosphamide or 4-NQ1O was found in the CA test and in the comet assay. However, RF had a potentiating effect in combination with cyclophosphamide or 4-NQ1O.
Maes et al. [125]	MMC	Human blood lymphocytes	SCE	Synergistic effect was observed with MMC.
Maes et al. [126]	MMC	Human blood lymphocytes	CA, SCE, comet assay	The combined exposure of the cells to the radiofrequency fields followed by their cultivation in the presence of mitomycin C revealed a very weak effect when compared to cells exposed to mitomycin C alone.
Manti et al. [11]	Previous 4 Gy X-ray radiation	Human blood lymphocytes	Chromosome aberration by FISH	No significant variations due to the UMTS exposure in the fraction of aberrant cells, but frequency of exchanges per cell in X-ray irradiated cells was significantly increased by UMTS at 2 W/kg.
Wang et al. [127]	254 nm UVC	Human blood lymphocytes	Comet assay	RF did not induce DNA damage but reduced or enhanced DNA damage by UVC at 1.5 or 4.0 h respectively.
Wang et al. [128]	MMC, BLM, MMS, 4-NQ1O	Human blood lymphocytes	Comet assay	RF did not induce DNA damage but enhanced DNA damage induced by MMC and 4-NQ1O.
Zhang et al. [129]	MMC	Human blood lymphocytes	Comet assay, micronucleus assay	No RF-induced DNA and chromosome damage, but increased MMC DNA damage by RF in comet assay.

Abbreviations: Mitomycin C (MMC), bleomycin (BLM), methylmethansulfonate (MMS), 4-nitroquinoline-1-oxide (4-NQ1O), ethylmethansulfonate (EMS), chromosomal aberration analysis (CA), fluorescence *in vitro* hybridization (FISH).

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fragments of chromosomes or from lagged chromosomes secondary to mitotic non-disjunction, the latter being detected by indirect immunofluorescence using kinetochore antibodies. Kinetochore-positive MN arise by epigenetic mechanisms (disturbances of the spindle apparatus). Kinetochore-negative MN arise from acentric chromosomal fragments. This is an important distinction, but has been performed in a few RF-EMF studies only, of which only one [12] reports an increase of kinetochore-positive MN albeit after a high SAR $\geq$ 78 W/kg. Two studies describe RF-EMF-induced disturbances of the spindle apparatus [13,14], and one reports an aneugenic RF-EMF effect on the basis of the size distribution of MN [15]. Of a total of 39 studies using the micronucleus assay 22 are MN-positive, and 17 MN-negative.

SCEs are analysed in metaphase chromosomes after two rounds of replication in the presence of 5-bromodeoxyuridine (BUDR). SCEs, which are induced during the S-phase of the cell cycle, represent an exchange between homologous chromatids, an event which by itself is genetically neutral. Nevertheless it is considered to reflect a recombinational repair of DNA double strand breaks (DSB), and may therefore serve as an indicator of genotoxic stress. Of 10 studies using SCE a GT(+) effect was reported in one only, 8 were negative, and one study reports RF-induced enhancement of genotoxicity by mitomycin C.

3. DNA fragmentation

The comet assay, also known as a “Single Cell Gel electrophoresis assay” (SCG), and the detection of gamma-H2AX foci are the most frequently used techniques to study RF-EMF-induced DNA strand breaks. The comet assay uses interphase nuclear DNA, which is unwinded under alkaline conditions and subsequently subjected to an electric field. Here DNA fragments migrate towards the anode, thereby forming a comet-like tail [16,17]. The alkaline comet assay detects DNA single strand as well as double strand breaks, but is not applicable in the presence of DNA crosslinking agents [18]. These breaks may occur not only by toxic influences but also by transcriptional and repair processes and by alkali-sensitive sites. Therefore this frequently used and very sensitive assay has a poor specificity. Of 41 studies using the comet assay 15 report comet-positive and 19 comet-negative results after RF-EMF exposure. RF-EMF enhancement of comet assay effects caused by other genotoxic agents is described in 7 studies.

Out of a multitude of DNA damage checkpoint proteins two have been used to detect DBS: H2AX, a member of the nuclear histone family [19], and P53 binding protein (53BP1). Both are rapidly phosphorylated only minutes after DNA damage and are then gathered in the vicinity of DNA double strand breaks. Here they form foci which can be visualized by indirect immunofluorescence [20,21]. These foci represent an initial and specific step in the repair process of exogenously induced DNA double strand breaks. It is important to realize, however, that repair processes of DSB are quantified, not DSB themselves. The method has been employed in 4 studies, predominantly using the yH2AX foci test. In all instances GT(+) effects have been detected.

DNA alterations have also been analysed by the anomalous viscosity time dependency test (AVTD, 1 GT(+) study), detecting conformational changes, and by quantitative PCR (QPCR, 1 GT(+) study) detecting structural changes in the DNA.

4. Gene mutations

In this category 6 studies have been performed using 4 different endpoints: (1) Altered restriction fragments (1 GT(+) study), (2) lacZ inversion in transgenic mice. This method has been used in 3 studies which all failed to detect an increased rate of inversions, but one found a reduced rate as compared to unexposed controls [22], which is interpreted as a RF-EMF-induced reduction of recombination repair. (3) Mutation at the thymidine kinase (TK) locus (1 negative study). (4) Bacterial his^- revertants (Ames test, 1 negative study).

5. Discussion

The large number of contradictory results among the 101 published studies on a genotoxic action of RF-EMF is tangling. Nevertheless patterns can be perceived. GT(+) as well as GT(−) findings have been reported at a standard absorption ratio (SAR) below 0.05 up to 100 W/kg and an exposure of 15 min and 48 h *in vitro*, and between hours and years *in vivo*. The outcome of studies was nearly independent from RF frequencies between 300 and 7700 MHz and the type of RF signal, either continuous wave (CW) or pulse-modulated (PM). GT(+) was obtained in 15 CW and 26 PM exposures, GT(−) in 14 CW and 27 PM exposures (some studies did not indicate the type of signal used). Contradictory results have been obtained even when two experienced groups performed the same experiments using the same cells and identical exposure conditions [23,24]. This may reflect a general problem of genotoxic studies being dependent on a multitude of factors which are difficult to control [25]. Some of the studies exploited here have shortcomings with respect to incompletely described or unreliable exposure conditions and/or an inadequate experimental design. Even a considerable publication bias in favour of negative results has been suspected (www.microwavenews.com/RR.html, 2006) [26].

The proportion of GT(+) effects is much higher *in vivo* (23/40) than i*n vitro* (29/77). (Since some studies have been performed on more than one biological system, the total number of GT(+) and GT(−) effects exceeds the total number of published studies.) Considering all genotoxic endpoints applied, the frequently used parameters chromosome analysis (9/21 GT(+)), comet assay (15/41 GT(+)), and sister-chromatid-exchange (1/10 GT(+)) showed the highest

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proportion of negative results, while the micronucleus assay yielded more positive than negative results (22/39 GT(+)). Since the SCE test which was negative in nearly all cases is known to be rather insensitive to radiomimetic (clastogenic) agents it can be speculated, that a clastogenic mechanism is involved in RF-EMF genotoxic action.

Epigenetic influences may also contribute to genotoxicity as demonstrated by RF-EMF-induced chromosomal non-disjunction and disturbances of the mitotic spindle. This is in agreement with the higher proportion of 22/39 GT(+) findings among studies using the micronucleus assay as compared to those using CA, because some of the micronuclei may represent lagged chromosomes. Epigenetic mechanisms may also be effective after a combined exposure to RF-EMF and various physical or chemical mutagens (Table 4). RF-EMF preferentially enhanced the genotoxic effect of 4-NQ1O (4/4), MMC (4/8), UVC (2/2), and cyclophosphamide (2/2). No synergistic effect was obtained using MMS and EMS (3/3), BLM (2/2), and adriamycine (2/2). Only one out of 3 studies reported a synergistic effect with X-rays.

Cells and tissues of different origin exhibit a clearly variable sensitivity for genotoxic RF-EMF effects (Table 4). This has also been observed with extremely low frequency (ELF)-EMF [27] and may be dependent on genetic differences [28]. GT(+) effects of RF-EMF were reported predominantly in the following biological systems: human lens epithelial cells (4/4), human buccal mucosa cells (2/2), rodent brain tissues (8/13), and rat hemopoietic tissues (5/7). GT(−) results have been obtained with mouse permanent cell lines (7/7) and permanent lymphoblastoid cells of various origin (7/7). This is in a striking analogy to RF-EMF-induced reduction of ornithine decarboxylase activity being detected in primary but not in secondary neural cells [29].

6. Proposed mechanisms of RF-EMF genotoxicity

Cells are unusually sensitive to electromagnetic fields [30]. Weak fields may accelerate electron transfer and thereby destabilize the H-bond of cellular macromolecules. This could explain the stimulation of transcription and protein expression, which has been observed after RF-EMF exposure [31,32]. However, the energy of weak EM fields is not sufficient directly to break a chemical bond in DNA. Therefore it can be concluded, that genotoxic effects are mediated by indirect mechanisms as microthermal processes, generation of oxygen radicals (ROS), or a disturbance of DNA-repair processes.

6.1. Thermal effects

An increase of temperature in the culture medium of RF-EMF exposed cells has been observed at very high SAR levels only [12]. The vast majority of GT(+) studies were conducted at SAR < 2.0 not leading to a detectable increase of temperature in the culture medium. Moreover, similar or larger effects have been observed at a 5′ on/10′ off intermittent exposure [23,33], a result that contradicts a

Table 4
Distribution RF-EMF effects in 101 published studies.

Biological system	RF-EMF effects		Synergistic effects	
	Positive	Negative	Positive	Negative
In vitro (all cells and tissues)	29	39	9	11
Human blood lymphocytes	18	23	8	4
Human lens epithelial cells	4			
Human cultured fibroblasts	2	2		
Human glioblastoma cells		3		
Human lymphoblastoid cells		2		
Mouse permanent cell lines		6		1
Mouse lymphoblastoid cells		1	1	1
Chinese hamster cells (CHO, V79)	4	2		3
E. coli		1		2
Yeast		1		
Rat granulosa cells	1			
In vivo (all species and tissues)	23	17	0	1
Human blood lymphocytes	4	2		
Human buccal mucosa cells	2			
Mouse sperm	1			
Mouse brain tissues	2			
Mouse polychromatic erythrocytes		4		
Rat brain tissues	6	4		1
Rat hemopoietic tissues	5	2		
Rat spleen, liver		2		
lacZ-transgenic mice		3		
Plants	2			
Cattle polychromatic erythrocytes	1			

Since several published studies have used more than 1 biological system the total of negative and positive effects exceeds the number of 101 publications.

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simple temperature-based mechanism of the observed genotoxic action. However, experimental results with microwave absorption at colloidal interfaces have demonstrated that the electric absorption of microwaves between 10 and 4000 MHz goes through a maximum with the size of bride droplets >100 and <10,000 nm, and depends on the type of ions and their concentrations [34]. This local absorption of microwaves may therefore lead to a considerable local heating in living cells during low energy microwave exposure.

6.2. Oxygen radicals

There is evidence that RF-EMF may stimulate the formation of reactive oxygen species in exposed cells *in vivo* [35–37] and *in vitro* [38–41]. Free oxygen radicals may form base adducts in DNA, the most important lesion being 8-OHdG, and oxidize also other cellular components, such as lipids leaving behind reactive species, that in turn can couple to DNA bases [42]. The first step in the generation of ROS by microwaves is mediated in the plasma membrane by NADH oxidase [43]. Subsequently ROS activates matrix metalloproteases (MMP), thereby initiating intracellular signalling cascades. It is interesting to note that these processes start within 5 min of radiation and at a very low field intensity of 0.005 W/cm^2. Moreover, higher effects have been obtained by intermittent radiation, when cells were left unirradiated for 10 min. This is in agreement with *in vitro* genotoxicity studies using the comet assay [23,33].

6.3. Alteration of DNA-repair processes

A considerable proportion of studies have investigated the consequences of a combined exposure to RF-EMF and various chemical or physical mutagens. 8/12 studies using human blood lymphocytes have demonstrated that RF-EMF enhanced the genotoxic action of other agents, preferentially of UV, MMC, or 4-NQ1O (an UV-mimetic agent). Since in all these experiments microwave exposure failed to induce detectable genotoxic effect by itself, an interference with DNA-repair mechanisms has been postulated, however, there is no direct experimental proof yet. An alteration of recombinational repair has also been proposed by Sykes et al. [22] as an explanation of the reduced rate of inversions in lacZ-transgenic mice after RF-EMF treatment.

An influence of microwave exposure on DNA-repair processes has long been proposed for power frequency electromagnetic fields [35]. A recent epidemiological investigation into the frequency of polymorphisms of DNA-repair genes in children with acute leukemia living in the vicinity of power line transformers [44] emphasizes the significance DNA-repair impairment for an EMF related increase of this malignancy. There was a significant gene–environment interaction (COR = 4.31) between the electromagnetic field intensities and a less active genetic variant of XRCC1, a crucial enzyme in base excision repair.

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Please cite this article in press as: H.W. Ruediger, Genotoxic effects of radiofrequency electromagnetic fields, Pathophysiology (2009), doi:10.1016/j.pathophys.2008.11.004

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Please cite this article in press as: H.W. Ruediger, Genotoxic effects of radiofrequency electromagnetic fields, Pathophysiology (2009), doi:10.1016/j.pathophys.2008.11.004

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Please cite this article in press as: H.W. Ruediger, Genotoxic effects of radiofrequency electromagnetic fields, Pathophysiology (2009), doi:10.1016/j.pathophys.2008.11.004

Pathophysiology xxx (2009) xxx–xxx

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Epidemiological evidence for an association between use of wireless phones and tumor diseases

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Received 7 November 2008; accepted 30 January 2009

Abstract

During recent years there has been increasing public concern on potential cancer risks from microwave emissions from wireless phones. We evaluated the scientific evidence for long-term mobile phone use and the association with certain tumors in case–control studies, mostly from the Hardell group in Sweden and the Interphone study group. Regarding brain tumors the meta-analysis yielded for glioma odds ratio (OR) = 1.0, 95% confidence interval (CI) = 0.9–1.1. OR increased to 1.3, 95% CI = 1.1–1.6 with 10 year latency period, with highest risk for ipsilateral exposure (same side as the tumor localisation), OR = 1.9, 95% CI = 1.4–2.4, lower for contralateral exposure (opposite side) OR = 1.2, 95% CI = 0.9–1.7. Regarding acoustic neuroma OR = 1.0, 95% CI = 0.8–1.1 was calculated increasing to OR = 1.3, 95% CI = 0.97–1.9 with 10 year latency period. For ipsilateral exposure OR = 1.6, 95% CI = 1.1–2.4, and for contralateral exposure OR = 1.2, 95% CI = 0.8–1.9 were found. Regarding meningioma no consistent pattern of an increased risk was found. Concerning age, highest risk was found in the age group <20 years at time of first use of wireless phones in the studies from the Hardell group. For salivary gland tumors, non-Hodgkin lymphoma and testicular cancer no consistent pattern of an association with use of wireless phones was found. One study on uveal melanoma yielded for probable/certain mobile phone use OR = 4.2, 95% CI = 1.2–14.5. One study on intratemporal facial nerve tumor was not possible to evaluate due to methodological shortcomings. In summary our review yielded a consistent pattern of an increased risk for glioma and acoustic neuroma after >10 year mobile phone use. We conclude that current standard for exposure to microwaves during mobile phone use is not safe for long-term exposure and needs to be revised.

Keywords: Brain tumors; Glioma; Acoustic neuroma; Meningioma; Cellular phones; Cordless phones

1. Introduction

During the last decade there has been a rapid development of wireless technology and along with that an increased use of wireless telephone communication in the world. Most persons use mobile phones and cordless phones. Additionally most populations are exposed to radiofrequency/microwave (RF) radiation emissions from wireless devices such as cellular antennas and towers, broadcast transmission towers, voice and data transmission for cell phones, pagers and personal digital assistants and other sources of RF radiation.

Concerns of health risks have been raised, primarily an increased risk for brain tumors, since the brain is the near field target organ for microwave exposure during mobile phone calls. Especially the ipsilateral brain (same side as the mobile phone has been used) is exposed, whereas the contralateral side (opposite side to the mobile phone) is much less exposed [1]. Thus, for risk analysis it is of vital importance to have information on the localisation of the tumor in the brain and which side of the head that has been predominantly used during phone calls.

Since Sweden was one of the first countries in the world to adopt this wireless technology a brief history is given in the following. First, analogue phones (NMT; Nordic Mobile Telephone System) were introduced on the market in the early 1980s using both 450 and 900 Megahertz (MHz) carrier waves. NMT 450 was used in Sweden since 1981 but closed down in December 31, 2007, whereas NMT 900 operated during 1986–2000.

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doi:10.1016/j.pathophys.2009.01.003

Table 1
Odds ratios (ORs) and 95% confidence intervals (CIs) from 11 case–control studies on glioma including meta-analysis of the studies. Numbers of exposed cases and controls are given.

Author, year of publication, country, reference number	No. of cases	No. of controls	OR	95% CI
Inskip et al., 2001, USA [23]	201	358	1.0	0.7–1.4
Auvinen et al., 2002, Finland [24]	Not given	Not given	1.5	1.0–2.4
Lönn et al., 2005, Sweden [25][a]	214	399	0.8	0.6–1.0
Christensen et al., 2005, low-grade glioma, Denmark [26][a]	47	90	1.1	0.6–2.0
Christensen et al., 2005, high-grade glioma, Denmark [26][a]	59	155	0.6	0.4–0.9
Hepworth et al., 2006, UK [27][a]	508	898	0.9	0.8–1.1
Schüz et al., 2006, Germany [28]	138	283	1.0	0.7–1.3
Hardell et al., 2006, Sweden [12], all glioma	346	900	1.4	1.1–1.7
Low-grade glioma	65	900	1.4	0.9–2.3
High-grade glioma	281	900	1.4	1.1–1.8
Lahkola et al., 2006, Denmark, Norway, Finland, Sweden, UK [29]	867	1 853	0.8	0.7–0.9
Hours et al., 2007, France [30]	59	54	1.2	0.7–2.1
Klaeboe et al., 2007, Norway [31][a]	161	227	0.6	0.4–0.9
Takebayashi et al., 2008, Japan [17]	56	106	1.2	0.6–2.4
Meta-analysis	>1667[b]	>3554[b]	1.0	0.9–1.1

[a] Not included in meta-analysis because already part of pooled data in Lahkola et al., 2006 [29].
[b] Total number could not be calculated since numbers were not presented in one publication [24].

The digital system (GSM; Global System for Mobile Communication) using dual band, 900 and 1800 MHz, started to operate in 1991 and now dominates the market. The third generation of mobile phones, 3G or UMTS (Universal Mobile Telecommunication System), using 1900 MHz RF broad band transmission has been introduced worldwide since a few years, in Sweden since 2003.

Desktop cordless phones have been used in Sweden since 1988, first analogue 800–900 MHz RF fields, but since early 1990s the digital 1900 MHz DECT (Digital Enhanced Cordless Telecommunications) system is used. In our studies on tumor risk associated with use of wireless phones, we have also assessed use of cordless phones. However, most other research groups have not published such data at all, or only in a scanty way, so exposure to RF from DECT is not further discussed here. Instead the reader is referred to our previous publications on this issue [2–13].

The initial studies on brain tumor risk had too short latency periods to give a meaningful interpretation. However, during recent years studies have been published that enable evaluation of ≥10-years latency period risk, although still mostly based on low numbers [14,15]. A ≥10-years latency period seems to be a reasonable minimum period to indicate long-term carcinogenic risks from exposure to RF fields during use of mobile or cordless phones.

Table 2
Odds ratios (ORs) and 95% confidence intervals (CIs) from six case–control studies on glioma including meta-analysis of the studies using ≥10 year latency period. Numbers of exposed cases and controls are given.

Study	Total			Ipsilateral			Contralateral		
Author, year of publication, country, latency, reference number	No. of cases/controls	OR	95% CI	No. of cases/controls	OR	95% CI	No. of cases/controls	OR	95% CI
Lönn et al., 2005, Sweden, ≥10 years [25][a]	25/38	0.9	0.5–1.5	15/18	1.6	0.8–3.4	11/25	0.7	0.3–1.5
Christensen et al., 2005, Denmark, low-grade glioma, ≥10 years [26][a]	6/9	1.6	0.4–6.1	–	–	–	–	–	–
Christensen et al., 2005, Denmark, high-grade glioma, ≥10 years [26][a]	8/22	0.5	0.2–1.3	–	–	–	–	–	–
Hepworth et al., 2006, UK, ≥10 years [27][a]	66/112	0.9	0.6–1.3	Not given	1.6	0.9–2.8	Not given	0.8	0.4–1.4
Schüz et al., 2006, Germany, ≥10 years [28]	12/11	2.2	0.9–5.1	–	–	–	–	–	–
Hardell et al., 2006, Sweden, >10 years [12], all glioma	78/99	2.7	1.8–3.9	41/28	4.4	2.5–7.6	26/29	2.8	1.5–5.1
Low-grade glioma	7/99	1.5	0.6–3.8	2/28	1.2	0.3–5.8	4/29	2.1	0.6–7.6
High-grade glioma	71/99	3.1	2.0–4.6	39/28	5.4	3.0–9.6	22/29	3.1	1.6–5.9
Lahkola et al., 2006, Denmark, Norway, Finland, Sweden, UK, ≥10 years [29]	143/220	0.95	0.7–1.2	77/117	1.4	1.01–1.9	67/121	1.0	0.7–1.4
Meta-analysis	233/330	1.3	1.1–1.6	118/145	1.9	1.4–2.4	93/150	1.2	0.9–1.7

[a] Not included in meta-analysis because already part of pooled data in Lahkola et al., 2006 [29].

Please cite this article in press as: L. Hardell, et al., Epidemiological evidence for an association between use of wireless phones and tumor diseases, Pathophysiology (2009), doi:10.1016/j.pathophys.2009.01.003

Table 3
Odds ratios (ORs) and 95% confidence intervals (CIs) from nine case–control studies on acoustic neuroma including meta-analysis of the studies. Numbers of exposed cases and controls are given.

Author, year of publication, country, reference number	No. of cases	No. of controls	OR	95% CI
Inskip et al., 2001, USA [23]	40	358	0.8	0.5–1.4
Lönn et al., 2004, Sweden [32][a]	89	356	1.0	0.6–1.5
Christensen et al., 2004, Denmark [33][a]	45	97	0.9	0.5–1.6
Schoemaker et al., 2005, Denmark, Finland, Sweden, Norway, Scotland, England [34]	360	1934	0.9	0.7–1.1
Hardell et al., 2006, Sweden [11]	130	900	1.7	1.2–2.3
Takebayashi et al., 2006, Japan [35]	51	192	0.7	0.4–1.2
Klaeboe et al., 2007, Norway [31][a]	22	227	0.5	0.2–1.0
Schlehofer et al., 2007, Germany [36]	29	74	0.7	0.4–1.2
Hours et al., 2007, France [30]	58	123	0.9	0.5–1.6
Meta-analysis	668	3581	1.0	0.8–1.1

[a] Not included in meta-analysis because already part of pooled data in Schoemaker et al., 2005 [34].

Long-term exposure to RF fields from mobile phones and brain tumor risk is of importance to evaluate, not the least since the use of cellular phones is globally widespread with high prevalence among almost all age groups in the population. In the following we discuss mobile phone use and the association with brain tumors, but also other tumor types that have been studied. Recently, we published a detailed review of studies on brain tumors [14] followed by meta-analyses of published studies regarding glioma, acoustic neuroma and meningioma [15]. We have now recalculated these results with the addition of two new recently published articles from the Interphone study group [16,17]. Studies from individual countries were only included in the meta-analyses if they were not also included in the joint publications for several countries. For odds ratio (OR) and 95% confidence interval (CI) we used fixed effects model as in the recent publication by Kundi [18]. The analyses were done using Stata/SE 10 (Stata/SE 10 for Windows; StataCorp., College Station, TX).

One case–control study was excluded since no separate data were presented for glioma, acoustic neuroma or meningioma [19], and another since no overall data on acoustic neuroma were published, only for some time periods without results for ≥10 year latency period [20].

Due to several methodological limitations a Danish cohort study on "mobile phone subscribers" [21] is not possible to include in the meta-analysis, and the same methodological shortcomings prevail in the published updated cohort [22]. In the following only a short overview of the results for brain tumors is given, since we have discussed these issues in more detail elsewhere [14,15]. The other tumor types that have been studied are salivary gland tumors, non-Hodgkin lymphoma (NHL), testicular cancer, eye melanoma and facial nerve tumor.

2. Glioma

Glioma is a malignant type of brain tumor and comprises about 60% of all central nervous system tumors. The highly malignant glioblastoma multiform, with poor survival, is included in this group.

Eleven case–control studies present results for glioma [12,17,23–31]. Of these eight [17,25–31] were part of the Interphone study and four of these [25–27,31] were included in a pooled-analysis with additional data for Finland [29]. The results are presented in Table 1. Overall no decreased

Table 4
Odds ratios (ORs) and 95% confidence intervals (CIs) from four case–control studies on acoustic neuroma including meta-analysis of the studies using ≥10 year latency period. Numbers of exposed cases and controls are given.

Study	Total			Ipsilateral			Contralateral		
Author, year of publication, country, latency, reference number	No. of cases/controls	OR	95% CI	No. of cases/controls	OR	95% CI	No. of cases/controls	OR	95% CI
Lönn et al., 2004, Sweden, ≥10 years [32][a]	14/29	1.8	0.8–4.3	12/15	3.9	1.6–9.5	4/17	0.8	0.2–2.9
Christensen et al., 2004, Denmark, ≥10 years [33][a]	2/15	0.2	0.04–1.1	–	–	–	–	–	–
Schoemaker et al., 2005, Denmark, Finland, Sweden, Norway, Scotland, England, ≥10 years [34]	47/212	1.0	0.7–1.5	31/124	1.3	0.8–2.0	20/105	1.0	0.6–1.7
Hardell et al., 2006, Sweden, >10 years [11]	20/99	2.9	1.6–5.5	10/28	3.5	1.5–7.8	6/29	2.4	0.9–6.3
Meta-analysis	67/311	1.3	0.97–1.9	41/152	1.6	1.1–2.4	26/134	1.2	0.8–1.9

[a] Not included in meta-analysis because already part of pooled data in Schoemaker et al., 2005 [34].

or increased risk was found for glioma in the meta-analysis; OR = 1.0, 95% CI = 0.9–1.1.

Results for 10 year latency period are presented in Table 2. Six studies [12,25–29] gave such information and three [25–27] of these were also part of the publication by Lahkola et al. [29]. The meta-analysis yielded significantly increased risk for glioma with OR = 1.3, 95% CI = 1.1–1.6 increasing to OR = 1.9, 95% CI = 1.4–2.4 for ipsilateral exposure. The latter results were based on 118 exposed cases and 145 exposed controls. Regarding contralateral exposure to microwaves from mobile phones a lower risk was calculated, OR = 1.2, 95% CI = 0.9–1.7 (n = 93 cases, 150 controls). It should be noted that in the study by Takebayashi et al. [17] analyses of maximum microwave energy absorbed at the location of the tumor gave OR = 1.6, 95% CI = 0.6–4.2 related to the highest quartile of cumulative phone time weighted by maxSAR and OR = 5.8, 95% CI = 0.96–36 for subjects with cumulative maxSAR-hour of $\geq$10 W/kg-h.

3. Acoustic neuroma

These tumors are benign and do not undergo malignant transformation. They tend to be encapsulated and grow in relation to the auditory and vestibular portions of nerve VIII. They are slow growing tumors initially in the auditory canal, but gradually grow out into the cerebellopontine angle, where they come into contact with vital brain stem centers.

Nine case–control studies have been published [11,23, 30–36], see Table 3. Seven [30–36] were part of the Interphone study and three [31–33] were included in the publication by Schoemaker et al. [34]. Analysis of the total material yielded OR = 1.0, 95% CI = 0.8–1.1 increasing to 1.3, 95% CI = 0.97–1.9 using 10 year latency period, Table 4. For ipsilateral exposure OR increased further to 1.6, 95% CI = 1.1–2.4, whereas contralateral exposure gave a non-significantly increased risk, OR = 1.2, 95% CI = 0.8–1.9.

4. Meningioma

Meningioma arises from the pia or archnoid, which are the covering layers of the central nervous system. The majority are benign tumors that are encapsulated and well-demarched from surrounding tissue.

Regarding meningioma results have been published from nine case–control studies, Table 5 [11,16,17,23,25,26, 28,30,31]. Of these, seven [16,17,25,26,28,30,31] were part of the Interphone studies. The Lahkola et al. study [16] included three separately published Interphone studies [25,26,31]. The meta-analysis in Table 5 gave a significantly reduced OR = 0.9, 95% CI = 0.8–0.9. These results were mainly caused by the findings in the Interphone study [16] with the largest numbers of cases and controls yielding OR = 0.8, 95% CI = 0.7–0.9 in that study.

Using 10 year latency period OR was close to unity and somewhat increased for ipsilateral exposure, OR = 1.3, 95% CI = 0.9–1.8, Table 6. Regarding contralateral exposure OR was non-significantly decreased to 0.8, 95% CI = 0.5–1.3. The results for laterality were based on only two studies [11,16].

5. Brain tumor risk in different age groups

We grouped cases and controls according to age when they started to use a mobile or a cordless phone [11,12]. Consistently we found the highest risk for those with first use <20 years age. Thus, for malignant brain tumors OR = 2.7, 95% CI = 1.3–6.0 was calculated for mobile phones and OR = 2.1, 95% CI = 0.97–4.6 for cordless phones. The corresponding results for benign brain tumors were OR = 2.5, 95% CI = 1.1–5.9 and OR = 0.6, 95% CI = 0.2–1.9, respectively. Previously, we published results for diagnosis of brain tumor in different age groups [37] and found highest OR = 5.9, 95% CI = 0.6–55 for ipsilateral use of analogue phones in the youngest age group 20–29 years at the time of diagnosis. Using a >5 years latency period increased the risk further.

6. Brain tumor risk for use of mobile phone in urban and rural areas

There is a difference in output power of digital mobile phones between urban and rural areas. Adaptive power control (APC) regulates power depending on the quality of the transmission. In rural areas with on average longer distance to the base station the output power level is higher than in urban areas with dense population and shorter distance to the base stations. We studied the risk for brain tumors in urban versus rural living from the data in our study with cases diagnosed January 1, 1997 to June 30, 2000 [38]. Regarding digital phones OR = 1.4, 95% CI = 0.98–2.0 was obtained for living in rural areas increasing to OR = 3.2, 95% CI = 1.2–8.4 with >5 years latency period. The corresponding results for living in urban areas were OR = 0.9, 95% CI = 0.8–1.2 and OR = 0.9, 95% CI = 0.6–1.4, respectively.

7. Salivary gland tumors

The salivary glands, especially the parotid gland, are targets for near-field microwave exposure during calls with wireless phones. A Finnish study reported OR = 1.3, 95% CI = 0.4–4.7 for those who had ever had a mobile phone subscription [24].

Results from three case–control studies have been published, one from Sweden, one from the Nordic countries and one from Israel. During the same period as our studies on brain tumors we performed a study on salivary gland tumors [39]. Our study included the whole Swedish pop-

Table 5
Odds ratios (ORs) and 95% confidence intervals (CIs) from nine case–control studies on meningioma including meta-analysis of the studies. Numbers of exposed cases and controls are given.

Author, year of publication, country, reference number	No. of cases	No. of controls	OR	95% CI
Inskip et al., 2001 (USA) [23]	67	358	0.8	0.5–1.2
Lönn et al., 2005 (Sweden) [25][a]	118	399	0.7	0.5–0.9
Christensen et al., 2005 (Denmark) [26][a]	67	133	0.8	0.5–1.3
Schüz et al., 2006 (Germany) [28]	104	234	0.8	0.6–1.1
Hardell et al., 2006 (Sweden) [11]	347	900	1.1	0.9–1.3
Klaeboe et al., 2007 (Norway) [31][a]	96	227	0.8	0.5–1.1
Hours et al., 2007 (France) [30]	71	80	0.7	0.4–1.3
Lahkola et al., 2008 (Denmark, Norway, Finland, Sweden, UK) [16]	573	1696	0.8	0.7–0.9
Takebayashi et al., 2008, Japan [17]	55	118	0.7	0.4–1.2
Meta-analysis	1217	3386	0.9	0.8–0.9

[a] Not included in meta-analysis because already part of pooled data in Lahkola et al., 2008 [16].

ulation. Cases were recruited by using the regional cancer registries, and most had a malignant disease. They were diagnosed during 1994–2000, but with some variation for the different medical regions in Sweden. Population based controls were used as reference group. The questionnaire was answered by 267 (91%) of the cases and 750 (92%) of the controls. Of the cases 245 had a cancer diagnosis. Overall no association was found; analogue phones yielded OR = 0.9, 95% CI = 0.6–1.4, digital OR = 1.0, 95% CI = 0.7–1.5 and cordless phones OR = 1.0, 95% CI = 0.7–1.4. No effect of tumor induction period was found, although regarding >10 year latency period only 6 cases had used an analogue phone, OR = 0.7, 95% CI = 0.3–1.7, whereas no case had used a digital or cordless phone with that latency period. The results did not change significantly for ipsilateral or contralateral tumors.

The Nordic part of the Interphone case–control study of an association between use of mobile phones and parotid gland tumors was published in 2006 [40]. Detailed information about mobile phone use was obtained from 60 (85%) cases with malignant tumor, 112 (88%) with benign tumor and 681 (70%) controls. Regular mobile phone use gave OR = 0.7, 95% CI = 0.4–1.3 for malignant tumors and OR = 0.9, 95% CI = 0.5–1.5 for benign parotid gland tumors. For ipsilateral mobile phone use a latency period of ≥10 year yielded OR 0.7, 95% CI = 0.1–5.7 for malignant tumors ($n = 1$) and OR = 2.6, 95% CI = 0.9–7.9 for benign tumors ($n = 6$). Contralateral use was reported by one case with benign tumor and no case with malignant tumor in the same latency group.

As part of the Interphone study results on parotid gland tumor were reported from Israel [41]. It included 402 benign and 58 malignant incident cases, total 460 (87%) of 531 eligible for the time period 2001–2003. Population based matched controls were used, in total 1266 (66%) out of 1920 eligible subjects. Thirteen cases had a latency period of ≥10 year, which gave OR = 0.9, 95% CI = 0.4–1.8. No significantly increased risk was found for duration of use; ≥10 year yielded OR = 1.0, 95% CI = 0.5–2.1. However, for cumulative number of calls >5479 OR = 1.6, 95% CI = 1.1–2.2 was found for ipsilateral and both ears used equally, whereas contralateral use gave OR = 0.8, 95% CI = 0.5–1.2. Similarly, cumulative call time >266.3 h yielded OR = 1.5, 95% CI = 1.1–2.1; contralateral use gave OR = 0.8, 95% CI = 0.6–1.3.

In the meta-analysis using 10 year latency period no overall increased risk was found, OR = 0.8, 95% CI = 0.5–1.4, but for ipsilateral use it increased to OR = 1.7, 95% CI = 0.96–2.9, whereas contralateral use gave OR = 0.4, 95% CI = 0.2–1.2, Table 7.

Table 6
Odds ratios (ORs) and 95% confidence intervals (CIs) from five case–control studies on meningioma including meta-analysis of the studies using ≥10 year latency period. Numbers of exposed cases and controls are given.

Study	Total			Ipsilateral			Contralateral		
Author, year of publication, country, latency, reference number	No. of cases/controls	OR	95% CI	No. of cases/controls	OR	95% CI	No. of cases/controls	OR	95% CI
Lönn et al., 2005, Sweden, ≥10 years [25][a]	12/36	0.9	0.4–1.9	5/18	1.3	0.5–3.9	3/23	0.5	0.1–1.7
Christensen et al., 2005, Denmark, ≥10 years [26][a]	6/8	1.0	0.3–3.2	–	–	–	–	–	–
Schüz et al., 2006, Germany, ≥10 years [28]	5/9	1.1	0.4–3.4	–	–	–	–	–	–
Hardell et al., 2006, Sweden, >10 years [11]	38/99	1.5	0.98–2.4	15/28	2.0	0.98–3.9	12/29	1.6	0.7–3.3
Lahkola et al., 2008 (Denmark, Norway, Finland, Sweden, UK) [16]	73/212	0.9	0.7–1.3	33/113	1.1	0.7–1.7	24/117	0.6	0.4–1.03
Meta-analysis	116/320	1.1	0.8–1.4	48/141	1.3	0.9–1.8	36/146	0.8	0.5–1.3

[a] Not included in meta-analysis because already part of pooled data in Lahkola et al., 2008 [16].

Please cite this article in press as: L. Hardell, et al., Epidemiological evidence for an association between use of wireless phones and tumor diseases, Pathophysiology (2009), doi:10.1016/j.pathophys.2009.01.003

Table 7
Odds ratios (ORs) and 95% confidence intervals (CIs) from three case–control studies on salivary gland tumors including meta-analysis of the studies using ≥10 year latency period.

Study	Total			Ipsilateral			Contralateral		
Author, year of publication, country, latency, reference number	No. of cases/controls	OR	95% CI	No. of cases/controls	OR	95% CI	No. of cases/controls	OR	95% CI
Hardell et al., 2004, Sweden, >10 years [39]	6/35	0.7	0.3–1.7	5/13	1.5	0.5–4.2	1/15	0.3	0.03–2.1
Lönn et al., 2006, malignant, Sweden, ≥10 years [40]	2/36	0.4	0.1–2.6	1/23	0.7	0.1–5.7	0/19	–[a]	–[a]
Lönn et al., 2006, benign, Sweden, ≥10 years [40]	7/15	1.4	0.5–3.9	6/9	2.6	0.9–7.9	1/9	0.3	0.0–2.3
Sadetzki et al., 2007, Israel, ≥10 years [41]	13/26	0.9	0.4–1.8	10/16	1.6	0.7–3.7	3/10	0.6	0.2–2.3
Meta-analysis	28/112	0.8	0.5–1.4	22/61	1.7	0.96–2.9	5/34	0.4	0.2–1.2

[a] Not included in meta-analysis because OR could not be estimated.

8. Non-Hodgkin lymphoma

The incidence of NHL increased since the 1960s in Sweden as well as in many western countries with reliable cancer registries. This trend has levelled off since the 1990s, and decreasing exposure to environmental contaminants such as PCBs and dioxins, and also certain pesticides has been postulated to be one explanation [42,43]. As part of a large case–control study on NHL, mainly on exposure to pesticides [44], also questions on the use of wireless phones were included. The study covered the time period December 1, 1999 to April 30, 2002. The questionnaire was answered by 910 (91%) cases and 1016 (92% controls). The majority of the cases had B-cell NHL and we did not find any association with use of wireless phones [45]. Regarding T-cell NHL ($n = 53$) we observed somewhat increased risks; use of analogue phone gave OR = 1.5, 95% CI = 0.6–3.7, digital phone OR = 1.9, 95% CI = 0.8–4.8 and cordless phone OR = 2.5, 95% CI = 1.1–5.6. For certain subtypes of T-cell NHL, the cutaneous and leukemia types, the risks increased further for analogue phone to OR = 3.4, 95% CI = 0.8–15, digital phone to OR = 6.1, 95% CI = 1.3–30, and cordless phone to OR = 5.5, 95% CI = 1.3–24. These results were, however, based on low numbers.

A study from USA included 551 NHL cases and 462 frequency matched controls [46]. Among regular mobile phone users NHL risk was not significantly associated with minutes per week, duration, cumulative lifetime or years of first use. However, total time >8 years gave OR = 1.6, 95% CI = 0.7–3.8. The risk increased with number of years, and was significant for the not specified group of NHL after ≥6 years use yielding OR = 3.2, 95% CI = 1.2–8.4.

9. Testicular cancer

An increasing incidence of testicular cancer has been noted in most western countries during the recent decades. It is the most common cancer type in young men and is not regarded to be an occupational disease. Cryptorchidism is an established risk factors, but also perinatal exposure to persistent organic pollutants with hormone activity has been suggested to be another risk factor [47,48]. There has been concern in the population that use of mobile phones might be a risk factor for testicular dysfunction. We performed a case–control study mainly on the use of PVC plastics as risk factor for testicular cancer [49], and included in the questionnaire also questions on the use of wireless phones. The results were based on answers from 542 (92%) cases with seminoma, 346 (89%) with non-seminoma and 870 (89%) controls [50]. Overall no association was found [50]. Only 13 cases with seminoma had used an analogue phone >10 years yielding OR = 2.1, 95% CI = 0.8–5.1 and one case with non-seminoma; OR = 0.3, 95% CI = 0.04–2.6. No case had used a digital or cordless phone with latency period >10 years. OR did not increase with cumulative use in hours for the different phone types. Regarding use of mobile phone in the stand by mode border line significance was found for seminoma, OR = 1.3, 95% CI = 1.03–1.7, but not for non-seminoma; OR = 0.9, 95% CI = 0.7–1.3. For different localisations during stand by, highest risk was found for seminoma for keeping the phone in ipsilateral trousers pocket, OR = 1.8, 95% CI = 0.97–3.4 whereas contralateral pocket gave OR = 1.0, 95% CI = 0.5–2.0.

10. Malignant melanoma of the eye

Stang et al. [51] conducted a hospital- and population-based case–control study of uveal melanoma and occupational exposures to different sources of radiofrequency radiation. A total of 118 cases with uveal melanoma and 475 controls were included. Exposure to RF-transmitting devices was rated as (a) no RF exposure, (b) possible exposure to mobile phones, or (c) probable/certain exposure to mobile phones. An elevated risk for exposure to RF-transmitting devices was reported. Exposure to radio sets gave OR = 3.0, 95% CI = 1.4–6.3 and probable/certain exposure to mobile phones OR = 4.2, 95% CI = 1.2–14.5. The authors concluded that several methodologic limitations prevented their results from providing clear evidence on the hypothesized association.

The study was commented among others Johansen et al. [52]. In their cohort of mobile phone subscribers in Denmark no support for an association between mobile phones and ocular melanoma was found. However, as discussed elsewhere [14,15,18,55], there are several methodological limitations in the Danish cohort [21,22] that hamper the interpretation of their findings.

The paper by Stang et al. [51] has also been commented by Inskip [53] in an editorial, the main point being that missing from the paper is any consideration of occupational or recreational exposure to UV radiation.

11. Intratemporal facial nerve tumor

So far only one investigation has studied the risk of intratemporal facial nerve (IFN) tumor and the use of mobile phone [54]. A case–control approach was used with 18 patients with IFN tumors matched with controls ($n = 192$) treated for other diseases, 51 patients treated for acoustic neuroma, 72 treated for rhinosinusitis, and 69 for dysphonia and gastroesophageal reflux. Risk of facial nerve tumorigenesis was compared by extent of mobile phone use. The OR of developing an IFN tumor was 0.6, 95% CI = 0.2–1.9 with any handheld mobile phone use and OR = 0.4, 95% CI = 0.1–2.1 for regular mobile phone use. However, they concluded that the short duration of use precludes definite exclusion as a risk for IFN tumor development. Certainly the cases were too few for a sound epidemiological study and it was not correct to include patients with acoustic neuroma in the reference group.

12. Discussion

A review on use of mobile phones and the association with brain tumors included all case–control studies that we have identified in the peer-review literature. Most studies have published data with rather short latency period and limited information on long-term users.

No other studies than from the Hardell group has published comprehensive results for use of cordless phones (DECT) [2–15]. As we have discussed in our publications it is pertinent to include also such use in this type of studies. Cordless phones are an important source of exposure to microwaves and they are usually used for a longer time period on daily basis as compared to mobile phones. Thus, to exclude such use, as was done in e.g. the Interphone studies, could lead to an underestimation of the risk for brain tumors from use of wireless phones.

We have discussed shortcomings in the Interphone studies in detail elsewhere [55]. Regarding glioma the Swedish Interphone study reported 23 ORs in Table 2 in that publication [25] and 22 of these were <1.0 and one OR = 1.0. For meningioma all 23 ORs were <1.0, six even significantly so. These results indicate a systematic bias in the study unless use of mobile phones prevents glioma and meningioma, which is biologically unlikely. It should be noted that several of the overall ORs also in other Interphone studies were <1.0, some even significantly so. As an example, in the Danish Interphone study on glioma [26] all 17 ORs for high-grade glioma were <1.0, four significantly decreased. Also other Interphone studies reported ORs significantly <1.0, that is a protective effect or rather systematic bias in the studies [16,29,31].

Use of cellular telephones was mostly assessed by personal interviews in the Interphone studies. It is not described how these personal interviews were organized, a tremendous task considering that vast parts of Sweden from north to south had to be covered. In the sparsely populated and extended area in northern Sweden personal interviews must have meant lots of long distance traveling and imposed additional stress on the interviewers. No information was given in the articles on how or if this methodological problem was solved, for example were controls only included from more densely populated areas.

The interviews in the Interphone study were extensive and computer aided. It is likely that such an interview creates a stressful situation for a patient with a recent brain tumor diagnosis and operation. These patients, especially under pressure with a newly diagnosed brain tumor and possible surgery, often have difficulties remembering past exposures and inevitably have problems with concentration and may have problems with other cognitive shortcomings. In the Danish part of the Interphone study it was concluded that the patients scored significantly lower than controls due to recalling words (aphasia), problems with writing and drawing due to paralysis [26]. According to our experience a better option would have been to start with a mailed questionnaire, that can be answered by the patient during a period of more well-being, if necessary this can be complemented by a telephone interview. After surgery it is easier to answer a questionnaire at home, also with the possibility to check phone bills to verify the use. This procedure has the additional advantage that it can be accomplished without disclosure during the data collection, whether a person is a case or a control. Certainly, knowing if it was a case or a control that was interviewed in the Interphone study may have introduced observational bias.

It has been argued that recall bias might be introduced in case–control studies on cancer patients, since the patients would be more prone to find a cause for their disease than the controls. However, the contrary is often the situation since patients do not want to blame themselves for their disease. In one article we presented data on the patients own assumptions of causes of their brain tumor [5]. Of 1429 cases only two expressed concern about mobile phones and no about cordless phones. Interestingly, cases with a previous cancer diagnosis reported lower frequency for use of wireless phones than those with no previous cancer. No interviewer bias could be demonstrated when exposure data in the questionnaire were compared before and after phone interviews [5].

The diagnosis of tumor type as well as grading is based on histopathology. X-ray investigation or MR alone is insufficient. Of the 371 cases with glioma in the Swedish Interphone study [25] histopathology examination of the tumor was available for 328 (88%) cases, and for 225 (82%) of the meningioma cases. Thus, it is possible that cases without histology confirmation of the diagnosis may have had another type of brain tumor or even brain metastases. Such misclassifications inevitably bias the result towards unity. It is remarkable that 345 glioma cases were stratified according to grade I–IV, although histopathology was available only for 328 cases. In our studies on brain tumors we have histopathology verification of all of the diagnoses. Also, the total number of included cases [25] is not completely consistent with those reported to the Swedish Cancer Registry as we have discussed elsewhere [55]. The study included cases from neurosurgery, oncology and neurology clinics as well as regional cancer registries in the study areas.

Among the controls in the glioma and meningioma study 282 (29%) refused to participate [25]. Among some of these non-responders a short interview was made and only 34% reported regular use of a cellular telephone compared with 59% of the responders. If this discrepancy extends to the total group of non-responders the true percentage of mobile phone users in controls would be approximately 52%. Hence this figure would be lower than in glioma (58% exposed) and acoustic neuroma cases (60%). Only for meningioma with 43% exposed cases a lower percentage was reported, however, considering the sex ratio (women:men) for meningioma of about 2:1 a lower percentage of mobile phone users has to be expected due to the lower rate of users among women. It should be noted that a similar procedure in another Interphone study yielded similar results regarding mobile phone use among responders and non-responders [17].

It was discussed in a medical dissertation [56] that: ‘Our Swedish study, that includes a large number of long-term mobile phone users, does not support the few previously reported positive findings, and does not indicate any risk increases neither for short-term or long-term exposures.’ Considering the methodological shortcomings and that in contrast to the cited assertion of ‘a large number of long-term users’ the study subjects included only 25 glioma and 12 meningioma cases with long-term use, its conclusion seems to be going a long way beyond what can be scientifically defended.

It might be mentioned that this area of research seems to be controversial *per se* with unfounded statements [57], easily rebutted [58] and not supported by evolving scientific evidence [59]. Statements on no risk for brain tumors based on short-time use of mobile phones [60] might be considered in a larger context [61].

We included in our studies use of mobile or cordless phone ‘any time’ in the exposed group and made dose-response calculations based on number of hours of cumulative use. The unexposed group included also subjects with use of wireless phones with ≤1-year latency period. On the contrary, mobile phone use in the Interphone studies was defined as ‘regular use’ on average once per week during at least 6 months, less than that was regarded as unexposed including also all use within <1 year before diagnosis. This definition of ‘regular use’ seems to have been arbitrary chosen and might have created both observational and recall bias in the interpretation of such a definition.

Use of cordless phones was not assessed or not clearly presented in the Interphone studies, e.g. [25,28]. We found a consistent pattern of an association between cordless phones and glioma and acoustic neuroma [11,12]. It has been shown that the GSM phones have a median power in the same order of magnitude as cordless phones [62]. Moreover, cordless phones are usually used for longer calls than mobile phones [11,12]. Including subjects using cordless phones in the “unexposed” group in studies on this issue, as for example in the Interphone investigations, would thus underestimate the risk and bias OR against unity.

The case participation was good in our studies, 88% for cases with benign brain tumors, 90% for malignant brain tumor cases and 89% for the controls. On the contrary case participation varied from 37% to 93% and control participation from 42% to 75% in the Interphone studies. Obviously low participation rates for cases and controls might give selection bias and influence the results in the Interphone studies.

Methodological issues in the Interphone studies have been discussed elsewhere [14,15,18,55,63–65]. It was concluded that the actual use of mobile phones was underestimated in light users and overestimated in heavy users. Random recall bias could lead to large underestimation in the risk of brain tumors associated with mobile phone use. It was further suggested that selection bias in the Interphone study resulted in under selection of unexposed controls. Refusal to participate was related to less prevalent use of mobile phones, and this could result in a downward bias in estimates of the disease risk associated with mobile phone use. As discussed by Kundi [18] there was also interview lag time between cases and controls in the Interphone studies that might have been a source of bias due to the fast increase of mobile phone use during the study period. This could have resulted in underestimation of risk.

For salivary gland tumors the results were based on three case-control studies. In the 10 year latency period the meta-analysis gave an almost significantly increased risk for ipsilateral use of mobile phones, and a non-significantly decreased risk for contralateral use. These results were based on few cases. Regarding NHL and testicular cancer some subgroup analysis yielded increased risks, but these results were based on low numbers. Use of mobile phone increased the risk significantly for melanoma of the eye. The study on intratemporal facial nerve tumors is not informative since it was based on few cases and included acoustic neuroma patients in the control group. It is concluded that all studies were hampered by low numbers of long-term users and need to be replicated for firm evidence of an association between use of mobile phones and these tumor types.

In summary our review yielded a consistent pattern of an increased risk for acoustic neuroma and glioma after >10 years mobile phone latency. Our studies showed also an association with use of cordless phones, an issue that has not been studied at all in most investigations or only rudimentary in two studies. We conclude that current standard for exposure to microwaves during mobile phone use is not safe for long-term exposure and needs to be revised.

Acknowledgements

Supported by grants from Cancer-och Allergifonden, Cancerhjälpen and Örebro University Hospital Cancer Fund. Contribution by co-workers in the various publications is acknowledged.

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Please cite this article in press as: L. Hardell, et al., Epidemiological evidence for an association between use of wireless phones and tumor diseases, Pathophysiology (2009), doi:10.1016/j.pathophys.2009.01.003

Pathophysiology xxx (2009) xxx–xxx

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Mobile phone base stations—Effects on wellbeing and health

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Received 11 September 2008; accepted 30 January 2009

Abstract

Studying effects of mobile phone base station signals on health have been discouraged by authoritative bodies like WHO International EMF Project and COST 281. WHO recommended studies around base stations in 2003 but again stated in 2006 that studies on cancer in relation to base station exposure are of low priority. As a result only few investigations of effects of base station exposure on health and wellbeing exist. Cross-sectional investigations of subjective health as a function of distance or measured field strength, despite differences in methods and robustness of study design, found indications for an effect of exposure that is likely independent of concerns and attributions. Experimental studies applying short-term exposure to base station signals gave various results, but there is weak evidence that UMTS and to a lesser degree GSM signals reduce wellbeing in persons that report to be sensitive to such exposures. Two ecological studies of cancer in the vicinity of base stations report both a strong increase of incidence within a radius of 350 and 400 m respectively. Due to the limitations inherent in this design no firm conclusions can be drawn, but the results underline the urgent need for a comprehensive investigation of this issue. Animal and in vitro studies are inconclusive to date. An increased incidence of DMBA induced mammary tumors in rats at a SAR of 1.4 W/kg in one experiment could not be replicated in a second trial. Indications of oxidative stress after low-level in vivo exposure of rats could not be supported by in vitro studies of human fibroblasts and glioblastoma cells.

From available evidence it is impossible to delineate a threshold below which no effect occurs, however, given the fact that studies reporting low exposure were invariably negative it is suggested that power densities around 0.5–1 mW/m^2 must be exceeded in order to observe an effect. The meager data base must be extended in the coming years. The difficulties of investigating long-term effects of base station exposure have been exaggerated, considering that base station and handset exposure have almost nothing in common both needs to be studied independently. It cannot be accepted that studying base stations is postponed until there is firm evidence for mobile phones.

Keywords: Mobile phone base station; Performance; Cancer; In vitro studies; Microwaves

1. Introduction

Modern mobile telecommunication is based on a cellular system. Each cell is covered by a base station that keeps track of the mobile phones within its range, connects them to the telephone network and handles carry-over to the next base station if a customer is leaving the coverage area. Early mobile telecommunication systems had very large cells with tens of kilometers radius and were predominantly located along highways due to offering service mainly for car-phones. With the introduction of digital mobile phone systems cell sizes got much smaller and base stations were erected in densely populated areas. The limited power of mobile phones made it necessary to reduce the distance to the customers. The cell size depends on (1) the radiation distance of the mobile phone; (2) the average number of connected calls; (3) the topographic characteristics of the covered area and the surrounding buildings, vegetation and other shielding objects; and (4) the type of antenna used. There are essentially three types of cells presently making up mobile telecommunication networks: (1) macro-cells in areas of average to low number of calls; (2) micro-cells in densely populated areas and areas with high telecommunication traffic density; (3) pico-cells within buildings, garages, etc. The types of antennas used, although hundreds of different models are operated, can be subdivided into: omni-directional antennas that radiate in all horizontal directions with the same power; sector antennas

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0928-4680/$ – see front matter © 2009 Published by Elsevier Ireland Ltd.
doi:10.1016/j.pathophys.2009.01.008

Please cite this article in press as: M. Kundi, H.-P. Hutter, Mobile phone base stations—Effects on wellbeing and health, Pathophysiology (2009), doi:10.1016/j.pathophys.2009.01.008

that radiate the main beam in one sector only but have varying aperture (usually 120° or 90°). These antennas can be mounted on masts (that sometimes are in the shape of trees for protection of landscape or are otherwise hidden), on the top of buildings, on pylons, and micro- and pico-cell antennas on various other places (walls of houses, shops, indoors, etc.). The width of the beam in vertical direction is typically 6°, but due to the presence of side lobes the actual pattern is more complicated.

Digital base stations of the second generation (GSM, TDMA) and third generation (UMTS, CDMA) have typically a nominal power for each channel of 10–20 W, micro- and pico-cells up to about 4 and 2 W, respectively. Due to the antenna gain the EIRP in the direction of the main beam is much greater (by a factor of $10^{g/10}$, where g is the antenna gain in dB, typically between 40 and 60). Most base stations of the second generation operate with two channels, one broadcast control channel (BCCH, channel used for transmitting information about the network, the location area code, frequencies of neighboring cells, etc.) and one traffic channel (TCH, channel used for transmission of calls), for third generation systems, due to code division multiplexing, control information needed for the maintenance of the system is at present transmitted together with the actual information (calls, pictures, etc.) within one broad-band channel. GSM systems operate the BCCH with all time slots occupied and therefore at maximal power, whereas TCH has as many time slots active as necessary to operate all active transmission not covered by the BCCH. Field strength at ground level depends on the characteristics of the antenna. Because the main beam reaches ground level typically in 50–200 m distance, in case of free sight to the antenna, maximum field strength is reached at that distance. However, due to the side lobes ups and downs of field strength occur as one approach the base station. In areas where objects are shadowing the beams, patterns are still more complex because of diffraction and reflection and multi-path propagation with constructive as well as destructive interference.

Free field propagation from the antenna along the main beam follows the law: $P(x) = \mathrm{EIRP}/(4\pi \cdot x^2)$, with $P(x)$ the power flux density in x meters distance and EIRP the equivalent isotropic radiated power of the antenna. Significant deviations from this expectation occur due to the side lobes, presence of interfering objects, differences in vertical beam width, and variations in the number of active transmissions. For these reasons distance to the antenna is a poor proxy for exposure level.

Since the early 1990s tens of thousands of base stations have been erected in countries where digital networks were introduced. While older systems with their low number of base stations have hardly received public attention, the vast increase in base stations has led to public concerns all over the world. Anecdotal reports about various effects on wellbeing and health have led also to an increased awareness of physicians [1,2] and increased research efforts have been demanded [3]. Despite these professional and public concerns, the WHO International EMF Project has discouraged research into effects of base stations, because it deemed research into effects of mobile phones of higher priority. This position was changed in 2003 when the new research agenda recommended studies around base stations. In 2006 it was again stated that research into potential health effects of base station is of low priority [4].

Due to these circumstances only very few investigations of effects of base stations on wellbeing and health exist. In addition some experimental studies have been conducted, most of which address the problem of short-term effects on complaints and performance.

The following review summarizes available evidence and critically assesses the investigations as to their ability to support or dismiss a potential effect of microwave exposure from base stations on wellbeing and health.

2. Epidemiological investigations

2.1. Wellbeing and performance

Santini et al. [5,6] report results of a survey in France to which 530 individuals (270 men and 260 women) responded. Study subjects were enrolled through information given by press, radio, and website, about the existence of a study on people living near mobile phone base stations. Frequency for each of 18 symptoms was assessed on a 4 level scale (never, sometimes, often, and very often). Participants estimated distance to the base station using the following categories: <10 m, 10–50 m, 50–100 m, 100–200 m, 200–300 m, >300 m. For comparison of prevalence of symptoms >300 m served as reference category. For all symptoms a higher frequency of the categories ‘often’ or ‘very often’ was found at closer (self-reported) distance to the base station. Fatigue, headaches, and sleeping problems showed highest relative increase. Due to a less than optimal statistical analysis comparing each distance category separately with the reference category the overall response pattern can only be assessed qualitatively. Fig. 1 shows relative prevalence averaged over all symptoms as a function of self-reported distance to the antenna. Interestingly the function is not monotonous but shows, after an initial drop, an increase at a distance of 50–100 m. Because of the fact that in many cases this is the distance at which the main beam reaches ground level this may indicate a relationship to actual exposure levels.

This study was a first attempt to investigate a potential relationship between exposure to base station signals and health and has, therefore, several shortcomings: (1) participants selected themselves into the study group by responding to public announcements; (2) distance was self-reported and no attempt was made to validate these reports (a German cross-sectional study in over 30,000 households revealed that more than 40% did not know they were living in the vicinity of a base station [7]); (3) no assessment of subjects’ concerns about the base station; and (4) no measurement or calcula-

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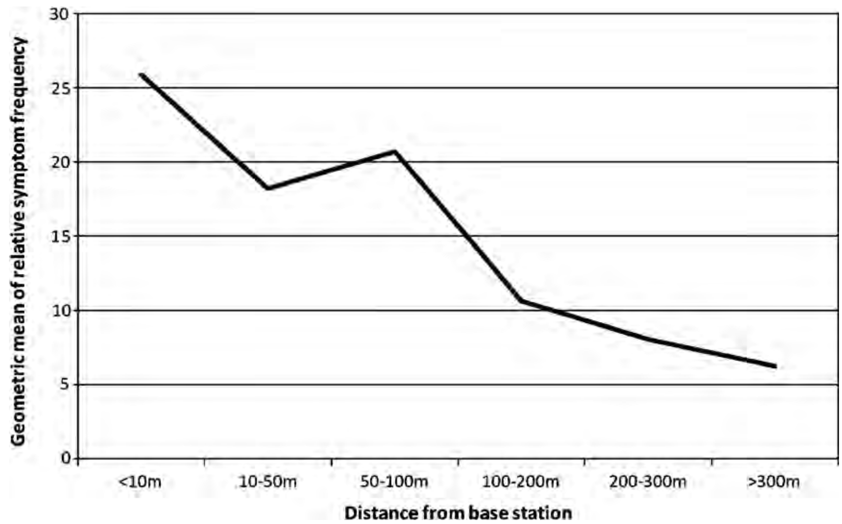

Fig. 1. Relative symptom frequency averaged over all 33 reported symptoms from Santini et al. [5] as a function of distance from base station.

tion of actual exposure. Although selection bias and wrong estimation of distance to the base station could have led to a spuriously increased prevalence of symptoms, the pattern of symptom frequency as a function of distance is intriguing and suggests that part of the increased symptom prevalence could be due to exposure because people do not know the typical pattern of field strengths found in the vicinity of base stations.

A Spanish version of the questionnaire as applied in the French study was distributed in La Nora, a small town in Murcia, Spain, to about 145 inhabitants [8]. Overall 101 questionnaires (from 47 men and 54 women) were included in the analyses. Electric field strength in the frequency range 1 MHz to 3 GHz was measured in the bedrooms of the participants. Data were analyzed in two different ways: first subjects were subdivided into those living less than 150 m from the base station and a second group living more than 250 m away (according to self-reports); the average exposure level of the first group was 1.1 mW/m^2, and of the second group 0.1 mW/m^2; self-reported symptom severity was compared across these groups. The second method correlated log transformed field strengths with symptom scores. The majority of symptoms showed a relationship both by comparison of the contrast groups according to distance from the base station as well as when correlated to measured field strength. Strongest effects were observed for headaches, sleep disturbances, concentration difficulties, and discomfort.

In contrast to the French investigation the study has assessed actual exposure by short-term measurements in the bedrooms of participants. The fact that both, reported distance as well as measured field strength, correlated with symptom severity supports the hypothesis of an association between microwaves from the base station and wellbeing. However, because subjects knew that the intention of the study was to assess the impact of the base station there is a potential for bias. Also concerns of the participants about effects of the base station on health were not assessed. Furthermore, method of selection of participants was not reported.

In a cross-sectional study in the vicinity of 10 GSM base stations in rural and urban areas of Austria, Hutter et al. [9] selected 36 households randomly at each location based on the characteristics of the antennas. Selection was done in such a way as to guarantee a high exposure gradient. Base stations were selected out of more than 20 locations based on the following criteria: (1) at least 2 years operation of the antenna; (2) no protest against it before or after erection; (3) no nearby other base station; (4) transmission only in the 900 MHz frequency band. (The last two criteria were not fully met in the urban area.) In order to minimize intervention of interviewers all tests and questionnaires were presented on a laptop computer and subjects fulfilled all tasks on their own. Wellbeing was assessed by a symptoms list (v. Zerssen scale), sleeping problems by the Pittsburgh sleeping scale. In addition several tests of cognitive performance were applied. Concerns about environmental factors were inquired and sources of EMF exposure in the household were assessed as well. It was not disclosed to the subjects that the study was about the base station, but about environmental factors in general. Among other measurements high-frequency fields were assessed in the bedrooms. From the measured field strength of the BCCH maximum and minimum exposure to the base station signals were computed. In addition overall power density of all high-frequency fields was measured. Results of measurements from 336 households were available for analysis. Exposure from the base station was categorized into three ranges: below 0.1 mW/m^2, between 0.1 and 0.5 mW/m^2, and above 0.5 mW/m^2. Cognitive performance tended to be better at higher exposure levels and was statistically significant for perceptual speed after correction for confounders (age, gender, mobile phone use, and concerns about the base station). Subjective symptoms were generally more frequent at higher exposure levels and statistically increased prevalence was found for headaches, cold hands or feet, and concentration difficulties. Although participants reported more sleeping problems at higher exposure levels, this effect was removed after controlling for concerns about the base station.

Despite limitations inherent in the cross-sectional study design the methodological problems mentioned in the French and Spanish investigations were avoided. Authors conclude: “The results of this study indicate that effects of very low but long lasting exposures to emissions from mobile telephone base stations on wellbeing and health cannot be ruled out. Whether the observed association with subjective symptoms after prolonged exposure leads to manifest illness remains to be studied.”

A study in employees working within or opposite a building with GSM base station antennas on the roof was reported by Abdel-Rassoul et al. [10]. The investigation took place in Shebin El-Kom City, Menoufiya Governorate, Egypt, where the first mobile phone base station was erected in 1998 on a building for agricultural professions. Overall 37 subjects working within this building and 48 subjects working in the agricultural directorate about 10 m opposite the building were considered exposed. A control group, working in another building of the agricultural administration located approximately 2 km away, consisted of 80 persons. Participants completed a structured questionnaire assessing educational and medical history. A neurological examination was performed and a neurobehavioral test battery (tests for visuomotor speed, problem solving, attention and memory) was presented. The combined exposed groups were compared to the control group that was matched by sex, age and other possible confounders. Statistical analysis accounted for these variables. Further comparisons were performed between subjects working in the building with the base station on the roof and those opposite. Exposed subjects performed significantly better in two tests of visuomotor speed and one test of attention, in two other tests the opposite was the case. The prevalence of headaches, memory problems, dizziness, tremors, depressive symptoms, and sleep disturbances was significantly higher among exposed inhabitants than controls. Measurements conducted 3 years before the investigation revealed compliance with the Egyptian standard (80 mW/m^2) with values between 27 and 67 mW/m^2, but locations of the measurements were not specified.

Like in the study of Hutter et al. [9] it was not disclosed to the participants that the study was about the base station. An important aspect is studying employees that occupy the area of exposure for 8–16 h a day. Several possible confounders (age, sex, education, smoking, and mobile phone use) were considered and did not change the reported results. Other factors like stressful working conditions, indoor pollutants and other attributes of the work place were not assessed and might have had an effect on the reported symptoms. Although no recent measurements were available it can be assumed that both, subjects working within the building as well as those opposite the building with the base station are exposed at comparatively high levels. The picture of one antenna shown in the article indicates that the panel is slightly uptilted. It can be assumed that the sidelobes of the antenna are directed downwards into the building below the base station as well as into the opposite building. Measurements in Germany revealed that, in contrast to a general belief that there is no significant exposure in buildings below a base station antenna, the field strength in buildings below an antenna is almost equal to field strength in opposite buildings.

An experimental field trial was conducted in Bavaria [11] during three months before an UMTS antenna on a governmental building started operation. Based on a random sequence the antenna was turned on or off one, two, or three days in a row during 70 working days in winter 2003. Conditions were double-blind since neither the experimenters nor the participants knew whether the antenna was on or off. This was guaranteed by software manipulation of the antenna output that prohibited UMTS mobile phones from contacting the base station and by locating the computer controlling the antenna in a sealed room. The UMTS antenna operated at a mean frequency of 2167.1 MHz. The protocol has not been specified, but considering that no real transmission occurred it is assumed that only the service channel was used. The antenna had a down-tilt of 8° expected to result in rather high exposure within the building. Measured electric field strength in the rooms of the participants varied between the detection limit of the field probe (0.05 V/m) and 0.53 V/m (corresponding to 0.75 mW/m^2) with an average of 0.10 ± 0.09 V/m (corresponding to 0.03 mW/m^2). Participants should answer an online questionnaire on each working day they were in the office in the morning when they arrived and in the evening shortly before leaving. The questionnaire consisted of a symptom list with 21 items, and in the evening participants should state whether or not they considered the antenna has been on during this day and whether they considered, if they experienced any adverse effects, these effects due to the base station. From approximately 300 employees working in the building 95 (28 females, 67 males) that answered the questionnaire on at least 25% of the working days were included in the analysis.

None of the 21 symptoms showed a statistically significant difference between days on and days off. A more comprehensive analysis of the overall score across all 21 items applying a mixed model with subjects as random factor and autoregressive residuals revealed a tendency ($p = 0.08$) for an effect of actual exposure on the difference between morning and evening values. Self-rated electrosensitivity had a significant effect on evening scores but did not affect difference scores. As expected, subjective rating of exposure had a significant influence both, on evening scores and score difference. Correct detection rate of base station transmission mode was 50% and thus equal to chance. No person was able to detect operation mode correctly on significantly more days than expected.

The study design was a great strength of this pilot investigation. It combined the advantages of a field trial with the rigorous control of exposure conditions in an experiment. However, there are a number of severe shortcomings too: first, no correction for actual exposure has been applied. As

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stated above, exposure varied considerably within the building and some participants were not exposed at detectable levels at all. The resulting exposure misclassification leads to a bias towards the null hypothesis. Furthermore, it was not specified which UMTS protocol was actually transmitted. Another important limitation is the quite low exposure even in the offices with the highest levels. Problems with the statistical evaluation are indicated by a highly significant time factor suggesting insufficient removal of autocorrelation. Finally, the symptom list contains several items that were not implicated previously as related to exposure from base stations (e.g. back pain). Such items reduce the overall power to detect an effect of base station exposure.

A cross-sectional study based on personal dosimetry was conducted in Bavaria [12]. In a sample of 329 adults (173 females, 155 males, and 1 unknown) chronic and acute symptoms were assessed. Chronic symptoms were taken from the Freiburger Beschwerdeliste and acute symptoms from the v. Zerssen list. Symptoms assessed were headache, neurological symptoms, cardiovascular symptoms, concentration problems, sleeping disorders and fatigue. Participants wore a dosimeter (Maschek ESM 140) for 24 h on the upper arm on the side used for holding a phone (during the night the dosimeter was placed next to the bed). The dosimeter measured exposure in frequency bands including GSM 900 up- and down-link, GSM 1800 up- and down-link, UMTS, DECT and WLAN (2.45 GHz).

Acute symptoms at noon and in the evening were dichotomized and related to exposure during the previous 6 h (night time measurements were considered biased and not analyzed). Exposure was expressed in percent of the ICNIRP reference levels. Odds ratios for the different symptom groups were computed in relation to exposure subdivided into quartiles with the first quartile as reference. Similarly, dichotomized chronic symptoms were related to average day time exposure levels. None of the symptom groups was significantly related to exposure. Odds ratios for headaches and cardiovascular symptoms during the last 6 months were increased for all three tested exposure quartiles (for headaches odds ratios were: 1.7, 2.7, and 1.2 for 2nd to 4th quartile; for cardiovascular symptoms these figures were 1.4, 3.3, and 2.4). But none of these odds ratios was statistically significant. Acute symptoms at noon and in the evening showed a tendency for lower prevalence of fatigue at higher exposure levels. Odds ratios for headaches and concentration problems in the evening were increased at higher exposure levels in the afternoon but also these results were statistically not significant (odds ratios for headaches were 1.7, 1.6, 3.1 and for concentration problems 1.4, 2.0, 1.4 for 2nd to 4th quartile of afternoon exposure levels).

Exposure was low and ranged from a daytime average of 0.05 V/m (at or below the limit of determination) to 0.3 V/m (corresponding to 0.24 mW/m^2 power density). (In order to make results comparable to other investigations figures expressed in percent of ICNIRP reference levels were recalculated to field strengths and power densities). Quartiles for daytime exposure were: up to 0.075 V/m, 0.075 to 0.087 V/m, 0.087 to 0.110 V/m, and 0.110 to 0.3 V/m. It can be seen that the first three quartiles are almost indiscernible with a ratio of the upper limit of the third and first quartiles of only 1.5.

Although the study of Thomas et al. [12] was the first one using personal dosimetry in the context of investigating effects of exposure to mobile phone base station signals on wellbeing it has not explored the potential of an almost continuous exposure measurement. Only average exposure was computed and the probably most important nighttime values were left out. A number of different exposure metrics should have been assessed, like duration of exposure above a certain limit, maximum exposure level, longest period below limit of determination, and variability of exposure levels to name but a few. Furthermore, prevalence of symptoms was so low that the power of the investigation to detect even substantially increased risks was inferior (less than 25%). Despite these shortcomings the study has its merits as a first step in using personal dosimetry. An earlier report of the group [13] with a comparison between two personal dosimeters (Maschek and Antennessa) demonstrated that improvements are necessary before personal dosimetry can be successfully used in epidemiological studies.

A large population-based cross-sectional study was conducted in the context of the German ‘Mobile Phone Research Program’ in two phases [7]. In the initial phase 30,047 persons from a total of 51,444 (58% response rate) who took part in a nationwide survey also answered questions about mobile phone base stations. Additionally a list of 38 health complaints (Frick’s list) was answered. Distance to the nearest base station was calculated based on geo-coded data of residences and base stations. In the second phase, all respondents (4150 persons) residing in eight preselected urban areas were contacted. In total, 3526 persons responded to a postal questionnaire (85% response rate) including questions about health concerns and attribution of symptoms to exposures from the base station as well as a number of standardized questionnaires: the Pittsburgh Sleep Quality Index, the Headache Impact Test, the v. Zerssen list of subjective symptoms, the profile of mental and physical health (SF 36), and a short version of the Trier Inventory of Chronic Stress. Overall 1808 (51%) of those that responded to the questionnaire agreed to have EMF measurement taken in their homes. Results of the large survey from the first phase of the study revealed a fraction of 10% of the population who attributed adverse health effects to the base station. An additional 19% were generally concerned about adverse effects of mobile phone base stations. Regression analysis of the symptoms summary score on distance to the base station (less or more than 500 m) and attribution/concerns about adverse effects adjusted for possible confounders (age, gender, SES, region and size of community) revealed a small but significant increase of the symptom score at closer distance to the base station. Higher effects, however, were obtained for concerns about adverse effects of the base station (with higher scores for those concerned) and still higher effects for those that attributed their health problems to exposures from mobile phone base stations. The latter result is only to be expected because attribution presupposes existence of symptoms and hence those with attribution must have higher scores than those without. Because effects of concerns/attribution were accounted for in the multivariate model, effect of distance to the base station is independent of these concerns or attributions. In the second phase measurements in the bedrooms revealed an overall quite low exposure to EMFs from the base station. Only in 34% of the households was the exposure above the sensitivity limit of the dosimeters of 0.05 V/m (~7 μW/m^2). On average power density was 31 μW/m^2 and the 99th percentile amounted to 307 μW/m^2. A dichotomization at the 90th percentile (exposure above 0.1 V/m, corresponding to 26.5 μW/m^2) did not indicate any effect of exposure on the different outcome variables but effects of attribution on sleep quality and overall symptom score (v. Zerssen list).

This large study has a number of important advantages: it started from a representative sample of the German population with over 30,000 participants and the second phase with a regional subsample had a participation rate of 85%. Furthermore, several well-selected standardized tests were used in the second phase. Results of the first phase are essentially in line with the Austrian study of Hutter et al. [9]. Not only the fraction with attribution of health complaints to exposure from the base station (10%) is identical, but also the higher symptom score in proximity to the base station independent of concerns/attributions found in the previous study has been replicated. However, the study has also severe shortcomings, most notably: the failure to include a sufficient number of participants that can be considered as exposed to microwaves from the base station. Note that Hutter et al. [9] selected households based on the characteristics of the antennas in such a way as to guarantee a large exposure gradient. In the randomly selected households of the study by Blettner et al. [7] the 90th percentile used as cutoff was well below the median (~100 μW/m^2) of the earlier investigation and the 99th percentile was still below the level (500 μW/m^2) that was found to increase the prevalence of several symptoms. Therefore it is unlikely that the investigation of the second phase could detect an effect if it occurs at levels consistent with those reported by Hutter et al. [9].

2.2. Cancer

Despite considerable public concerns that exposure to microwaves from mobile phone base stations could be detrimental to health and may, in particular, cause cancer, up to now only two studies of cancer in the vicinity of base stations applying basically an ecological design have been published.

In a Bavarian town, Neila, the physicians of the town conducted an epidemiological investigation [14] to assess a possible association between exposure to base station radiation and cancer incidence. The design used was an improved ecological one. Two study areas were defined: one within a circle of 400 m radius around the only base stations (two that were located in close proximity to each other) of the town, and one area further than 400 m from the base stations. Within these defined areas streets were randomly selected (after exclusion of a street where a home for retired people was situated) and all general practitioners of the town that were active during the whole period of operation of the base stations (one base station started operation September 1993 the other December 1997) scanned their files for patients living in the selected streets. Overall 967 individuals were found, constituting approximately 90% of the reference population. The study period 1/1994 to 3/2004 was subdivided into two segments: The first 5 years of operation of the base station (1994 through 1998) and the period from the sixth year, 1999, until 3/2004. Among the identified individuals 34 incident cases of cancer (excluding non-melanoma skin cancer) were found. Assessment of cancer cases was assumed to be complete and all cases were verified histologically and by hospital discharge letters (note that there is no cancer registry in Bavaria). Age distribution was similar in the two areas with a mean age of 40.2 years in both, the area within 400 m of the base station and the area further apart. Crude annual cancer incidence in the first 5 years after start of operation of the base station was 31.3×10^{-4} and 24.7×10^{-4} in the closer and farther area, respectively. In the second period these figures were 76.7×10^{-4} and 24.7×10^{-4}. The age and gender adjusted expected value of incident cancer cases in the study population based on data from Saarland, a German county with a cancer registry, is 49×10^{-4}. In the second period cancer incidence in the area within 400 m of the base station was significantly elevated, both, compared to the area further away as well as compared to the expected background incidence. The incidence in the region further apart was reduced but not significantly when compared to the expected value.

Although this so-called Neila-study applied an improved ecological design with a random selection of streets and inclusion of some information from selected individuals, it is still subject to potential bias because relevant individual risk factors could not be included in the analyses.

A similar though less rigorous study has been performed in Netanya, Israel. Wolf and Wolf [15] selected an area 350 m around a base station that came into operation 7/1996. The population within this area belongs to the outpatient clinic of one of the authors. The cohort within this area consisted of 622 people living in this area for at least 3 years at study onset, which was one year after start of operation of the base station and lasted for 1 year. Overall cancer incidence within the study area was compared to a nearby region, to the whole city of Netanya, and to national rates. In the second year after onset of operation 8 cancer cases were diagnosed in the study area. In the nearby area with a cohort size of 1222 individuals, 2 cases were observed. Comparison to the total population with an expected incidence of 31×10^{-4} indicates a pronounced increase in the study area with an incidence of 129×10^{-4}. Also against the whole town of Netanya an increased incidence was noted especially in women. In an

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addendum authors noted that also in the subsequent year 8 new cases were detected in the study area while in the period 5 years before the erection of the base station 2 cases occurred annually. Spot measurements of high frequency fields were conducted in the homes of cancer cases and values between 3 and 5 mW/m^2 were obtained. Although these values are well below guideline levels, they are quite high compared to typical values measured in randomly selected homes [7].

Also in the case of the Netanya study lack of information on individual risk factors makes interpretation difficult. Furthermore, migration bias has not been assessed although only subjects were included that occupied the area for at least 3 years. The short latency after start of operation of the base station rules out an influence of exposure on induction period of the diseases. The substantial increase of incidence is also hardly explainable by a promotional effect.

3. Experimental studies

3.1. *Experiments in human sensitive and non-sensitive individuals*

There are persons who claim to suffer from immediate acute as well as chronic effects on exposure to EMF and in particular to those from mobile phones or their base stations. Often these persons are called EMF hypersensitive (EHS). The preferred term agreed upon at a WHO workshop [16] was Idiopathic Environmental Intolerance with attribution to EMF (IEI-EMF). Indeed, it would be a misunderstanding to confuse EHS with allergic reactions; rather these persons react with different unspecific symptoms such as headaches, dizziness, loss of energy, etc. Whether these persons have actually the ability to tell the difference between situations with and without exposure to EMFs is an open question. In a recent review Röösli [17] concluded that "...the large majority of individuals who claim to be able to detect low level RF-EMF are not able to do so under double-blind conditions. If such individuals exist, they represent a small minority and have not been identified yet." However, it is important to differentiate between EMF sensitivity and sensibility [18]. Independent of the question whether or not there are individuals that sense the presence of low levels of EMFs such as those measured in homes near mobile phone base stations, there could well be an effect of such exposures on wellbeing and performance even under short-term exposure conditions. In several experimental investigations this question has been addressed by exposure of persons with self-reported symptoms and also in persons without known adverse reaction to an assumed exposure.

The first of these investigations was carried out by the Netherlands Organization for Applied Scientific Research (TNO) and published as a research report [19]. Two groups of persons were included in the experiment. One group consisted of individuals (25 females, 11 males) who have previously reported complaints and attributed them to GSM exposure. The other group consisted of subjects without such complaints (14 females, 22 males). Four experimental conditions were applied in a double-blind fashion: Sham exposure, exposure to 945 MHz GSM, 1840 MHz GSM, and 2140 MHz UMTS. Each participant underwent sham exposure and two of the active exposure conditions. Sequence of exposure was balanced such that each active exposure condition was tested equally often at each of three experimental sessions. Each experimental session and a training session lasted for 45 min. All three experimental sessions and the training session were completed on one day for each participant. Both, for GSM and UMTS exposure, a base station antenna was used and a simulated base station signal was transmitted during sessions. For the GSM conditions a 50% duty cycle (4 slots occupied) was applied with pulses of peak amplitudes of 1 V/m (0.71 V/m effective field strength; corresponding to 1.3 mW/m^2). For UMTS exposure a protocol was used with different low frequency components and an effective field strength of 1 V/m (corresponding to 2.7 mW/m^2). During each session several performance tests were conducted and immediately after each session a wellbeing questionnaire was administered (an adapted version of the Quality-of-Life Questionnaire of Bulpitt and Fletcher [20] with 23 items).

Overall score of wellbeing was significantly reduced in both groups after the UMTS condition compared to sham exposure. Considering subscores anxiety symptoms, somatic symptoms, inadequacy symptoms, and hostility symptoms were increased in the groups of sensitive individuals whereas in the control group only inadequacy symptoms were increased after UMTS exposure compared to sham. No effects were found in the two GSM exposure conditions. Concerning cognitive performance both groups revealed significant exposure effects in almost all tests in different exposure conditions. In most of these tests reaction time was reduced except for one simple reaction time task.

This study had an enormous echo both in the media as well as in the scientific community because it was the first experimental investigation with very low exposure to base station like signals and in particular to UMTS signals, and because it was conducted by a highly respected research institution reporting systematic effects of exposure that seemed to support citizens initiatives claiming that base stations have adverse effects on wellbeing and health. Immediately doubts were expressed that results could be biased due to a faulty methodology. In fact, study design can be improved. First of all testing all exposure conditions on the same day has the advantage to reduce variance from between day differences but could cause transfer effects if biological reactions do not immediately terminate after end of exposure and start of the next condition. Also time-of-day effect from chronobiological variations could be superimposing the reactions from exposure. Such effects are sometimes not removed by balancing exposure conditions. Second, not all subjects were tested under all exposure conditions. The decision to reduce total experimental duration by presenting only two of the three exposure conditions together with sham was sound but on the other hand led to a reduced power. Several other arguments such as the different gender distribution in the two groups are not very important because each subject served as his/her own control and comparison between groups was not important in this investigation. Other criticism was expressed against statistical analysis. No correction for multiple testing was applied. While some advice protection against inflation of type I error others recommend correction only for crucial experiments and not for pilot studies like this. Another, more serious, criticism was put forward against disregarding sequence of experimental conditions. As mentioned above, sequence, transfer, and time-of-day effects could have compromised results because such effects are not completely removed by balancing exposure sequence. Due to this criticism several studies were planned that should investigate whether the effects observed in the TNO study are robust and could be replicated under improved study designs.

One of these experiments was performed in Switzerland [21]. Like in the TNO study, two groups of individuals were included: one with self-reported sensitivity to RF-EMF (radio-frequency EMF) and a reference group without complaints. The first group consisted of 33 persons (19 females, 14 males) and the reference group of 84 persons (43 females, 41 males). The experiment consisted of three experimental and one training session each 1 week apart performed on the same time of day (±2 h). Design was a randomized double-blind cross-over design like in the case of the TNO study, however, with a week between sessions and with all subjects tested under all experimental conditions that were solely simulated UMTS base station exposure at 1 V/m, 10 V/m and sham. The same UMTS protocol as in the TNO study was used. Each exposure condition lasted for 45 min. During exposure two series of cognitive tasks were performed. After each exposure condition the same questionnaire as has been used in the TNO study was applied and questions about sleep in the previous night, alcohol, coffee consumption, etc., were asked. Moreover, subjects had to rate the perceived field strength of the previous exposure condition on a visual analogue scale. In addition, before and after each session the short Questionnaire on Current Disposition [22] was answered by participants. Questionnaires were presented in a separate office room.

Except for a significant reduction of performance speed of sensitive participants in the 1 V/m condition in one of six cognitive tests no effect of exposure was detected. In particular, no reduction of wellbeing neither as assessed by the TNO questionnaire nor from scores of the Questionnaire on Current Disposition was found. Also correlation between perceived and real exposure was not more often positive than expected from chance. Fig. 2 compares results of the TNO study and the results of Regel et al. [21] for the matching conditions (UMTS at 1 V/m). There are some notable differences between the two studies: first, the reference group in the study of Regel et al. [21] had significantly higher scores (reduced wellbeing) as the reference group in the TNO study in both the sham and the UMTS 1 V/m condition; second,

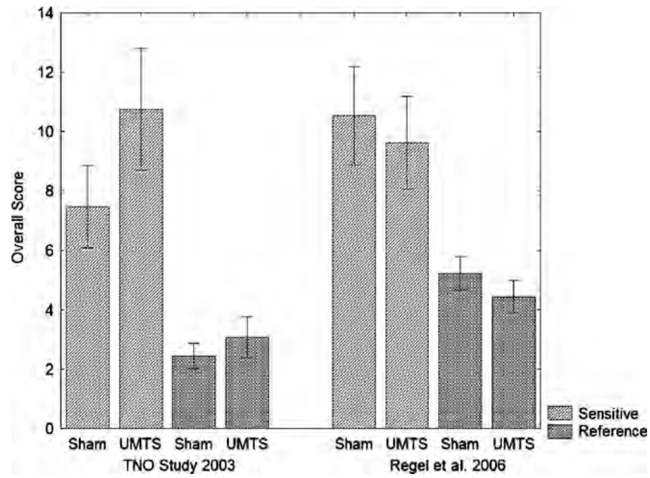

Fig. 2. Comparison of mean (±SEM) overall wellbeing scores (TNO questionnaire) obtained in the TNO study [19] and in the study of Regel et al. [21] for the matching conditions: Sham exposure and UMTS exposure at 1 V/m in sensitive participants and the reference group.

average scores from sensitive participants after exposure at 1 V/m are comparable in both studies but the sham condition resulted in much lower scores (better wellbeing) in the TNO study. There are several explanations for this difference between the two studies. It is possible that the reference group in the TNO study consisted of exceptionally robust individuals. The fraction of males was higher in the TNO study and males have typically lower scores. However, considering that the reference group in the TNO study was almost 10 years older (mean age 47 years) as compared to the study of Regel et al. [21] (mean age 38 years) this is not a satisfactory explanation. It is possible that the basic adversity of the experimental setup was higher in the latter study resulting in overall greater reduction of wellbeing. That this has not been observed in the sensitive group assumed to be more vulnerable to a ‘nocebo’ effect (the nocebo effect is the inverse of the placebo effect describing a situation when symptoms occur due to expecting adverse reactions) in both conditions could be due to a ceiling phenomenon. Although the study by Regel et al. [21] had an improved design and could not replicate the earlier findings of the TNO study, doubts exist whether this can be considered a refutation of an effect of UMTS exposure on wellbeing.

Another experimental study in sensitive and non-sensitive participants has been conducted in Essex, Great Britain, by Eltiti et al. [23]. The experiment consisted of two phases: an open provocation test and a series of double-blind tests. In the open provocation phase 56 self-reported sensitive and 120 non-sensitive control individuals participated. Of these, 44 sensitive (19 females, 25 males) and 115 controls (49 females, 66 males) also completed the double-blind tests. Participants took part in four separate sessions each at least 1 week apart. First session was the open provocation trial, sessions 2–4 were double-blind exposure trials with a sham, a GSM and a UMTS exposure condition. Double-blind sessions were reported to last for 1.5 h, however, Table 1 of the article showed an overall length of 48 min only. GSM exposure was a simulated base station signal with both a 900 and a 1800 MHz component each at an average level of 5 mW/m^2 and with a simulated BCCH with all time slots occupied and a TCH with a simulated 40% call activity resulting in a total of 10 mW/m^2 GSM exposure at the position of the participants (corresponding to 1.9 V/m E-field strength). The UMTS signal had a frequency of 2020 MHz with a power flux density of 10 mW/m^2 over the area where the participant was seated. Traffic modeling for the UMTS signal was achieved using a test model representing a realistic traffic scenario, with high peak to average power changes. During double-blind sessions participants watched a BBC "Blue Planet" video for 20 min, performed a mental arithmetic task for 20 min, performed a series of cognitive tasks lasting 8 min, and made 'on/off' judgments. During the first 40 min every 5 min subjective wellbeing was recorded on visual analogue scales (VAS) measuring anxiety, tension, arousal, relaxation, discomfort, and fatigue. In addition a symptom scale consisting of 57 items was answered. During the whole period physiological measurements of heart rate, blood volume pulse, and skin conductance were performed.

Physiological measurements revealed higher average values for sensitive individuals compared to controls which were especially high under UMTS exposure conditions. Symptom list did not reveal any differences between double-blind conditions, but the overall frequency of solicited symptoms was low. Concerning subjective wellbeing as assessed by VAS there were increased values for anxiety, tension, and arousal under GSM and especially UMTS exposure conditions. Combining all scores of the six scales (with relaxation reflected) reveals a significant increase during UMTS exposure compared to sham for the sensitive group and a significant reduction for the control group (see Fig. 3). Judgment of participants about presence of exposure was not correct more often than inferred from chance.

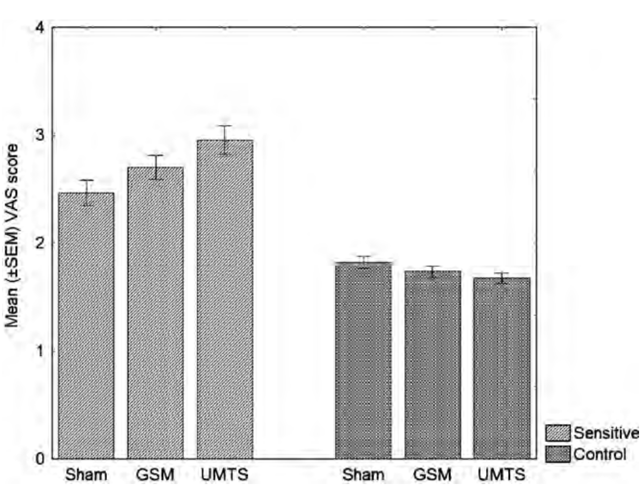

Fig. 3. Mean (±SEM) total visual analogue scale scores computed from Table 2 of Eltiti et al. [23] during sham, GSM, or UMTS exposure in sensitive and control individuals.

The increased values for anxiety, tension, and arousal found in this investigation were interpreted by the authors as due to an imbalance in the sequence of conditions with UMTS being more often the first exposure condition presented in the double-blind sessions. The imbalance was due to not reaching the predefined sample size. This points to the importance of setting the block size for randomization to a low level (e.g. in this experiment with 6 possible exposure sequences a block size of 18 would have been appropriate). Interpretation of authors, however, is questionable as pointed out by Röösli and Huss [24]. For arousal tabulated values stratified for sequence of presentation (Table 3 in [23]) demonstrates that the difference between sham and UMTS is present regardless of sequence of presentation. An additional analysis of the authors presented in response to the criticism in their statistical analysis seems to support their view that the observed difference to sham is due to a sequence effect. However, it seems that this analysis has not been correctly applied as the sequence was introduced as a between subjects factor which corrects only the interaction between group and condition. Also the figure they provided [23] is inconclusive as it only demonstrates what is already known: that first exposure leads to higher reduction of wellbeing (higher values of arousal). This investigation, although well designed and applying a more realistic exposure scenario than the other two studies, leaves some questions open. Despite an apparent corroboration of the findings of the TNO study, the imbalance in the sequence of exposures makes it difficult to decide whether the interpretation of authors that the observed effect is due to an excess number of UMTS exposures presented first in the sequence is correct or an actual effect occurred. Irrespective of these difficulties, consistent with the other investigations, wellbeing was not strongly affected.

There are several other investigations of a similar type that have been completed and already reported at scientific meetings (e.g. Watanabe, Japan; Augner, Austria, personal communication) but have not yet been published.

3.2. Animal and in vitro experiments

Anane et al. [25] applied the DMBA (7,12-dimethylbenz(a)anthracene) model of mammary tumor induction in female Sprague–Dawley rats to test whether a sub-chronic exposure to microwaves from a GSM-900 base station antenna affects tumor promotion or progression. Exposure was 2 h/day, 5 days/week for 9 weeks starting 10 days after application of 10 mg DMBA administered at an age of animals of 55 days. Exposure was applied in an anechoic chamber with animals placed in Plexiglas compartments that confined animals to a position parallel to the E-field. Details of the exposure protocol were not provided. Two series of experiments were conducted with four groups of 16 animals each. In the first experiment groups were: sham, 1.4, 2.2, and 3.5 W/kg whole-body SAR, and the second experiment with sham, 0.1, 0.7, and 1.4 W/kg. In the first experiment the tumor incidence rate was significantly increased at 1.4

and 2.2 W/kg exposure, while in the second experiment the incidence at 1.4 W/kg was significantly reduced.

The experiment by Anane et al. [25] is inconclusive not only because of the divergent results of the two experiments at the same exposure condition (1.4 W/kg SAR) but mainly because of the insufficient size of experimental groups. With a 70% background tumor incidence as observed in this investigation even for an increase to 100% in the exposed group the power to detect this difference at a significance level of 5% is less than 60%. Furthermore, considering experimental and biological variation substantial differences may occur by chance simply due to different distribution of background risk between experimental groups. Therefore, in contrast to the statement of authors that relevant differences would be detected with 16 animals per group, the study was severely underpowered and prone to spurious effects from uneven distribution of background risk. Also stress from confinement of animals could have contributed to the ambiguous results.

Yurekli et al. [26] report an experiment in male Wistar albino rats with the aim to analyze oxidative stress from whole-body exposure to a GSM 945 MHz signal at a SAR level of 11.3 mW/kg. In a gigahertz transverse (GTEM) cell a base station exposure in the far field was simulated. Two groups of rats, 9 animals in each group, were either exposed 7 h a day for 8 days or sham exposed. At the end of the exposure blood was withdrawn and malondialdehyde (MDA), reduced glutathione (GSH), and superoxide dismutase (SOD) were measured. MDA as well as SOD was significantly increased after exposure compared to sham, while GSH was significantly reduced. These results indicate that exposure may enhance lipid peroxidation and reduce the concentration of GSH which would increase oxidative stress. A disadvantage in this experiment was that the experiments were carried out sequentially and therefore animals differed in weight and no blinding could be applied.

In a series of experiments conducted in the Kashima Laboratory, Kamisu, Japan, different in vitro assays were applied to test whether irradiation with 2.1425 GHz, which corresponds to the middle frequency allocated to the down-link signal of IMT-2000 (International Mobile Telecommunication 2000, a 3G wide-band CDMA system), leads to cellular responses relevant for human health [27–29]. In the first experiment phosphorylation and gene expression of p53 was assessed [27]. In the second experiment heat-shock protein expression was evaluated in the human glioblastoma cell line A172 and human IMR-90 fibroblasts [28]. The effect of exposure of BALB/T3T cells on malignant transformation, on promotion in MCA (3-methylcholanthrene) treated cells, and on co-promotion in cells pretreated with MCA and co-exposed to TPA (12-O-tetradecanoylphorbol-13-acetate) was investigated by Hirose et al. [29]. In none of these experiments applying the same exposure regimen but different intensities and exposure durations (80 mW/kg SAR up to 800 mW/kg SAR, 2 h to several weeks) an effect of exposure was observed. Exposure facility comprised of two anechoic chambers allowing blinded simultaneous exposure of an array of 7 × 7 dishes in each chamber. Dishes were placed in a culture cabinet located in the anechoic chamber and exposed to radiation from a horn antenna whose signals were focused by a dielectric lens to obtain homogenous irradiation of the dishes. Details of the exposure protocol were not disclosed. It is stated that an IMT-2000 signal at a chiprate (a chip is a byte of information) of 3.84 Mcps was used for exposure. Assuming that it did not contain any low-frequency components as typically present in actual exposures the implications of the findings are unclear. It is rarely supposed that the high-frequency components of RF-EMFs itself are able to elicit any relevant effects in the 'low-dose' range. Rather low-frequency modulation may contribute to biological responses. Therefore, results of these Japanese investigations are of limited value for risk assessment, conditional on them having no such biologically relevant exposure attributes.

4. Discussion

Although there is considerable public concern about adverse health effects from long-term exposure to microwaves from mobile phone base stations there are only few studies addressing this issue. Several reasons can be identified for the scarcity of scientific investigations. First of all, WHO has discouraged studies of base stations, at least concerning cancer as endpoint, because retrospective assessment of exposure was considered difficult. Also COST 281 did not recommend studies of base stations and stated in 2002: "If there is a health risk from mobile telecommunication systems it should first be seen in epidemiological studies of handset use."

It is not appreciated that there are substantial and important differences between exposure to handsets and base stations. The typically very low exposure to microwaves from base stations, rarely exceeding 1 mW/m^2, was deemed very unlikely to produce any adverse effect. Assuming energy equivalence of effects a 24 h exposure at 1 mW/m^2 from a base station would be roughly equivalent to 30 min exposure to a mobile phone operating at a power of 20 mW (average output power in areas of good coverage). Because we do not know whether time-dose reciprocity holds for RF-EMF and whether there is a threshold for biological effects, there is no a priori argument why such low exposures as measured in homes near base stations could not be of significance for wellbeing and health. As an example from a different field of environmental health consider noise exposure: it is well known that at noise levels exceeding 85 dB(A) a temporary shift of hearing threshold occurs and that, besides this short-term effect, after years of exposure noise induced hearing loss may occur. On the other hand, at a sound pressure of more than a factor of 1000 below, when exposure occurs during the night, exposed individuals will experience sleep disturbances that could affect health in the long run. From this example it follows that exposure may have qualitatively different effects at different exposure levels.

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The most important difference between mobile phone use and exposure from base station signals is duration of exposure. While mobile phones are used intermittently with exposure duration seldom exceeding 1 h per day, exposure to base stations is continuous and for up to 24 h a day. It has also to be mentioned that the exposure of mobile phone users is in the near field and localized at the head region, while base stations expose the whole body to the far field. Strictly speaking exposure from mobile phones and their base stations have almost nothing in common except for the almost equal carrier frequency that is likely of no importance for biological effects.

Concerning reconstruction of exposure to base station signals there is no greater difficulty than for retrospective assessment of exposure to mobile phones. It is not always necessary to determine exposure precisely. For epidemiological investigations it often suffices to have a certain gradient of exposures. As long as any two persons can be differentiated along such a gradient epidemiological investigations can and should be carried out.

There are seven field studies of wellbeing and exposure to base station signals available to date. Two were in occupational groups working in a building below [11] or below as well as opposite a building with a roof-mounted base station antenna [10]. The other five were in neighbors of base stations: Santini et al. [5,6], Navarro et al. [8], Hutter et al. [9], Blettner et al. [7], and Thomas et al. [12]. Studies had different methodologies with the least potential for bias in the studies of Hutter et al. [9] and Blettner et al. [7]. All other studies could be biased due to self-selection of study participants. One study explored personal dosimetry during 24 h [12] but results were inconclusive due to insufficient power and omission of nighttime measurements. The study of Blettner et al. [7] had an interesting design with a first phase in a large population based representative sample and a second phase with individual measurements in the bedrooms of participants that were a subgroup of the larger sample. Unfortunately this second sample did not contain a sufficiently large fraction of individuals with relevant exposure (99% had bedside measurements below 0.3 mW/m^2).

Despite some methodological limitations of the different studies there are still strong indications that long-term exposure near base stations affects wellbeing. Symptoms most often associated with exposure were headaches, concentration difficulties, restlessness, and tremor. Sleeping problems were also related to distance from base station or power density, but it is possible that these results are confounded by concerns about adverse effects of the base station, or more generally, by specific personality traits. While the data are insufficient to delineate a threshold for adverse effects the lack of observed effects at fractions of a mW/m^2 power density suggests that, at least with respect to wellbeing, around 0.5–1 mW/m^2 must be exceeded in order to observe an effect. This figure is also compatible with experimental studies of wellbeing that found effects at 2.7 and 10 mW/m^2.

There are regular media reports of an unusually high incidence of cancer in the vicinity of mobile phone base stations. Because there are several hundred thousand base stations operating all over the world some must coincide by chance with a high local cancer incidence. Regionally cancer incidence has a distribution with an overdispersion compared to the Poisson distribution. Overdispersion is predominantly due to variations in the distribution of age and gender. Therefore, a much higher number of cases than expected from average incidences can occur by chance. Unfortunately there are no multi-regional systematic investigations of cancer incidence related to mobile phone base stations available to date. Only studies in a single community, one in Bavaria [14] and one in Israel [15], have been published that reported a significantly increased incidence in an area of 400 and 350 m around a base station, respectively. Although incidence in proximity to the base station strongly exceeded the expected values and was significant even considering overdispersion in the case of the Neila study in Bavaria, still no far reaching conclusions can be drawn due to the ecological nature of the studies. However, both studies underline the urgent need to investigate this problem with an appropriate design. Neubauer et al. [30] have recommended focusing initially on short-term effects and ‘soft’ outcomes given the problems of exposure assessment. However, as has been mentioned previously, the problems of exposure assessment are less profound as often assumed. A similar approach as chosen in the study of leukemia around nuclear power plants [31] could be applied also for studying cancer in relation to base station exposure. Such a case–control design within areas around a sufficiently large sample of base stations would provide answers to the questions raised by the studies of Eger et al. [14] and Wolf and Wolf [15].

In 2003 the so-called TNO study [19] had received wide publicity because it was the first experimental investigation of short-term base station exposure in individuals that rated themselves sensitive to such signals. A lot of unfounded criticism was immediately raised such as complaints about the limited sample size and the not completely balanced design. But also valid arguments have been put forward. The consecutive tests with all experimental conditions presented one after the other could result in sequential effects that may not be completely removed by balancing the sequence of exposures. In several countries follow-up studies were initiated two of which have already been published [21,23]. One of these experiments partly supported the TNO study the other found no effect. While the study of Regel et al. [21] closely followed the conditions of the previous experiment only avoiding the shortcomings of a sequential within-day design and improvements by including two intensities of UMTS exposure, the study of Eltiti et al. [23] had a different procedure and included physiological measurements. Regel et al. [21] applied the same questionnaire as has been used in the TNO study. Because non-sensitive participants and sensitive participants during sham exposure (despite their almost 10 years younger age) reported considerably lower wellbeing, it is possible that the experimental setup was more adverse and imposed too much stress such that these conditions confounded the effect of the base station exposure. Results of the other replication experiment of Eltiti et al. [23] may be compromised by an imbalance in the sequence of experiments with more sensitive participants receiving UMTS exposure in the first session. Hence, based on available evidence, it cannot be firmly decided whether such weak signals as applied in these experiments to simulate short-term base station exposure affects wellbeing.

Concerning animal experiments and in vitro investigations the data base is insufficient to date. While in vivo exposure of Wistar albino rats [26] imply an induction of oxidative stress or an interaction with antioxidant cellular activity, in vitro experiments [27] found no indication of cellular stress in human glioblastoma cells and fibroblasts. While some may be inclined to attribute effects in the low-dose range to experimental errors there is the possibility that the characteristics of the exposure that are relevant for an effect to occur simply vary in the experiments and lead to ambiguous results. As long as these decisive features of the exposure (if they actually exist) are unknown and in particular the type and components of low-frequency modulation vary across experiments, it is impossible to coherently evaluate the evidence and to come to a science based conclusion.

Overall results of investigations into the effects of exposure to base station signals are mirroring the broader spectrum of studies on handsets and on RF-EMF in general. There are indications from epidemiology that such exposures affect wellbeing and health weakly supported by human provocation studies and an inconclusive body of evidence from animal and in vitro studies.

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Please cite this article in press as: M. Kundi, H.-P. Hutter, Mobile phone base stations—Effects on wellbeing and health, Pathophysiology (2009), doi:10.1016/j.pathophys.2009.01.008

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Pathophysiology xxx (2009) xxx–xxx

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Review

Long-term exposure to magnetic fields and the risks of Alzheimer's disease and breast cancer: Further biological research

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Received 1 November 2008; accepted 30 January 2009

Abstract

Objective: Extremely low frequency (ELF) and radio frequency (RF) magnetic fields (MFs) pervade our environment. Whether or not these magnetic fields are associated with increased risk of serious diseases, e.g., cancers and Alzheimer's disease, is thus important when developing a rational public policy. The Bioinitiative Report was an effort by internationally recognized scientists who have spent significant time investigating the biological consequences of exposures to these magnetic fields to address this question. Our objective was to provide an unbiased review of the current knowledge and to provide our general and specific conclusions. **Results:** The evidence indicates that long-term significant occupational exposure to ELF MF may certainly increase the risk of both Alzheimer's disease and breast cancer. There is now evidence that two relevant biological processes (increased production of amyloid beta and decreased production of melatonin) are influenced by high long-term ELF MF exposure that may lead to Alzheimer's disease. There is further evidence that one of these biological processes (decreased melatonin production) may also lead to breast cancer. Finally, there is evidence that exposures to RF MF and ELF MF have similar biological consequences. **Conclusion:** It is important to mitigate ELF and RF MF exposures through equipment design changes and environmental placement of electrical equipment, e.g., AC/DC transformers. Further research related to these proposed and other biological processes is required.

Keywords: Extremely low frequency (ELF); Magnetic fields (MFs); Amyloid beta (Aβ); Melatonin; Alzheimer's disease (AD)

Contents

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doi:10.1016/j.pathophys.2009.01.005

1. Introduction

In this review, we emphasize (a) two proposed biological models "explaining" the apparent relationship between high, long-term exposure to extremely low frequency (ELF) magnetic fields (MFs) and Alzheimer's disease (AD), one of which also relates to breast cancer and (b) areas of biological research needed to confirm or refute these models. Prior to this discussion, we provide the conclusions from our detailed review chapter (Section 12: Davanipour and Sobel [1]) in the Bioinitiative Report [2] related to epidemiologic research, which initially identified these relationships. We refer the reader to Section 12 and supporting, peer-reviewed papers for details of the epidemiologic studies discussed in that section. Other papers in this issue of Pathophysiology (e.g., on the stress response and DNA strand breaks) demonstrate that exposures to ELF MF and radio frequency (RF) MF often have the same biological consequences.

2. Epidemiologic studies presented in the Bioinitiative Report related to Alzheimer's disease and breast cancer

The conclusions reached from our detailed review of the literature in Section 12 in the Bioinitiative Report (see references for URL) on long-term significant ELF MF exposure and Alzheimer's disease and breast cancer are provided below [1]. The section references below refer to sub-sections of Section 12 of the Bioinitiative Report.

Melatonin production (Section II). Eleven of the 13 published epidemiologic residential and occupational studies are considered to provide (positive) evidence that high long-term ELF MF exposure can result in decreased melatonin production. The two negative studies had important deficiencies which may certainly have biased the results. Thus, there is sufficient evidence to conclude that long-term relatively high ELF MF exposure can result in a decrease in melatonin production. It has not been determined to what extent personal characteristics, e.g., medications, interact with ELF MF exposure in decreasing melatonin production.

2.1. Alzheimer's disease

Section 12 of the Bioinitiative Report provides the details of the following conclusions.

- There is initial evidence that (i) a high level of peripheral amyloid beta, generally considered the primary neurotoxic agent when aggregated, is a risk factor for AD and (ii) medium to high MF exposure can increase peripheral amyloid beta. High brain levels of amyloid beta are also a risk factor for AD and medium to high MF exposure to brain cells likely also increases these cells' production of amyloid beta (Section IIIA).
- There is considerable *in vitro* and animal evidence that melatonin protects against AD. Therefore, it is certainly possible that low levels of melatonin production are associated with an increase in the risk of AD (Section IIIB).
- There is strong epidemiologic evidence that long-term exposure to ELF MF is a risk factor for AD. There are seven studies of ELF MF exposure and AD that met our inclusion criteria. Six of these studies are more of less positive and only one is negative. The negative study has a serious deficiency in ELF MF exposure classification which results in subjects with rather low exposure being considered as having significant exposure. Several published studies were excluded from further consideration due to serious deficiencies, primarily diagnostic inaccuracy (e.g., use of death certificates for diagnosis of AD) and/or serious exposure assessment problems. These latter studies likely had risk estimated seriously biased towards the null hypothesis of no risk. It should be noted, however, that even some of these studies were positive (Sections IIIC and IIID).

2.2. Breast cancer

There is sufficient evidence from *in vitro* and animal studies, from human biomarker studies, from occupational and light at night case-control studies, and the only two longitudinal studies with appropriate collection of urine samples to conclude that high ELF MF exposure may certainly be a risk factor for breast cancer (Section IV). Note that at the time the Bioinitiative Report was made public, there was only one longitudinal study with appropriate collection of urine samples. There are now two such studies [3,4].

Seamstresses. Seamstress is, in fact, one of the most highly ELF MF exposed occupations, with exposure levels generally well above 10 mG over a significant proportion of the workday. Seamstresses have been consistently found to be at higher risk of Alzheimer's disease and breast cancer. This occupation deserves specific attention in future studies. We are unaware of any measurements of RF MF among seamstresses (Section V and throughout Section 12).

3. Biological hypotheses relating ELF MF exposure to Alzheimer's disease and breast cancer

Two biological hypotheses are discussed. The first one relates ELF MF exposure to increased amyloid beta (Aβ) production and subsequent development of AD. The second one relates ELF MF exposure to decreased melatonin production. Decreased melatonin production appears to have differing deleterious consequences related to AD and breast cancer development.

Please cite this article in press as: Z. Davanipour, E. Sobel, Long-term exposure to magnetic fields and the risks of Alzheimer's disease and breast cancer: Further biological research, Pathophysiology (2009), doi:10.1016/j.pathophys.2009.01.005

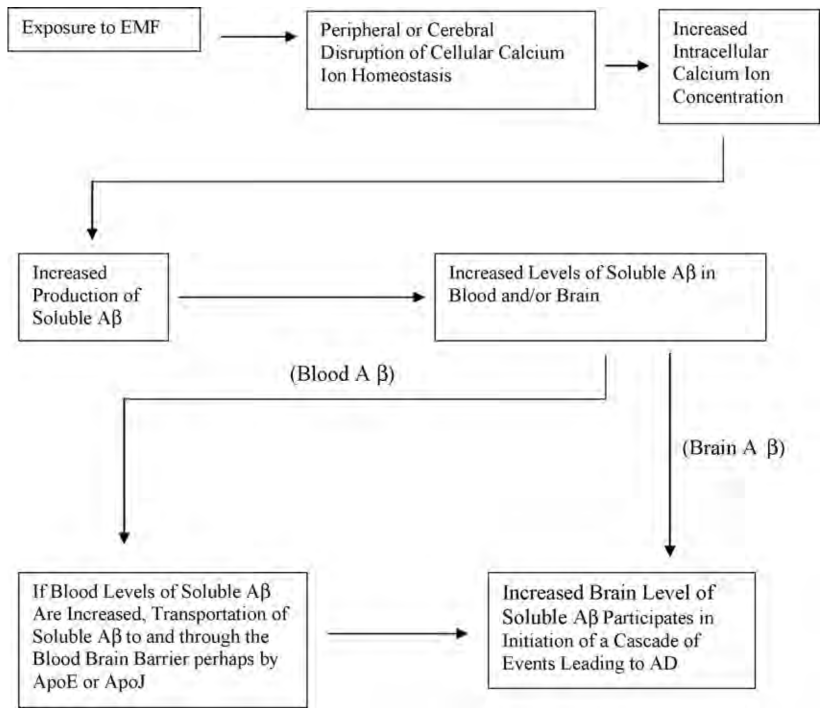

Fig. 1. Hypothesized biological pathway from MF exposure to AD Development (from Sobel and Davanipour [5]).

3.1. ELF MF exposure and peripheral and brain production of amyloid beta (Fig. 1)

The ELF MF exposure and increased amyloid beta hypothesis was developed by Sobel and Davanipour as a result of our initial findings that long-term ELF MF occupational exposure was a risk factor for AD [5] (see Fig. 1). Seamstress was the most common occupation among subjects with AD in the five databases we investigated [6–8]. ELF MF exposure among seamstresses had not been measured prior to our 1995 study [6]. Beginning in 1994, we measured a very large number of seamstresses working in either a factory setting or individually. Their exposures were very high, particularly when using an industrial sewing machine. The highest exposures were, however, not to the brain, because the motor on industrial machines is located at the knees. The motor or AC/DC transformer in home sewing machines is in the machine arm located near the operator's chest and right arm. This peripheral exposure led us to consider how peripheral ELF MF exposure might be associated with development of amyloid plaques in the brain.

Our biologically plausible hypothesis relating MF exposure to AD is based on the independent work of many researchers in several different fields. Details and references are provided in Sobel and Davanipour [5]. Briefly, the hypothesized process involves increased peripheral or brain production of Aβ as a result of MF exposure causing voltage-gated calcium ion channels to be open longer than normal. This results in abnormally high intracellular levels of calcium ions which in turn results in the production of Aβ. The resulting Aβ is quickly secreted into the blood. If peripheral, the Aβ is then transported to and through the blood–brain barrier, perhaps best chaperoned by the ε4 isoform of apolipoprotein E (apoE). (Note that this might be one reason why the ε4 isoform is a risk factor for AD.) Fig. 1 provides a schematic outline of the hypothesis. Each step in the proposed pathway is supported by *in vitro* studies.

At the time of publication of this hypothesis, no human studies related to this hypothesis had been conducted. There are now two groups that have published relevant studies, without apparently any knowledge of our hypothesis—or at least no reference to the hypothesis: (1) high levels of peripheral $A\beta_{1-42}$, the more neurotoxic version of Aβ, has been found to be a risk factor for AD [9,10]; acute exposure to ELF MF increases peripheral Aβ [11]. Details may also be found in the Bioinitiative Report (Section IIIA) [1].

3.2. Melatonin—background

Melatonin is found in every cell of the body and readily crosses the blood–brain barrier. It scavenges reactive oxygen species (ROS) at both physiologic and pharmacologic concentrations. In the literature, "physiologic" refers to blood level concentrations of melatonin, while "pharmacologic" indicates 2–3 orders of magnitude higher concentration. Recently, intracellular levels of melatonin, especially within the nucleus, have been shown to be naturally at "pharmacologic" levels for all cellular organelles studied to date [12,13].

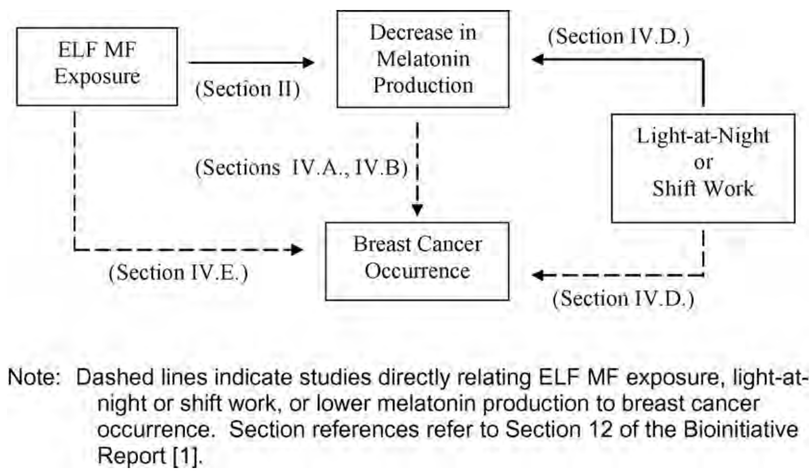

Fig. 2. Outline of the evidence that ELF MF exposure causes breast cancer through decreases in melatonin production—with section references to Section 12, Bioinitiative Report [1]. Note: Dashed lines indicate studies directly relating ELF MF exposure, light-at-night or shift work, or lower melatonin production to breast cancer occurrence.

3.3. *Low melatonin production and Alzheimer's disease*

Numerous *in vitro* and animal studies indicate that melatonin may be *protective* against AD and thus low or lowered melatonin production may be a risk factor for AD. These studies have found that melatonin has the following effects:

- Inhibition of the neurotoxicity and cytotoxicity of Aβ, including in mitochondria [14–19];
- Inhibition of the formation of β-pleated sheet structures and Aβ fibrils [20–25];
- Reversal of the profibrillogenic activity of apolipoprotein E ε4, an isoform conferring increased risk of AD [21];
- Inhibition of the oxidative stress *in vitro* and in transgenic mouse models of AD, if given early [23,26,27], but not necessarily if given to old mice [28];
- Increase in survival time in mouse models of AD [23];
- Reduction of oxidative stress and of proinflammatory cytokines induced by $A\beta_{1-40}$ in rat brain *in vitro* and *in vivo* [29–31];
- Decrease of the prevalence of $A\beta_{1-40}$ and $A\beta_{1-42}$ in the brain in young and middle aged mice [32];
- Improvement of memory and learning in rat models of AD pathology [33,34], but not necessarily in Aβ-infused rat models [35].

Note that transgenic mouse models of AD mimic senile plaque accumulation, neuronal loss, and memory impairment. There have been several reviews, e.g., [36–39]. Thus, chronic low levels of melatonin production may be etiologically related to AD incidence [40].

3.4. *Low melatonin production and breast cancer*

See Fig. 2 for a diagram of the discussed relationships between ELF MF exposure and breast cancer risk.

In vitro studies related to prevention of oxidative damage. Well over 1000 publications have found that melatonin neutralizes hydroxyl radicals and reduces oxidative damage. For reviews see Tan et al. [41] and Peyrot and Ducrocq [42]. Melatonin has also been shown to act synergistically with vitamin C, vitamin E and glutathione [43] and stimulates the antioxidant enzymes superoxide dismutase, glutathione peroxidase and glutathione reductase [44]. Furthermore,

- melatonin neutralizes hydroxyl radicals more efficiently than does reduced glutathione [45,46];
- melatonin reduces oxidative damage to macromolecules in the presence of free radicals [47,48] due at least to its free radical scavenging properties [49];
- melatonin increases the effectiveness of other antioxidants, e.g., superoxide dismutase, glutathione peroxidase, and catalase [50–54];
- melatonin has protective effects against ultraviolet and ionizing radiation [55–57];
- melatonin has been found to be a more potent protector from oxidative injury than vitamin C or vitamin E (micromoles/kg) (for a review of the evidence, see: Tan et al. [43];
- melatonin was also found *in vitro* to scavenge peroxyl radicals more effectively than vitamin E, vitamin C or reduced glutathione [58], although melatonin is not a very strong scavenger of peroxyl radicals [49].

Animal studies of melatonin and mammary tumor prevention. Several studies have found that melatonin inhibits the incidence of mammary tumors in laboratory animals either prone to such tumors or exposed to a carcinogen (e.g., [50–63]). Tan et al. [64,65] found that melatonin at both physiological and pharmacological levels protected Sprague–Dawley rats from safrole induced liver DNA adduct formation. Melatonin and retinoic acid appear to act synergistically in the chemoprevention of animal model tumors [66] and *in vitro* systems [67].

Melatonin prevents oxidative DNA damage by estradiol and radiation. Karbownik et al. [68] found that melatonin protects against DNA damage in the liver and kidney of male hamsters caused by estradiol treatment. Several studies have found that laboratory animals are protected by melatonin from lethal doses of ionizing radiation (e.g., [69–71]). Vijayalaxmi et al. [70] and Karbownik et al. [71] also investigated markers of oxidative DNA damage and found significant decreases in these markers in the melatonin treated animals.

Melatonin: Scavenger of •OH and Other ROS. Melatonin is a powerful, endogenously produced scavenger of reactive oxygen species (ROS), particularly the hydroxyl radical (•OH). Other ROS which melatonin scavenges include hydrogen peroxide (H_2O_2), nitric oxide ($NO^•$), peroxynitrite anion ($ONOO^-$), hypochlorous acid (HOCl), and singlet oxygen ($^1O_2$) [50,72–75]. •OH is produced at high levels by natural aerobic activity. ROS are also produced by various biological activities or result from certain environmental and lifestyle (e.g., smoking) exposures. •OH is the most reactive and cytotoxic of the ROS [76]. •OH appears not to be removed by antioxidative enzymes, but is only detoxified by certain direct radical scavengers such as melatonin [77].

4. Discussion and future research

Other papers in this special issue of Pathophysiology provide evidence that RF MF exposure and ELF MF exposure may have similar biological consequences.

We primarily limit our discussion of future research to studies in humans with experimental medicine components, emphasizing the latter. However, we initially discuss limiting exposures.

It should be noted that ELF MF exposure may also be associated with other cancers. This may be because of the decrease in melatonin production and melatonin's varying antioxidant, anti-inflammation, and immune response enhancement properties.

4.1. Epidemiologic studies

The incidence rates of Alzheimer's disease and breast cancer are increasing. These increases are certainly in part due to our living longer, at least for AD, if not better lives. However, environmental exposures are likely to play important roles. At the same time, ELF and RF MF exposure is becoming more and more common in our world. In our three published studies of MF and AD, approximately 7.4–12.0% of the cases and 3.4–5.3% of the controls had primary occupations associated with medium or high ELF MF exposure [6–8]. Many more subjects may have had exposures from sources generally not identified in epidemiologic studies, because individualized 'on-site' exposure assessment is usually not feasible. We give two examples coming from 'onsite' inspections we have performed: a subject who had developed amyotrophic lateral sclerosis (ALS) had spent many years with a 75 mG ELF MF exposure due to having his foot on a deadbolt lock/unlock foot devise for his office door under his desk; a subject who had developed AD who spent over 25 years sitting at his home desk for at least 4 h per day in a chair backed up to a wall with a fuse box directly on the other side of the wall which produced a very high ELF MF exposure to his back and head. (Note that there is also significant epidemiologic evidence that ELF MF exposure is a risk factor for ALS.) The frequencies of such exposures in studies are unknown.

As is often the case, more research is required. However, the designs of this future research should be informed and directed by the results of previous research. Future epidemiologic studies should use subjects for whom it is unequivocally known that the ELF MF and/or RF MF exposure is high and matched subjects for whom such exposure is known to be low. Matching criteria should include age, gender, and residential environment so as to at least partially exclude other exposures.

There should be additional studies related to the levels of production of peripheral amyloid beta, particularly $A\beta_{1-42}$, and melatonin, on the one hand, and both MF exposure and the risk of AD, on the other hand. Such studies need to be able to investigate the possible associations between peripheral amyloid beta and melatonin levels and both earlier/concurrent MF exposure and subsequent development of AD. Similar studies need to be carried out for breast cancer, excluding the amyloid beta component. This effort will likely require both retrospective and longitudinal studies. There are only two known longitudinal studies [3,4] which collected urine samples at baseline so that overnight premorbid melatonin production was reliably estimated. These studies found an association between low melatonin production and breast cancer. These studies may also be able to provide important additional information if it is possible to determine MF exposures with reasonable accuracy and follow-up AD status on a sufficient number of participants.

Case-control studies of melatonin as a risk factor for AD and breast cancer are hampered by the fact that biological sequelae of both AD and breast cancer result in a decline of melatonin production to an unknown extent. (In breast cancer patients, there is a melatonin production rebound when tumors are surgically removed. In AD patients, the production of serotonin, the precursor of melatonin, is decreased and noradrenergic regulation becomes dysfunctional [78].) However, melatonin production is partially under genetic control. We have conducted a study of relatively healthy members of nuclear families and melatonin production (DOD Congressionally Directed Medical Research Program Grant: DAMD17-00-1-0692). The production of melatonin of the mother was successfully modelled as a function of the melatonin of a daughter, after adjusting for both the daughter's age and the influence of the father. This work allows for the design of case-control studies of the influence of long-term MF exposure on both melatonin production and the risks of breast cancer and AD.

4.2. ELF and/or RF MF exposure mitigation

It is also vital to mitigate both the extent of MF exposure and the effects of such exposure. Mitigation means efforts to both locate and shield or move the sources of MF away from individuals and design equipment which produces lower levels of MF. Little effort has apparently been spent on design issues. There are simple things that can be done. For example, almost all AC/DC transformers emit about 75 mG ELF MF fields. The exception, in our experience, has been a few transformers for Apple laptops measured about 10 years ago. AC/DC transformers are now everywhere, specifically under and around office desks and in nearly every room in a residence, often near the heads of beds. Maximizing one's distance from a transformer is important, because the strength of the MF field drops off with the square or cube of the distance from the source.

Seamstress is a very common profession and being a seamstress is clearly a risk factor for AD and quite possibly for breast cancer also. Seamstresses experience higher ELF MF exposure than members of almost any other profession. Older industrial sewing machines are extremely common all over the world. They produce extremely strong MFs, but it is possible to design "covers" for the motor to interfere with these fields, much as "headphones" can mitigate sound waves. Newer computer driven home sewing machines produce MF because of the AC/DC transformer. These transformers are placed in the arm of the machine, which results in high MF exposure to the operator. Simply by connecting the transformer to the machine by an electrical cord about three or more feet from the operator would mitigate a significant percentage of the MF exposure.

4.3. Biological mechanisms/experimental medicine research

We argue that, to the extent possible, research should now be conducted in humans. We list the following research questions as important examples of studying the biological effects of ELF and/or RF MF exposure:

1. Generation of peripheral amyloid beta
   a. Determination of intracellular Ca^{2+} ion concentration changes as a consequence of ELF or RF MF exposure.
   b. Measurement of the amount of $A\beta_{1-42}$ and $A\beta_{1-40}$ produced by and secreted from cells.
      i. This could be done at least by measuring blood levels of amyloid before and after ELF and/or RF MF exposure.
      ii. Perhaps there are more sophisticated experimental designs.
   c. Determination of which cell types in fact produce more amyloid beta after or during ELF and/or RF MF exposure.
   d. Determination of the dose response relationship(s) between ELF and/or RF MF exposure and cellular amyloid beta production.
   e. Measurement of the accumulation of amyloid beta in the brain, perhaps using PET scans [79,80].
2. Decrease in melatonin production

   Note: it is known that the pineal gland, the primary source of melatonin, has a tendency to become calcified and, perhaps, this is the reason why generally there is a reduction of melatonin production during aging.
   a. Determination of the extent of intracellular calcium within the pineal gland as a result of acute ELF and/or RF MF exposure.
   b. Determination of the extent of calcification of the pineal gland as a result of varying levels of long-term ELF and/or RF MF exposure.

Acknowledgement

The authors would like to thank Dr. James Burch, Arnold School of Public Health, University of South Carolina, for his review of Section 12 in the Bioinitiative Report.

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Please cite this article in press as: Z. Davanipour, E. Sobel, Long-term exposure to magnetic fields and the risks of Alzheimer's disease and breast cancer: Further biological research, Pathophysiology (2009), doi:10.1016/j.pathophys.2009.01.005

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Pathophysiology xxx (2009) xxx–xxx

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Reproductive and developmental effects of EMF in vertebrate animal models

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Received 10 August 2008; received in revised form 28 August 2008; accepted 30 January 2009

Abstract

This paper reviews the literature data on the effects of electromagnetic fields (EMF), in the reproductive organs as well as in prenatal and postnatal development of vertebrate animals. Review articles which have been published till 2001, regarding the reproductive and developmental effects of the entire range of frequency of electromagnetic fields, were surveyed. Experimental studies which were published from 2001 onwards were summarized. Special focus on the effects of radiofrequencies related to mobile communication in the above mentioned topics has been made. According to the majority of the investigations, no strong effects resulted regarding the exposure to EMF of mobile telephony in the animal reproduction and development. However further research should be done in order to clarify many unknown aspects of the impact of EMF in the living organisms.

Keywords: Electromagnetic fields (EMF); Mobile phones; Teratology; Endometrium; Testis

1. Introduction

During the 20th century, the exposure to electromagnetic fields (EMF) became an important source of concern about the possible effects in the living organisms. The artificial sources of electromagnetic radiation have risen tremendously because of the ongoing needs on electricity, telecommunications, and electronic devices. In this context, World Health Organisation (WHO) established in 1996 the International EMF project in order to assess health and environmental effects of exposure to EMF in the frequency range from 0 to 300 GHz. For the purpose of this paper this range will be divided into static (0 Hz), extremely low frequency (ELF > 0–300 kHz), intermediate frequencies (IF > 300–10 MHz) and radiofrequency (RF 10 MHz–300 GHz) fields [J. Juutilainen, Developmental effects of electromagnetic fields, Bioelectromagnetics 7 (2005) S107–S115]. The mobile phone technology is based on radiofrequency radiation with transmission of microwaves carrying frequencies between 880 and 1800 MHz [P.A. Valberg, T.E. van Deventer, M.H. Repacholi, Workgroup report: base stations and wireless networks-radiofrequency (RF) exposures and health consequences, Environ. Health Perspect. 115 (2007) 416–424].

The mobile telephony revolution took place in the last decade. There is an increasing number of cell phone users all over the world. Also, new technologies which use the spectrum of high frequency emissions are incorporated in many aspects of telecommunications. As a consequence, there is a lot of interest about the possible effects of the radiation emitted from the machines which are engaged in the telephony such as hand phones, base stations and transmitters.

The biological effects of EMF have been and are being investigated on different levels of organization. On the level of human populations, epidemiological studies are used whereas, on the level of individuals human, animal and plant *in vivo* experiments are carried out. Furthermore, on the level of organs, tissues and cells *in vitro* investigations are employed. Finally, on the sub-cellular level, biochemical and molecular techniques are utilized.

From another point of view, many studies have been carried out or are in progress about the various effects of radiation emissions regarding the behaviour, cancer, central nervous system, sleep, children, cardiovascular system, immune function, reproduction and development [3].

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doi:10.1016/j.pathophys.2009.01.010

The present paper will focus on the existing data about the reproductive and developmental effects of EMF in vertebrates. Reproduction is a critical function of the organisms and involves two body systems the male and female genital system. The development comprises a series of events which begins with fertilization, continues with implantation, embryonic growth and terms with sexual maturity. In the context of systematic zoology, the vertebrates are close to the humans. Therefore, the animal studies could provide useful information on the comprehension of interaction of EMF with the living organism and on the possible commonality with the humans.

The biological effects of EMF of interest can be broadly grouped into thermal and non-thermal [4]. The thermal effects are associated with local heat production just like the mechanism of a microwave oven. The non-thermal mechanism is triggered by an amount of energy absorption, which is not directly associated with temperature change but rather to some other changes produced in the tissues.

The goal of this paper is to present the up to date available data about the EMF and their potential effects on reproduction and development, filling the gap of information from the most recent published reviews. All the bibliographic data which will be presented were collected exclusively from scientific journals published in English and partially in other languages. The survey includes studies which were published from 2001 onward. The studies which relate to the impact of mobile phone electromagnetic fields will be presented thoroughly and independently from the date of their publication.

2. Historical background

The first paper which I found in the medical literature, regarding the effects of EMF on the development of vertebrates, was published in 1893 in an anatomical journal from Windle [5]. The author summarized the observations of three scientists and added his own about the effects of electricity on the chicken embryos. Two years later the same author [6], published an account on the effects of electricity and magnetism on development.

In 1980 two papers were published about the biological effects of microwave radiation. Cook et al. [7] published a comprehensive survey regarding the very early research on the biological effects of electromagnetic fields. The early work on short waves from 1885 to 1940 was presented. Following, the authors summarized the available data from 1940 to 1960. Leach [8] provided an account on the genetic, growth and reproductive effects of microwave radiation including early studies in this field that were published from 1959 to 1979. The majority of revised papers dealt with animals. Later, Algers and Hennichs [9] summarized the biological effects on vertebrates, of electromagnetic fields where the frequency did not exceed 100 Hz. The authors included many studies about the impact of EMF on farm animals. The same year, a specialized review was published on the effects of non-ionizing radiation on birds [10].

Berman et al. [11], presented the results of a large multinational experimental effort (Henhouse project) regarding the low frequency EMF effects on chick embryos. Juutilainen [12], Chernoff et al. [13], Brent et al. [14] presented detailed reviews of the literature about the effects on reproduction related to low frequency EMF.

Jensh [15] reviewed behavioral teratologic studies using microwave radiation with special interest to continuous wave (CW) 915, 2450, or 6000 MHz radiation.

Verschaeve and Maes [16] reviewed the genetic, carcinogenic and teratogenic effects of RF (300 MHz–300 GHz). Regarding the effects on reproduction and teratogenesis, studies from 1961 to 1991 were surveyed. The majority of these experimental studies dealt with the exposure of animals at 2.45 GHz. The same year, Huuskonen et al. [17] reported on the teratogenic and reproductive effects of low frequency (0–100 kHz) magnetic fields associated with the use or transmission of electric power or emitted from video display terminals. The animal studies that were surveyed, have been published from 1987 to 1997 regarding the effects of alternating magnetic fields on prenatal development of rats and mice. In the same paper, studies on the effects of prenatal exposure of alternating magnetic fields on postnatal development were included. Brent [18] provided a thorough review of *in vivo* and *in vitro* studies on the reproductive and teratologic effects of low frequency EMF. The survey of reproductive effects has involved studies with chick embryos, chickens, cows, mice, and rats from 1969 to 1996. O'Connor [19] recorded the intrauterine effects in animals exposed to radiofrequency and microwave fields with a special feature. The SAR of the surveyed studies was above the limit of 0.4 W/kg.

Experimental studies on the teratologic effects or developmental abnormalities from exposure to RF electromagnetic fields in the range 3 kHz–300 GHz were reviewed from Heynick and Merritt [20]. The review included investigations with insects, birds (chicken, quails, turkeys) and mammalian species (mice, rats) as well as non-human primates which appeared from 1974 to 2000. A brief critical review on the developmental effects of extremely low frequency (ELF) electric and magnetic fields provided by Juutilainen [21]. Löscher [22] published a survey of the effects of radiofrequency electromagnetic fields on production, health and behaviour of farm animals.

Juutilainen [1] reported on the effects of EMF on animal development. In his review, he surveyed specific topics such as the Henhouse project, the interaction of LF-IMF EMF with known teratogens, and the behavioral teratology of RF. Saunders and McCaig [23] summarized the possible effects on prenatal development of physiologically weak electric fields induced in the body by exposure to extremely low frequency electromagnetic fields and of elevated temperature levels that might result from exposure to radiofrequency (RF) radiation.

Please cite this article in press as: A.F. Pourlis, Reproductive and developmental effects of EMF in vertebrate animal models, Pathophysiology (2009), doi:10.1016/j.pathophys.2009.01.010

Table 1
Overview of investigations on EMF effects on animal genital system.

Animal species	Exposure frequency	Exposure parameters	Exposure duration	Endpoint	Results	Comments	Reference
Mouse Swiss	50 Hz	25 mT	Continuous 90 days	Effects on reproductive ability	No effect on the fertility of male and female mice. The ovarian weight was significantly increased		[27]
Mouse CD1 (BALB/c X DBA/2)	60 Hz	2 mT	Continuous for 72 h or 8 h/day for 10 days	Sperm morphology	No statistically differences were observed	Two groups were treated with mitomycin C. Sperm abnormalities were found in the group exposed versus the group treated with mitomycin C alone	[28]
Mouse BALB/c	60 Hz	0.1 or 0.5 mT	24 h/day for 8 weeks	Germ cell apoptosis in the testes	No significant changes in testicular weights. Decrease of normal seminiferous tubules. Increase of the germ cell death		[29]
Rat Sprague–Dawley	60 Hz	5, 83.3, 500 mT	Continuous 21 h/day from day 6 of gestation to day 21 of lactation	Spermatotoxicity and reproductive dysfunction inthe F1 offspring	No detectable alterations in offspring spermatogenesis and fertility		[30]
Rat Sprague–Dawley	50 Hz	$25 \pm 1\ \mu T$	Continuous for 18 weeks	Effects on sperm count, weights of testes, seminal vesicles, preputial glands	No effect on the weight of testes. Significant reduction of the weight of seminal vesicles and preputial glands. Significant reduction in sperm count		[31]
Rat Sprague–Dawley	50 Hz	1.35 ± 0.018 mT	2 h/day, 7days/week for 2 months	Sperm count, morphological changes of testes	No significant alterations were observed	Funding not mentioned	[32]
Rat Wistar albino♀♂	50 Hz	1 mT (mean value)	3 h/day for 50 or 100 days	Morphological evaluation of uterus and ovaries	Ultrastructural alterations in germinal epithelium of ovaries in the experimental group (50 days) as well as in tunica albuginea (100 days)	Ambiguous observations in the uterus	[33]
Rat Sprague–Dawley♂♀	20 kHz	6.25 mT	8 h/day, 5 days/week for 90 days	Histopathological examination of various organs	No differences were seen in testis and ovary		[34]

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Table 1 (*Continued*)

Animal species	Exposure frequency	Exposure parameters	Exposure duration	Endpoint	Results	Comments	Reference
Rat Wistar ♂♀	50 Hz		3 weeks *in utero* and 5 weeks postnatal	Testes	Morphological changes in the boundary tissue of the seminiferous tubules		[35]
Rat Sprague–Dawley♀♂	20 kHz sine waves	6.25 mT	8 h/day for 12 or 18 months	Histopathological examination of various organs	No differences were seen in testis and ovary		[36]
Rat Wistar	30–300 GHz	>0.3 mW/cm^2	30 min for 63 days	Spermatogenesis	Morphological changes in spermatozoa	Scanty data presentation	[37]
Rat Wistar	50 Hz		8 h/day for 8 months	Histological evaluation of testes	Mean seminiferous tubule diameter and testicular weight were significantly lower in exposed group. Histologic damage score was threefold in experimental group versus control		[38]

A special topic, the effects of EMF from power lines on avian reproductive biology, was reviewed by Fernie and Reynolds [24]. Krewski et al. [25], reviewed studies referring to various disciplines regarding the effects of RF. The included literature was published between 2001 and 2003. A novelty of this paper, was a discussion of the reports of various authorities and committees about the potential health risks associated with exposure to RF fields. A gap in the literature regarding the biological effects of EMF in the intermediate frequency range was covered by the review of Shigemitsu et al. [26].

During the last decade, many reports from authorities (local, national and international) and expert panels have been uploaded on the web [2].

It is suggested that the reader refer to the above-mentioned review articles and electronic addresses, in order to assemble a more complete and detailed view of the biological effects of EMF.

3. Male genital system

The testes are very important organs situated externally to the body and enclosed by the scrotum. The testicular parenchyma is the site of an intense proliferation and differentiation of the germinal cells that will become the sperm cells. The testes are very sensitive to temperature variations and for this reason the scrotum, which contains the testicular parenchyma, has a specialized contractile structure.

Studies that have evaluated EMF effects (mainly LF) on the genital systems of the vertebrates are summarized in Table 1.

Regarding mobile telephony, the first study conducted by Dasdag et al. [39] investigated whether there are adverse effects due to microwave exposure emitted by cellular phones in male Wistar albino rats. The animals (n = 18) were divided in three groups (control, standby exposed group, speech exposed group). Specific energy absorption rate (SAR) was 0.141 W/kg. Rats in the experimental groups were exposed for 2 h/day for 1 month in standby position, whereas phones were turned to the speech position three times for 1 min. The decrease of epididymal sperm counts in the speech groups was not found to be significant. Differences in terms of normal and abnormal sperm forms were not observed. Histological changes were especially observed in the testes of rats in the speech group. Seminiferous tubular diameter of rat testes in the standby and speech groups was found to be lower than the sham group. Rectal temperatures of rats in the speech group were found to be higher than the sham and standby groups. The rectal temperatures of rats before and after exposure were also found to be significantly higher in the speech group.

The same group of authors [40], failed to reproduce the results of their previous work. Sixteen Sprague–Dawley rats were separated into two groups (control, experimental). They were exposed to 890–915 MHz pulsed wave (PW) daily for

20 min/day for 1 month. For 250 mW average radiated power, SAR was 0.52 W/kg. No differences were observed in the percentages of epididymal normal and abnormal sperms, the epididymal sperm count, as well as in the seminiferous tubule diameter between control and experimental groups. Also, the testicular biopsy score as evaluated by Johnson's scale did not differ significantly.

Aitken et al. [41] assessed the testis of mice irradiated with 900 MHz in a waveguide, with an exposure condition SAR 90 mW/kg for 7 days at 12 h/day. The authors did not observe abnormalities regarding the sperm number, morphology and vitality. However, they reported significant damage to the mitochondrial genome as well as to the nuclear-globin locus.

Results similar to a previous study [39] regarding the diameter of the seminiferous tubules of rat testes were obtained by Ozguner et al. [42]. During the experiment, 20 male Sprague–Dawley rats (5 months of age) were either exposed to 900 MHz CW (average power density $1 \pm 0.4\,mW/cm^2$) or not (control group). Rats exposed 30 min/day, for 5 days/week for 4 weeks. The authors also did not observe significantly different values of weight of testes, testicular biopsy score count and the percentage of interstitial tissue. However, the mean height of the germinal epithelium was found decreased in the group of rats that had been irradiated.

Forgács et al. [43] repeatedly exposed male NMRI mice to 1800 MHz GSM like microwave radiation at 0.018–0.023 W/kg whole body SAR. 11–12 sham exposed and 11–12 exposed mice were used. The animals were exposed ten times (over 2 weeks) and the duration of exposure was 2 h/day. No microwave exposure-related morphological alterations were found in testis, epididymis and prostate.

Adult male rats were examined after exposure at sub-crhronic exposure to RF emitted from a conventional cell phone on their testicular function. Sixteen Wistar rats were used at age 30 days. The animals were exposed for 1 h daily during 11 weeks. The experimental group ($n = 8$) was exposed to 1835–1850 MHz at $0.04–1.4\,mW/cm^2$. Total body weight and absolute and relative testicular and epididymal weights did not change significantly. Epididymal sperm count was not significantly different between the groups. Regarding the histomorphological endpoints of the study, no difference was found between the experimental and control arm [44].

The effect of cellular phone emissions on sperm characteristics in 16 Sprague–Dawley rats were studied [45]. The laboratory animals were divided in two groups (experimental, control) and exposed to four cell phones which had a personal communications service code division multiple access frequency band of 1.9 GHz (800 MHz digital and 800 MHz analog). The rats received daily (3 h–30 min rest–3 h) cell phone exposure for 18 weeks. The SAR ranged from 0.9 to 1.80 W/kg whereas the power from 0.00001 to 0.607 W, according to the specific mode of function. The authors analyzed the morphology of the sperm cells from epididymis of rats. The percentage of deformities for the experimental group was 34.3% and the percentage of deformities for the control group was 32.1%. This difference in the occurrence of deformities between the two groups was not statistically significant ($p > .05$) through a paired t test. The total sperm counts from the testes were not significantly different between the two groups. None of the temperature differences between the two groups were statistically significant.

Sixteen Sprague–Dawley rats were used to evaluate the bcl-2 protein (an anti-apoptotic protein) in rat testes. The experimental group ($n = 8$) was exposed to commercial (GSM) cellular phones irradiation for 20 min/day for 1 month. Average power density was measured at $0.047\,mW/cm^2$ and SAR levels changed between 0.29 and 0.87 W/kg. The testes were investigated by means of immunohistochemistry. No difference was observed between testes sections of the sham and experimental groups in terms of bcl-2 staining. These results indicate that the radiation emitted from 900 MHz cellular phones did not alter the anti-apoptotic protein in the testes of rats [46].

In order to investigate the apoptosis-inducing effect of mobile phone exposure on spermatogonia in seminiferous tubules, 31 Wistar albino male rats were divided in three groups such as cage control ($n = 10$), sham exposed ($n = 7$), and experimental ($n = 14$). The 2 h/day (7 days/week) exposure of 900 MHz radiation (power density $0.012–0.149\,mW/cm^2$ and SAR 0.07–0.57 W/kg) over a period of 10 months was evaluated by means of immunohistochemistry. The long-term radiation did not affect the active caspace-3 levels in testes of rats. Caspace-3 is a typical feature of apoptosis [47].

4. Female genital system

Studies on the impact of RF in the female genital system are scarce. Two studies were conducted in order to evaluate the effects on endometrial apoptosis and the ameliorating effects of a combination of vitamin E and C against EMF damage.

Oral et al. [48], exposed sexually mature female rats (16 weeks old) to 900 MHz radiation, 30 min/day for 30 days. Twenty-four Wistar albino rats were divided in three groups (sham exposed, EMF exposed, EMF exposed treated with vitamin C and E). The animals were exposed at $1.04\,mW/cm^2$ (SAR 0.016–4 W/kg). The effect of microwaves was examined in rat endometrium by means of immunohistochemistry. Endometrial apoptosis was observed. Guney et al. [49], repeated the experiment with the addition of another group (control). Histological changes in endometrium, diffuse and severe apoptosis in the endometrial surface, epithelial and glandular cells were reported regarding the group exposed to EMF. Also, eosinophilic leucocyte and lymphocyte infiltration were seen in the endometrial stroma.

Table 2
Overview of investigations on EMF effects on animal development.

Animal species	Exposure frequency	Exposure parameters	Exposure duration	Endpoint	Results	Comments	Reference
Rat Sprague–Dawley	50 Hz	7, 70, 350 mT	22 h/day during 0–7 or 8–15 day of gestation	Effects on teratogenicity and embryonic development	No differences regarding embryonic deaths, fetal weight and teratogenicity		[50]
Mouse ICR	50 Hz	Sham (0.1–1 μT), 0.5, 5 mT	9 weeks♂ 2 weeks♀ prior to mating	Effects on teratogenicity and embryonic development	No differences regarding embryonic deaths, fetal weight and teratogenicity		[51]
Mouse Swiss Webster	0 Hz–25 MHz		1 week beginning from the 18th day of pregnancy	Morphological changes in brain, thymus, adrenal gland during embryonic development	Pathological changes were observed in the neonates		[52]
Rat Sprague–Dawley	60 Hz	0 (sham group), 5, 83.3, 500 mT.	22 h/day during 6–20 day of gestation	Developmental toxicity	No differences regarding embryonic deaths, fetal weight and teratogenicity		[53]
Chicken	50 Hz	1.33–7.32 mT	24 h	Effects on teratogenicity and embryonic development	Significant difference in the percentage of abnormal embryos versus control was found in 4.19, 5.32, 5.86, and 6.65 densities. Some embryos with extra ribs, defects in ribs and vertebrae, anuria and abnormal beaks were observed	Funding not mentioned	[54]
Mouse ICR	20 kHz	6.5 mT	8 h/day from 2.5 to 15.5 days post-coitum	Effects on teratogenicity and embryonic development	No statistically significant differences in the number of implantation, embryonic death, resorption, growth retarded fetuses, external and skeletal abnormalities		[55]
Chicken Leghorn HR7	50 Hz	1 μT, 500 μT, 1 mT	Continuous for 15 or 21 days	Effects on embryo/fetus	At 15 days of incubation body weight was significantly lower versus controls. At 21 days of incubation the body weight and cranial diameters were smaller versus control. No differences in brain weight were observed in all groups	Funding not mentioned	[56]
Mouse ♀	Static magnetic field	400 mT	6 min/day from 7.5 to 14.5 day of pregnancy	Teratogenic effects	Polydactylism, abdominal fissure, fused ribs, vestigial 13th rib, brain hernia, curled tail		[57]
Mouse ♀	50 Hz	1.2 mT	8 h/day during pregnancy	Body weight of dams, development of offspring	Fetal loss, malformed fetuses, retardation of growth of the offspring in the first 2 weeks after birth	Article in chinese	[58]
Chicken White Leghorn eggs	50 Hz	1.33–7.32 mT	4 days	Morphological evaluation of embryos/fetuses	Abnormal brain cavities, spina bifida, monophthalmia, ocular defects and growth retardation		[59]

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5. Developmental effects

The critical phases in the dynamic process of development take place mainly *in utero* (mammals) or *in ovo* (birds) i.e. during the embryonic period. The main bulk of investigations were performed regarding the possible effects on animals after irradiation, during *in utero* or *in ovo* development. The effects on development are determined by endpoints such as weight gain, congenital malformations, resorptions, and number of litters. These endpoints will be considered for various exposure conditions.The effects of EMF (mainly LF) on animal development are summarized in Table 2. Egg production was reduced (8%) when young laying hens have been continuously exposed to CW 915 MHz with an incident power of 800 mW during the first 2.5 weeks, 0 mW during the following week and 200 mW for the rest of experiment. Hatching of fertile and total eggs was not significantly influenced. No macroscopic malformations were observed in the chicks or dead embryos [60].

Jensh et al. [61] irradiated pregnant Wistar albino rats at a power density level of 10 mW/cm^2, at a frequency of 915 MHz and average SAR 3.57 W/kg. The animals were exposed for 6 h/day from day 1 to day 21 of gestation. No significant teratogenic signs were observed regarding the resorption rate, malformation rate, mean litter size, fetal weight and number of live and dead fetuses. The experiment was repeated and extended in order to analyze the embryonic and postnatal development of offspring [62]. Eleven pregnant rats were irradiated and 19 rats were used as control animals. All animals delivered and raised their offspring (F_{1a}) until weaning at 30 days of age. Ten days later females were rebred and teratologic evaluation was conducted on the resultant F_{1b} fetuses. At 90 days of age, reproductive capability was evaluated and a standard teratologic analysis performed on the resultant F_2 offspring. No significant morphologic changes were revealed.

Pregnant rats were exposed at 970 MHz for 22 h/day from the 1st to 19th day of pregnancy [63]. The SAR values varied from 0.07, 2.4 and 4.8 W/kg. The embryo mortality, fetal weight, skeletal ossification, as well as maternal fertility were evaluated. The exposure with SAR 4.8 W/kg caused reduced (−12%) fetal body weight versus the control. All the other examined parameters were not significantly different.

Klug et al. [64] exposed rat embryos (9.5 days old) for up to 36 h to 900 MHz. The modulation frequency was fixed at 215 Hz and the SAR values were calculated at 0.2, 1 and 5 W/kg. The endpoints of the experiment were crown-rump length, number of somites as well as embryonic malformations. No significant changes were observed on the growth and differentiation parameters of the embryos. Magras and Xenos [65] investigated the possible effects of radiofrequency radiation on prenatal development in mice. The study consisted of *in vivo* experiments at several places around an “antenna park” where the frequency emissions ranged from 88.5 to 950 MHz. At these locations RF power densities between 168 and 1053 nW/cm^2 were measured. Twelve pairs of mice, divided in two groups, were placed in locations of different power densities and were repeatedly mated five times. One hundred eighteen newborns were collected. They were measured, weighed, and examined macro- and microscopically. A progressive decrease in the number of newborns per dam was observed, which ended in irreversible infertility. The prenatal development of the newborns, however, evaluated by the crown-rump length, the body weight, and the number of the lumbar, sacral, and coccygeal vertebrae, was improved. Wistar albino rats [15] were exposed through pregnancy for 6 h each day to CW 915 MHz radiation at a power density level of 10 mW/cm^2. Teratologic evaluation included the following parameters: mean litter size, maternal organ weight and organ weight/body weight ratios, body weight ratios of various organs (brain, liver, kidneys, and ovaries), number of resorptions and resorption rate, number of abnormalities and abnormality rate, mean term fetal weight. Mothers were rebred, and the second, unexposed litters were evaluated for teratogenic effects. Animals exposed to 915 MHz did not exhibit any consistent significant alterations in any of the above parameters.

Wistar rats were continuously exposed [66] during pregnancy to a low-level (0.1 mW/cm^2) 900 MHz, 217 Hz pulse modulated EMF. Whole body average SAR values for the freely roaming, pregnant animals were measured in models; they ranged between 17.5 and 75 mW/kg. No differences between exposed and sham exposed dams or offspring were recorded in terms of litter size, evolution of body mass and developmental landmarks of litter mates. The effects of microwaves emitted by cellular phones on birth weights of rats were investigated by Dasdag et al. [67]. Thirty-six Wistar albino rats were divided into four groups. Each experimental or sham exposed group comprised six males or 12 females. The rats were exposed at 890–915 MHz (SAR 0.155 W/kg). Males were exposed daily for 3 × 1 min during 2 h/day for 1 month. Females were exposed in the same way until they gave birth. When the offspring became adult the experiment was repeated on them. No significant differences were observed between rectal temperatures in the sham and experimental groups. The birth weight of offspring in the experimental group was significantly lower than in the sham exposed group. However in the next generation of rats all parameters investigated were normal. Pregnant Sprague–Dawley rats were exposed [68] to ultra wide band (UWB) 0.1–1 GHz radiation in order to determine if teratological changes occur in rat pups as a result of (1) daily UWB exposures during gestation days 3 ± 18, or (2) as a result of both prenatal and postnatal (10 days) exposures. Dams were exposed either to (I) UWB irradiation with average whole body specific absorption rate 45 mW/kg (II) sham irradiation or (III) a positive control. Offspring were examined regarding litter size, sex-ratios, weights, coat appearance, and tooth eruption. The pups postnatally exposed were examined for hippocampal morphology. Generally, no significant differences were found between the exposed and sham group. The medial-to-lateral length of the hippocampus was significantly longer in the

Table 3
Summary of animal studies on effects of EMF (related to mobile telephony), on reproduction and development.

Animal species	Exposure frequency	Endpoint	Effect	Reference
Chicken	915 MHz	Development	No	[60]
Rat	915 MHz	Development	No	[61]
Rat	915 MHz	Development	No	[62]
Rat	970 MHz	Development	No	[63]
Rat	915 MHz	Development	No	[15]
Rat	900 MHz	Development	No	[64]
Mouse	88.5–950 MHz	Fertility/development	Yes/no	[65]
Rat	890–915 MHz	Testes	Yes	[39]
Rat	900 MHz	Development	No	[66]
Rat	0.1–1 GHz	Development	No	[68]
Rat	890–915 MHz	Development	Yes	[67]
Chicken	900 MHz	Development	Yes	[69]
Rat	890–915 MHz	Testes	No	[40]
Chicken		Development	Yes	[70]
Rat	900 MHz	Testes	No	[42]
Mouse	900 MHz	Testes	No	[41]
White stork	900–1800 MHz phone mast	Reproduction	Yes	[74]
Chicken	900 MHz	Kidney development	Yes	[71]
Mouse	1800 MHz	Testes	No	[43]
Rat	900 MHz	Endometrium	Yes	[48]
Rat	900 MHz	Brain development	No	[72]
Rat	1835–1850 MHz	Testes	No	[44]
Rat	1.9 GHz	Sperm	No	[45]
Tit	1200–3000 MHz	Reproduction	No	[75]
Rat	900 MHz	Endometrium	Yes	[49]
Chicken	900 MHz	Development	Yes	[73]
Rat	900 MHz	Testes	No	[46]
Rat	900 MHz	Testes	No	[47]

UWB-exposed pups than in the sham exposed animals but could not correlated with neurological dysfunction. The male offspring exposed *in utero* to UWB mated significantly less frequently than sham exposed males, but when they did mate there was no difference in fertilization and offspring numbers from the sham group.

Bastide et al. [69] reported chicken embryo mortality from day 7 to day 11 of incubation. This mortality reached 64% compared to 11% in controls. The maximum level of embryonic mortality was observed in the eggs placed near the telephone.

Chicken embryos were exposed to EMF from GSM mobile phone during the embryonic development [70]. The embryo mortality rate in the incubation period increased to 75% versus 16% in control group.

Ingole and Ghosh [71] studied by means of light microscopy the developmental effects on the avian kidney of radiation, from a cell phone handset (900 MHz frequency, power of 2 W and SAR of 0.37 W/kg). The authors reported morphological alterations on the epithelium of the renal tubules as well as of the renal corpuscles in E6, E8 and E10 chicken embryos.

The possible impact of cell phone radiation in the developing central nervous system of male Wistar rats was examined [72]. The animals were exposed to 900 MHz signal for 2 h/day on 5 days/week. After 5 weeks of exposure at whole body average SAR of 0.3 or 3 W/kg or sham exposure no degenerative morphological changes were found.

The results about the effects of exposing fertilized chicken eggs to a mobile phone over the entire period of incubation were published recently [73]. In this study, a series of 4 incubations were employed. During each incubation, 4 groups were used (control I, control II, experimental, sham). In the experimental group, the cell phone in call position was placed near ($\leq$25 cm) the eggs, whereas in the sham group the cell phone in off position was placed 1.5 m away from the exposed group. A significantly higher percentage of embryo mortality was observed in the experimental compared to the sham group in 2 of the 4 incubations. The lethal effects of embryo development in the experimental group were mainly observed between the 9th and 12th day of incubation.

Another issue that in recent years has attracted the attention of scientists is the effects of radiation from RF antennas on the biology of wild birds.

Balmori [74] investigated the possible effects of EMF from phone masts on a population of White stork (*Ciconia ciconia*). The total productivity in the nests located within 200 m of antennas was 0.86 ± 0.16 versus 1.6 ± 0.14 for those located further than 300 m. Another interesting observation, was that, 40% of the nests within 200 m of the antennae never had any chicks, while only 3.3% located further than 300 m never had chicks.

The influence of a military radar station [75] emitting pulsed modulated microwave radiation of 1200–3000 MHz was examined in tits (*Parus* sp). Experimental nest-boxes were either exposed to a mean level of 3.41 ± 1.38 or $1.12 \pm 0.84\,W/m^2$. For control nest-boxes the exposure ranged from 0.001 to 0.01 W/m^2. No statistically significant differences in the number of eggs or in the number of nestlings were observed between the two series (exposed, control) of tits.

6. Conclusions

The EMF were, are and will be a part of our life. The progress of science will provide the world with new EMF emitting technologies and subsequently with new problems. The monitoring of literature on this scientific field shows a shift of research which follows exactly the new technologies. The era of mobile telephony is beginning.

The evaluation of the possible effects of EMF on the living organism is a complex process that needs the combined contributions of many scientific disciplines. Due to the need for expertise in many different sciences, together with the technical problems of radiation studies, many times the published results are considered deficient in certain aspects. This is inevitable, and not an indication of poor quality. The inability to observe a biological effect in a particular study does not necessarily mean that such effect or/and adverse health effect is not present.

The vertebrate animal studies summarized in the present paper do not suggest strong effects of LF EMF on the male genital system. However, some studies on the development of animals, showed sensitivity, mainly observed in chickens. There is no convincing evidence from studies of mammals (Table 3), that exposure to EMF at levels associated with mobile telecommunications could be harmful for embryonic or postnatal development or for male fertility. On the other hand, the birds appeared to be more sensitive. The effects of EMF on the female genital system need further attention, since two experimental studies cannot lead to definitive conclusions.

The positive findings of the experimental studies with vertebrate animals are mainly attributed to the thermal effects of EMF. No valid evidence was found for the occurrence of non-thermal effects. However the non-thermal mechanisms must be the next target of the research.

The majority of reviewed studies were conducted in laboratories. This fact cannot represent the realistic situation of cell phone communication. On the other hand, the *in vivo* and simultaneously *in situ* studies are very scarce. Only Magras and Xenos conducted an *in situ* experiment which took place near an antenna park. That is because this kind of experiment is very difficult to carry out, and interaction with other exogenous factors could change the results.

One particular deficiency in most studies is that they describe experiments with acute or short-term exposure of animals on EMF. Experiments are needed to perform long-term exposure in order to demonstrate the chronic impact of EMF.

Another point that must be elucidated is that the majority of experimental animals used were small rodents (mice and rats), as well as chicken embryos. Further research is needed with the use of bigger animals such as dog and sheep.

The radiations emitted from masts that are situated in many rural and sylvatic areas could be possibly pathogenic in the wild animals. The wild animal populations could be candidate "experimental material" for closer observation of the possible effects of EMF on vertebrate models.

An important and intriguing aspect of the research is the possible role of the combination of RF with other pollutants such as chemical substances and other forms of radiation, as well as the interaction with drugs.

The potential health effects of EMF should be continually reassessed as new research results become available. EMF exposure guidelines also need to be updated or reconsidered as new scientific information on radiation and health risks is produced. However, additional studies might increase our understanding of the sensitivity of organisms to EMF.

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Pathophysiology xxx (2009) xxx–xxx

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Electromagnetic pollution from phone masts. Effects on wildlife

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Received 10 August 2008; received in revised form 28 August 2008; accepted 30 January 2009

Abstract

A review on the impact of radiofrequency radiation from wireless telecommunications on wildlife is presented. Electromagnetic radiation is a form of environmental pollution which may hurt wildlife. Phone masts located in their living areas are irradiating continuously some species that could suffer long-term effects, like reduction of their natural defenses, deterioration of their health, problems in reproduction and reduction of their useful territory through habitat deterioration. Electromagnetic radiation can exert an aversive behavioral response in rats, bats and birds such as sparrows. Therefore microwave and radiofrequency pollution constitutes a potential cause for the decline of animal populations and deterioration of health of plants living near phone masts. To measure these effects urgent specific studies are necessary.

Keywords: Effects on wildlife; Effects on birds; Electromagnetic radiation; Mammals; Microwaves; Mobile telecommunications; Non-thermal effects; Phone masts; Radiofrequencies

1. Introduction

Life has evolved under the influence of two omnipresent forces: gravity and electromagnetism. It should be expected that both play important roles in the functional activities of organisms [1]. Before the 1990's radiofrequencies were mainly from a few radio and television transmitters, located in remote areas and/or very high places. Since the introduction of wireless telecommunication in the 1990's the rollout of phone networks has caused a massive increase in electromagnetic pollution in cities and the countryside [2,3].

Multiple sources of mobile communication result in chronic exposure of a significant part of the wildlife (and man) to microwaves at non-thermal levels [4]. In recent years, wildlife has been chronically exposed to microwaves and RFR (Radiofrequency radiation) signals from various sources, including GSM and UMTS/3G wireless phones and base stations, WLAN (Wireless Local Area Networks), WPAN (Wireless Personal Area Networks such as Bluetooth), and DECT (Digital Enhanced (former European) Cordless Telecommunications) that are erected indiscriminately without studies of environmental impact measuring long-term effects. These exposures are characterized by low intensities, varieties of signals, and long-term durations. The greater portion of this exposure is from mobile telecommunications (geometric mean in Vienna: 73% [5]). In Germany the GSM cellular phone tower radiation is the dominating high frequency source in residential areas [6]. Also GSM is the dominating high frequency source in the wilderness of Spain (personal observation).

Numerous experimental data have provided strong evidence of athermal microwave effects and have also indicated several regularities in these effects: dependence of frequency within specific frequency windows of "resonance-type"; dependence on modulation and polarization; dependence on intensity within specific intensity windows, including super-low power density comparable with intensities from base stations/masts [4,7–9]. Some studies have demonstrated different microwave effects depending on wavelength in the range of mm, cm or m [10,11]. Duration of exposure may be as important as power density. Biological effects resulting from electromagnetic field radiation might depend on dose, which indicates long-term accumulative effects [3,9,12]. Modulated and pulsed radiofrequencies seem to be more effective in producing effects [4,9]. Pulsed waves (in blasts), as well as certain low frequency modulations exert greater

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0928-4680/$ – see front matter © 2009 Published by Elsevier Ireland Ltd.
doi:10.1016/j.pathophys.2009.01.007

biological activity [11,13–15]. This observation is important because cell phone radiation is pulsed microwave radiation modulated at low frequencies [8,9].

Most of the attention on possible biological effects of electromagnetic radiation from phone masts has been focused on human health [5,16–21]. The effects of electromagnetic pollution on wildlife, have scarcely been studied [22–25].

The objective of this review is to detail advances in knowledge of radiofrequencies and microwave effects on wildlife. Future research may help provide a better understanding of electromagnetic field (EMF) effects on wildlife and plants and their conservation.

2. Effects on exposed wildlife

2.1. Effects on birds

2.1.1. Effects of phone mast microwaves on white stork

In monitoring a white stork (*Ciconia ciconia*) population in Valladolid (Spain) in vicinity of Cellular Phone Base Stations, the total productivity in nests located within 200 m of antennae, was 0.86 ± 0.16. For those located further than 300 m, the result was practically doubled, with an average of 1.6 ± 0.14. Very significant differences among total productivity were found ($U = 240$; $P = 0.001$, Mann–Whitney test). Twelve nests (40%) located within 200 m of antennae never had chicks, while only one (3.3%) located further than 300 m had no chicks. The electric field intensity was higher on nests within 200 m (2.36 ± 0.82 V/m) than nests further than 300 m (0.53 ± 0.82 V/m). In nesting sites located within 100 m of one or several cellsite antennae with the main beam of radiation impacting directly (Electric field intensity >2 V/m) many young died from unknown causes. Couples frequently fought over nest construction sticks and failed to advance the construction of the nests. Some nests were never completed and the storks remained passively in front of cellsite antennae. These results indicate the possibility that microwaves are interfering with the reproduction of white stork [23]. (Fig. 1)

2.1.2. Effects of phone mast microwaves on house sparrows

A possible effect of long-term exposure to low-intensity electromagnetic radiation from mobile phone (GSM) base stations on the number of house sparrows during the breeding season was studied in Belgium. The study was carried out sampling 150 point locations within six areas to examine small-scale geographic variation in the number of house sparrow males and the strength of electromagnetic radiation from base stations. Spatial variation in the number of house sparrow males was negative and highly significantly related to the strength of electric fields from both the 900 and 1800 MHz downlink frequency bands and from the sum of these bands (Chi-square-tests and AIC-criteria, $P < 0.001$). This negative relationship was highly similar within each of the six study areas, despite differences among areas in both the number of birds and radiation levels. Fewer house sparrow males were seen at locations with relatively high electric field strength values of GSM base stations and therefore support the notion that long-term exposure to higher levels of radiation negatively affects the abundance or behavior of house sparrows in the wild [24].

In another study with point transect sampling performed at 30 points visited 40 times in Valladolid (Spain) between 2002 and 2006, counting the sparrows and measuring the mean electric field strength (radiofrequencies and microwaves: 1 MHz to 3 GHz range). Significant declines ($P = 0.0037$) were observed in mean bird density over time, and significantly low bird density was observed in areas with high electric field strength. The logarithmic regression of the mean bird density vs. field strength groups (considering field strength in 0.1 V/m increments) was $R = -0.87$; $P = 0.0001$ According to this calculation, no sparrows would be expected to be found in an area with field strength >4 V/m [25]. (Fig. 2)

In the United Kingdom a decline of several species of urban birds, especially sparrows, has recently happened [26]. The sparrow population in England has decreased in the last 30 years from 24 million to less than 14. The more abrupt decline, with 75% descent has taken place from 1994 to 2002. In 2002, the house sparrow was added to the Red List of U.K. endangered species [27]. This coincides with the rollout of mobile telephony and the

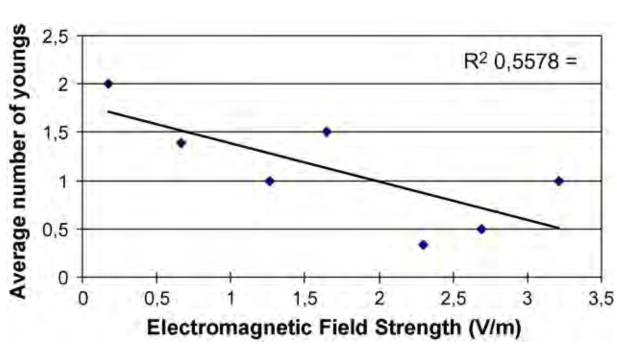

Fig. 1. Average number of youngs and electric field intensity (V/m) in 60 nests of white storks (*Ciconia ciconia*) (Hallberg, Ö with data of Balmori, 2005 [23]).

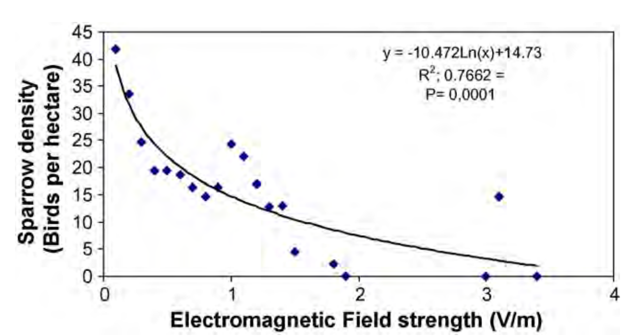

Fig. 2. Mean sparrow density as a function of electric field strength grouped in 0.1 V/m. (Balmori and Hallberg, 2007 [25]).

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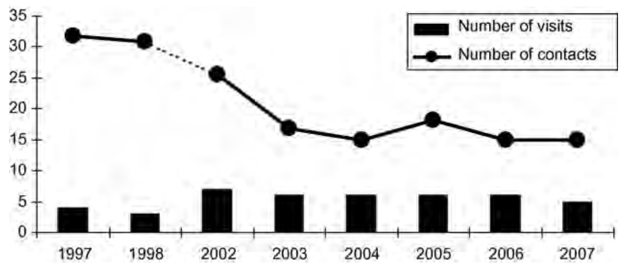

Fig. 3. Annual number of contacts (Mean) for 14 species studied in "Campo Grande" urban park (lack the information of the years 1999–2001).

possible relationship of both circumstances should be investigated.

In Brussels, many sparrows have disappeared recently [28]; similar declines have been reported in Dublin [29]. Van der Poel (cited in Ref. [27]) suggested that sparrows might be declining in Dutch urban centres also.

2.1.3. Effects on the bird community at an urban park

Microwaves may be affecting bird populations in places with high electromagnetic pollution. Since several antennas were installed in proximities of "Campo Grande" urban park (Valladolid, Spain) the bird population has decreased and a reduction of the species and breeding couples has occurred. Between 1997 and 2007, of 14 species, 3 species have disappeared, 4 are in decline and 7 stay stable (Balmori, unpublished data) (Fig. 3). In this time the air pollution (SO2, NO2, CO and Benzene) has diminished.

During the research some areas called "silence areas" contaminated with high microwave radiation (>2 V/m), where previously different couples usually bred and later disappeared, have been found. Several anomalies in magpies (*Pica pica*) were detected: plumage deterioration, locomotive problems (limps and deformations in the paws), partial albinism and melanism, especially in flanks [30]. Recently cities have increased cases of partial albinism and melanism in birds (*Passer domesticus*, *Turdus merula* and *P. pica*) (personal observation).

2.1.4. Possible physiological mechanisms of the effects found in birds

Current scientific evidence indicates that prolonged exposure to EMFs, at levels that can be encountered in the environment, may affect immune system function by affecting biological processes [3,31,32]. A stressed immune system may increase the susceptibility of a bird to infectious diseases, bacteria, viruses, and parasites [33].

The plumage of the birds exposed to microwaves looked, in general, discolorated and lack of shine. This not only occurred in ornamental birds; such as peacocks, but also in wild birds; such as, tits, great tits, house sparrows, etc (personal observation). We must mention that plumage deterioration is the first sign of weakening or illnesses in birds since damaged feathers are a sure sign of stress.

Physiological conditions during exposure minimize microwave effects. Radical scavengers/antioxidants might be involved in effects of microwaves [4].

Microwaves used in cellphones produce an athermal response in several types of neurons of the birds nervous system [34]. Several studies addressed behavior and teratology in young birds exposed to electromagnetic fields [23,25,35–37]. Most studies indicate that electromagnetic field exposure of birds generally changes, but not always consistently in effect or in direction, their behavior, reproductive success, growth and development, physiology and endocrinology, and oxidative stress [37]. These results can be explained by electromagnetic fields affecting the birds' response to the photoperiod as indicated by altered melatonin levels [38].

Prolonged mobile phone exposure may have negative effects on sperm motility characteristics and male fertility as has been demonstrated in many studies made in man and rats [39–46]. EMF and microwaves can affect reproductive success in birds [23,25,35,36,47]. EMF exposure affected reproductive success of kestrels (*Falco sparverius*), increasing fertility, egg size, embryonic development and fledging success but reducing hatching success [35,36].

The radiofrequency and microwaves from mobile telephony can cause genotoxic effects [48–55]. Increases in cytological abnormalities imply long-term detrimental effects since chromosomal damage is a mechanism relevant to causation of birth defects and cancer [55].

Long-term continuous, or daily repeated EMF exposure can induce cellular stress responses at non-thermal power levels that lead to an accumulation of DNA errors and to inhibition of cell apoptosis and cause increased permeability of blood–brain barrier due to stabilization of endothelial cell stress fibers. Repeated occurrence of these events over a long period of time (years) could become a health hazard due to a possible accumulation of brain tissue damage. These findings have important implications with regards to potential dangers from prolonged and repeated exposure to non-ionizing radiation [56,57].

Pulsed magnetic fields can have a significant influence on the development and incidence of abnormalities in chicken embryos. In five of six laboratories, exposed embryos exhibited more structural anomalies than controls. If the data from all six laboratories are pooled, the difference for the incidence of abnormalities in exposed embryos and controls is highly significant [58]. Malformations in the nervous system and heart, and delayed embryo growth are observed. The embryo is most sensitive to exposure in the first 24 h of incubation [58]. An increase in the mortality [59] and appearance of morphological abnormalities, especially of the neural tube [13,60,61] has been recorded in chicken embryos exposed to pulsed magnetic fields, with different susceptibility among individuals probably for genetic reasons. A statistically significant high mortality rate of chicken embryos subjected to radiation from a cellphone, compared to the control group exists [62,63]. In another study eggs exposed to a magnetic

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field intensity of 0.07 T showed embryonic mortality during their incubation was higher. The negative effect of the magnetic field was manifested also by a lower weight of the hatched chicken [64]. Bioelectric fields have long been suspected to play a causal role in embryonic development. Alteration of the electrical field may disrupt the chemical gradient and signals received by embryo cells. It appears that in some manner, cells sense their position in an electrical field and respond appropriately. The disruption of this field alters their response. Endogenous current patterns are often correlated with specific morphogenetic events [65].

Available data suggests dependencies of genotype, gender, physiological and individual factors on athermal microwave effects [4,9]. Genomic differences can influence cellular responses to GSM Microwaves. Data analysis has highlighted a wide inter-individual variability in response, which was replicated in further experiments [4]. It is possible that each species and each individual, show different susceptibility to radiation, since vulnerability depends on genetic tendency, and physiologic and neurological state of the irradiated organism [15,35–37,61,66–68]. Different susceptibility of each species has also been proven in wild birds exposed to electromagnetic fields from high-voltage power lines [47].

2.2. Effects on mammals

2.2.1. Alarm and aversion behavior

Rats spent more time in the halves of shuttle boxes that were shielded from 1.2 GHz. Microwaves irradiation. The average power density was about 0.6 mW/cm^2. Data revealed that rats avoided the pulsed energy, but not the continuous energy, and less than 0.4 mW/cm^2 average power density was needed to produce aversion [69]. Navakatikian & Tomashevskaya [70] described a complex series of experiments in which they observed disruption of rat behavior (active avoidance) from radiofrequency radiation. Behavioral disruption was observed at a power density as low as 0.1 mW/cm^2 (0.027 W/kg). Mice in an experimental group exposed to microwave radiation expressed visible individual panic reaction, disorientation and a greater degree of anxiety. In the sham exposed group these deviations of behavior were not seen and all animals show collective defense reaction [71]. Microwave radiation at 1.5 GHz pulsing 16 ms. At 0.3 mW/cm^2 power density, in sessions of 30 min/day over one month produced anxiety and alarm in rabbits [72].

Electromagnetic radiation can exert an aversive behavioral response in bats. Bat activity is significantly reduced in habitats exposed to an electromagnetic field strength greater than 2 V/m [73]. During a study in a free-tailed bat colony (*Tadarida teniotis*) the number of bats decreased when several phone masts were placed 80 m from the colony [74].

2.2.2. Deterioration of health

Animals exposed to electromagnetic fields can suffer a deterioration of health and changes in behavior [75,76].

There was proof of frequent death in domestic animals; such as, hamsters and guinea pigs, living near mobile telecommunication base stations (personal observation).

The mice in an experimental group exposed to microwave radiation showed less weight gain compared to control, after two months. The amount of food used was similar in both groups [71]. A link between electromagnetic field exposure and higher levels of oxidative stress appears to be a major contributor to aging, neurodegenerative diseases, immune system disorders, and cancer in mammals [33].

The effects from GSM base transceiver station (BTS) frequency of 945 MHz on oxidative stress in rats were investigated. When EMF at a power density of 3.67 W/m^2, below current exposure limits, were applied, MDA (malondialdehyde) level was found to increase and GSH (reduced glutathione) concentration was found to decrease significantly ($P < 0.0001$). Additionally, there was a less significant ($P = 0.0190$) increase in SOD (superoxide dismutase) activity under EM exposure [77].

2.2.3. Problems in reproduction

In the town of Casavieja (Ávila, Spain) a telephony antenna was installed that had been in operation for about 5 years. Then some farmers began blaming the antenna for miscarriages in many pigs, 50–100 m from the antenna (on the outskirts of the town). Finally the topic became so bad that the town council decided to disassemble the antenna. It was removed in the spring 2005. From this moment onwards the problems stopped (C. Lumbreras personal communication).

A Greek study reports a progressive drop in the number of rodent births exposed to radiofrequencies. The mice exposed to 0.168 μW/cm^2 become sterile after five generations, while those exposed to 1.053 μW/cm^2 became sterile after only three generations [22].

In pregnant rats exposed to 27.12 MHz continuous waves at 100 μW/cm^2 during different periods of pregnancy, half the pregnancies miscarried before the twentieth day of gestation, compared to only a 6% miscarriage rate in unexposed controls, and 38% of the viable foetuses had incomplete cranial ossification, compared to less than 6% of the controls. Findings included a considerable increase in the percentage of total reabsorptions (post-implantation losses consequent to RF radiation exposure in the first post-implantation stage). Reduced body weight in the exposed dams reflected a negative influence on their health. It seems that the irradiation time plays an important role in inducing specific effects consequent to radiofrequency radiation exposure [78]. There was also a change in the sex ratio, with more males born to rats that had been irradiated from the time of conception [2]. Moorhouse and Macdonald [79] find a substantial decline in female Water Vole numbers in the radio-collared population, apparently resulting from a male skew in the sex ratios of offspring born to this population. Recruits to the *radio-tracked* population were skewed heavily in favour of males (43:13). This suggests that radio-collaring of females caused male-skewed sex ratios.

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Mobile phone exposure may have negative effects on sperm motility characteristics and male fertility in rats [46]. Other studies find a decrease of fertility, increase of deaths after birth and dystrophic changes in their reproductive organs [11]. Intermittent exposure showed a stronger effect than continuous exposure [4]. Brief, intermittent exposure to low-frequency EM fields during the critical prenatal period for neurobehavioral sex differentiation can demasculinize male scent marking behavior and increase accessory sex organ weights in adulthood [80].

In humans, magnetic field exposures above 2.0 mG were positively associated with miscarriage risk [81]. Exposure of pregnant women to mobile phone significantly increased foetal and neonatal heart rate, and significantly decreased the cardiac output [82].

2.2.4. Nervous system

Microwaves may affect the blood brain barrier which lets toxic substances pass through from the blood to the brain [83]. Adang et al. [84] examined the effect of microwave exposure to a GSM-like frequency of 970 MHz pulsed waves on the memory in rats by means of an object recognition task. The rats that have been exposed for 2 months show normal exploratory behavior. The animals that have been exposed for 15 months show derogatory behavior. They do not make the distinction between a familiar and an unfamiliar object. In the area that received radiation directly from “Location Skrunda Radio Station” (Latvia), exposed children had less developed memory and attention, their reaction time was slower and neuromuscular apparatus endurance was decreased [85]. Exposure to cell phones prenatally and, to a lesser degree, postnatally was associated with behavioral difficulties such as emotional and hyperactivity problems around 7 years of age [86]. Electromagnetic radiation caused modification of sleep and alteration of cerebral electric response (EEG) [87–89]. Microwave radiation from phone masts may cause aggressiveness in people and animals (personal observation).

2.3. Effects on amphibians

Disappearance of amphibians and other organisms is part of the global biodiversity crisis. An associated phenomenon is the appearance of large numbers of deformed amphibians. The problem has become more prevalent, with deformity rates up to 25% in some populations, which is significantly higher than previous decades [90]. Balmori [91] proposed that electromagnetic pollution (in the microwave and radiofrequency range) is a possible cause for deformations and decline of some wild amphibian populations.

Two species of amphibians were exposed to magnetic fields at various stages of development. A brief treatment of early amphibian embryos produced several types of abnormalities [92]. Exposure to a pulsed electromagnetic field produced abnormal limb regeneration in adult Newts [93]. Frog tadpoles (*Rana temporaria*) developed under electromagnetic field (50 Hz, 260 A/m) have increased mortality. Exposed tadpoles developed more slowly and less synchronously than control tadpoles and remain at the early stages for longer. Tadpoles developed allergies and EMF caused changes in blood counts [94].

In a current study exposing eggs and tadpoles ($n = 70$) of common frog (*R. temporaria*) for two months, from the phase of eggs until an advanced phase of tadpole, to four telephone base stations located 140 m away: with GSM system 948.0–959.8 MHz; DCS system: 1830.2–1854.8; 1855.2–1879.8 MHz. and UMTS system: 1905–1910; 1950–1965; 2140–2155 MHz. (electric field intensity: 1.847–2.254 V/m). A low coordination of movements, an asynchronous growth, with big and small tadpoles, and a high mortality (90%) was observed. The control group ($n = 70$), under the same conditions but inside a Faraday cage (metallic shielding component: EMC-reinforcement fabrics 97442 Marburg Technic), the coordination of movements was normal, the development was synchronously and the mortality rate was only 4.2% [95].

2.4. Effects on insects

The microwaves may affect the insects. Insects are the basis and key species of ecosystems and they are especially sensitive to electromagnetic radiation that poses a threat to nature [96].

Carpenter and Livstone [97] irradiated pupae of Tenebrio molitor with 10 GHz microwaves at 80 mW for 20–30 min and 20 mW for 120 min obtained a rise in the proportion of insects with abnormalities or dead. In another study exposing fruit flies (*Drosophila melanogaster*) to mobile phone radiation, elevated stress protein levels (Hsp70) was obtained, which usually means that cells are exposed to adverse environmental conditions (’non-thermal shock’) [98]. Panagopoulos et al. [99] exposed fruit flies (*D. melanogaster*) to radiation from a mobile phone (900 MHz) during the 2–5 first days of adulthood. The reproductive capacity of the species reduced by 50–60% in modulated radiation conditions (emission while talking on the phone) and 15–20% with radiation nomodulated (with the phone silent). The results of this study indicate that this radiation affects the gonadal development of insects in an athermal way. The authors concluded that radio frequencies, specifically GSM, are highly bioactive and provoke significant changes in physiological functions of living organisms. Panagopoulos et al. [100] compare the biological activity between the two systems GSM 900 MHz and DCS 1800 MHz in the reproductive capacity of fruit flies. Both types of radiation were found to decrease significantly and non-thermally the insect’s reproductive capacity, but GSM 900 MHz seems to be even more bioactive than DCS 1800 MHz. The difference seems to be dependent mostly on field intensity and less on carrier frequency.

A study in South Africa finds a strong correlation between decrease in ant and beetle diversity with the electromagnetic radiation exposure (D. MacFadyen, personal communication.). A decrease of insects and arachnids near base stations was detected and corroborated by engineers and antenna's maintenance staff [101]. In houses near antennas an absence of flies, even in summer, was found.

In a recent study carried out with bees in Germany, only a few bees irradiated with DECT radiation returned to the beehive and they needed more time. The honeycomb weight was lower in irradiated bees [102]. In recent years a "colony collapse disorder" is occurring that some authors relate with pesticides and with increasing electromagnetic pollution [96].

The disappearance of insects could have an influence on bird's weakening caused by a lack of food, especially at the first stages in a young bird's life.

2.5. Effects on trees and plants

The microwaves may affect vegetables. In the area that received radiation directly from "Location Skrunda Radio Station" (Latvia), pines (*Pinus sylvestris*) experienced a lower growth radio. This did not occur beyond the area of impact of electromagnetic waves. A statistically significant negative correlation between increase tree growth and intensity of electromagnetic field was found, and was confirmed that the beginning of this growth decline coincided in time with the start of radar emissions. Authors evaluated other possible environmental factors which might have intervened, but none had noticeable effects [103]. In another study investigating cell ultrastructure of pine needles irradiated by the same radar, there was an increase of resin production, and was interpreted as an effect of stress caused by radiation, which would explain the aging and declining growth and viability of trees subjected to pulsed microwaves. They also found a low germination of seeds of pine trees more exposed [104]. The effects of Latvian radar was also felt by aquatic plants. *Spirodela polyrrhiza* exposed to a power density between 0.1 and 1.8 $\mu W/cm^2$ had lower longevity, problems in reproduction and morphological and developmental abnormalities compared with a control group who grew up far from the radar [105].

Chlorophylls were quantitatively studied in leaves of black locust (*Robinia pseudoacacia* L.) seedlings exposed to high frequency electromagnetic fields of 400 MHz. It was revealed that the ratio of the two main types of chlorophyll was decreasing logarithmically to the increase of daily exposure time [106].

Exposed tomato plants (*Lycopersicon esculentum*) to low level (900 MHz, 5 V/m) electromagnetic fields for a short period (10 min) measured changes in abundance of three specific mRNA after exposure, strongly suggesting that they are the direct consequence of application of radio-frequency fields and their similarities to wound responses suggests that this radiation is perceived by plants as an injurious stimulus [107]. Non-thermal exposure to radiofrequency fields induced oxidative stress in duckweed (*Lemna minor*) as well as unespecific stress responses, especially of antioxidative enzymes [108].

For some years progressive deterioration of trees near phone masts have been observed in Valladolid (Spain). Trees located inside the main lobe (beam), look sad and feeble, possibly slow growth and a high susceptibility to illnesses and plagues. In places we have measured higher electric field intensity levels of radiation (>2 V/m) the trees show a more notable deterioration [109]. The tops of trees are dried up where the main beams are directed to, and they seem to be most vulnerable if they have their roots close to water. The trees don't grow above the height of the other ones and, those that stand out far above, have dried tops (Hargreaves, personal communication and personal observation). White and black poplars (*Populus sp.*) and willows (*Salix sp.*) are more sensitive. There may be a special sensitivity of this family exists or it could be due to their ecological characteristics forcing them to live near water, and thus electric conductivity. Other species as *Platanus sp.* and *Lygustrum japonicum*, are more resistant (personal observation). Schorpp [110] presents abundant pictures and explanations of what happens to irradiated trees.

3. Conclusions

This literature review shows that pulsed telephony microwave radiation can produce effects especially on nervous, cardiovascular, immune and reproductive systems [111]:

- Damage to the nervous system by altering electroencephalogram, changes in neural response or changes of the blood–brain barrier.
- Disruption of circadian rhythms (sleep–wake) by interfering with the pineal gland and hormonal imbalances.
- Changes in heart rate and blood pressure.
- Impairment of health and immunity towards pathogens, weakness, exhaustion, deterioration of plumage and growth problems.
- Problems in building the nest or impaired fertility, number of eggs, embryonic development, hatching percentage and survival of chickens.
- Genetic and developmental problems: problems of locomotion, partial albinism and melanism or promotion of tumors.

In the light of current knowledge there is enough evidence of serious effects from this technology to wildlife. For this reason precautionary measures should be developed, alongside environmental impact assessments prior to installation, and a ban on installation of phone masts in protected natural areas and in places where endangered species are present. Surveys should take place to objectively assess the severity of effects.

Please cite this article in press as: A. Balmori, Electromagnetic pollution from phone masts. Effects on wildlife, Pathophysiology (2009), doi:10.1016/j.pathophys.2009.01.007

Acknowledgment

The author is grateful to Denise Ward and Örjan Hallberg.

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Please cite this article in press as: A. Balmori, Electromagnetic pollution from phone masts. Effects on wildlife, Pathophysiology (2009), doi:10.1016/j.pathophys.2009.01.007

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Pathophysiology xxx (2009) xxx–xxx

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FM-radio and TV tower signals can cause spontaneous hand movements near moving RF reflector

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Received 2 January 2009; received in revised form 23 January 2009; accepted 30 January 2009

Abstract

For testing human sensitivity to radio frequency (RF) standing waves a movable reflecting wall was constructed. Radio waves from the radio–TV tower reflected back and formed a standing wave near the reflector. When the reflector was moved, the position of the maximums of the standing waves changed and the electromagnetic intensity changed in the body of the standing test subject. The computer with an AD-converter registered the signals of the hand movement transducer and the RF-meter with 100 MHz dipole antennas. A total of 29 adults of different ages were tested. There were 9 persons whose hand movement graphs included features like the RF-meter. Six showed responses that did not correlate with the RF-meter. There were also 14 persons who did not react at all. Sensitive persons seem to react to crossing standing waves of the FM-radio or TV broadcasting signals.

Keywords: Sensorimotor responses; Radio frequency standing waves

1. Introduction

Radio frequency radiation (RFR) has been studied intensively in the near GHz region. Subjective symptoms, sleeping problems and cognitive performance have been reported in subjects living near mobile phone base stations [1]. In the recent past, frequencies of FM-radio and television (TV) signals have been much less studied even though these frequencies cause biological and health effects, too. The whole body resonance frequency of an average man and thus the maximum absorption of RF energy occur at 70–80 MHz [2]. This is near the frequencies used in very high frequency (VHF) broadcasting. The head and limbs absorb much more energy than the torso at frequencies above body resonance [3]. Greatest absorption in the head region of man occurs at a frequency of about 375 MHz [4]. Absorption is stronger for wave propagation from head to toe than it is when the electric field is parallel to the long axis. The authors [4] believed that the enchanced absorption in the head region may make head resonance significant in the study of behavioral effects, blood–brain barrier permeability, cataractogenesis, and other microwave bioeffects. Even increased health risks like cancer, especially melanoma incidence, near FM broadcasting and television transmitters have been reported [5,6].

Nerve impulses initiate muscle contraction by calcium ion release from the sarcoplasmic reticulum, which takes place when electric nerve signals reach the plasma membrane and T-tubules of muscle fibers [7]. Voltage dependent Ca-channels open. Acetylcholine esterase (AChE) breaks down the acetylcholine, and Na-channels close [7]. It has been reported that the number of Ca^{2+} ions liberated from hen's frontal brain depends on the modulation frequency of the weak VHF radiation, with a maximum at a frequency of 16 Hz, while an unmodulated field causes no ion release [2,8]. Multiple RF power-density windows in calcium ion release from brain tissue have presented [9]. A significant decrease in AChE activity has been found in rats exposed to radio frequency radiation of 147 MHz and its sub-harmonics 73.5 and 36.75 MHz amplitude modulated at 16 and 76 Hz. A decrease in AChE activity was independent of carrier wave frequencies [10].

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doi:10.1016/j.pathophys.2009.01.002

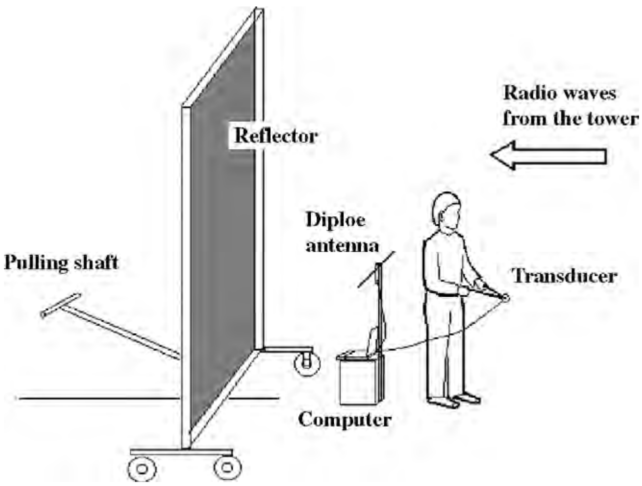

Fig. 1. Testing human radio wave sensitivity. Radio waves from the TV tower reflect back from the reflector and form a standing wave. When the reflector moves, the position of the maximums of the standing wave change, and the electromagnetic intensity changes in the body of the test subject. The computer with an AD-converter registers the signals of hand movement transducer and the RF-meter with the dipole antennas.

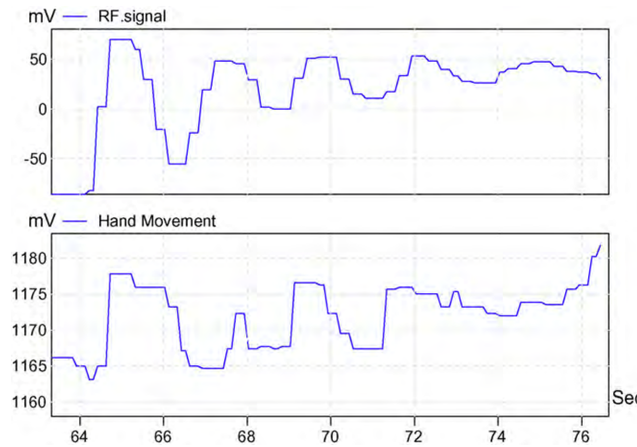

Fig. 2. Hand movements near the moving RF reflector. The standing waves moved slowly with the reflector. Intensity of the electric field was measured with the broadband RF-meter with horizontal dipole antennas. Variation of the field intensity is presented in the upper curve and the hand movements of the standing test person are in the lower curve.

As there is previous evidence from human and animal studies that electromagnetic irradiation has effects in the brain, the aim of the present study was to find out, if the motor responses are generated in sensitive persons, when they move across a set of standing waves caused by radiation of a FM-radio and TV tower. The connection between the hand movements and the integrated intensity of electromagnetic field of FM-radio broadcasting were recorded.

2. Methods

The wavelength of a 100-MHz radio wave is 3 m. For testing human sensitivity to moving standing waves a movable reflecting wall with wooden frame 3 m height and 5 m wide was constructed (Fig. 1). Steel net of 20 mm × 20 mm mesh was used. Five horizontal net slices of 60 cm wide were bound together with steel wire forming a radio waves reflecting surface. The test place was 5 km from the FM-radio tower. The frame was placed in an open field perpendicular to the incoming wave. The test subject was standing back towards the frame, and he had the hand movement transducer in his hands. The RF-meter with horizontal dipole antenna was close behind him. When started, the frame was 2 m from his back and it was moved 20 m forth and back. The computer registered both signals. The method and the aim of the test were at first presented, in brief, to the test persons. All together 29 adult persons of different ages were tested. They were participants in a seminar relating to effects of electric fields, and thus they possibly do not represent a normal population.

The broadband (30–300 MHz) RF-meter and the hand movement transducer were constructed for this study by the authors. The signals were digitised by Pico high resolution data logger (ADC16). The radio frequency spectrum was measured using a spectrum analyser (GW instek GSP-827, 2.7 GHz) with 1.5 m horizontal dipole antennas. When measured, the antenna was fastened to a wooden frame 1 m from the ground.

3. Results and discussion

Results on the movable frame showed different hand movement reactions of the test subjects. There were 9 persons who reacted like the RF-meter (Fig. 2), 6 persons whose graphs, though obvious, showed no correlation to the RF-meter and 14 persons who did not react or showed only small noise like changes in their graphs (Table 1). Spectrum at the test place contains mainly the FM-radio broadcasting signals and four digital TV signals (Fig. 3). Most prominent (85 dB μV, approximately 50 mV/m) are the 6 horizontally polarized FM-radio signals (Fig. 4).

Resonances in body parts affects the power absorption. Theoretically, the optimal length of a thin antenna in radio-frequency reception is nearly half of the wavelength of the

Table 1
Reactions to standing waves of FM-radio signals. Classification of results of 29 tested persons. Test subject was standing and the radio wave reflector was moved behind him/her. The hand movement graphs were compared to the graphs of the broadband radio frequency (RF) meter.

Reactions to standing waves	9 persons	Hand movement graphs include features like graphs of RF-meter.
Possible reaction	6 persons	Changes in the graphs but no correlation to RF-meter.
No reaction	14 persons	Only small noise like changes in the graphs.

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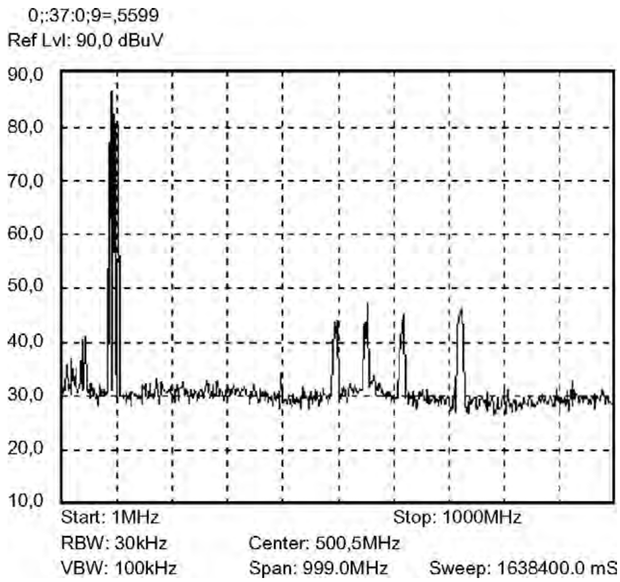

Fig. 3. Spectrum 1–1000 MHz at the test place. The highest peaks at the left are FM-radio broadcasting signals and the four lower peaks in the middle are the digital TV signals. Because the measurement was made with 1.5 m dipoles, signals near 100 MHz are more prominent because of antenna resonance.

incoming radio wave. The experimental maximum whole body resonance frequency is lower than the resonance frequency for an ideal half wave dipole antenna [11]. The whole body resonance length of a human at the frequencies of 80–108 MHz applied to FM broadcasting is about 1.1–1.5 m. Because in this experiment the test subjects were standing and the 100 MHz FM-radio signals and TV signals at higher frequencies are horizontally polarized, the absorption is obviously higher in the shoulder area. The distance between two maximums of the 100 MHz standing wave is 1.5 m. The half

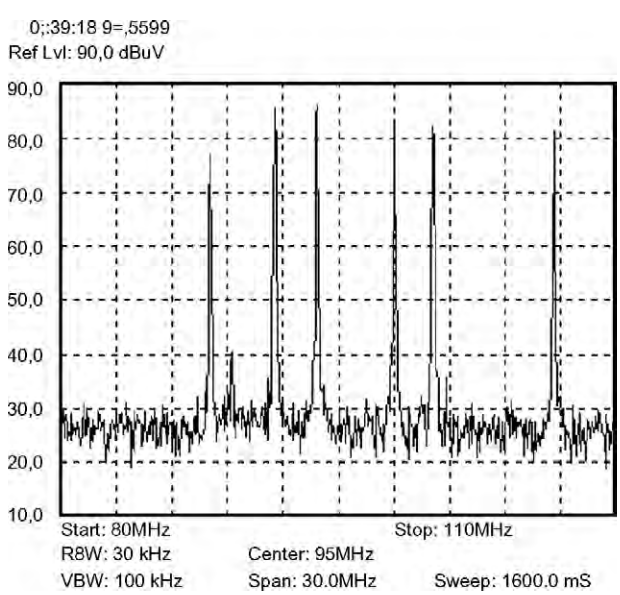

Fig. 4. Spectrum of the FM-radio broadcasting at the test place. Six channels were sending and the maximum electric field intensity was 85 dB μV.

waves of local digital TV signals (500–700 MHz) are only about 20–30 cm. This means that there can be many maximums of standing waves of TV signals in the body at the same time, even near the reflector.

The biggest variation in the local field intensity was caused by the FM broadcasting. There were 6 channels in the tower. Because of different wave lengths, the standing waves near the reflector are at the same phase and they amplify each other, but further away, the phases are mixed and so the amplitude of the summed standing waves is smaller.

With this experiment, we cannot exactly say where the reaction occurs, in limbs, muscles or in the head. It is possible that a change of intensity in standing radiowaves causes a small change in the nerve-muscle permeability of the nerve signal. The person feels it like a spontaneous muscle contraction. His hands are moving away and closer when the standing waves are passing. By some persons, the distance from hand to hand varied 0–60 cm. That means that some of muscles in arms and shoulders should react.

The spectrum contains many frequencies of electromagnetic radiation. The radiation is not only coming from the nearest tower, and it is impossible to clean the test area from other waves. This experiment was made at rural area, but even there, the private hand held telephone signals cause interferences to RF-instruments.

4. Conclusions

Sensitive persons seem to react to crossing standing waves of the FM-radio or TV broadcasting signals. The reactions were apparently initiated by RFR near reflecting objects, but they became more random in very weak variations of total field intensity. In any case, individuals are different, and in natural situations many sources interfere with each other.

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Pathophysiology xxx (2009) xxx–xxx

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Cell phone radiation: Evidence from ELF and RF studies supporting more inclusive risk identification and assessment☆

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Received 21 January 2009; received in revised form 3 February 2009; accepted 3 February 2009

Abstract

Many national and international exposure standards for maximum radiation exposure from the use of cell phone and other similar portable devices are ultimately based on the production of heat particularly in regions of the head, that is, thermal effects (TE). The recent elevation in some countries of the allowable exposure, that is, averaging the exposure that occurs in a 6 min period over 10 g of tissue rather than over 1 g allows for greater heating in small portions of the 10-g volume compared to the exposure that would be allowed averaged over 1-g volume. There is concern that 'hot' spots, that is, momentary higher intensities, could occur in portions of the 10-g tissue piece, might have adverse consequences, particularly in brain tissue.

There is another concern about exposure to cell phone radiation that has been virtually ignored except for the National Council of Radiation Protection and Measurements (NCRP) advice given in a publication in 1986 [National Council for Radiation Protection and Measurements, Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields, National Council for Radiation Protection and Measurements, 1986, 400 pp.]. This NCRP review and guidance explicitly acknowledge the existence of non-thermal effects (NTE), and included provisions for reduced maximum-allowable limits should certain radiation characteristics occur during the exposure.

If we are to take most current national and international exposure standards as completely protective of thermal injury for acute exposure only (6 min time period) then the recent evidence from epidemiological studies associating increases in brain and head cancers with increased cell phone use per day and per year over 8–12 years, raises concerns about the possible health consequences on NTE first acknowledged in the NCRP 1986 report [National Council for Radiation Protection and Measurements, Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields, National Council for Radiation Protection and Measurements, 1986, 400 pp.].

This paper will review some of the salient evidence that demonstrates the existence of NTE and the exposure complexities that must be considered and understood to provide appropriate, more thorough evaluation and guidance for future studies and for assessment of potential health consequences. Unfortunately, this paper is necessary because most national and international reviews of the research area since the 1986 report [National Council for Radiation Protection and Measurements, Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields, National Council for Radiation Protection and Measurements, 1986, 400 pp.] have not included scientists with expertise in NTE, or given appropriate attention to their requests to include NTE in the establishment of public-health-based radiation exposure standards. Thus, those standards are limited because they are not comprehensive.

Keywords: Non-thermal effects; Electromagnetic fields; Exposure standards

1. Introduction

1.1. *The current approach to exposure limits (based on heating and electric current flow in tissues)*

It is universally accepted that radiofrequency radiation (RFR) can cause tissue heating (thermal effects, TE) and that extremely low-frequency (ELF) fields, e.g., 50

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doi:10.1016/j.pathophys.2009.02.001

and 60 Hz, can cause electrical current flows that shock and even damage or destroy tissues. These factors alone are the underlying bases for present exposure standards. EMF exposures that cause biological effects at intensities that do not cause obvious thermal changes, that is, non-thermal effects (NTE), have been widely reported in the scientific literature since the 1970s including beneficial applications in development and repair processes. The current public safety limits do not take modulation into account and thus are no longer sufficiently protective of public health where chronic exposure to pulsed or pulse-modulated signal is involved, and where sub-populations of more susceptible individuals may be at risk from such exposures.

1.2. Modulation as a critical element

Modulation signals are one important component in the delivery of EMF signals to which cells, tissues, organs and individuals can respond biologically. At the most basic level, modulation can be considered a pattern of pulses or repeating signals which have specific meaning in defining that signal apart from all others. Modulated signals have a specific 'beat' defined by how the signal varies periodically or aperiodically over time. Pulsed signals occur in an on–off pattern, which can be either smooth and rhythmic, or sharply pulsed in quick bursts. Amplitude and frequency modulation involves two very different processes where the high-frequency signal, called the carrier wave, has a lower frequency signal that is superimposed on or 'rides' on the carrier frequency. In amplitude modulation, the lower frequency signal is embedded on the carrier wave as changes in its amplitude as a function of time, whereas in frequency modulation, the lower frequency signal is embedded as slight changes in the frequency of the carrier wave. Each type of low-frequency modulation conveys specific 'information', and some modulation patterns are more effective (more bioactive) than others depending on the biological reactivity of the exposed material. This enhanced interaction can be a good thing for therapeutic purposes in medicine, but can be deleterious to health where such signals could stimulate disease-related processes, such as increased cell proliferation in precancerous lesions. Modulation signals may interfere with normal, non-linear biological functions. More recent studies of modulated RF signals report changes in human cognition, reaction time, brainwave activity, sleep disruption and immune function. These studies have tested the RF and ELF-modulated RF signals from emerging wireless technologies (cell phones) that rely on pulse-modulated RF to transmit signals. Thus modulation can be considered as information content embedded in the higher frequency carrier wave that may have biological consequences beyond any effect from the carrier wave directly.

In mobile telephony, for example, modulation is one of the underlying ways to categorize the radiofrequency signal of one telecom carrier from another (TDMA from CDMA from GSM). Modulation is likely a key factor in determining whether and when biological reactivity might be occurring, for example in the new technologies which make use of modulated signals, some modulation (the packaging for delivery for an EMF 'message') may be bioactive, for example, when frequencies are similar to those found in brain wave patterns. If a new technology happens to use brain wave frequencies, the chances are higher that it will have effects, in comparison, for example, to choosing some lower or higher modulation frequency to carry the same EMF information to its target.

This chapter will show that other EMF factors may also be involved in determining if a given low-frequency signal directly, or as a modulation of a radiofrequency wave, can be bioactive. Such is the evolving nature of information about modulation. It argues for great care in defining standards that are intended to be protective of public health and well-being. This chapter will also describe some features of exposure and physiological conditions that are required in general for non-thermal effects to be produced, and specifically *to illustrate how modulation is a fundamental factor which should be taken into account in public safety standards*.

2. Laboratory evidence

Published laboratory studies have provided evidence for more than 40 years on bioeffects at much lower intensities than cited in the various widely publicized guidelines for limits to prevent harmful effects. Many of these reports show EMF-caused changes in processes associated with cell growth control, differentiation and proliferation, that are biological processes of considerable interest to physicians for potential therapeutic applications and for scientists who study the molecular and cellular basis of cancer. EMF effects have been reported in gene induction, transmembrane signaling cascades, gap junction communication, immune system action, rates of cell transformation, breast cancer cell growth, regeneration of damaged nerves and recalcitrant bone-fracture healing. These reports have cell growth control as a common theme. Other more recent studies on brainwave activity, cognition and human reaction time lend credence to modulation (pulsed RF and ELF-modulated RF) as a concern for wireless technologies, most prominently from cell phone use.

In the process of studying non-thermal biological effects, various exposure parameters have been shown to influence whether or not a specific EMF can cause a biological effect, including intensity, frequency, the co-incidence of the static magnetic field (both the natural earth's magnetic field and anthropogenic fields), the presence of the electrical field, the magnetic field, or their combination, and whether EMF is sinusoidal, pulsed or in more com-

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plex wave forms. These parameters will be discussed below.

Experimental results will be used to illustrate the influence of each EMF parameter, while also demonstrating that it is highly unlikely the effects are due to EMF-caused current flow or heating.

2.1. Initial studies that drew attention to NTE

Several papers in the 1960s and early 1970s reported that ELF fields could alter circadian rhythms in laboratory animals and humans. In the latter 1960s, a paper by Hamer [2] reported that the EMF environment in planned space capsules could cause human response time changes, i.e., the interval between a signal and the human response. Subsequent experiments by a research group led by Adey were conducted with monkeys, and showed similar response time changes and also EEG pattern changes [3,4]. The investigators shifted the research subject to cats and decided they needed to use a radiofrequency field to carry the ELF signal into the cat brain, and observed EEG pattern changes, ability to sense and behaviorally respond to the ELF component of RFR, and the ability of minor electric current to stimulate the release of an inhibitory neurotransmitter, GABA, and simultaneous release of a surrogate measure, calcium ions, from the cortex [5,6]. At this time Bawin, a member of the research group, adopted newly hatch chickens as sources of brain tissue and observed changes in the release of calcium ions from in vitro specimens as a function of ELF frequency directly or as amplitude modulation (‘am’) of RFR (RFRam) [7–11]. Tests of both EMF frequency and intensity dependences demonstrated a single sensitive region (termed ‘window’) over the range of frequency and intensity examined. This series of papers showed that EMF-induced changes could occur in several species (human, monkey, cat and chicken), that calcium ions could be used as surrogate measures for a neurotransmitter, that ELF fields could produce effects similar to RFRam (note: without the ‘am’, there was no effect although the RFR intensity was the same), and that the dose and frequency response consisted of a single sensitivity window.

Subsequent, independent research groups published a series of papers replicating and extending this earlier work. Initial studies by Blackman, Joines and colleagues [12–25] used the same chick brain assay system as Bawin and colleagues. These papers reported multiple windows in intensity and in frequency within which calcium changes were observed in the chick brain experimental systems under EMF exposure. Three other independent groups offered confirmation of these results by reporting intensity and frequency windows for calcium, neurotransmitter or enolase release under EMF exposure of human and animal nervous system-derived cells in vitro by Dutta et al. [26–29], of rat pancreatic tissue slices by Albert et al. [30], and of frog heart by Schwartz et al. [31] but not frog-heart atrial strips in vitro [32]. This series of papers showed that multiple frequency and intensity windows were a common phenomenon that required the development of new theoretical concepts to provide a mechanism of action paradigm.

2.2. Refined laboratory studies reveal more details

Additional aspects of the EMF experiments with the chick brain described by Blackman and colleagues, above, also revealed critical co-factors that influenced the action of EMF to cause changes in calcium release, including the influence of the local static magnetic field, and the influence of physico-chemical parameters, such as pH, temperature and the ionic strength of the bathing solution surrounding the brain tissue during exposure. This information provides clues for and constraints on any theoretical mechanism that is to be developed to explain the phenomenon. Most current theories ignore these parameters that need to be monitored and controlled for EMF exposure to produce NTE. These factors demonstrate that the current risk assessment paradigms, which ignore them, are incomplete and thus may not provide the level of protection currently assumed.

2.3. Sensitivity of developing organisms

An additional study was also conducted to determine if EMF exposure of chicken eggs while the embryo was developing could influence the response of brain tissue from the newly hatched chickens. The detailed set of frequency and intensity combinations under which effects were observed, were all obtained from hatched chickens whose eggs were incubated for 21 days in an electrically heated chamber containing 60-Hz fields. Thus tests were performed to determine if the 60-Hz frequency of ELF fields (10 V/m in air) during incubation, i.e., during embryogenesis and organogenesis, would alter the subsequent calcium release responses of the brain tissue to EMF exposure. The reports of Blackman et al. [19] and Joines et al. [25] showed that the brain tissue response was changed when the field during the incubation period was 50 Hz rather than 60 Hz. This result is consistent with an anecdotal report of adult humans, institutionalized because of chemical sensitivities, who were also responsive to the frequency of power-line EM fields that were present in the countries where they were born and raised [33]. This information indicates there may be animal and human exposure situations where EMF imprinting during development could be an important factor in laboratory and epidemiological situations. EMF imprinting, which may only become manifest when a human is subjected to chemical or biological stresses, could reduce ability to fight disease and toxic insult from environmental pollution, resulting in a population in need of more medical services, with resulting lost days at work.

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3. Fundamental exposure parameters—to be considered when establishing a mode (or mechanism) of action for non-thermal EMF-induced biological effects

3.1. Intensity

There are numerous reports of biological effects that show intensity "windows", that is, regions of intensity that cause changes surrounded by higher and lower intensities that show no effects from exposure. One very clear effect by Blackman and colleagues is 16-Hz, sine wave-induced changes in calcium efflux from brain tissue in a test tube because it shows two very distinct and clearly separated intensity windows of effects surrounded by regions of intensities that caused no effects [17]. There are other reports for similar multiple windows of intensity in the radiofrequency range [22,26,29,31]. Note that calcium ions are a secondary signal transduction agent active in many cellular pathways. These results show that intensity windows exist, they display an unusual and unanticipated "non-linear" (non-linear and non-monotonic) phenomenon that has been ignored in all risk assessment and standard setting exercises, save the NCRP 1986 publication [1]. Protection from multiple intensity windows has never been incorporated into any risk assessment; to do so would call for a major change in thinking. These results mean that lower intensity is not necessarily less bioactive, or less harmful.

Multiple intensity windows appeared as an unexpected phenomenon in the late 1970s and 1980s. There has been one limited attempt to specifically model this phenomenon by Thompson et al. [34], which was reasonably successful. This modeling effort should be extended because there are publications from two independent research groups showing multiple intensity windows for 50, 147, and 450 MHz fields when amplitude modulated at 16 Hz using the calcium ion release endpoint in chicken brains, in vitro. The incident intensities (measured in air) for the windows at the different carrier frequencies do not align at the same values. However, Joines et al. [23,24] and Blackman et al. [20] noted the windows of intensity align across different carrier frequencies if one converts the incident intensity to the intensity expected within the sample at the brain surface. This conversion was accomplished by correcting for the different dielectric constants of the sample materials due to the different carrier frequencies. The uniqueness of this response provides a substantial clue to theoreticians but it is interesting and disappointing that no publications have appeared attempting to address this relationship. It is obvious that this phenomenon is one that needs further study.

3.2. Frequency

Frequency-dependent phenomena are common occurrences in nature. For example, the human ear only hears a portion of the sound that is in the environment, typically from 20 to 20,000 Hz, which is a frequency "window". Another biological frequency window can be observed for plants grown indoors. Given normal indoor lighting the plants may grow to produce lush vegetation but not produce flowers unless illuminated with a lamp that emits a different spectrum of light partially mimicking the light from the sun. Thus, frequency windows of response to various agents exist in biological systems from plants to homo sapiens.

In a similar manner, there are examples of EMF-caused biological effects that occur in a frequency-dependent manner that cannot be explained by current flow or heating. The examples include reports of calcium ion efflux from brain tissue in vitro by Blackman and Joines and colleagues at low frequency [15,19] and at high frequency modulated at low frequency [20,35,24]. An additional example of an unexpected result is by Liboff [36].

In addition, two apparently contradictory multiple-frequency exposure results provide examples of the unique and varied non-thermal interactions of EMF with biological systems. Litovitz and colleagues showed that an ELF sinusoidal signal could induce a biological response in a cell culture preparation, and that the addition of a noise signal of equal average intensity could block the effect caused by the sinusoidal signal, thereby negating the influence of the sinusoidal signal [37]. Similar noise canceling effects were observed using chick embryo preparations [38,39]. It was also shown that the biological effects caused by microwave exposures imitating cell phone signals could be mitigated by ELF noise [40]. However, this observation should not be generalized; a noise signal is not always benign. Milham and Morgan [41] showed that a sinusoidal ELF (60-Hz) signal was not associated with the induction of cancer in humans, but when that sinusoidal signal was augmented by a noise signal, basically transients that added higher frequencies, an increase in cancer was noted in humans exposed over the long-term. Thus, the addition of noise in this case was associated with the appearance of a health issue. Havas [42–44] has described other potential health problems associated with these higher frequency transients, termed "dirty power." The bioactive frequency regions observed in these studies have never been explicitly considered for use in any EMF risk assessments, thus demonstrating the incomplete nature of current exposure guideline limits.

There are also EMF frequency-dependent alterations in the action of nerve growth factor (NGF) to stimulate neurite outgrowth (growth of primitive axons or dendrites) from a peripheral-nerve-derived cell (PC-12) in culture shown by Blackman et al. [45,46] and by Trillo et al. [47]. The combined effect of frequency and intensity is also a common occurrence in both the analogous sound and the light examples given above. Too much or too little of either frequency or intensity show either no or undesirable effects. Similarly, Blackman et al. [15] has reported EMF responses composed of effect "islands" of intensity and frequency combinations, surrounded by a "sea" of intensity and frequency combinations of null effects. Although the mechanisms responsible

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for these effects have not been established, the effects represent a here-to-fore unknown phenomenon that may have complex ramifications for risk assessment and standard setting. Nerve growth and neurotransmitter release that can be altered by different combinations of EMF frequencies and intensities, especially in developing organisms like children, could conceivably produce over time a subsequent altered ability to successfully or fully respond behaviorally to natural stressors in the adult environment; research is urgently needed to test this possibility in animal systems.

Nevertheless, this phenomenon of frequency dependence is ignored in the development of present exposure standards. These standards rely primarily on biological responses to intensities within an arbitrarily defined engineering-based frequency bands, not biologically based response bands, and are solely based on an energy deposition determinations.

4. Static magnetic field—a completely unexpected complexity

The magnetic field of the earth at any given location has a relatively constant intensity as a function of time. However, the intensity value, and the inclination of the field with respect to the gravity vector, varies considerable over the face of the earth. More locally, these features of the earth's magnetic field can also vary by more than 20% inside manufactured structures, particularly those with steel support structures.

At the Bioelectromagnetics Society annual meeting in 1984 [48], Blackman revealed his group's discovery that the intensity of the static magnetic field could establish and define those oscillatory frequencies that would cause changes in calcium ion release in his chick brain preparation. This result was further discussed at a NATO Advanced Research workshop in Erice, Italy in the fall of 1984 and by publications from that meeting and subsequent research: Blackman et al. [14,18] and Liboff et al. [36,49,50]. Substantial additional research on this feature was reported by Liboff and colleagues [51,52,50]. Blackman et al. also reported on the importance of the relative orientation of the static magnetic field vector to the oscillating magnetic field vector [21] and demonstrated a reverse biological response could occur depending on parallel or perpendicular orientations of the static and oscillating magnetic fields [53].

There have been many attempts to explain this phenomenon by a number of research teams led by Smith [49], Blackman [15], Liboff [36,54], Lednev [55], Blanchard [56], Zhadin [57], del Giudice [58], Binhi [59–62], and Matronchik [63] but none has been universally accepted. Nevertheless, experimental results continued to report static and oscillating field dependencies for non-thermally induced biological effects in studies led by Zhadin [64,65], Vorobyov [66], Baureus Koch [67], Sarimov [68], Prato [69,70], Comisso [71], and Novikov [72].

With this accumulation of reports from independent, international researchers, it is now clear that if a biological response depends on the static magnetic field intensity, and even its orientation with respect to an oscillating field, then the conditions necessary to reproduce the phenomenon are very specific and might easily escape detection (see for example, Blackman and Most [73]. The consequences of these results are that there may be exposure situations that are truly detrimental (or beneficial) to organisms, but that are insufficiently common on a large scale that they would not be observed in epidemiological studies; they need to be studied under controlled laboratory conditions to determine impact on health and wellbeing.

5. Electric and magnetic components—both biological active with different consequences

Both the electric and the magnetic components have been shown to directly and independently cause biological changes. There is one report that clearly distinguishes the distinct biological responses caused by the electric field and by the magnetic field. Marron et al. [74] show that electric field exposure can increase the negative surface charge density of an amoeba, Physarum polycephalum, and that magnetic field exposure of the same organism causes changes in the surface of the organism to reduce its hydrophobic character. Other scientists have used concentric growth surfaces of different radii and vertical magnetic fields perpendicular to the growth surface to determine if the magnetic or the induced electric component is the agent causing biological change. Liburdy et al. [75], examining calcium influx in lymphocytes, and Greene et al. [76], monitoring ornithine decarboxylase (ODC) activity in cell culture, showed that the induced electric component was responsible for their results. In contrast, Blackman et al. [77,78] monitoring neurite outgrowth from two different clones of PC-12 cells and using the same exposure technique used by Liburdy and by Greene showed the magnetic component was the critical agent in their experiments. EMF-induced changes on the cell surface, where it interacts with its environment, can dramatically alter the homeostatic mechanisms in tissues, whereas changes in ODC activity are associated with the induction of cell proliferation, a desirable outcome if one is concerned about wound healing, but undesirable if the concern is tumor cell growth. This information demonstrates the multiple, different ways that EMF can affect biological systems. Present analyses for risk assessment and standard setting have ignored this information, thus making their conclusions of limited value.

6. Sine and pulsed waves—like different programs on a radio broadcast station

Important characteristics of pulsed waves that have been reported to influence biological processes include the following: (1) frequency, (2) pulse width, (3) intensity, (4) rise and fall time, and (5) the frequency, if any, within the pulse ON time. Chiabrera et al. [79] showed that pulsed fields caused de-differentiation of amphibian red blood cells. Scarfi et al. [80] showed enhanced micronuclei formation in lymphocytes of patients with Turner's syndrome (only one X chromosome) but no change in micronuclei formation when the lymphocytes were exposed to sine waves (Scarfi et al. [81]). Takahashi et al. [82] monitored thymidine incorporation in Chinese hamster cells and explored the influence of pulse frequency (two windows of enhancement reported), pulse width (one window of enhancement reported) and intensity (two windows of enhancement reported followed by a reduction in incorporation). Ubeda et al. [83] showed the influence of difference rise and fall times of pulsed waves on chick embryo development.

6.1. Importance for risk assessment

It is important to note that the frequency spectrum of pulsed waves can be represented by a sum of sine waves which, to borrow a chemical analogy, would represent a mixture of chemicals, anyone of which could be biologically active. Risk assessment and exposure limits have been established for specific chemicals or chemical classes of compounds that have been shown to cause undesirable biological effects. Risk assessors and the general public are sophisticated enough to recognize that it is impossible to declare all chemicals safe or hazardous; consider the difference between food and poisons, both of which are chemicals. A similar situation occurs for EMF; it is critical to determine which combinations of EMF conditions have the potential to cause biological harm and which do not.

Obviously, pulse wave exposures represent an entire genre of exposure conditions, with additional difficulty for exact independent replication of exposures, and thus of results, but with increased opportunities for the production of biological effects. Current standards were not developed with explicit knowledge of these additional consequences for biological responses.

7. Mechanisms

Two papers have the possibility of advancing understanding in this research area. Chiabrera et al. [84] created a theoretical model for EMF effects on an ion's interaction with protein that includes the influence of thermal energy and of metabolism. Before this publication, theoreticians assumed that biological effects in living systems could not occur if the electric signal is below the signal caused by thermal noise, in spite of experimental evidence to the contrary. In this paper, the authors show that this limitation is not absolute, and that different amounts of metabolic energy can influence the amount and parametric response of biological systems to EMF. The second paper, by Marino et al. [85], presents a new analytical approach to examine endpoints in systems exposed to EMF. The authors, focusing on exposure-induced lymphoid phenotypes, report that EMF may not cause changes in the mean values of endpoints, but by using recurrence analysis, they capture exposure-induced, statistically significant, non-linear movements of the endpoints to either side of the mean endpoint value. They provide further evidence using immunological endpoints from exposed and sham treated mice [86–88]. Additional research has emerged from this laboratory on EMF-induced animal and human brain activity changes that provides more evidence for the value of their research approach (Marino et al. [89–92], Kolomytkin et al. [93] and Carrubba et al. [94–98]). Further advanced theoretical and experimental studies of relevance to non-thermal biological effects are emerging; see for example reports by Binhi et al. [59–62], Zhadin et al. [64,99,65], and Novikov et al. [72]. *It is apparent that much remains to be examined and explained in EMF biological effects research through more creative methods of analysis than have been used before. The models described above need to be incorporated into risk assessment determinations.*

8. Problems with current risk assessments—observations of effects are segregated by artificial frequency bands that ignore modulation

One fundamental limitation of most reviews of EMF biological effects is that exposures are segregated by the physical (engineering/technical) concept of frequency bands favored by the engineering community. This is a default approach that follows the historical context established by the incremental addition of newer technologies that generate increasingly higher frequencies. However, this approach fails to consider unique responses from biological systems that are widely reported at various combinations of frequencies, modulations and intensities.

When common biological responses are observed without regard for the particular, engineering-defined EMF frequency band in which the effects occur, this reorganization of the results can highlight the commonalities in biological responses caused by exposures to EMF across the different engineering-defined frequency bands. An attempt to introduce this concept to escape the limitations of the engineering-defined structure occurred with the development of the 1986 NCRP radiofrequency exposure guidelines because published papers from the early 1970s to the mid 1980s (to be discussed below) demonstrated the need to include amplitude modulation as a factor in setting of maximum exposure limits. The 1986 NCRP guideline [1] was the one and only risk evaluation that included an exception for modulated fields.

The current research and risk assessment attempts are no longer tenable. The 3-year delay in the expected report of the 7-year Interphone study results has made this epidemiological approach a 10-year long effort, and the specific exposure conditions, due to improved technology, have changed so that the results may no longer be applicable to the current exposure situation. It is unproductive to continue to fund epidemiological studies of people who are exposed to a wide variety of diversified, uncontrolled, and poorly characterized EMF in their natural and work environments. In place of the funding of more epidemiological studies should be funding to support controlled laboratory studies to focus on the underlying processes responsible for the NTE described above, so that mechanisms or modes of action can be developed to provide a theoretical framework to further identify, characterize and unify the action of the heretofore ignored exposure parameters shown to be important.

8.1. Potential explanation for the failure to optimize research in EMF biological effects

Unfortunately, risk evaluations following the 1986 NCRP example [1], returned to the former engineering-defined analysis conditions, in part because scientists who reported non-thermal effects were not placed on the review committees, and in the terms of Slovic [100] "Risk assessment is inherently subjective and represent a blend of science and judgment with important psychological, social, cultural, and political factors. . . . Whoever controls the definition of risk controls the rational solution to the problem at hand. . . . Defining risk is thus an exercise in power." It appears that by excluding scientists experienced with producing non-thermal biological effects, the usually sound judgment by the selected committees was severely limited in its breadth-of-experience, thereby causing the members to retreat to their own limited areas of expertise when forced to make judgments, as described by Slovic [100], "Public views are also influenced by worldviews, ideologies, and values; so are scientists' views, particularly when they are working at limits of their expertise." The current practice of segregating scientific investigations (and resulting public health limits) by artificial divisions of frequency dramatically dilutes the impact of the basic science results, thereby reducing and distorting the weight of evidence in any evaluation process (see evaluations of bias by Havas [101], referring to NRC 1997 [102] compared to NIEHS 1998 [103] and NIEHS 1999 [104]).

9. Suggested research

Are there substitute approaches that would improve on the health-effects evaluation situation? As mentioned above, it may be useful in certain cases to develop a biologically based clustering of the data to focus on and enrich understanding of certain aspects of biological responses. Some examples to consider for biological clustering include: (1) EMF features, such as frequency and intensity inter-dependencies, (2) common co-factors, such as the earth's magnetic field or co-incident application of chemical agents to perturb and perhaps sensitize the biological system to EMF, or (3) physiological state of the biological specimen, such as age or sensitive sub-populations, including genetic predisposition as described by Fedrowitz et al. [105,106], and for human populations, recently reported by Yang et al. [107].

To determine if this approach has merit, one could combine reports of biological effects found in the ELF (including sub-ELF) band with effects found in the RF band when the RF exposures are amplitude modulated (AM) using frequencies in the ELF band. The following data should be used: (a) human response time changes under ELF exposure [2], (b) monkey response time and EEG changes under ELF exposure [3,4], (c) cat brain EEG, GABA and calcium ion changes induced by ELF and AM-RF [8,9,7,10,6,11,108,5], (d) calcium ion changes in chick brain tissue under ELF and AM-RF [8,9,7,10,13–15,21,16–18,12,19,20,22,35,23–25,11], and (e) calcium changes under AM-RF in brain cells in culture [26–28] and in frog heart under AM-RF [31]. The potential usefulness of applying biological clustering in the example given above even though AM is used, is that the results may have relevance to assist in the examination of some of the effects reportedly caused by cellular phone exposures which include more complex types of modulation of RF. This suggestion is reasonable because three groups later reported human responses to cell phone emissions that include changes in reaction times – Preece et al. [109,110], Koivisto et al. [111,112] and Krause et al. [113,114] – or to brain wave potentials that may be associated with reaction time changes—Freude et al. [115,116].

Subsequently, Preece et al. [117] tested cognitive function in children and found a trend, but not a statistically significant change in simple reaction time under exposure, perhaps because he applied a Bonferroni correction to his data (alpha for significance was required to be less than 0.0023). It would appear that a change in the experimental protocol might provide a more definitive test of the influence of exposure on simple reaction time because it is known that a Bonferroni correction is a particularly severe test of statistical significance, or as the author observed, "a particularly conservative criterion."

Krause et al. [118] examined cognitive activity by observing oscillatory EEG activity in children exposed to cell phone radiation while performing an auditory memory task and reported exposure related changes in the ∼4–8 Hz EEG frequencies during memory encoding, and changes in that range and also ∼15 Hz during recognition. The investigators also examined cognitive processing, an auditory memory task or a visual working memory task, in adults exposed to CW or pulsed cell phone radiation on either the right or left side of the head, and reported modest changes in brain EEG activity in the ∼4–8 Hz region, compared to CW exposure, but with caveats that no behavior changes were observed, and that the data were varying, unsystematic and inconsistent with previous reports (Krause et al. [119]). Haarala and colleagues conducted an extensive series of experiments, examining reaction time [120], short-term memory [121], short-term memory in children [122], and right versus left hemisphere exposure [123]. Although these studies did not support the positive effects from exposure reported by others, they provided possible explanations for the apparent lack of agreement.

Other research groups have also examined the effects of cell phone radiation on the central nervous system, including Borbely et al. [124], Huber et al. [125], Loughran et al. [126], and D'Costa et al. [127], who found changes in sleep EEG patterns and other measures during or after short-term exposures, while others, such as Fritzer et al. [128] exposed for longer time periods found no changes in sleep parameters, EEG power spectra, correlation dimension nor cognitive function. The work of Pritchard [129] served as the basis to examining correlation dimensions, which is opening a potentially fertile avenue for investigation. Although this approach provides more indepth information on ongoing processes and function, it has not yet been used to address potential consequences associated with long-term cell phone use.

The papers published in the 1960s through 1991, described in earlier sections of this paper, foreshadowed the more recent publications in 1999 through 2008 showing response time changes, or associated measures, in human subjects during exposure to cell phone-generated radiation. It is unfortunate that essentially none of the earlier studies was acknowledged in these recent reports on cognition, reaction time and other measures of central nervous system processes. Without guidance from this extensive earlier work, particularly those demonstrating the variety of exposure parameter spaces that must be controlled to produce repeatable experiments, the development of the mechanistic bases for non-thermal effects from EMF exposures will be substantially delayed. The omission of the recognition of the exposure conditions that affect the biological outcomes continues as recently as the National Academy of Science 2009 publication [130] of future directions for research, which emphasizes the modest perspective in the results from committee members working at the limits of expertise, as anticipated by Slovic [100].

Let us hope that subsequent national and international committees that consider future directions for EMF research include members who have performed and reported non-thermal effects, in order to provide a broader perspective to develop programs that will more expeditiously address potential health problems as well as to provide guidance to industry on prudent procedures to establish for their technologies.

At present, we are left with a recommendation voiced in 1989 by Abelson [131] in an editorial in Science Magazine that addressed electric power-specific EMF, but is applicable to higher frequency EMF as well, to "adopt a prudent avoidance strategy" by "adopting those which look to be 'prudent' investments given their cost and our current level of scientific understanding about possible risks."

10. Conclusions

There is substantial scientific evidence that some modulated fields (pulsed or repeated signals) are bioactive, which increases the likelihood that they could have health impacts with chronic exposure even at very low exposure levels. Modulation signals may interfere with normal, non-linear biological processes. Modulation is a fundamental factor that should be taken into account in new public safety standards; at present it is not even a contributing factor. To properly evaluate the biological and health impacts of exposure to modulated RFR (carrier waves), it is also essential to study the impact of the modulating signal (lower frequency fields or ELF-modulated RF). Current standards have ignored modulation as a factor in human health impacts, and thus are inadequate in the protection of the public in terms of chronic exposure to some forms of ELF-modulated RF signals. The current IEEE and ICNIRP standards are not sufficiently protective of public health with respect to chronic exposure to modulated fields (particularly new technologies that are pulse-modulated and heavily used in cellular telephony). The collective papers on modulation appear to be omitted from consideration in the recent WHO and IEEE science reviews. This body of research has been ignored by current standard setting bodies that rely only on traditional energy-based (thermal) concepts. More laboratory as opposed to epidemiological research is needed to determine which modulation factors, and combinations are bioactive and deleterious at low intensities, and are likely to result in disease-related processes and/or health risks; however this should not delay preventative actions supporting public health and wellness. If signals need to be modulated in the development of new wireless technologies, for example, it makes sense to use what existing scientific information is available to avoid the most obviously deleterious exposure parameters and select others that may be less likely to interfere with normal biological processes in life. The current membership on Risk Assessment committees needs to be made more inclusive, by adding scientists experienced with producing non-thermal biological effects. The current practice of segregating scientific investigations (and resulting public health limits) by artificial, engineering-based divisions of frequency needs to be changed because this approach dramatically dilutes the impact of the basic science results and eliminates consideration of modulation signals, thereby reducing and distorting the weight of evidence in any evaluation process.

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Please cite this article in press as: C. Blackman, Cell phone radiation: Evidence from ELF and RF studies supporting more inclusive risk identification and assessment, Pathophysiology (2009), doi:10.1016/j.pathophys.2009.02.001

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Pathophysiology xxx (2009) xxx–xxx

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Apparent decreases in Swedish public health indicators after 1997—Are they due to improved diagnostics or to environmental factors?

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Received 19 October 2008; accepted 27 December 2008

Abstract

The object of this work was to review recent trends in public health in Sweden. Data on different adverse health indicators were collected from official Swedish registries. We found that population health generally improved during the early 1990s but suddenly started to deteriorate from 1997 onwards. This quite dramatic change is not likely to be explained only by improved diagnostics but physical causes need immediately to be searched for. A connection with the increasing exposure of the population to GHz radiation from mobile phones, base stations and other communication technologies cannot be ruled out.

Keywords: Alzheimer's disease; Heart malformations; Lung cancer; Melanoma; Prostata carcinoma; Traffic accidents; Mobile phone speech time

1. Introduction

During the first half of the 1990s, the Swedish population appeared increasingly healthy. Sick leave registrations decreased; in addition, lung cancer among older men steadily decreased and the incidence of prostate cancer levelled out, becoming stable or slightly decreasing between 1993 and 1997. In Stockholm, even the number of traffic accidents with injuries went down each year from 1985 to 1996. Mortality due to Alzheimer's disease increased in the early 1980s, but remained steady at 2.5–4 per 100,000 person-years (age standardized) from 1990 to 1997.

Objective of the present study: After 1997, public health appeared to decline markedly. Was this decrease the result of improvements in detection and diagnosis, or did maladies actually increase? In this paper, we take a look at several health trends, one by one, and analyze the suggested causes underlying the adverse health- and traffic safety indicators.

2. Materials and methods

All data were retrieved from the official databases of the National Health and Welfare Board (Socialstyrelsen; SoS) and of the Swedish Road Administration (Vägverket; VV). Hallberg and Johansson (2004) have presented worrying trends related to public health in Sweden [1]. Hallberg (2007) showed that many adverse health indicators were worse in sparsely populated areas, as hypothesized caused by higher average output power from mobile phones in those areas [2].

3. Results and discussion

1. Lung cancer among elderly men increased markedly beginning after 1997 (Fig. 1). For men aged 80–84 years, the incidence increased from 160 to 230/100,000. For men aged 85+, the incidence increased from 95 to a high of 180/100,000 in 2005. The SoS has not publicly offered any explanation for these increases or commented on this matter.
2. In 1997, the incidence of prostate cancer abruptly increased in all age groups (Fig. 2). In Stockholm, the number of cases in men aged 50–59 stayed fairly stable

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[1] This Research Institution was founded in 2001 and is registered by the Swedish National Patent and Registration Office.

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doi:10.1016/j.pathophys.2008.12.004

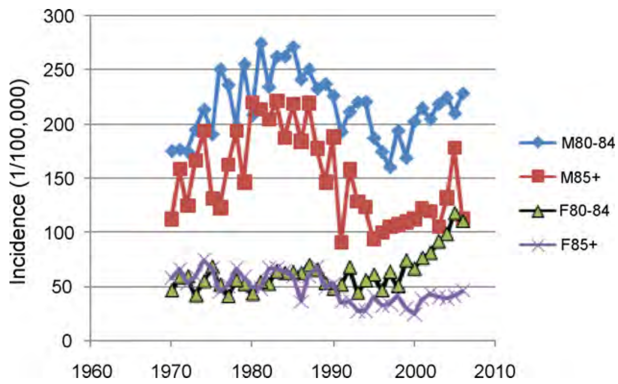

Fig. 1. Lung cancer in the elderly (male (M) and female (F)) has increased in Sweden since 1997.

at around 30 cases per year up to 1996, despite the fact that PSA tests were used routinely starting in 1991. After 1996, when 33 cases of prostate cancer were reported, the number of cases increased to around 300 per year in 2004 and 2005. SoS originally suggested that the apparent increase in prostate cancer was due to the improved diagnostic capabilities of the PSA test. When asked again, the SoS said, “It cannot, however, be ruled out that a certain increase would have been noticed even without these PSA tests, but we don’t know how large this increase would have been.” Notably, however, the step-like increase in prostate cancer did not coincide with the introduction of the PSA test in 1991.

3. For several decades, the rate of skin melanoma was very stable among younger people (<50 years), despite publicity about the dangers of sun exposure. However, after 2000 the incidence of melanoma of the head and neck region suddenly started to increase in this population (Fig. 3). Simultaneously, the rate of more benign skin tumours dropped, and the sum total of tumours and melanoma continued to increase. However, small carcinomas that would previously have developed into relatively benign tumours now seem to increasingly develop into melanoma. SoS has not commented on this in their reports.

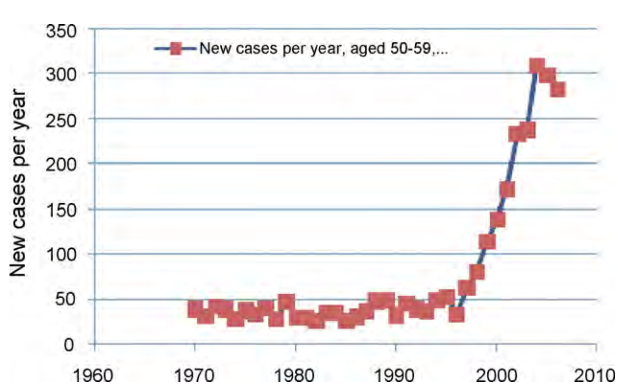

Fig. 2. The number of newly reported cases of prostate cancer in men aged 50–59 years in Stockholm County, Sweden.

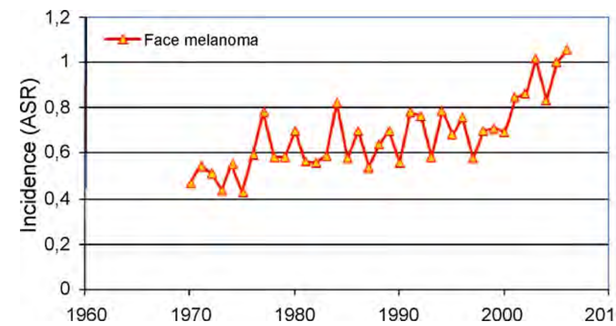

Fig. 3. Melanoma of the face has increased in Sweden among people <60 years since 2000.

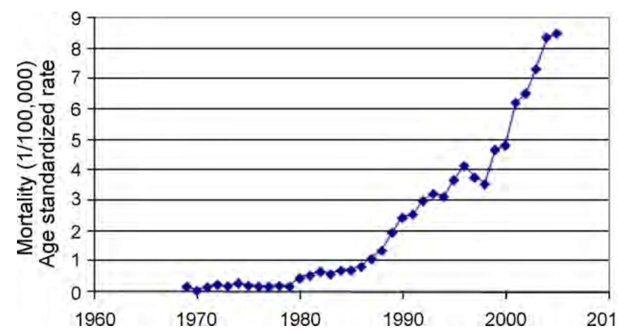

Fig. 4. Alzheimer’s mortality has increased steeply since 1998 in Sweden.

4. Mortality associated with Alzheimer’s disease has increased dramatically since 1998 (Fig. 4). Today, the incidence is 9/100,000, an increase of 300% in 10 years. When queried, the SoS suggested that this increase can be attributed to an increase in the practice of declaring Alzheimer’s disease as the cause of death when signing the death certificate. SoS also claims that there are no grounds for stating that mortality has actually increased. However, a thorough analysis of the data indicates that there is an increase in mortality in older people with this disease [3].
5. In 1985, the number of people seriously injured in Stockholm traffic accidents was around 650. Subsequently, there was a decrease in injuries to a low of 350 in 1997. After 1997, the number of people injured annually started

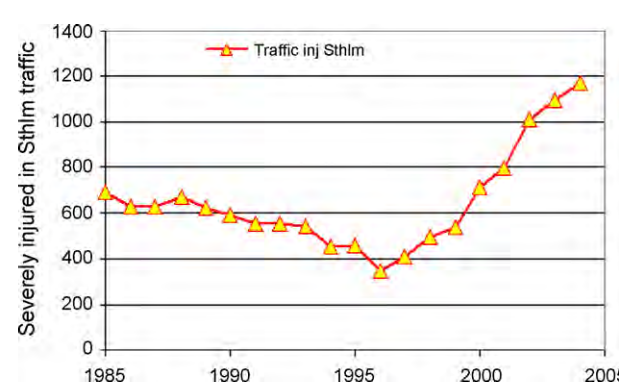

Fig. 5. Traffic injuries in Stockholm have increased since 1997.

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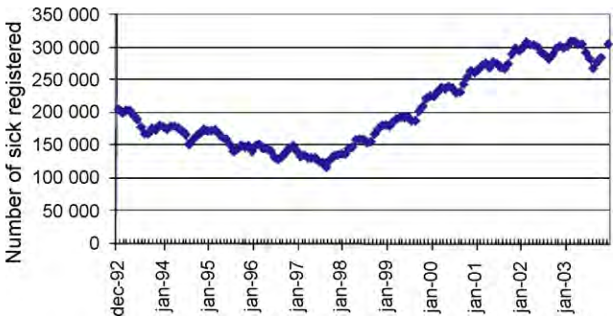

Fig. 6. The number of people in Sweden registered as sick suddenly increased starting in September 1997.

Fig. 7. Brain tumours among in the elderly (>60 years) have increased since 2001 in Sweden.

increasing, reaching 1200 in 2005 (Fig. 5). According to VV, this trend is partly the result of the introduction of a better reporting system in Stockholm. Nonetheless, the increasing number of people severely injured in Swedish traffic ended the downward trend observed until 1997: This number has rapidly increased since 2000. Today, VV reports that the number of people who were severely injured per killed increased rapidly in Stockholm County in the time period 2000–2004.

6. The total number of people taking sick leave was just over 200,000 in 1992. This number decreased steadily to around 125,000 in September 1997. After that time, the trend broke, and we saw an increase to over 300,000 people registering as sick in 2003 (Fig. 6). The authorities have not given any explanation for this abrupt increase in the number of people who registered as sick. It is not likely due to improved diagnostics, but rather to the fact that more people needed to take sick leave. In November 2001, the leader of the KD party, Alf Svensson, commented that "sick-cheating" was one explanation. In contrast to earlier trends, the increase in sickness appears to be greater in more sparsely populated regions. In the beginning of the 80s, it was considered healthy to live in the countryside, since people were healthier there. A closer analysis of sick leave data in different counties shows that the Northern counties and the Gotland island were the last counties to show an increase in sick leave rates. These counties did not show increasing rates until February 1998. In contrast, the increase was observed early on in Blekinge and Kronoborg, where the increase was noticeable in September/October of 1997.
7. The number of new brain tumours in people >60 years old suddenly increased after 2000 (Fig. 7). This development paralleled the increase of melanoma in the face region of people <60 years. In general, the incidence of brain tumours is increasing most in more sparsely populated regions where mobile phones often need to use full output power [2,4].
8. The percentage of newborns with heart problems began to increase after 1998 (Fig. 8). It was recently reported that fetuses and neonates react to their mother's mobile phone use with an increased pulse rate and decreased blood flow [5]. Another report published in the well-known journal *Epidemiology* [6] suggests that such mobile phone use may also influence emotional development and may increase the risk of hyperactivity, behaviour problems, and relational problems with other children up to the time that children start school.

A dramatic environmental change took place in Sweden in the autumn of 1997. At this time, GSM 1800 MHz transmitters were put into use to increase transmission capacity, especially in urban areas, see Fig. 8. Much of the population began to be exposed to 1.8 GHz microwaves both at night and during the day. In the Stockholm area, people began to steer cars using only their right hands while holding the mobile phones by their left hands. The Post- and Telecom Administration states that GSM 1800 MHz began to be used in 1997, but has no information on starting months in different counties. When Telia were queried about starting dates

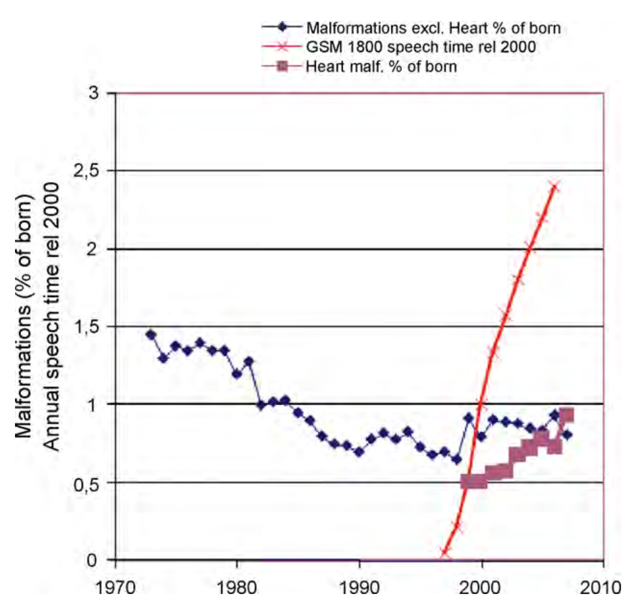

Fig. 8. The percentage of newborns with heart problems has increased since 1998 in Sweden. Also shown is the annual speech time in dual band mobile phones relative to year 2000. The down going trend of malformed newborns excluding heart problems is now broken since 1998.

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for transmitter operation, Telia responded that they will not release this information. "The reason is that this information reasonably has no association with sick registration levels in Sweden in 1997." In 2001, the roll-out of the 3G network started and the use of the higher and probably more biological hazardous frequency, around 2.1 GHz, increased. More details about relevant events in 1997 are described in reference [1].

4. Conclusion

The negative trends in public health indicators in Sweden are not fully explained by better diagnostics, better instrumentation, or better doctors. Because these indicators may reflect real world changes, efforts should be made, starting immediately, to determine the underlying cause or causes.

Conflict of interest

There is no conflict of interest known to the authors related to this work.

Acknowledgements

Supported by the Karolinska Institute, the Help Foundation (Hjälpfonden), and the Cancer and Allergy Foundation (Cancer- och Allergifonden).

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Pathophysiology xxx (2009) xxx–xxx

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Public health implications of wireless technologies

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Received 18 January 2008; accepted 30 January 2009

Abstract

Global exposures to emerging wireless technologies from applications including mobile phones, cordless phones, DECT phones, WI-FI, WLAN, WiMAX, wireless internet, baby monitors, and others may present serious public health consequences. Evidence supporting a public health risk is documented in the BioInitiative Report. New, biologically based public exposure standards for chronic exposure to low-intensity exposures are warranted. Existing safety standards are obsolete because they are based solely on thermal effects from acute exposures. The rapidly expanding development of new wireless technologies and the long latency for the development of such serious diseases as brain cancers means that failure to take immediate action to reduce risks may result in an epidemic of potentially fatal diseases in the future. Regardless of whether or not the associations are causal, the strengths of the associations are sufficiently strong that in the opinion of the authors, taking action to reduce exposures is imperative, especially for the fetus and children. Such action is fully compatible with the precautionary principle, as enunciated by the Rio Declaration, the European Constitution Principle on Health (Section 3.1) and the European Union Treaties Article 174.

Keywords: Wireless technology; Brain cancer; Radiofrequency; Cell phones; Wireless antenna facilities; Childrens' health

1. Introduction and background

Exposure to electromagnetic fields (EMF) has been linked to a variety of adverse health outcomes that may have significant public health consequences [1–13]. The most serious health endpoints that have been reported to be associated with extremely low frequency (ELF) and/or RF include childhood and adult leukemia, childhood and adult brain tumors, and increased risk of the neurodegenerative diseases, Alzheimer's and amyotrophic lateral sclerosis (ALS). In addition, there are reports of increased risk of breast cancer in both men and women, genotoxic effects (DNA damage and micronucleation), pathological leakage of the blood–brain barrier, altered immune function including increased allergic and inflammatory responses, miscarriage and some cardiovascular effects [1–13]. Insomnia (sleep disruption) is reported in studies of people living in very low-intensity RF environments with WI-FI and cell tower-level exposures [85–93]. Short-term effects on cognition, memory and learning, behavior, reaction time, attention and concentration, and altered brainwave activity (altered EEG) are also reported in the scientific literature [94–107]. Biophysical mechanisms that may account for such effects can be found in various articles and reviews [136–144].

The public health implications of emerging wireless technologies are enormous because there has been a very rapid global deployment of both old and new forms in the last 15 years. In the United States, the deployment of wireless infrastructure has accelerated greatly in the last few years with 220,500 cell sites in 2008 [14–16]. Eighty-four percent of the population of the US own cell phones [16]. Annualized wireless revenues in 2008 will reach $144 billion and US spending on wireless communications will reach $212 billion by 2008. Based on the current 15% annual growth rate enjoyed by the wireless industry, in the next 5 years wireless will become a larger sector of the US economy than both the agriculture and automobile sectors. The annualized use of cell phones in the US is estimated to be 2.23 trillion minutes in 2008 [16]. There are 2.2 billion users of cell phones worldwide in 2008 [17] and many million more users of cordless phones.

Over 75 billion text messages were sent in the United States, compared with 7.2 billion in June 2005, according to

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doi:10.1016/j.pathophys.2009.01.011

CTIA, the Wireless Association, the leading industry trade group [16]. The consumer research company Nielsen Mobile, which tracked 50,000 individual customer accounts in the second quarter of this year, found that Americans each sent or received 357 text messages a month then, compared with 204 phone calls. That was the second consecutive quarter in which mobile texting significantly surpassed the number of voice calls [17].

The Electronics Industries Alliance (EIA) represents 80% of the $550 billion US electronics industry "that provides two million jobs for American workers." Its members include companies from the consumer electronics and telecommunications industries, among others [17].

There is intense industry competition for market share. Telecom taxes form an immense revenue generator for the government sector. Sale of the airwaves (auctions selling off wireless bandwidth) is a multi-million dollar industry for governments, and multi-billion dollar global advertising budgets are common. Lobbying dollars from the telecom-related industries are estimated to be $300 million annually. The media is nearly silent on health issues, perhaps in part because of global advertising revenues that compromise journalistic independence and discourage balanced coverage of health, equity and economic issues.

2. Evidence supporting a public health risk

Even if there is only a small risk to health from chronic use of and exposure to wireless technologies, there is the potential for a profound public health impact. RF radiation now saturates the airwaves, resulting in exposure to both users and non-users. The effects are both short-term (sleep disruption, hormone disruption, impairment of cognitive function, concentration, attention, behavior, and well-being) and they are almost certainly long-term (generational impacts on health secondary to DNA damage, physiological stress, altered immune function, electrosensitivity, miscarriage risks, effects on sperm quality and motility leading to infertiility, increased rates of cancer, and neurological diseases including Alzheimer's disease and ALS—at least for ELF exposures). (Chapters 5–12 of the BioInitiative Report [1] and papers in this Supplement.)

There is credible scientific evidence that RF exposures cause changes in cell membrane function, metabolism and cellular signal communication, as well as activation of proto-oncogenes and triggering of the production of stress proteins at exposure levels below current regulatory limits. There is also generation of reactive oxygen species, which cause DNA damage, chromosomal aberrations and nerve cell death. A number of different effects on the central nervous system have also been documented, including activation of the endogenous opioid systems, changes in brain function including memory loss, slowed learning, motor dysfunction and performance impairment in children, and increased frequency of headaches, fatigue and sleep disorders. Melatonin secretion is reduced, resulting in altered circadian rhythms and disruption of several physiological functions. (Chapters 5–12 of the BioInitiative Report [1] and papers in this Supplement.)

These effects can reasonably be presumed to result in adverse health effects and disease with chronic and uncontrolled exposures, and children may be particularly vulnerable [1,19]. The young are also largely unable to remove themselves from such environments. Second-hand non-ionizing radiation, like second-hand smoke may be considered of public health concern based on the evidence at hand.

2.1. Malignant brain tumors

At present, the most persuasive evidence for cancer resulting from RF exposure is that there is a significantly increased risk of malignant glioma in individuals that have used a mobile phone for 10 or more years, with the risk being elevated only on the side of the head on which the phone is used regularly (ipsilateral use) [1,3,4,6–8,18]. While the risk for adults after 10 or more years of use is reported to be more than doubled, there is some evidence beginning to appear that indicates that the risk is greater if the individual begins to use a mobile phone at younger ages. Hardell et al. [18] reported higher odds ratios in the 20–29-year-old group than other age ranges after more than 5 years of use of either analog or cordless phones. Recently in a London symposium Hardell reported that after even just 1 or more years of use there is a 5.2-fold elevated risk in children who begin use of mobile phones before the age of 20 years, whereas for all ages the odds ratio was 1.4. Studies from Israel have found that the risk of parotid gland tumors (a salivary gland in the cheek) is increased with heavy cell phone use [7]. The risk of acoustic neuroma (a benign but space-occupying tumor on the auditory nerve) is also significantly increased on the ipsilateral side of the head after 10 or more years of mobile phone use [1,3]. This relationship has also been documented in some of the published reports of the WHO Interphone Study, a decade-long 13-country international assessment of cell phone risks and cancer [6,8].

Kundi reports that "(E)pidemiological evidence compiled in the last 10 years starts to indicate an increased risk, in particular for brain tumors (glioma, meningioma, acoustic neuroma), from mobile phone use. Considering biases that may have been operating in most studies the risk estimates are rather too low, although recall bias could have increased risk estimates. The net result, when considering the different errors and their impact is still an elevated risk" [19].

The latency for most brain tumors is 20 years or more when related to other environmental agents, for example, to X-ray exposure. Yet, for cell phone use the increased risks are occurring much sooner than twenty years, as early as 10 years for brain tumors in adults and with even shorter latencies in children. This suggests that we may currently be significantly underestimating the impact of current levels of

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use of RF technology, since we do not know how long the average latency period really is. If it is 20 years, then the risk rate will likely be much higher than an overall doubling of risk for cell phone users if the peak comes later than 10 years. It may also signal very troubling risks for those who start using cell phones, and perhaps all wireless devices, in early childhood. We may not have proof of effect for decades until many hundreds of thousands of new cases of malignant gliomas are set in motion by long-term cell phone use.

The preliminary evidence that mobile phone use at younger ages may lead to greater risk than for older persons is of particular concern. There is a large body of evidence that childhood exposure to environmental agents poses greater risk to health than comparable exposure during adulthood [20,21]. There is reason to expect that children would be more susceptible to the effects of EMF exposure since they are growing, their rate of cellular activity and division is more rapid, and they may be more at risk for DNA damage and subsequent cancers. Growth and development of the central nervous system is still occurring well into the teenage years so that neurological changes may be of great importance to normal development, cognition, learning, and behavior.

A greater vulnerability of children to developing brain cancer from mobile phone use may be the consequence of a combination of patterns of use, stage of development and physical characteristics related to exposure. In addition to the fact that the brain continues to develop through the teen years, many young children and teenagers now spend very large periods of time using mobile phones. The brain is the main target organ of cell phones and cordless phones, with highest exposure to the same side as the phone is used. Further, due to anatomical reasons, the brain of a child is more exposed to RF radiation than the brain of an adult [22,23]. This is caused by the smaller brain size, a thinner pinna of the ear, thinner skin and thinner skull bone permitting deeper penetration into the child's brain. A recent French study showed that children absorb twice the RF from cell phone use as do adults [24].

In addition to concerns about cancer, there is evidence for short-term effects of RF exposure on cognition, memory and learning, behavior, reaction time, attention and concentration, altered brainwave activity (altered EEG) [95–108], and all of these effects argue for extreme caution with regard to exposure of children. The development of children into adults is characterized by faster cell division during growth, the long period needed to fully develop and mature all organ systems, and the need for properly synchronized neural development until early adulthood. Chronic, cumulative RF exposures may alter the normal growth and development of children and adversely affect their development and capacity for normal learning, nervous system development, behavior and judgment [1,97,102].

Prenatal exposure to EMF has been identified as a possible risk factor for childhood leukemia (1). Maternal use of cell phones has been reported to adversely affect fetal brain development, resulting in behavioral problems in those children by the time they reach school age [25]. Their exposure is involuntary in all cases. Children are largely unable to remove themselves from exposures to harmful substances in their environments.

2.2. Plausible biological mechanisms for a relationship between RF exposure and cancer

2.2.1. DNA damage and oxidative stress

Damage to DNA from ELF and from RF cell phone frequencies at very low intensities (far below FCC and ICNIRP safety limits) has been demonstrated in many studies [1,2,26–35]. Both single- and double-strand DNA damage have been reported by various researchers in different laboratories. This is damage to the human genome, and can lead to mutations which can be inherited, or which can cause cancer, or both.

Non-ionizing radiation is assumed to be of too low energy to cause direct DNA damage. However both ELF and RF radiation induce reactive oxygen species, free radicals that react with cellular molecules including DNA. Free-radical production and/or the failure to repair DNA damage (secondary to damage to the enzymes that repair damage) created by such exposures can lead to mutations. Whether it is greater free-radical production, reduction in anti-oxidant protection or reduced repair capacity, the result will be altered DNA, increased risk of cancer, impaired or delayed healing, and premature aging [36–54]. Exposures have also been linked to decreased melatonin production, which is a plausible biological mechanism for decreased cancer surveillance in the body, and increased cancer risk [34,39,44,46,47,49,50,54]. An increased risk of cancers and a decrease in survival has been reported in numerous studies of ELF and RF [55–69].

2.2.2. Stress proteins (heat shock proteins or HSP)

Another well-documented effect of exposure to low-intensity ELF and RF is the creation of stress proteins (heat shock proteins) that signal a cell is being placed under physiological stress) [70–80]. The HSP response is generally associated with heat shock, exposure to toxic chemicals and heavy metals, and other environmental insults. HSP is a signal of cells in distress. Plants, animals and bacteria all produce stress proteins to survive environmental stressors like high temperatures, lack of oxygen, heavy metal poisoning, and oxidative stress.

We can now add ELF and RF exposures to this list of environmental stressors that cause a physiological stress response. Very low-level ELF and RF exposures can cause cells to produce stress proteins, meaning that the cell recognizes ELF and RF exposures as harmful. This is another important way in which scientists have documented that ELF and RF exposures can be harmful, and it happens at levels far below the existing public safety standards. An additional concern is that if the stress goes on too long, the protective effect is diminished. The reduced response with prolonged exposure means the cell is less protected against damage, and this is why prolonged or chronic exposures may be harmful, even at very low intensities.

2.2.3. RF-induced gene expression changes

Many environment agents cause diseases, including cancer, not by direct damage to DNA but rather by up- or down-regulation of genes that regulate cell growth and function. Usually there are many genes whose expression is changed, and it is difficult to determine the exact changes responsible for the disease. Both ELF and RF exposures have been shown to result in altered gene expression. Olivares-Banuelos et al. [81] found that ELF exposure of chromaffin cells resulted in changed expression of 53 transcripts. Zhao et al. [82] investigated the gene expression profile of rat neurons exposed to 1800 MHz RF fields (2 W/kg) and found 24 up-regulated genes and 10 down-regulated genes after a 24-h exposure. The altered genes were involved in multiple cellular functions including cytoskeleton, signal transduction pathways and metabolism. Kariene et al. [83] exposed human skin to mobile phone radiation, and found by punch biopsy that 8 proteins were significantly altered in expression, consistent with gene induction. Several other studies have found altered gene expression following RF exposure, although none have been found that explain specific disease states [84].

DNA activation at very low ELF and RF levels, as in the stress response, and DNA damage (strand breaks and micronuclei) at higher levels, are molecular precursors to changes that are believed to lead to cancer. These, along with gene induction, provide plausible biological mechanisms linking exposure to cancer.

The biochemical pathways that are activated are the same for ELF and for RF exposures, and are non-thermal (do not require heating or induced electrical currents). This is true for the stress response, DNA damage, generation of reactive oxygen species as well as gene induction. Thus it is not surprising that the major cancers resulting from exposure to ELF and RF are the same, namely leukemia and brain cancer. The safety standards for both ELF and RF, based on protection from heating, are irrelevant and not protective. ELF exposure levels of only 5–10 mG have been shown to activate the stress response genes (http://www.bioinitiative.org, Sections 1 and 7 [1]).

3. Sleep, cognitive function and performance

The relationship of good sleep to cognition, performance and healing is well recognized. Sleep is a profoundly important factor in proper healing, anti-inflammatory benefits, reduction in physical symptoms of such as tendonitis, over-use syndrome, fatigue-induced lethargy, cognition and learning. Incomplete or slowed physiological recovery is common when sleep is impaired. Circadian rhythms that normalize stress hormone production (cortisol, for example) depend on synchronized sleep patterns.

People who are chronically exposed to low-level wireless antenna emissions report symptoms such as problems in sleeping (insomnia), as well as other symptoms that include fatigue, headache, dizziness, grogginess, lack of concentration, memory problems, ringing in the ears (tinnitus), problems with balance and orientation, and difficulty in multi-tasking [85–93,99]. In children, exposures to cell phone radiation have resulted in changes in brain oscillatory activity during some memory tasks [97,102]. Cognitive impairment, loss of mental concentration, distraction, speeded mental function but lowered accuracy, impaired judgment, delayed reaction time, spatial disorientation, dizziness, fatigue, headache, slower motor skills and reduced learning ability in children and adults have all been reported [85–108].

These symptoms are more common among “electrosensitive” individuals, although electrosensitivity has not been documented in double-blind tests of individual identifying themselves as being electrosensitive as compared to controls [109,110]. However people traveling to laboratories for testing are pre-exposed to a multitude of RF and ELF exposures, so they may already be symptomatic prior to actual testing. There is also evidence that RF exposures testing behavioral changes show delayed results; effects are observed after termination of RF exposure. This suggests a persistent change in the nervous system that may be evident only after time has passed, so is not observed during a short testing period.

3.1. Plausible biological mechanisms for neurobehavioral effects

3.1.1. The melatonin hypothesis

While there remains controversy as to the degree that RF and ELF fields alter neurobehavioral function, emerging evidence provides a plausible mechanism for both effects on sleep and cognition. Sleep is controlled by the central circadian oscillator in the suprachiasmatic nucleus, located in the hypothalamus. The activity of this central circadian oscillator is, in turn, controlled by the hormone, melatonin, which is released from the pineal gland [111]. There is considerable evidence that ELF exposure reduces the release of melatonin from the pineal gland—see Section 12 of the Bioinitiative Report [1]. There has been less study of the effects of RF exposure on melatonin release, but investigations have demonstrated a reduced excretion of the urinary metabolite of melatonin among persons using a mobile phone for more than 25 min per day [112]. In a study of women living near to radio and television transmitters, Clark et al. [113] found no effect on urinary melatonin metabolite excretion among pre-menopausal women, but a strong effect in post-menopausal women.

The “melatonin hypothesis” also provides a possible basis for other reported effects of EMFs. Melatonin has important actions on learning and memory, and inhibits electrophysiological components of learning in some but not all areas of the brain [114,115]. Melatonin has properties as a free-radical scavenger and anti-oxidant [116], and consequently, a reduction in melatonin levels would be expected to increase susceptibility to cancer and cellular damage. Melatonin could also be the key to understanding the relationship between EMF exposure and Alzheimer's disease. Noonan et al. [117] reported that there was an inverse relationship between excretion of the melatonin metabolite and the 1–42 amino acid form of amyloid beta in electric utility workers. This form of amyloid beta has been found to be elevated in Alzheimer's patients.

3.1.2. Blood–brain barrier alterations

Central nervous system effects of EMFs may also be secondary to damage to the blood–brain barrier (BBB). The blood–brain barrier is a critical structure that prevents toxins and other large molecules that are in peripheral blood from having access to the brain matter itself. Salford et al. [118] have reported that a 2-h exposure of rats to GSM-900 radiation with a SAR of 2–200 mW/kg resulted in nerve cell damage. In a follow-up study, Eberhardt et al. report that 2-h exposures to cell phone GSM microwave RF resulted in leakage of albumin across the blood–brain barrier and neuronal death [119]. Neuronal albumin uptake was significantly correlated to occurrence of damaged neurons when measured at 28 days post-exposure. The lowest exposure level was 0.12 mW/kg (0.00012 W/kg) for 2 h. The highest exposure level was 120 mW/kg (0.12 W/kg). The weakest exposure level showed the greatest effect in opening the BBB [118]. Earlier blood–brain studies by Salford and Schirmacher [120,121] report similar effects.

4. What are sources of wireless radiation?

There are many overlapping sources of radiofrequency and microwave emissions in daily life, both from industrial sources (like cell towers) and from personal items [cell and cordless phones, personal digital assistants (PDAs), wireless routers, etc.]. Published data on typical levels found in some cities and from some sources are available at http://www.bioinitiative.org [1,122–124].

Cell phones are the single most important source of radiofrequency radiation to which we are exposed because of the relatively high exposure that results from the phone being held right against the head. Cell phones produce two types of emissions that should be considered. First, the radiofrequency radiation (typically microwave frequency radiation) is present. However, there is also the contribution of the switching battery pack that produces very high levels of extremely low frequency electromagnetic field [125–127].

Cordless telephones have not been widely recognized as similar in emissions to cell phones, but they can and do produce significant RF exposures. Since people tend to use them as substitutes for in-home and in-office corded or traditional telephones, they are often used for long periods of time. As the range of cordless phones has increased (the distance away that you can carry on a conversation is related to the power output of the phone), the more powerful the RF signal will be. Hence, newer cordless phones may in some cases be similar to the power output of cell phones. The cumulative emissions from cell and cordless phones taken together should be recognized when considering the relative risks of wireless communication exposures.

PDAs such as the BlackBerry, Treo and iPhone units are 'souped-up' versions of the original voice communication devices (cell phones). The often produce far higher ELF emissions than do cell phones because they use energy from the battery very intensively for powering color displays and during data transmission functions (email, sending and receiving large files, photos, etc.) [125–127]. ELF emissions have been reported from PDAs at several tens to several hundreds of milligauss. Evidence of significantly elevated ELF fields during normal use of the PDA has public health relevance and has been reported in at least three scientific papers [125,128,129]. In the context of repetitive, chronic exposure to significantly elevated ELF pulses from PDAs worn on the body, relevant health studies point to a possible relationship between ELF exposure and cancer and pregnancy outcomes [130–133].

We include discussion of the ELF literature for two reasons. As mentioned above ELF activates the same biology as RF, it contributes to the total EMF burden of the body. In addition, PDAs and cell phones emit both radiofrequency/microwave radiation (RF) and extremely low frequency ELF from the battery switching of the device (the power source). Studies show that some devices produce excessively high ELF exposures during voice and data transmission. ELF is already classified as a 2B (Possible) Carcinogen by IARC, which means that ELF is indisputably an issue to consider in the wireless technology debate. ELF has been classified as a Group 2B carcinogen for all humans, not just children. The strongest evidence came from epidemiological studies on childhood leukemia, but the designation applies to all humans, both adults and children [1,25].

Wireless headsets that allow for conversations with cell phones at a distance from the head itself reduce the emissions. Depending on the type of wireless device, they may operate (transmit signal) only during conversations or they may be operational continuously. The cumulative dose of wireless headsets has not been well characterized under either form of use. Substantial cumulative RF exposure would be expected if the user wears a wireless headset that transmits a signal continuously during the day. However a critical factor is where the cell phone is placed. If worn on a belt with a headset, the exposure to the brain is reduced but the exposure to the pelvis may be significant.

Cell towers (called "masts" in Europe and Scandinavian countries) are wireless antenna facilities that transmit the cell phone signals within communities. They are another major source of RF exposures for the public. They differ from RF exposures from wireless devices like cell phones in that they produce much lower RF levels (generally 0.05 to 1–2 $\mu W/cm^2$ in the first several hundred feet around them) in comparison to several hundred microwatts per centimeter

Please cite this article in press as: C. Sage, D.O. Carpenter, Public health implications of wireless technologies, Pathophysiology (2009), doi:10.1016/j.pathophys.2009.01.011

squared for a cell phone held at the head. However they create a constant zone of elevated RF for up to 24 h per day. many hours per day, and the exposure is whole body rather than localized at the head. These facilities are the distribution system for wireless voice communications, internet connections and data transmission within communities. They are often erected on free-standing towers. They may be constructed on telephone poles or electrical poles. They may be built into the façade or rooftops of buildings behind wood screening. These are called stealth installations for wireless antenna facilities. Some installations are camouflaged to resemble 'false trees or rocks'. They emit RF to provide cell service to specific "cells" or locations that receive the signal.

Other forms of wireless transmission that are common in areas providing cell service are wireless land area networks (WLAN), (WiMAX) and WIFI networks. Some cities are installing city-wide WIFI service to allow any user on the street to log into the internet (without cables or wire connections). WIFI installations may have a signal reach for a few hundred feet where WiMAX installations may transmit signal more than 10 miles, so produce a stronger RF emission for those in close proximity. Each type has its particular signal strength and intended coverage area, but what they have in common is the production of continuous RF exposure for those within the area. We do not know what the cumulative exposure (dose) might be for people living, working or going to school in continuously elevated RF fields, nor are the possible health implications yet known. However, based on studies of populations near cell sites in general, there is a constellation of generally observed health symptoms that are reported to occur [85–107]. In this regard it is important to note that children living near to AM radio transmitters have been found to elevated risks of leukemia [134,135]. While AM radio RF fields are lower in frequency than that common in mobile phones, this is a total body irradiation with RF. The fact that leukemia, not brain cancer, is apparent in these studies suggests that leukemia is the cancer seen at the lowest levels of both ELF and RF fields under the circumstances of whole-body exposure.

Commercial surveillance systems or security gates pose an additional source of strong RF exposures. They are ubiquitous in department stores, markets and shops at the entry and exit points to discourage shoplifting and theft of goods. Security gates can produce excessively high RF exposures (although transitory) and have been associated with interference with pacemakers in heart patients. The exposure levels may approach thermal public safety limits in intensity, although no one expects a person to stand between the security gate bars for more than 6 min (safety limits for uncontrolled public access are variable depending on the frequency, but are all averaged over a 6-min exposure period).

RFID chips (radiofrequency identification chips) are being widely used to track purchases and for security of pets, and in some cases to keep track of patients with Alzheimer's disease and of children. RFID chips are implanted in fabrics, inserted in many types of commercial goods, and can be implanted under the skin. They create a detectable signal to track the location of people and goods.

5. Problems with existing public health standards (safety limits)

If the existing standards were adequate none of the effects documented above should occur at levels to which people are regularly exposed. The fact that these effects are seen with our current ambient levels of exposure means that our existing public safety standards are obsolete. It also means that new, biologically based public exposure standards for wireless technologies are urgently needed. Whether it is feasible to achieve low enough levels that still work and also protect health against effects of chronic RF exposure – for all age groups – is uncertain. Whether we can protect the public and still allow the kinds of wireless technology uses we see today is unknown.

The nature of electromagnetic field interactions with biological systems has been well studied [136–144]. For purposes of standard-setting processes for both ELF and RF, the hypothesis that tissue damage can result only from heating is the fundamental flaw in the misguided efforts to understand the basic biological mechanisms leading to health effects.

The thermal standard is clearly untenable as a measure of dose when EMF stimuli that differ by many orders of magnitude in energy can stimulate the same biological response. In the ELF range, the same biological changes occur as in the RF, and no change in temperature can even be detected. With DNA interactions the same biological responses are stimulated in ELF and RF ranges even though the frequencies of the stimuli differ by many orders of magnitude. The effects of EMF on DNA to initiate the stress response or to cause molecular damage reflect the same biology in different frequency ranges. For this reason it should be possible to develop a scale based on DNA biology, and use it to define EMF dose in different parts of the EM spectrum. We also see a continuous scale in DNA experiments that focus on molecular damage where single and double strand breaks have long been known to occur in the ionizing range, and recent studies have shown similar effects in both ELF and RF ranges [144].

Existing standard-setting bodies that regulate wireless technologies, assume that there are no bioeffects of concern at exposure levels that do not cause measurable heating. However, it has been established beyond any reasonable doubt that bioeffects and some adverse health effects occur at far lower levels of RF and ELF exposure where no heating (or induced current) occurs; some effects are shown to occur a thousand times or more below the existing public safety limits. New, biologically based public exposure limits are urgently needed. New wireless technologies for cell and cordless phones, other wireless communication and data transmission systems affect living organisms in new ways that our antiquated safety limits have not foreseen, nor protected against.

The exposure of children to electromagnetic fields has not been studied extensively; in fact, the Federal Communications Commission (FCC) standards for exposure to radiofrequency radiation are based on the height, weight and stature of a 6-foot tall man, not scaled to children or adults of smaller stature. They do not take into account the unique susceptibility of growing children to exposures, nor are there studies of particular relevance to children.

In addition there is a problem in the consideration of the level of evidence taken into consideration by these bodies. There have not been adequate animal models shown to have cancer as an endpoint, and a perception that no single mechanism is proven to explain these associations. Thus these committees have tended to ignore or minimize the evidence for direct hazard to humans, and believe there is no proof of cause and effect. These bodies assume from the beginning that only conclusive scientific evidence (absolute proof) will be sufficient to warrant change, and refuse to take action on the basis of a growing body of evidence which provides early but consequential warning of risks.

The Radiofrequency Interagency Working Group of the US governmental agencies involved in RF matters (RFIAWG) issued a Guidelines Statement in June of 1999 that concluded the present RF standard "may not adequately protect the public" [145]. The RFIAWG identified fourteen (14) issues that they believe are needed in the planned revisions of ANSI/IEEE RF exposure guidelines including "to provide a strong and credible rationale to support RF exposure guidelines". In particular, the RFIAWG criticized the existing standards as not taking into account chronic, as opposed to acute exposures, modulated or pulsed radiation (digital or pulsed RF is proposed at this site), time-averaged measurements that may erase the unique characteristics of an intensity-modulated RF radiation that may be responsible for reported biologic effects, and stated the need for a comprehensive review of long-term, low-level exposure studies, neurological-behavioral effects and micronucleus assay studies (showing genetic damage from low-level RF) [145]. This important document from relevant US agencies questions existing standards in the following ways: (a) selection of an adverse effect level for chronic exposures not based on tissue heating and considering modulation effects; (b) recognition of different safety criteria for acute and chronic exposures at non-thermal or low-intensity levels; (c) recognition of deficiencies in using time-averaged measurements of RF that does not differentiate between intensity-modulated RF and continuous wave (CW) exposure, and *therefore may not adequately protect the public*; (d) having standards based on adult males rather than considering children to be the most vulnerable group.

6. Prudent public health responses

Emerging environmental health problems require preventative public health responses even where scientific and medical uncertainties still exist, but where policy decisions today may greatly reduce human disease and societal costs tomorrow.

Policy decisions in public health must address some amount of uncertainty when balancing likely benefits and estimated costs. Although new insight will allow better appreciation of difficult issues, such as those occurring in environmental and occupational health, an expanded perspective may also enlarge the list of problems that need to be managed. Ignoring the problems carries its own costs (as deferring a decision is a decision in itself). With environmental and other public health problems becoming increasingly complex and international in scope, scientific documentation alone rarely justifies simple solutions [146].

Social issues regarding the controversy over public and occupational exposures to ELF and RF center on the resolute adherence to existing ICNIRP and FCC/IEEE standards by many countries, in the face of growing scientific evidence of health risks at far lower levels [10]. The composition of these committees, usually with excessive representation of the physics and engineering communities rather than public health professionals, results in a refusal to adopt biologically based exposure standards. Furthermore, there is widespread belief that governments are ignoring this evidence and there is widespread distrust of and lack of confidence in governments and their health agencies. The basis on which most review bodies and standard-setting agencies have avoided the conclusion that the science is strong enough to warrant new safety limits for ELF and RF is to require a demonstration of absolute proof before taking action. A causal level of evidence, or scientific certainty standard is implicit in nearly all reviews of the ELF and RF science, although this runs counter to good public health protection policies.

There is no question that global implementation of the safety standards proposed in the Bioinitiative Report, if implemented abruptly and without careful planning, have the potential to not only be very expensive but also disruptive of life and the economy as we know it. Action must be a balance of risk to cost to benefit. The major risk from maintaining the status quo is an increasing number of cancer cases, especially in young people, as well as neurobehavioral problems at increasing frequencies. The benefits of the status quo are expansion and continued development of communication technologies. But we suspect that the true costs of even existing technologies will only become much more apparent with time. Whether the costs of remedial action are worth the societal benefits is a formula that should reward precautionary behavior. Prudent corporate policies should be expected to address and avoid future risks and liabilities, otherwise, there is no market incentive to produce safe (and safer) products.

The deployment of new technologies is running ahead of any reasonable estimation of possible health impacts and estimates of probabilities, let alone a solid assessment of risk. However, what has been missing with regard to EMF has been an acknowledgement of the risk that is demonstrated by

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the scientific studies. There is clear evidence of risk, although the magnitude of the risk is uncertain, and the magnitude of doing nothing on the health effects cost to society is similarly uncertain. This situation is very similar to our history of dealing with the hazards of smoking decades ago, where the power of the industry to influence governments and even conflicts of interest within the public health community delayed action for more than a generation, with consequent loss of life and enormous extra health care costs to society. New standards are warranted now, based on the totality of scientific evidence; the risks of taking no-action, the large population at risk, costs associated with ignoring the problem in new and upgraded site selection and construction, and the loss of public trust by ignoring the problem.

Direct medical and rehabilitative health costs associated with treatment for diseases that are reasonably related to wireless technologies may be very large. Although there is uncertainty involved in how much disease is related to wireless exposures, the mere scale of the problem with several billion users of cell phones and even larger impacts on bystander populations (from cell site exposures, from other WI-FI and wireless exposures in-home and commercial use, etc.) the associated public health costs will likely be monumental. Furthermore the costs to families with cancers, neurological diseases or learning disabilities in children related in part or in whole to wireless technologies extend beyond medical costs. They may reasonably extend to family disruption and family psychological problems, losses in job productivity and income loss.

The history of governments and their official health agencies to deal with emerging and newly identified risks to health is not good [147–149]. This is particularly true where industry investments in new products and technologies occur without full recognition, disclosure or even knowledge of possible health consequences. Large economic investments in polluting industries often make for perilously slow regulatory action, and the public health consequences may be very great as a result [150,151].

Free markets do not internalize the costs to society of "guessing wrong". Unexpected or hidden health costs of new technologies may not be seen for many years, when the ability to recall or to identify the precise exposures related to disease outcomes is difficult or impossible. The penalty nearly always falls to the individual, the family or the taxpayer and not to the industry that benefits economically—at least in free-market economies. Thus, the profits go to industry but the costs may go to the individual who can suffer both diminished quality of life and health and economic disadvantage. If all disease endpoints that may be reasonably related to chronic exposure to electromagnetic fields are considered even a small attributable fraction for one or more industries, it will have enormous global impact on public health. The public health implications are immense. But they can be reduced by strong government and public health interventions providing information on alternatives to wireless technologies, public education campaigns, health advisories, requirements for redesign of wireless devices, proscription of use of wireless devices by children and teenagers, strong and independent research programs on causes and prevention of EMF-related diseases, and consultation with all stakeholders on issues relating to involuntary exposures (bystander or second-hand radiation exposures from wireless technologies) (Table 1).

Table 1
Public health implications of wireless technologies argue for change in governmental and health agency actions.

Secure US and EU legislative mandates for safer technologies for communication and data transmission, for security and surveillance needs.
Promote wired alternatives for voice and data communication (cable, fiber-optic)
Discourage or ban use of cell phones by children and young teen-agers
Provide permanent (unremovable) labels on cell phones "Not for use by children under the age of 16"
Implement national public education campaigns on health issues (cell phones, cordless phones, PDAs, wireless internet, city-wide WI-FI, WLAN and WiMAX exposures
Promote industry redesign for safer products: support innovation for alternatives and solutions
Slow or stop deployment of wireless technologies to discourage reliance on wireless technologies for communication and security needs
Put the burden of proof on industry to show "new wireless tech" is safe before deployment
Adopt and enforce restricted use areas for sensitive or more vulnerable segments of society including low-EMF environments in public areas and "No Cell" zones in airports, hospitals, schools
Acknowledge FCC and ICNIRP thermal safety standards are obsolete for wireless technologies
Appoint new standard-setting bodies familiar with biological effects to develop new guidelines for public safety limits.
Develop new biologically based standards that address low-intensity, chronic exposures
Require standard of evidence and level of proof = public health
Reject "causal" standard of evidence for taking action on science
Make industry financially liable for "guessing wrong" and ignoring health risks

The scientific information contained in this Supplement argues for thresholds or guidelines that are substantially below current FCC and ICNIRP standards for localized exposures to wireless devices and for whole-body exposure. Uncertainty about how low such standards might have to go to be prudent from a public health standpoint should not prevent reasonable efforts to respond to the information at hand. No lower limit for bioeffects and adverse health effects from RF has been established, so the possible health risks of wireless WLAN and WI-FI systems, for example, will require further research. No assertion of safety at any level of wireless exposure (chronic exposure) can be made at this time. The lower limit for reported human health effects has dropped 100-fold below the safety standard (for mobile phones and PDAs); 1000–10,000-fold for other wireless (cell towers at distance; WI-FI and WLAN devices). The entire basis for safety standards is called into question, and it is not unreasonable to question the safety of RF at any level.

It is likely that for both ELF and RF, as for other carcinogens, there is no threshold of exposure that is without risk, but the magnitude of the risk increases linearly with the level of exposure. Our society will not go back to the pre-electric and pre-wireless age, but the clear evidence of health hazards to the human population from exposure mandates that we develop ways in which to reduce exposure through education, new technologies and the establishment of biomedically based standards.

7. Conclusions and recommended actions

New ELF limits are warranted based on a public health analysis of the overall existing scientific evidence. These limits should reflect environmental levels of ELF that have been demonstrated to increase risk for childhood leukemia, and possibly other cancers and neurological diseases. ELF limits should be set below those exposure levels that have been linked in childhood leukemia studies to increased risk of disease, plus an additional safety factor. It is no longer acceptable to build new power lines and electrical facilities that place people in ELF environments that have been determined to be risky. These levels are in the 2–4 milligauss (mG) range (0.2–0.4 μT), not in the 10 s of mG or 100 s of mG. The existing ICNIRP limit is 1000 mG (100 μT) and 904 mG (90.4 μT) in the US for ELF is outdated and based on faulty assumptions. These limits are can no longer be said to be protective of public health and they should be replaced. A safety buffer or safety factor should also be applied to a new, biologically based ELF limit, and the conventional approach is to add a safety factor lower than the risk level.

While new ELF limits are being developed and implemented, a reasonable approach would be a 1 mG (0.1 μT) planning limit for habitable space adjacent to all new or upgraded power lines and a 2 mG (0.2 μT) limit for all other new construction. It is also recommended that a 1 mG (0.1 μT) limit be established for existing habitable space for children and/or women who are pregnant (because of the possible link between childhood leukemia and *in utero* exposure to ELF). This recommendation is based on the assumption that a higher burden of protection is required for children who cannot protect themselves, and who are at risk for childhood leukemia at rates that are traditionally high enough to trigger regulatory action. This situation in particular warrants extending the 1 mG (0.1 μT) limit to existing occupied space. "Establish" in this case probably means formal public advisories from relevant health agencies. While it is not realistic to reconstruct all existing electrical distribution systems, in the short-term; steps to reduce exposure from these existing systems need to be initiated, especially in places where children spend time, and should be encouraged. These limits should reflect the exposures that are commonly associated with increased risk of childhood leukemia (in the 2–5 mG (0.2–0.5 μT) range for all children, and over 1.4 mG (0.14 μT) for children age 6 and younger). Nearly all of the occupational studies for adult cancers and neurological diseases report their highest exposure category is 4 mG (0.4 μT) and above, so that new ELF limits should target the exposure ranges of interest, and not necessarily higher ranges.

Avoiding chronic ELF exposure in schools, homes and the workplace above levels associated with increased risk of disease will also avoid most of the possible bioactive parameters of ELF discussed in the relevant literature.

It is not prudent public health policy to wait any longer to adopt new public safety limits for ELF. These limits should reflect the exposures that are commonly associated with increased risk of childhood leukemia (in the 2–5 mG (0.2–0.5 μT) range for all children, and over 1.4 mG (0.14 μT) for children age 6 and younger). Avoiding chronic ELF exposure in schools, homes and the workplace above levels associated with increased risk of disease will also avoid most of the possible bioactive parameters of ELF discussed in the relevant literature.

The rapid deployment of new wireless technologies that chronically expose people to pulsed RF at levels reported to cause bioeffects, which in turn, could reasonably be presumed to lead to serious health impacts, is a public health concern. There is suggestive to strongly suggestive evidence that RF exposures may cause changes in cell membrane function, cell communication, metabolism, activation of proto-oncogenes and can trigger the production of stress proteins at exposure levels below current regulatory limits. Resulting effects can include DNA breaks and chromosome aberrations, cell death including death of brain neurons, increased free-radical production, activation of the endogenous opioid system, cell stress and premature aging, changes in brain function including memory loss, retarded learning, performance impairment in children, headaches and fatigue, sleep disorders, neurodegenerative conditions, reduction in melatonin secretion and cancers (BioInitiative Report Chapters 5–10, 12) [1].

This information now argues for thresholds or guidelines that are substantially below current FCC and ICNIPR standards for whole-body exposure. Uncertainty about how low such standards might have to go to be prudent from a public health standpoint should not prevent reasonable efforts to respond to the information at hand. No lower limit for bioeffects and adverse health effects from RF has been established, so the possible health risks of wireless WLAN and WI-FI systems, for example, will require further research and no assertion of safety at any level of wireless exposure (chronic exposure) can be made at this time. The lower limit for reported human health effects has dropped 100-fold below the safety standard (for mobile phones and PDAs); 1000–10,000-fold for other wireless (cell towers at distance; WI-FI and WLAN devices). The entire basis for safety standards is called into question, and it is not unreasonable to question the safety of RF at any level.

A cautionary target level for pulsed RF exposures for ambient wireless that could be applied to RF sources from cell tower antennas, WI-FI, WI-MAX and other similar sources is proposed. The recommended cautionary target level is 0.1 microwatts per centimeter squared ($\mu W/cm^2$) (or 0.614 V per meter or V/m) for pulsed RF where these exposures affect the general public; this advisory is proportionate to the evidence and in accord with prudent public health policy. A precautionary limit of 0.1 $\mu W/cm^2$ should be adopted for outdoor, cumulative RF exposure. This reflects the current RF science and prudent public health response that would reasonably be set for pulsed RF (ambient) exposures where people live, work and go to school. This level of RF is experienced as whole-body exposure, and can be a chronic exposure where there is wireless coverage present for voice and data transmission for cell phones, pagers and PDAs and other sources of radiofrequency radiation. An outdoor precautionary limit of 0.1 $\mu W/cm^2$ would mean an even lower exposure level inside buildings, perhaps as low as 0.01 $\mu W/cm^2$. Some studies and many anecdotal reports on ill health have been reported at lower levels than this; however, for the present time, it could prevent some of the most disproportionate burdens placed on the public nearest to such installations. Although this RF target level does not preclude further rollout of WI-FI technologies, we also recommend that wired alternatives to WI-FI be implemented, particularly in schools and libraries so that children are not subjected to elevated RF levels until more is understood about possible health impacts. This recommendation should be seen as an interim precautionary limit that is intended to guide preventative actions; and more conservative limits may be needed in the future.

Broadcast facilities that chronically expose nearby residents to elevated RF levels from AM, FM and television antenna transmission are also of public health concern given the potential for very high RF exposures near these facilities (antenna farms). RF levels can be in the 10 s to several 100 s of $\mu W/cm^2$ in residential areas within half a mile of some broadcast sites (for example, Lookout Mountain, Colorado and Awbrey Butte, Bend, Oregon). Like wireless communication facilities, RF emissions from broadcast facilities that are located in, or expose residential populations and schools to elevated levels of RF will very likely need to be re-evaluated for safety.

For emissions from wireless devices (cell phones, personal digital assistant or PDA devices, etc.) there is enough evidence for increased risk of brain tumors and acoustic neuromas now to warrant intervention with respect to their use. Redesign of cell phones and PDAs could prevent direct head and eye exposure, for example, by designing new units so that they work only with a wired headset or on speakerphone mode.

These effects can reasonably be presumed to result in adverse health effects and disease with chronic and uncontrolled exposures, and children may be particularly vulnerable. The young are also largely unable to remove themselves from such environments. Second-hand radiation, like second-hand smoke is an issue of public health concern based on the evidence at hand.

In summary, the following recommendations are made:

- ELF limits should be set below those exposure levels that have been linked in childhood leukemia studies to increased risk of disease, plus an additional safety factor. It is no longer acceptable to build new power lines and electrical facilities that place people in ELF environments that have been determined to be risky (at levels generally at 2 mG (0.2 μT) and above).
- While new ELF limits are being developed and implemented, a reasonable approach would be a 1 mG (0.1 μT) planning limit for habitable space adjacent to all new or upgraded power lines and a 2 mG (0.2 μT) limit for all other new construction, It is also recommended for that a 1 mG (0.1 μT) limit be established for existing habitable space for children and/or women who are pregnant. This recommendation is based on the assumption that a higher burden of protection is required for children who cannot protect themselves, and who are at risk for childhood leukemia at rates that are traditionally high enough to trigger regulatory action. This situation in particular warrants extending the 1 mG (0.1 μT) limit to existing occupied space. “Establish” in this case probably means formal public advisories from relevant health agencies.
- While it is not realistic to reconstruct all existing electrical distributions systems, in the short-term; steps to reduce exposure from these existing systems need to be initiated and should be encouraged, especially in places where children spend time.
- A precautionary limit of 0.1 $\mu W/cm^2$ (which is also 0.614 V per meter) should be adopted for outdoor, cumulative RF exposure. This reflects the current RF science and prudent public health response that would reasonably be set for pulsed RF (ambient) exposures where people live, work and go to school. This level of RF is experienced as whole-body exposure, and can be a chronic exposure where there is wireless coverage present for voice and data transmission for cell phones, pagers and PDAs and other sources of radiofrequency radiation. Some studies and many anecdotal reports on ill health have been reported at lower levels than this; however, for the present time, it could prevent some of the most disproportionate burdens placed on the public nearest to such installations. Although this RF target level does not preclude further rollout of WI-FI technologies, we also recommend that wired alternatives to WI-FI be implemented, particularly in schools and libraries so that children are not subjected to elevated RF levels until more is understood about possible health impacts. This recommendation should be seen as an interim precautionary limit that is intended to guide preventative actions; and more conservative limits may be needed in the future.

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Please cite this article in press as: C. Sage, D.O. Carpenter, Public health implications of wireless technologies, Pathophysiology (2009), doi:10.1016/j.pathophys.2009.01.011

Science of the Total Environment 767 (2021) 144913

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

Electromagnetic radiation as an emerging driver factor for the decline of insects

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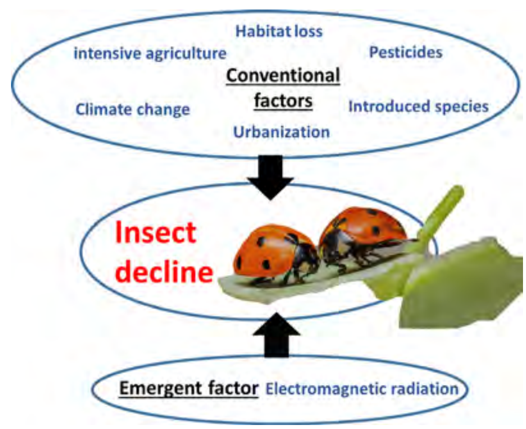
HIGHLIGHTS

- Biodiversity of insects is threatened worldwide.
- These reductions are mainly attributed to agricultural practice and pesticide use.
- There is sufficient evidence on the damage caused by electromagnetic radiation.
- Electromagnetic radiation may be a complementary driver in this decline.
- The precautionary principle should be applied before any new deployment (e.g. 5G).

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 7 October 2020
Received in revised form 10 December 2020
Accepted 29 December 2020
Available online 28 January 2021

Editor: Pavlos Kassomenos

Keywords:
Biological diversity
Cascading effects
Conservation
Pollinators
Precautionary principle

ABSTRACT

The biodiversity of insects is threatened worldwide. Numerous studies have reported the serious decline in insects that has occurred in recent decades. The same is happening with the important group of pollinators, with an essential utility for pollination of crops. Loss of insect diversity and abundance is expected to provoke cascading effects on food webs and ecosystem services. Many authors point out that reductions in insect abundance must be attributed mainly to agricultural practices and pesticide use. On the other hand, evidence for the effects of non-thermal microwave radiation on insects has been known for at least 50 years. The review carried out in this study shows that electromagnetic radiation should be considered seriously as a complementary driver for the dramatic decline in insects, acting in synergy with agricultural intensification, pesticides, invasive species and climate change. The extent that anthropogenic electromagnetic radiation represents a significant threat to insect pollinators is unresolved and plausible. For these reasons, and taking into account the benefits they provide to nature and humankind, the precautionary principle should be applied before any new deployment (such 5G) is considered.

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https://doi.org/10.1016/j.scitotenv.2020.144913
0048-9697/

1. Insects and their importance in ecosystem services

There are numerous studies that show the fundamental importance of insects as key species in ecosystems (see for example: Noriega et al., 2018). Some of the most important ecosystem services they provide are climate regulation, crop pollination, pest control, decomposition and seed dispersal (Kremen and Chaplin-Kramer, 2007; Schowalter, 2013). Insects are at the structural and functional base of many of the world's ecosystems (Sánchez-Bayo and Wyckhuys, 2019), and numerous birds, lizards, frogs and bats feeds on insects (Nocera et al., 2012). The group of insect pollinators plays an important role in crop pollination, and insects provide an important contribution to crops as well as to wild plants (Powney et al., 2019).

2. The current decline of insects and causative drivers of this decline

Numerous studies have reported the serious decline in insects that has occurred in recent decades (Vogel, 2017). A study carried out in protected nature areas throughout Germany found a 76–82% decline in total flying insects between 1989 and 2016. The authors consider that agricultural intensification, with increased use of pesticide and fertilisers, may have aggravated the reduction in insect abundance over the last decades, whereas landscape modifications and climate change are unlikely explanatory factors (Hallmann et al., 2017).

A study of insects crashing into car windscreens in rural Denmark, based on data collected between 1997 and 2017, concluded that the number of insects had decreased by 80% in those 20 years, and the authors point out that reductions in insect abundance must mainly be attributed to agricultural practices and pesticide use (Møller, 2019). In a survey conducted in Kent (UK) in 2019, which examined the presence of crushed insects in the front grille above the licence plates of cars, a 50% reduction compared to 2004 was reported (Tinsley-Marshall et al., 2019).

Some authors also point out climate change as a cause of insect decline (Baranov et al., 2020). In a tropical rainforest in Puerto Rico, one study found a 30- to 60-fold decline (a 97–98% decline) in total insects captured in sticky traps between 1976 and 2012. This decline may be attributed to climate change, since between 1976 and 2012, mean maximum temperatures have risen by 2.0 °C, and tropical arthropods are particularly vulnerable to climate warming (Lister and Garcia, 2018). However, in colder climes and the mountains of temperate zones, this factor affects only a minority of species (Sánchez-Bayo and Wyckhuys, 2019).

After reviewing 73 historical reports of insect declines from across the globe, a recent study revealed that the biodiversity of insects is threatened worldwide (Sánchez-Bayo and Wyckhuys, 2019). The rates of decline may lead to the extinction of 40% of the world's insect species, both specialists and generalists. Based on the results of this review, the most affected groups in terrestrial ecosystems are *Lepidoptera*, *Hymenoptera* and *Coleoptera*, whereas in terms of aquatic taxa, *Odonata*, *Plecoptera*, *Trichoptera* and *Ephemeroptera* are most affected. The authors conclude that the main plausible drivers are, in order of importance: i) habitat loss and conversion to intensive agriculture and urbanisation; ii) pollution, mainly by synthetic pesticides and fertilisers; iii) pathogens and introduced species; iv) climate change (Sánchez-Bayo and Wyckhuys, 2019).

This same is happening with the important group of pollinators. A study has found evidence of declines across a large proportion of pollinator species in Britain between 1980 and 2013 (Powney et al., 2019). Another study strongly suggests a causal connection between local extinctions of functionally linked plant and pollinator species (Biesmeijer et al., 2006). Further, pollinator populations may collapse suddenly once drivers of pollinator decline reach a critical point (Lever et al., 2014). Key threats to pollinators include agricultural intensification (particularly habitat loss and pesticide use), climate change and the spread of alien species (Powney et al., 2019). The decline of pollinators may have important ecological and economic impacts that could significantly affect the maintenance of wild plant diversity, crop production and human welfare (Lázaro et al., 2016).

Loss of insect diversity and abundance is expected to provoke cascading effects on food webs and ecosystem services (Hallmann et al., 2017; Møller, 2019). For example, associated with the decline of insects, parallel decreases in insectivorous lizards, frogs and birds have been documented (Lister and Garcia, 2018). Pesticides have dramatically altered insect community structures and decimated populations, triggering nutritional consequences for aerially foraging insectivorous birds and bats (Nebel et al., 2010; Nocera et al., 2012). Agriculture is the largest contributor to insect and biodiversity loss, destroying biodiversity by converting natural habitats into intensely managed systems and by releasing pollutants, fertilisers and pesticides (Dudley and Alexander, 2017).

3. Scientific evidence for electromagnetic radiation as a factor contributing to insect decline

Insects are especially sensitive to electromagnetic radiation. An increasing number of reports indicate that flies and spiders, among other invertebrates, disappear from areas that receive the highest levels of radiation from mobile telephone antennas, and these observations are consistent with numerous laboratory studies showing the negative effects of electromagnetic radiation (EMR) on reproductive success, development and navigation (Balmori, 2009; Lázaro et al., 2016).

Evidence for the effects of non-thermal microwave radiation on insects has been known for at least 50 years, e.g., the abnormal development of irradiated coleopteran pupae (Carpenter and Livstone, 1971). Radio frequency (RF) signals produced by mobile phones increased the numbers of offspring, elevated hsp70 levels by non-thermal stress and caused other effects on reproduction and development of the fruit fly *Drosophila melanogaster* (Weisbrot et al., 2003). Another study showed that the reproductive capacity of fruit flies decreased by 50–60% after exposure to the RF signal of a mobile phone during the first 2–5 days of adult life (Panagopoulos et al., 2004). The same authors compared the biological activities of the two systems, GSM (900 MHz) and DCS (1800 MHz), and concluded that both types of radiation significantly decrease the reproductive capacity of fruit flies (Panagopoulos et al., 2007). This non-thermal effect diminished with distance (decreasing intensity) and is provoked by induction of cell death (Panagopoulos et al., 2010).

Other authors have also worked with this species and have observed a statistically significant decrease in mean fecundity (Atli and Ünlü, 2006). Further, the mean pupation time was delayed linearly with an increasing period of exposure to an electromagnetic field (EMF), and the mean offspring number was significantly lower than that of the control (Atli and Ünlü, 2007). Pupae from another dipteran, the house fly *Musca domestica*, were exposed to an EMF (50 Hz), and the results showed that the field significantly slowed down metamorphosis (Stanojević et al., 2005).

Insects may be equipped with the same magnetoreception system as birds, and there is evidence that the geomagnetic field reception in the American cockroach is sensitive to a weak RF field (Vácha et al., 2009). Several laboratory studies have been carried out with ants, demonstrating the important effects of artificial EMFs on their orientation by geomagnetic fields (Camlitepe et al., 2005). Other authors demonstrate how changes of low intensity in the normal local magnetic field values affect the behaviour of workers of three magnetosensitive ant species, inducing significant changes in their foraging activities (Pereira et al., 2019). Belgian researchers experimentally demonstrated the effect of 900-MHz electromagnetic waves on ant olfactory and visual learning, revealing an impact on their physiology (Cammaerts et al., 2012). The ants' speed of movement was immediately altered by the presence of electromagnetic waves (Cammaerts and Johansson, 2014). These authors state that electromagnetic radiation affects the behaviour and physiology of social insects, and such results provide convincing evidence of a negative impact of electromagnetic waves on insects, at least on those whose life depends on communication and memory (Cammaerts et al., 2012). Wireless technology has negative impacts on living organisms; ants react quickly to the existence of electromagnetic waves in their environment, and bees may behave abnormally when exposed to EMFs generated by GSM masts (Cammaerts et al., 2013).

To replace chemical insecticides for controlling pests of various species of plants and seeds, in several different studies, radiofrequency exposure was applied to *Callosobruchus chinensis* (Coleoptera), *Maruca vitrata* (Lepidoptera), *Nysius plebeius* and *Nysius hidakai* (Hemiptera). The EMF affected the developmental period, adult longevity, adult weight and the fecundity of subsequent generations in all these species of insects from different orders in the same way (Maharjan et al., 2019a, 2019b, 2020).

Studies have also been conducted on other invertebrates. A study performed in an RF electromagnetic field (RF-EMF) anechoic chamber, irradiating ticks (*Dermacentor reticulatus*) with a 900-MHz RF-EMF at levels below the proposed limit for public exposure to mobile phone base stations, found that exposure induces an immediate tick locomotor response manifested as a jerking movement, and ticks exhibited overall significantly greater movement in the presence of this electromagnetic radiation (Vargová et al., 2017).

In some studies conducted in natural habitats with real phone masts, electromagnetic radiation (EMR) emitted by telecommunication antennas affected the abundance and composition of several guilds of wild pollinator insects (Lázaro et al., 2016). Another study, also carried out in the field, examined the impact of exposure to the fields from mobile phone base stations (GSM 900 MHz) for a 48-h period on the reproductive capacity of four different invertebrate species. Although a significant impact on reproductive capacity was not found, probably because the exposure time was too short, the authors warned that more attention should be paid to the possible impacts of EMF radiation on biodiversity because the exposure to an RF-EMF is ubiquitous and is still increasing rapidly over large areas (Vijver et al., 2014).

As a result of most of the studies carried out, EMF radiation can be a problem for insects and for their orientation (Balmori, 2006, 2009, 2014 and 2015), and both laboratory and field studies on different invertebrate species have shown this.

4. Bee studies on electromagnetic radiation

Bees are highly sensitive to magnetic fields, especially for orientation and navigation, and for this reason, most of such studies have been carried out on bees. Adult honeybees possess a magnetoreception sense, and significant differences in their return rates have indicated that interactions exist between forager losses and exposure to magnetic fields, as well as during fluctuations in the Earth's magnetosphere (Ferrari, 2014).

The first study on the effects of EMFs on bees were carried out under power lines. Honeybee colonies exposed to a 765-kV, 60-Hz transmission line at 7 kV/m showed increased motor activity, abnormal propolisation, impaired hive weight gain, queen loss, abnormal production of queen cells, decreased sealed brood and poor winter survival. When the colonies were exposed to different electric fields with increasing distance from the line, different thresholds for biological effects were obtained (Greenberg et al., 1981). Another more recent study has shown that the extremely low-frequency EMF (50 Hz) emitted from powerlines affects honeybee olfactory learning, flight, foraging activity and feeding and may represent a prominent environmental stressor for honeybees, potentially reducing their ability to pollinate crops (Shepherd et al., 2018). In Italy, deleterious results of both pesticides and EMFs from a 132-kV (50-Hz) high-voltage power line have been found. In the electromagnetic-stress site, the effect of a behavioural over-activation of all analysed biomarkers was observed at the end of the season, and this finding poses potential problems for the winter survival of bees (Lupi et al., 2020).

Lopatina et al. (2019) studied the effect of non-ionising EMR from a Wi-Fi router on sensory olfactory excitability, food motivation and memory in honeybees and observed that a 24-hour exposure to Wi-Fi EMR had a significant inhibitory effect on food excitability and short-term memory. In natural conditions, worker piping announces either the swarming process of the bee colony or is a signal of disturbance, and active mobile phone handsets have a dramatic impact on the behaviour of the bees by inducing the worker piping signal (Favre, 2011). In another study, with GSM (900-MHz) cell phones, a significant decline in colony strength and egg-laying rate by the queen was observed. The behaviour of exposed foragers was negatively influenced by such exposure: there was neither honey nor pollen in the colony at the end of the experiment (Sharma and Kumar, 2010). In another study, queens exposed to telephone radiation in the test colonies produced fewer eggs/day compared to the control (Sainudeen Sahib, 2011). A more recent study provided solid evidence that mobile phone radiation significantly reduces hatching and may alter pupal development (Odemer and Odemer, 2019).

In a study carried out in Germany, with bees exposed to DECT radiation, only a few bees returned to the beehive, and they needed more time; also, honeycomb weight was lower in irradiated beehives (Stever et al., 2005; Harst et al., 2006). The concentrations of carbohydrates, proteins and lipids in the haemolymph increased under the influence of cell phone radiation (Kumar et al., 2013). Another study observed an increase in mortality in two conditions: after exposure to HF (13.56 MHz) and to UHF (868 MHz) (Darney et al., 2016).

Regarding the colony collapse disorder (CCD) observed in honeybee colonies around the world, several authors consider that EMR exposure provides a better explanation than other theories (Sainudeen Sahib, 2011; Cammaerts et al., 2012). Several authors warn that the massive amount of radiation produced by mobile phones and towers disturbs the navigational skills of honeybees, preventing them from returning to their hives (Warnke, 2009; Sainudeen Sahib, 2011). In fact, winter colony losses in the northeast USA correlated with the occurrence of annual geomagnetic storms, and abnormal fluctuations in magnetic fields related to the epidemiology of honeybee losses are consistent with their behaviour and development (Ferrari, 2014).

5. Action mechanisms

There are well-known mechanisms of action of low-frequency pulsed RF, such as interference with calcium channels in cells (Pall, 2013; Panagopoulos and Balmori, 2017) and deleterious effects on sperm and reproductive systems (Panagopoulos et al., 2004;

Panagopoulos, 2012; Adams et al., 2014). In vertebrates, studies have also found a pathologic leakage across the blood-brain barrier (Salford et al., 2003) and interference with brain waves (Mann and Roschkle, 1996; Beasond and Semm, 2002; Kramarenko and Tan, 2003). Microwave radiation has particular effects on nervous, immune and reproductive systems (Balmori, 2009).

In recent years, there has been an important advance in understanding the underlying mechanisms for orientation in birds, insects and other groups. It has also been verified that RF-EMFs alter the biological response characteristics of cryptochrome receptors. These results are consistent with the radical-pair mechanism of magnetosensing. Since cryptochromes are molecules highly sensitive to RF radiation and are found in many organisms, including humans, these results also may have more general implications for the capacity of living organisms to respond to man-made electromagnetic noise by analogy with broadband RF, which has previously been shown to disrupt the orientation of birds (Engels et al., 2014). These possible risks have already been indicated by Balmori (2015).

A recent study has warned that future, more short wavelengths of electromagnetic fields used for the wireless telecommunication systems (5G), will become comparable to the body size of insects, and therefore, the absorption of RF-EMF in this group is expected to increase (Thielens et al., 2018).

6. The precautionary principle and the importance of seriously considering EMR as a factor of insect decline

Despite the strong scientific evidence of the negative impacts of electromagnetic radiation on insects, a recent study funded by the European Union's Horizon 2020 Research and Innovation Programme (EKLIPSE) stated that our current knowledge concerning the impact of anthropogenic RF-EMR on pollinators (and other invertebrates) is inconclusive (Vanbergen et al., 2019). Thus, the extent to which anthropogenic EMR represents a significant threat to insect pollinators is unresolved. For these reasons, and taking into account the benefits they provide to nature and humankind, the precautionary principle of the European Union (Communication from the Commission on the Precautionary Principle, 2000) should be applied.

The potential effects of RF-EMFs on most taxonomic groups, including migratory birds, bats and insects, are largely unknown, and the potential effects on wildlife could become more relevant with the expected adoption of new mobile network technology (5G), raising the possibility of unintended biological consequences (Sutherland et al., 2018). Thus, before any new deployment (such 5G) is considered, its effects should be clearly assessed, at least while conclusions are drawn and these existing uncertainties are overcome, according to the official document 'Late Lessons of Early Warnings' (European Environment Agency, 2013).

A letter by the United States Department of the Interior sent to the National Telecommunications and Information Administration in the Department of Commerce warns about the scarcity of studies carried out on the impacts from non-ionising EMR emitted by communication towers (United States Department of the Interior, 2014). The precise potential effects of increases in EMR on wildlife, which are not yet well recognised by the global conservation community, have been identified as an important emerging issue for global conservation and biological diversity (Sutherland et al., 2018). Thus, as we have explained in this review, EMR should be seriously considered as a complementary driver for the dramatic decline in insects in recent studies, acting in synergy with agricultural intensification, pesticides, invasive species and climate change.

Funding

This work has not had any funding support.

Declaration of competing interest

The author declare that have no conflict of interest.

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Electromagnetic Radiation

And Honey Bee Health - Part 1

The potential for harmful impacts from electromagnetic radiation to bees first came into the general public's consciousness shortly after the emergence of Colony Collapse Disorder (CCD). It was the result of reports of a study in which cordless telephone base stations that emitted 1900-MHz electromagnetic field (EMF) radiation were set in hives and found to decrease comb building and increase the duration of foraging trips. (Kimmel et. al. 2007) The study was poorly designed, had a small sample size, and there was the small issue that beekeepers do not typically place mobile phone base stations used by cordless landline phones in their hives. As a result the idea of electromagnetic radiation harming bees was quickly discredited and became the subject of jokes and ridicule. I certainly wrote it off as inconsequential. This was an unfortunate situation because I have since found that when you look at the studies on the subject with an independent mind, there just happens to be enough peer reviewed research to suggest that there may in fact be cause for concern. The collective evidence drawn from scientific studies of the adverse health and biological impacts of artificial electrical field exposure from sources such as cell phone towers, cell phones, smart meters, power lines and WiFi routers may be jeopardizing the health of our bees and more.

What is EMF and EMR?

An electromagnetic field (EMF) is produced when electric and magnetic charges radiate energy (aka radiation). Electromagnetic radiation (EMR) is a kind of energy that includes radio waves and visible light. Even solar wind generated from the sun creates an electromagnetic field as it hits the earth which means that all life on earth is in the presence of electromagnetic fields. EMF radiation in wireless communication only works because the transmission is more powerful than the natural background radiation. These man-made sources of electromagnetic radiation greatly increase normal background exposure. Common sense suggests that biologically based scientifically sound public exposure standards be developed to protect the health and well-being of people, bees and other wildlife. Unfortunately, such standards do not exist for pollinators and wildlife, and studies suggest that even the human standards that exist are outdated and inadequate.

Electromagnetic radiation is measured in hertz (Hz) which represents the cycles per second of the wavelength. One hertz represents a single time that a analog sound wave or digital pulse repeats each second (e.g. one cycle per second). Kilohertz (kHz) measures thousands of cycles per second, Megahertz (MHz) refers to millions and Gigahertz billions of cycles per second. It is well established that EMR has the ability to seriously impact living organisms and that EMR of 900 MHz is highly bioactive causing significant changes in the physiological function of living organisms. (Aday 1975)

Radiofrequency electromagnetic fields (RF-EMF) are emitted from the wireless communication devices we use daily: radios and televisions, satellite communication systems, WiFi systems and wireless mobile phones and cell phones. RF-EMFs emit non-ionizing radiation. This differs from ionizing radiation of nuclear power plants in that while non-ionizing radiation has enough energy to excite the electrons in molecules and atoms (moving the electrons to a higher energy state) they do not knock electrons out of their orbits around atoms like ionizing radiation does.

The agency responsible for regulating the wireless communications industry is the Federal Communications Commission (FCC). Unfortunately, FCC radiofrequency (RF) safety guidelines have not been updated since their implementation in 1996. This is significant since these fields are about to get significantly stronger with the current roll-out of the fifth generation technology standard (aka 5G) for broadband cellular networks. Today no-one, including the Federal Communications Commission (FCC) knows whether 5G is safe or not. Even wireless carriers have to admit that they are not aware of any independent studies on 5G safety. When asked during Senate hearings what research has been done on the safety of 5G technology, the answer was "none". (Blumenthal 2019)

Meanwhile, the public is consistently told that there is no need for anything to worry about concerning the rollout of this new technology that the FCC is pushing and if current plans come to fruition has the potential to result in over 800,000 new antenna installations throughout the U.S. providing fast 5G internet service to many Americans by the end of the decade.

Effects on insects

There is a growing body of evidence of harm from wireless non-ionizing radiation such as from cell phones, cell towers, WiFi, and smart meters can harm insects. A 2013 review of 113 studies that found that 70 percent of papers analyzed reported a significant impact of RF-EMF on birds and insects. This suggests an urgent need for more research and repetitions of studies given the fast pace of cellular telephone technological progress. (Cucurachi et. al. 2013)

Lab studies on insects show negative effects of EMR on reproductive success, development, and naviga-

tion abilities. However, the impact of widespread mobile telecommunication antennas on wild pollinator communities in field-realistic conditions is still largely unknown. In one trial, beetle, wasp and hoverfly abundance **decreased** with EMR, while the abundance of underground-nesting bees and bee flies **increased** with EMR. This cries out for additional research to understand the ecological impacts of EMR on wild pollinators and the subsequent effects on plant diversity, crop production, as well as human welfare. (Lázaro et. al. 2016)

In 2012 Sivani and Sudarsanam published a paper that states: "Based on current available literature, it is justified to conclude that RF-EMF radiation exposure can change neurotransmitter functions, blood-brain barrier, morphology, electrophysiology, cellular metabolism, calcium efflux, and gene and protein expression in certain types of cells even at lower intensities. The biological consequences of such changes remain unclear." The authors further noted that short-term studies on frogs, honey bees, birds, bats and even humans are scarce and long-term studies are non-existent.

A review of the literature published just this past year came to the conclusion that there is sufficient evidence to support claims of damage caused by electromagnetic radiation. The study's author goes on to state that "...electromagnetic radiation should be considered seriously as a complementary driver for the dramatic decline in insects, acting in synergy with agricultural intensification, pesticides, invasive species and climate change. The extent that anthropogenic electromagnetic radiation represents a significant threat to insect pollinators is unresolved and plausible." (Balmori 2021)

Honey bees and wild pollinators like this sweat bee pictured, are among the many insects that can be negatively affected by man-made sources of electromagnetic radiation.

Up until recently, the range of frequencies used for wireless communication has not risen above 6 GHz (2G, 3G, 4G, and WiFi). The impending deployment of the new and highly anticipated 5G technology utilizes a signal of 120 GHz. Research on insects showed that as the power density of frequencies above 6 GHz increased, the power absorbed by the invertebrates studied increased from three to 370 percent (Thielens et. al. 2018) making the importance of being able to understand the potential threat to pollinators from electromagnetic radiation all the more urgent.

Cell phones and the towers use to transmit their signals are just one of many sources of man-made electromagnetic radiation.

Worker Bee Exposure

While lots of research documents the impacts of EMF on insects generally, some studies have looked at the impacts of electromagnetic radiation on honey bees and the majority of the papers have found potential cause for concern when honey bees are exposed to EMFs. Such exposure has been shown to cause significant cognitive impairment and behavioral changes. These include reduced locomotion activity, impaired homing and orientation abilities, fewer foraging flights and short-term memory loss. (Harst et. al. 2006; Warnke 2007; Kimmel et. al. 2007; Sharma and Kurmar 2010; Shepherd et. al. 2018; Lopatina et. al. 2019; Shepherd et. al. 2019) Many of these studies, and others, document increased aggression when bees are exposed to EMR. (Mixson et. al. 2009; Halabi et. al. 2014).

Meanwhile, in 2017 researchers found that DNA damage in honey bee larvae increased significantly when exposed to modulating EMR fields. Exposure levels during the trial were much higher than what honey bees in nature could reasonably be expected to encounter but the results suggest the need for further intensive research on all stages of honey bee development. (Vilić et. al. 2017)

Cell Phone Towers

Cell phone towers have been a focus of additional research, but unfortunately the few studies that have looked at the effect from cell phone towers suffer from small sample sizes.

Some studies have concluded that the effect of cell tower electromagnetic radiation on colonies placed directly under cell-phone towers is insignificant. (Mall and Kumar 2014, Patel and Mall 2019) However, these researchers placed colonies under the transmission antennae at the base of the tower where the radiation broadcast angle approaches zero degrees resulting in little-to-no radiation exposure.

One of the more realistic studies that looked at the impact of electromagnetic radiation (EMR) on hives exposed to cell phone tower emissions was done on the Eastern honey bee *Apis cerana*. (Taye 2017) Foraging behavior was observed in colonies placed at distances of 100 meters, 200m, 300m, 500m, and 1000m from a cell phone tower. Researchers documented significantly reduced colony foraging activity in the hives closest to the radiation source. Clearly more research is needed on impacts of cell towers before firm conclusions can be drawn on exactly how and under what circumstances cell phone towers may be harmful to bees and other pollinators.

Next month in part two of this article, we will look at the effects of RF-EMR on queens and share some ideas on what we as beekeepers might do to help reduce exposure to our bees and ourselves.

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Part 1, Supplement 1
Environmental EMF measurements from around the world

Locations of measurements	**Type of RFR**	**Level (μW/cm²)**	**Reference**
Australia	870-1200 MHz	0.8	Henderson and Bangay (2006)
Australia and Belgium	In various public places	Australia : 0.15-4.97 (0.75-4.33 V/m) ; Belgium : 0.2-1.008 (0.90-1.95 V/m)	Bhatt et al. (2016)
Australia (Melbourne kindergartens)	88 MHz – 5.8 GHz	0.0017 (total all bands) (0.179 V/m)	Bhatt et al. (2017)
Belgium	FM, GSM900, GSM1800 and UMTS	0.07	Joseph et al. (2008)
Belgium, Switzerland, Slovania, Hungary, the Netherlands	Several fréquency bands	outdoor urban fields: 0.021-0.057	Joseph et al. (2010)
Brazil	Cell tower	0.04 - 40.78 (0.4-12.4 V/m)	Dode et al. (2011)
Denmark, the Netherlands, Slovenia, Switzerland, and Spain (children)	16 frequency bands including DECT, radio and TV, mobile phone,mobile phone base stations, and WiFi,	Median total field 0.00755 Outdoor : 0.0157-0.0171 Home/in school: 0.0033-0.00351	Birks et al. (2018)
France	12 bands: FM to mobile phone	0.6	Viel et al. (2009)
Germany (Cities of Bamberg and Hallstadt)	Mobile phone base station	0.001-1.69	Waldmann-Salsam et al. (2016)

Ghana	900-1800 MHz	0.001	Amoako et al. (2009)
Ghana	GSM 900, 1800 and UMTS 2100 (61.1-25.7 m from a basestation)	0.00717-0.0895	Deatanyah et al (2018)
Greece	62 primary and secondary schools in Athens (2- MHz – 3 GHz)	Average 0.049 (0.4292 v/m)	Aris et al. (2020)
Hungary	9 bands between 80-2200 MHz	0.025	Thuroczy et al. (2006)
India	10 MHz-8 GHz	1.148	Dhami (2012)
Korea	CDMA800 and CDMA1800	0.6	Kim et al. (2010)
Southern Spain	100 KHz – 6 GHz	0.0286	Calvente et al.(2015)
Sweden	30 MHz- 3 GHz	rural area 0.0016; urban area 0.027; city area 0.24	Estenberg and Augustsson (2014)
Sweden (Stockholm Central Railway Station)	88-5850 MHz	0.092 (median) 0.2817 -0.4891(mean total)	Hardell et al. (2016)
Sweden (Stockholm Old Town)	87-5850 MHz	0.0404 – 2.43	Hardell et al. (2017)
Switzerland	12 different bands from FM (88 MHz-108 MHz) to W-LAN (2.4-2.5 GHz)	0.013 (0.0014- 0.0881)	Frei et al. (2009)
Switzerland (Basel) and the Netherlands (Amsterdam)	Base stations	downtown: 0.024-0.0745 residential areas: 0.0021- 0.0445	Urbinello et al. (2014)

Switzerland, Ethiopia, Nepal, South Africa, Australia, USA	Public RFR emitting devices	Outdoor: 0.014-0.91 Public transport vehicles: 0.027-0.49	Sagar et al. (2018)
Turkey	GSM9 00 MHz	3	Firlarer et al. (2003)
USA (cities of Spokane, WA and Raleigh, NC)	VHF-FM-UHF-mobile phone	0.11- 0.00028	Tell and Kavet (2014)
West Bank-Palestine major cities, outdoor levels	FM and TV broadcasting stations and mobile phone base stations	Average 0.37 Maximum 3.86	Lahham and Hammash (2012)
West Bank-Palestine, City of Hebron, indoor levels	FM and TV broadcasting stations, mobile phone base stations, cordless phone (DECT) and WLAN	Average 0.08 Maximum 2.3	Lahham et al. (2015)
West Bank-Palestine	WLENS (Wi-Fi), 1 meter from access points, 75 MHz – 3 GHz	0.12 (0.001-1.9)	Lahham et al. (2017)

The above table shows a large variation in levels, ranging from 0.002 to 41 μW/cm^2 (median =0.18 μW/cm^2). The variation could most likely be due to the extent of deployment of wireless systems in different areas. Since each study measured only a section of the RF-spectrum, the total levels summing emissions in all parts of the spectrum are expected to be higher. These levels also are bound to increase with time given the constant deployment of new wireless communication devices and infrastructure. Some of the above are old measurements that probably are now higher as the wireless communication systems proliferated. For other relevant studies, readers should also read the review by Sagar et al. (2017)

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Review Article

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Effects of non-ionizing electromagnetic fields on flora and fauna, Part 2 impacts: how species interact with natural and man-made EMF

https://doi.org/10.1515/reveh-2021-0050
Received April 20, 2021; accepted May 26, 2021;
published online July 8, 2021

Abstract: Ambient levels of nonionizing electromagnetic fields (EMF) have risen sharply in the last five decades to become a ubiquitous, continuous, biologically active environmental pollutant, even in rural and remote areas. Many species of flora and fauna, because of unique physiologies and habitats, are sensitive to exogenous EMF in ways that surpass human reactivity. This can lead to complex endogenous reactions that are highly variable, largely unseen, and a possible contributing factor in species extinctions, sometimes localized. Non-human magnetoreception mechanisms are explored. Numerous studies across all frequencies and taxa indicate that current low-level anthropogenic EMF can have myriad adverse and synergistic effects, including on orientation and migration, food finding, reproduction, mating, nest and den building, territorial maintenance and defense, and on vitality, longevity and survivorship itself. Effects have been observed in mammals such as bats, cervids, cetaceans, and pinnipeds among others, and on birds, insects, amphibians, reptiles, microbes and many species of flora. Cyto- and geno-toxic effects have long been observed in laboratory research on animal models that can be extrapolated to wildlife. Unusual multi-system mechanisms can come into play with non-human species — including in aquatic environments — that rely on the Earth's natural geomagnetic fields for critical life-sustaining information. Part 2 of this 3-part series includes four online supplement tables of effects seen in animals from both ELF and RFR at vanishingly low intensities. Taken as a whole, this indicates enough information to raise concerns about ambient exposures to nonionizing radiation at ecosystem levels. Wildlife loss is often unseen and undocumented until tipping points are reached. It is time to recognize ambient EMF as a novel form of pollution and develop rules at regulatory agencies that designate air as 'habitat' so EMF can be regulated like other pollutants. Long-term chronic low-level EMF exposure standards, which do not now exist, should be set accordingly for wildlife, and environmental laws should be strictly enforced — a subject explored in Part 3.

Keywords: cell phone towers/masts/base stations; Earth's geomagnetic fields; magnetoreception, radiofrequency radiation (RFR); nonionizing electromagnetic fields (EMF); plants; wildlife.

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Introduction: electromagnetic fields — natural and man-made

In Part 1 of this three-part series, rising ambient EMF levels were explored. Part 2 focuses specifically on the unique magnetoreception physiologies found in wildlife as well as the mechanisms by which they interact with the Earth's natural geomagnetic fields and man-made EMF at intensities now commonly found in the environment. Part 2 Supplements contain tables of studies showing effects at extremely low intensity exposures comparable to today's ambient levels.

Energy is a part of nature affecting every living thing in positive, negative and neutral ways. The Earth itself is a dipole magnet with a north and a south pole. All living things have evolved within the protective cradle of the Earth's natural geomagnetic fields. In fact, magnetic oscillations emanate from the Earth's molten iron core around 10 times per second (10 Hz) where relaxed but alert human thought/brainwaves occur between 8 and 14 Hz.

In addition to the Earth's natural emanations, vast Schumann Resonances (SR) that constantly circle the globe were theorized in 1952 by physicist Windfried Otto Schumann and reliably measured in the 1960s [1, 2]. SR are a global electromagnetic phenomenon caused by a complex relationship between lightening at the Earth's surface and the ionosphere. Excited by the 2,000 thunderstorms that occur globally at any given time and approximately 50 flashes of lightening every second, the space between Earth and the ionosphere 60 miles (97 km) above it form a resonant cavity and closed waveguide [3]. Schumann Resonances occur in the ELF bands between 3 and 60 Hz with distinct fundamental peaks around 7.83 Hz. Since the 1960s, scientists have discovered that variations in the resonances correspond to seasonal changes in solar activity, the Earth's magnetic environment, in atmospheric water aerosols and various other earth-bound phenomena, including increased weather activity due to climate change. There are an estimated 1.2 billion lightening flashes globally each year, 25 million in the U.S. alone [4], not all of which are of sufficient length to contribute to the resonances.

Many behavioral aspects in biology are thought to be synchronized with both the Earth's natural fields and the Schumann Resonances. Many species rely on the Earth's natural fields for daily movement, seasonal migration, reproduction, food-finding, and territorial location, as well as diurnal and nocturnal activities. Human circadian rhythms, mainly regulated by light targeting signaling pathways in the hypothalamic suprachiasmatic nucleus, are known to be finely tuned to the Earth's day/night cycles as well as natural seasonal variations, as are most species [5–8]. Artificial ELF-EMF is also known to adversely affect human circadian clocks, possibly through modulation in circadian clock gene expression itself [9].

Nonionizing electromagnetic fields (EMF; 0–300 GHz) include all the frequencies that fall between visible light below the ultraviolet range and the Earth's natural static fields. The nonionizing bands are used in virtually everything involved with communications and energy propagation so useful in modern life, including electric power production/distribution, all wireless technologies and accompanying infrastructure for cell phones, WiFi, baby/home monitoring systems, 'smart'grid/meters, all 'smart' technology/devices, 2-through-5G Internet of Things, AM/FM broadcast radio and television, shortwave and HAM radio, surveillance/security systems, satellites, radar, many military applications, and myriad medical diagnostic tools like MRI's, to name but a few (see Figure 1).

In its natural state, very little radiofrequency radiation (RFR) reaches the Earth's surface. Aside from the Earth's natural extremely low frequency (ELF) direct current (DC) magnetic fields, lightening and sunlight would primarily comprise our normal exposures to the electromagnetic spectrum. Most harmful radiation coming from outer space is blocked by the Earth's magnetosphere. But now, for the first

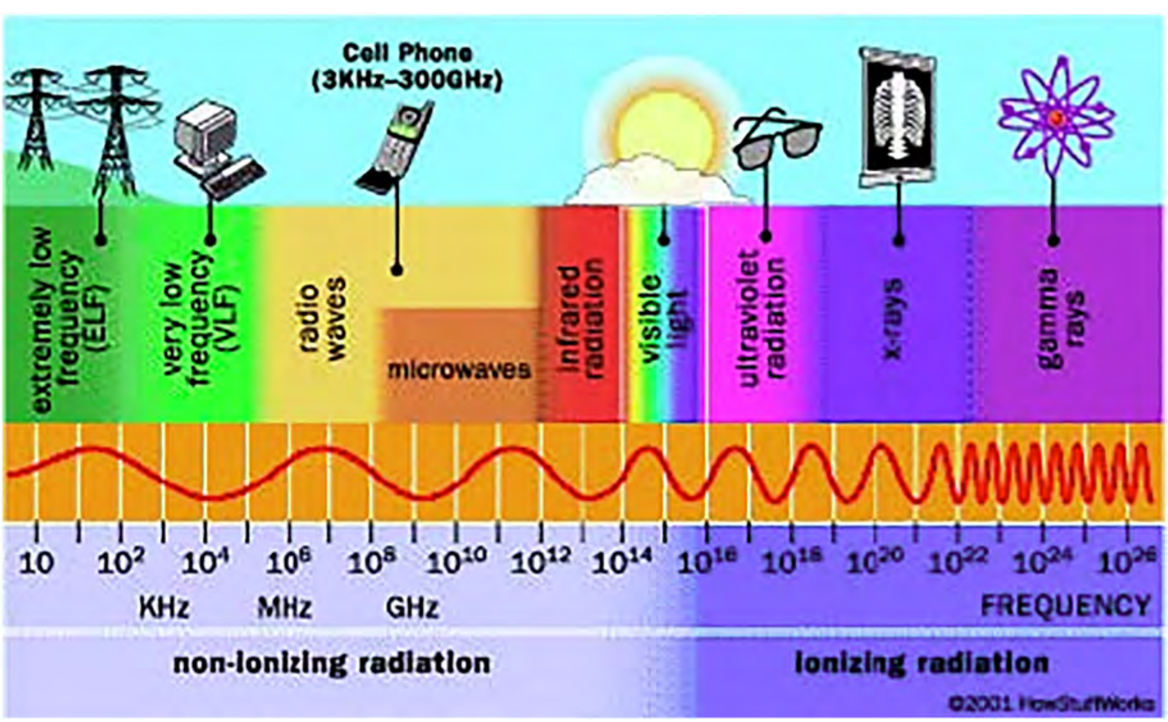

Figure 1: The electromagnetic spectrum.
The electromagnetic spectrum is divided into ionizing and nonionizing radiation. Ionizing radiation falls at and above the ultra violet range in the light frequencies. Examples of ionizing radiation include gamma rays, cosmic rays, X-rays and various military and civilian nuclear activities. It is the nonionzing bands that we have completely filled in with modern technology.

time in evolutionary history, we have infused the Earth's surface with a blanket of artificial energy exposures with no clear understanding of what the consequences may be.

And although "natural," not all energy is alike. Man-made exposures contain propagation characteristics — such as alternating current, modulation, complex signaling characteristics (e.g., pulsed, digital, and phased array), unusual wave forms (e.g., square and sawtooth shapes), and at heightened power intensities at the Earth's surface that simply do not exist in nature. These are all man-made artifacts. In our embrace of technology, we have completely altered the Earth's electromagnetic signature in which all life has evolved, in essence bypassing the magnetosphere's protection. And because so much of wireless technology is satellite based, increasing exposures are no longer just ground-generated. All atmospheric levels are now affected by increasing ambient exposures (see Part 1 and Part 1 Supplement). This is especially true in the lower atmosphere, which is 'habitat' (beyond mere oxygen and clean air standards) for all species that mate, migrate, and feed in the air — including birds, mammals (such as bats), insects and some arachnids.

Species extinctions

There has been an unprecedented rate of biodiversity decline in recent decades according to the International Union for Conservation of Nature [10] which maintains a "Red List of Threatened Species" that is considered the world's most comprehensive source on the global conservation status of animal, fungi and plant species — all critical indicators of planetary health.

IUCN's 2018 list showed that 26,000 species are threatened with extinction, which reflected more than 27% of all species assessed. This was greatly increased from their 2004 report that found at least 15 species had already gone extinct between 1984 and 2004, and another 12 survived only in captivity. Current extinction rates are now at least 100 to 1,000 times higher than natural rates found in the fossil record.

The more recent May 2019 report by the Intergovernmental Science and Policy Platform on Biodiversity and Ecosystem Services, Paris, France [11] projected that at least 1 million plant and animal species worldwide are at imminent threat of extinction if our current human actions and activities are not immediately reversed. A review of 73 reports by Sanchez-Bayo and Wyckhuys [12] found those rates had greatly accelerated. The authors noted that biodiversity of insects in particular is threatened worldwide with dramatic declines that could lead to a 40% extinction of insect species over the next several decades. In terrestrial ecosystems they found *Lepidoptera, Hymenoptera, and Coleoptera* (dung beetles) were most affected, while in aquatic ecosystems *Odonata, Plecoptera, Trichoptera and Ephemeroptera* have already lost a considerable proportion of species. Affected insect groups included niche specialist species, as well as common and generalist species, many of which are critically important for pollination, as well as seed, fruit, nut and honey production, and natural pest control, among others of immeasurable economic and ecological value.

Humans are the primary cause for most declines via habitat destruction/degradation; over-exploitation for food, pets, cattle and medicine; artificially introduced species; pollution/contamination; pesticides; and disease. Climate change is increasingly established as a serious threat, as well as agricultural practices like monoculture crops for cattle feed, biofuels, and timber. New pesticides and weed killers introduced within the last 20 years, using neonicotinoids, glyphosphate, and fipronil, are especially damaging since they are long-lasting and capable of sterilizing soil of beneficial microorganisms, including worms and grubs, which can then extend to areas far beyond applications sites.

One example of multi-factorial damage includes the iconic American Monarch butterfly (*Danaus plexippus)* which is found across America and Southern Canada and generally geographically divided into eastern and western migratory groups by the Rocky Mountains. That species has declined by a full 99.4% in the west since the 1980s — 85% of that being since 2017 [13, 14]. According to the Center for Biological Diversity [15], the eastern monarch population has shrunk by 90% in the past two decades. Massive habitat loss, wildfires, climate change, droughts, enhanced storm ferocity, and the 1990s introduction of Monsanto "Roundup Ready" crops capable of surviving herbicides that kill other weeds — including milkweed, which monarchs need for breeding and as their sole food supply along their migratory routes — are thought to be the primary culprits.

Here, we argue, environmental EMF should be added to this list since many insects and other living species have sensitive receptors for EMF, e.g., monarchs were found to have light sensitive magnetoreceptors in their antennae that serve as an inclination compass when daylight is absent [16]. RFR is also known to alter the time period needed for a butterfly to complete morphogenesis, plus gastrulation and larval growth can be accelerated [17]. And the devastating loss of pollinating insects like honey bees and other wild pollinators may also be related to environmental EMF (see "Insects" below.)

Anecdotally, many people recall when there were significantly more insects and far more abundant wildlife. Since about 1980, there has been a steady, almost imperceptible, biodiversity diminishment among many species globally [18–20]. In 2018, scientists estimated that the largest king penguin colony shrank by 88% in just 35 years [21] due in major part to effects from climate change, while according to the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, over 97% of bluefin tuna have disappeared from the world's oceans, primarily due to industrial overfishing but exacerbated by oil spills, contamination, and climate change. Tree and cave-dwelling bats until recently were common, including in the Eastern United States. Now with the massive impacts from White-nosed Syndrome (a fatal bat fungal disease), annual wind-turbine bat collision mortality estimated at nearly 1 million per year in the U.S. alone [22, 23], and pesticide use, few bats are seen. Bats species are also sensitive to EMF. Impacts from EMF as now seen in extensive reviews add only yet another troubling variable for all wildlife [24–36].

Since all food webs are uniquely tied together, there are negative cascading effects across all ecosystems. Birds that eat insects are hard hit: 8-in-10 partridges have disappeared from French farmlands while there has been a 50–80% reduction in nightingales and turtledoves respectively in the UK. Since 1980 the number of birds that typically inhabit Europe's farmlands has shrunk by 55%, while in the last 17 years, French farmland-bird counts dropped by a full third. Intensified agricultural practices are thought responsible, with loss of insects being the largest contributor [12, 37]. In the United States, of the 1,027 species of migratory birds currently protected under the Migratory Bird Treaty Act of 1918, an estimated 40% are in decline based on breeding bird surveys [38], Christmas Bird Counts [39], and other monitoring tools [22, 23]. This trend is comparable to what is happening globally. What role EMF plays in these declines is unclear but remains a disturbing possibility. Nor do we understand the limits of tolerance any given species has for environmental disturbance — some show high flexibility while others thrive only within the narrowest ranges.

One estimate of Earth's species finds that since 1970, wild animal populations have been reduced on average by 60%. Popularly called the "sixth mass extinction" [40], the term connotes the sixth time in the Earth's history that large numbers of species have rapidly disappeared over a relatively short period, this time due to human activity, not asteroid strikes or volcanic activity. Though not officially so-designated, many now refer to this most recent geologic/ecosystem period as the "Anthropocene" — the Age of Man [41–46].

Insect populations have been especially hard hit with extinctions eight times faster than that of mammals, birds and reptiles [12]. Insect total mass is falling by an estimated 2.5% per year, suggesting they could vanish by the next century. And what affects insect populations affects everything in the food web in one way or another. Loss of insect diversity and abundance can cause devastating effects throughout food webs and endanger entire ecosystems [12]. In Europe, Hallmann et al. [47] found a more than 75% decline over 27 years in total flying insect biomass in 63 protected areas, many throughout Germany. There was an 82% decline in mid-summer flying insect mass. Many European insect species migrate from distances as far away as Africa. The researchers noted that changes in weather, land use, and habitat characteristics alone cannot explain the overall decline and that there may be more than one unrecognized factor involved in evaluating declines in overall species abundance. That unrecognized factor may be the steadily rising ambient EMF that directly parallels these declines (see Part 1, Supplement 1).

Similar alarming invertebrate declines were discovered in the Western Hemisphere in 2017 when American entomologist Bradford Lister, after 40 years, revisited the El Yunque National Forest in Puerto Rico to follow up on a study begun in 1976 [48]. In the ensuing decades, populations of arthropods, including numerous flying insects, centipedes and spiders, had fallen by 98% in El Yunque, a pristine tropical rainforest within the U.S. National Forest System. Insectivores — including birds, lizards, and toads — showed similar declines, with some species vanishing entirely. After controlling for factors like habitat degradation or loss and pesticide use, the researchers concluded that climate change was the primary factor since the average maximum temperature in that rainforest had increased by 4 °F during that period. They did not factor in the large U.S. military VLF installation in Aquada that communicates with submarines all over the world, or the multiple sweeping over-the-horizon phased array radar units aimed at Puerto Rico from coastal sites in the U.S. that irradiate deep into that forest, or the multiple NOAA Doppler weather radar sites scattered all over the small island to track hurricanes, or the many cell towers there too.

These global declines are truly alarming with implications for planetary health as well as human and wildlife integrity. Many who study this say that climate change alone is not the only factor and that something new is going on [47]. The question is: could steadily rising environmental EMF, as one of the most ubiquitous but unrecognized new environmental genotoxins introduced since the 1980s, be contributing to these unprecedented species losses, beginning with insects but now manifesting in other species too? The upper microwave bands couple maximally with some insects the size of fruit flies and are capable of creating devastating resonance and other effects. Historically, radiofrequency radiation (RFR) impacts to insects were among the first biological effects to be studied [49] with the hope of discovering new forms of insect control [50]. All insect metamorphic developments have been studied, including egg, larva, pupa, and adult stages. One hypothesis holds that some adult species are more sensitive than at larval stages because adult appendages act as conducting pathways to the body (see "Insects" below).

It is these exact frequency bands between 30 kHz and 3 GHz used in telecommunications technology that have been on the rise during this period. And 5G is on the horizon which may specifically target insect populations (see Part 1).

Species sensitivity to EMFs

Other species have vastly more complex electromagnetic sensing tools than humans, as well as unique physiologies that evolved to sense weak fields. Many species are highly sensitive to the Earth's natural electromagnetic fields, as well as geographic and seasonal variations. In fact, it appears that most living things — including many species of mammals, birds, fish, and bacteria — are tuned to the Earth's electromagnetic background in ways once considered as "superpowers" but are now known to be physiological, even as mechanisms are still imperfectly understood. For example, many animals have been observed sensing earthquakes long before human instruments detect them, including snakes and scorpions that seek shelter; cattle that stampede; birds that sing at the wrong times of day; and female cats that frantically move kittens [7].

This ability is likely due, in part, to numerous species reacting to changes in the Earth's magnetic field and electrostatic charges in the air detected through a naturally occurring mineral called magnetite found in many species [51, 52]. In fact, honey bees are able to detect static magnetic field fluctuations as weak as 26 nT against background earth-strength magnetic fields that are much higher [53] and to sense weak alternating fields at frequencies of 10 and 60 Hz [54]. Magnetite reacts a million times more strongly to external electromagnetic fields than any other known magnetic material. Authors Kobayshi and Kirchvink [52] and Kirchvink et al. [53, 54] hypothesized results were consistent with biophysical predictions of a magnetite-based magnetoreceptor. Other mechanisms, like radical pair mechanisms and cryptochromes, may also be responsible (see "Mechanisms" below).

Much has been written about magnetoreception — the term used to describe how species sense electromagnetic fields — which is well established but not well understood. Many species use information about the Earth's natural fields for migration, mating, food-finding, homing, nesting, and numerous other activities. Migratory bird species [55, 56], honey bees [57], fish [58], mammals [59], bats [60], numerous insect species [61], mollusks [62], and even bacteria [63] are known to sense Earth's magnetic fields in various ways. Magnetoreception may enable some bird species to actually see the Earth's fields [64].

Some insect and arachnid species (e.g., Trichobothria) can detect natural atmospheric electric fields [65] which trigger ballooning behavior — e.g., climbing to the highest place, letting out silk, and traveling on wind currents using hair-like Trichobothria that detects airborne vibrations, currents, and electrical charge. Some have been found as high as 2.5 mi (4 km) in the sky, dispersing over hundreds of kilometers. Morley and Robert [65] found that the presence of a weak natural vertical e-field elicited ballooning behavior and takeoff in the spiders; their mechano-sensory hairs function as putative sensory receivers which are activated by natural weak electric-fields in response to both e-field and air-flow stimuli. The researchers hypothesized that atmospheric electricity was key to the mass migration patterns of some arthropod fauna.

Even soil nematodes (*Caenorhabditis elegans)* orient to earth-strength magnetic fields in their burrowing behaviors and a recent study by Vidal-Gadea [66] found that weak static fields slightly above Earth's natural fields determined stem cell regeneration in flatworms (*Planaria*) [67].

Large ruminant mammalian species also orient to the Earth's fields. Grazing cattle and deer were first observed aligning to geomagnetic field lines by Begall et al. [68]. Using satellite imagery, field observations, and measuring "deerbeds" in snow, they noted that domestic cattle across the globe, as well as grazing and resting red (*Cervus alphas*) and roe (*Capreolus capreolus*) deer, consistently align their body axis in a general north–south direction and that roe deer also orient their heads northward when grazing or resting. Burda et al. [69] discovered, however, that man-made ELF-EMF disrupted the north-south alignment with the geomagnetic field in resting cattle and roe deer when they found body orientation was random on pastures under or near power lines, with the disturbed pattern diminishing with distance from conductors. Cattle exposed to various magnetic field patterns directly beneath or near power lines exhibited distinct patterns of alignment. They concluded there was evidence for magnetic sensation in large mammals, as well as overt behavioral reactions to weak ELF-MF in vertebrates, implying cellular and molecular effects. Slaby et al. [70] also found cattle align along a north-south axis but suggested that such alignment may depend on herd density as the affect disappeared in herds with higher numbers. Fedrowitz [71] expanded this to include bovine sensitivity to other weak ELF-EMF from powerlines but with observed effects due to combined electric and magnetic fields rather than the electric field exposure alone (see “Bovines”below).

Cerveny et al. [72] found red fox (*Vulpes vulpes)* use geomagnetic fields during hunting. Even domestic dogs were found by Hart et al. [73] to be sensitive to small variations in the Earth’s orientation in their excretion habits, preferring a general north-south axis for both defecation and urination depending on geomagnetic field changes. And Nießner et al. [74] found dogs and some other species may actually “see” geomagnetic fields through blue-light sensing photoreceptor proteins in their eyes called cryptochromes.

According to the US/UK World Magnetic Model [75], sensitivity to the geomagnetic field may further complicate issues for migratory species (e.g., some turtles, sea animals, birds, and insects) because the Earth’s magnetic north pole is shifting faster than at any time in human history. Compared to the period between 1900 and 1980, it has greatly accelerated to about 30 mi (50 km) distance per year — moving west from over Canada’s Ellesmere Island, its traditional allocation for most of recorded history — toward Russia [76]. Magnetic north fluctuates according to changes in the Earth’s molten core, unlike true north which aligns according to the Earth’s axis. This trend may indicate a coming pole reversal with north and south trading places, something that occurs approximately every 400,000 years with the last being about 780,000 years ago. Some animals may be capable of recalibrating navigational cues but that remains to be seen. Since some migratory bird species may see geomagnetic fields through special receptor cells in their eyes and via other mechanisms, they could be thrown off course. It is unclear how many other species also see geomagnetic fields but some crustaceans and several insect species, especially those with compound eye structures consisting of thousands of ommatidia — tiny independent photoreception units with a cornea, lens, and photoreceptor cells that orient in different directions and distinguish brightness and many more bands of color than humans — are good candidates. Compared to single-aperture eyes, compound eyes have a very large view angle that can detect fast movement and in some cases light polarization.

In aquatic environments, some lakes have more than 200 species of fish that use some form of electromagnetism to locate food and reproduce. Electric eels can deliver a 500-V zap to kill prey. Sharks have an array of electromagnetic sensors. These include: magnetic field receptors in their mouths, eyes that are 10 times more sensitive than humans, and their perception of tiny electric neuronal discharges from the moving muscles in prey (including humans) guides their attacking/feeding behavior (see “Fish”below). Sharks are often attracted by low-level electromagnetic fields surrounding underwater electric cables and are sometimes electrocuted when they mistake the conduit for living prey and bite into it. Many fish have lateral lines on either side of their bodies that are composed of magnetite, which allows fish to swim in synchronous schools [52].

Many other animals evolved special receptor organs to detect environmental EMF. The duck-billed platypus (*Ornithorhynchus anatinus),* a semi-aquatic primitive egg-laying mammal, has thousands of electric sensors on its bill skin. As noted in Lai [77], using these electroreceptors and interacting with another type of mechanoreceptor, a platypus can detect an electric field of 20 μV/cm [78] — equivalent to that produced by the muscles of a shrimp. The information is processed by the somatosensory cortex of the platypus to fix the location of prey. This type of electroreception is common in the three species of monotremes: platypus, and long (*Zaglossus bruijni)* and short-bill (*Tachyglossus aculeatus*) echidna. Electric fish (elasmobranchs) emit EMF that covers a distance of several centimeters [79, 80]. This allows location of potential prey by comparing its electrical properties with that in its immediate vicinity. Their electroreceptors have been shown to detect a field of 5 nV/cm. Such EMF-sensing systems are highly sensitive and efficient but also highly vulnerable to disruption by unnatural fields. Organisms that use the geomagnetic field for migration have the capability not only to detect the field but also the orientation of the field.

Anthropogenic light frequencies affect wildlife in ways we have only recently grasped. Ecological studies have found that artificial light-at-night is disrupting nocturnal animals in devastating ways, including disorientation and disruption in breeding and migration cycles in turtles, flying insects, birds, butterflies and a host of other wildlife including mammals [81–84]. As much as 30% of nocturnal vertebrates and over 60% of invertebrates may be affected by artificial light [85]. Illumination reflected off of clouds known as “sky glow” can produce unnaturally bright conditions at night from various wavelength spectra that impact different species, with the potential to alter the balance of species interactions [86, 87]. It has been found that changing the color of the light can help some species yet harm another [88]. For instance, low-pressure sodium lights that have more yellow in their spectrum reduce moth deaths around the bulbs, but salamanders cannot navigate from one pond to the next under yellow or red light. Some frogs have been observed to freeze for hours, even after lights have been turned off, and to suspend both feeding and reproduction [83].

One of nature's great mysteries involves "natal homing behavior" — the ability of some animal species to return to their original location of birth in order to reproduce, sometimes over great distances. Natal homing behavior is known in sea turtles [89]; eels [90]; and salmon [91], among other species. The underlying mechanism, though imperfectly understood, involves such species "remembering" the geomagnetic field configurations of their birthplace via a process known as "imprinting," and thus can locate and return to it even if they are thousands of miles/kilometers away at reproduction time. Apparently, newborns of these species are imprinted with the memory of the intensity and the inclination angle of the local geomagnetic field. This information is then later used to locate their place of birth where they return to breed.

The question is whether man-made EMF could distort this imprinting memory in later locating the site. For example, what if RFR-emitting facilities are located near turtle breeding sites? Could that interfere with imprinting? There is some evidence from Landler et al. [92] of adverse effects in turtles. The researchers found that RFR could disrupt a natural orientation, establish its own orientation, and reverse completely a natural orientation, indicating a need for research to further investigate as we simply do not know the full effects to other species from anthropogenic EMF.

Energy conduction in different species: unique physiologies and morphologies

The unique physiology and morphology of non-human species create additional complexities. For instance, quadrapedal species with four feet on the ground have different and potentially more efficient conductivity than bipedal species with two feet. One example is bovine heightened sensitivity to increased ground current near high tension lines [93, 94] and cell towers [95–97]. Also, bodies that are predominately parallel to the ground, which includes most four-legged mammals, rather than a perpendicular upright gait, conduct EMF in different ways than vertical species like humans, apes, and other primates. Species that hug the ground, like snakes, salamanders, and frogs, have unique exposures to ground currents, especially on rainy nights when water, as a conductive medium, can increase exposures [98]. This may make some species more sensitive to artificial ground current caused by electric utility companies using the Earth as their neutral return back to the substation for excess alternating current on their lines instead of running additional neutral lines on utility poles [99].

Hair and whiskers and related appendages in various species are known to detect small variations in electromagnetic fields as well as water and weather alterations [100]. In fact, ants have been observed to use their antennae as "EMF antennas" when subjected by researchers to external electromagnetic fields, aligning themselves to "channel" RFR away from the colony [7]. Species such as birds, as well as some insects with compound eyes structures, can see vastly more colors than humans, while cats, dogs, and owls, for instance, hear many more sound frequencies at incredibly low levels.

Magnetoreception mechanisms: electroreceptor cells, magnetite, cryptochromes/radical pairs

According to Lai [77], "…in order for an environmental entity to affect the functions of an organism, the following criteria have to be met: the organism should be able to detect the entity; the level of the entity should be similar to those in the normal ambient environment which is generally much lower than the level of the entity used in experimental studies; and the organism must have response mechanisms tuned to certain parameters of the entity that allow immediate detection of the presence and changes of the entity. Thus, a variation of the entity would be detected as an aberrant input and trigger a response reaction. In order to understand how man-made EMF affects wildlife, the above criteria must be considered, including multiple sensory mechanisms that vary from species to species."

The questions are: How do diverse species detect weak natural geomagnetic signals, distinguish the subtle internal microcurrent and magnetic fields inherent to all biology from external fields, then get beyond both internal and external background noise to make use of that electromagnetic information?

There are three primary mechanisms used to understand magnetoreception:

(1) Magnetic induction of weak electrical signals in specialized sensory receptors [101].
(2) Magnetomechanical interactions with localized deposits of single-domain magnetite crystals [52, 102, 103].
(3) Radical-pair photoreceptors, which may be the most plausible [104–111].

In the induction model (mechanism 1), according to Lin [102], the first category of electrodynamic interactions with weak magnetic fields is epitomized by elasmobranchs, including sharks, rays, and skates, with heads that contain long jelly-filled canals with high electrical conductivity known as the Ampullae of Lorenzini. As these fish swim through the Earth's geomagnetic lines of flux, small voltage gradients are induced in these canals with electric field detections as low as 0.5 μV/m [101] The polarity of the induced field in relation to the geomagnetic field provides directional cues for the fish. However, in birds, insects, and land-based animals, such cells have not been found, indicating this may not be a universal mechanism but rather are environment/species-specific factors [111].

The magnetomechanical model (mechanism 2) involves the naturally occurring iron-based crystalline mineral called magnetite found in most species [52]. Its function is most simply demonstrated in magnetotactic bacteria [63] with high iron content where biogenic magnetite is manufactured in 20–30 single domain crystal chains [112]. Orientation is patterned according to the geomagnetic field. Blakemore et al. [113] found that magnetotactic bacteria in the northern hemisphere migrate toward the north pole of the geomagnetic field whereas the same strains migrate toward the South Pole in the southern hemisphere. At the equator, they are nearly equally divided in north- and- south seeking orientations [114]. And they all migrate downward in response to the geomagnetic field's vertical component, which, in aqueous environments may be essential for their survival in bottom sediments.

Among the many species where magnetite has been found include the cranium and neck muscles of pigeons [115, 116]; denticles of mollusks [117, 118]; and the abdominal area of bees [119]. Tenforde [103] delineated other species with localized magnetite, including dolphins, tuna, salmon, butterflies, turtles, mice, and humans.

The third mechanistic model (mechanism 3) getting research attention today involves a complex free-radical-pair reaction and conversion of the forms of electrons (singlet-triplet inter-conversion) in a group of protein compounds known as cryptochromes. Cryptochromes have been found in the retinas of nocturnal migratory songbirds by Heyers et al. [55] and Moller et al. [56], showing complex communication with the brain for orientation when relying on magnetoreception. Gegear et al. [61] found cryptochromes to be a critical magnetoreception component in fruit flies (*Drosophila melanogaster)*. As noted in Lai [77], cryptochrones are also present in the retinas of some animals [120]. RFR [121] and oscillating magnetic fields [122] have been reported to disrupt the migratory compass orientation in migratory birds. There are also reports that indicate the presence of cryptochromes in plants, which may be responsible for the effect of EMF on plant growth [123]. Cryptochromes are also known to be involved with circadian rhythms [56, 124]. For an excellent review on plausibility, theories, and complexities of cryptochrome/radical pairs, see Ritz et al. [111].

Many species likely use a combination of these mechanisms as well as more subtle influences as yet undetected. The vector of the geomagnetic field may provide the directional information, while intensity and/or inclination provide the positional information needed for orientation. In behavioral studies [125, 126], Wiltschko et al. found that birds used both magnetite and cryptochrome mechanisms when they responded to a short, strong magnetic pulse capable of changing magnetization of magnetite particles, while their orientation was light-dependent and easily disrupted by high-frequency magnetic fields in the MHz range indicating radical pair processes. These findings suggest that along with electrophysiological and histological studies, birds have a radical pair mechanism located in the right eye that provides compass-like directional information while magnetite in the upper beak senses magnetic intensity, thus providing positional information. However, Pakhomov et al. [122] pointed out that the songbird magnetic compass can be disrupted by an oscillating 1.403-MHz magnetic field of 2–3 nT, at a level that cannot be explained by the radical-pair mechanism.

Light plays a significant role [127], which is of environmental concern today as more technology moves toward using the infrared bands for communications and the increase of satellites create artificial/unfamiliar star-like lights in the night sky that are potentially capable of impacting night migration patterns. There is other evidence that species use a combination of photoreceptors and magnetite-based magnetoreception. As mentioned above, in birds the two mechanisms exist side by side, mediating different types of magnetic information as needed, such as flight on sunny vs. cloudy days or nocturnal flights, and they can be easily disrupted [106, 128–130]. Birds may co-process visual information with magnetic information and be able to distinguish between the two [131, 132]. This function likely occurs in the eye or higher avian brain areas via light-dependent information processing and radical pair cryptochromes [131, 133]. Birds' magnetic compass is an inclination compass and RFR fields in the Larmor frequencies near 1.33 MHz were found to disrupt birds' orientation in an extremely sensitive resonance relationship. Blue-light absorbing photopigment cryptochromes have been found in the retinas of birds. RFR appears to directly interfere with the primary processes of magnetoreception and disable the avian compass as long as the exposure is present [126, 128].

Mammals have also demonstrated magnetoreception indicating radical-pair mechanisms. Malkemper et al. [134] found that the surface-dwelling wood mouse (*Apodemus sylvaticus*) built nests in the northern and southern sectors of a visually symmetrical, circular arena, using the ambient magnetic field, or in a field rotated by 90°, indicating the animals used magnetic cues. When the mice were also tested in the ambient magnetic field with a superimposed radio frequency magnetic field (100 nT, 0.9 to 5 MHz frequency sweep), they changed preference from north-south to east-west nest building. But unlike birds that have been found sensitive to a constant Larmor frequency exposure at 1.33 MHz, that range had no effect on mice orientation. Individual animal physiology clearly plays a role in how various species respond. Malewski et al. [135] also found that the Earth's magnetic field acts as a common directional indicator in five species of subterranean digging rodents. And for the first time, research also found that human brain waves exhibit a strong response to ecologically-relevant rotations of Earth-strength magnetic fields [136].

We need far better understanding of magnetoreception's neural, cellular, and molecular processes because the ultimate question is, given our constant rising background levels of EMF, is this ambient noise reaching a tipping point beyond which species simply cannot "hear?" Are we artificially overwhelming living species' ability to function with innate natural biological sensors that evolved over eons in a far more "electro-silent" world? The electroreception mechanisms described above — electroreceptors, magnetite, and cryptochrone/radical-pairs — enable living organisms to detect the presence and immediate changes in environmental fields of very low intensity. And thus they can be easily disturbed by the presence of unfamiliar low-intensity man-made fields.

Electrohypersensitivity in humans has also shown instantaneous response to EMF at low intensity [137]. According to Lai [77], one wonders whether the underlying mechanisms of electrohypersensivity are similar to those described above. Electrohypersensitivity may be a remnant of the evolutionary responses of living organisms to electromagnetic fields — particularly magnetic fields — in the environment. Similarities include responsiveness to very low-field intensity; the response is persistent and built into the physiology of an organism; and the response is immediate and reacts quickly to the fields. Cryptochrome-free radical mechanisms may be involved. Some people are more sensitive than others. Perhaps non-sensitive people can tolerate and compensate for effects, and/or have lost responsiveness to natural magnetic fields and thus have become evolutionarily aberrant. Electrosensitivity is an issue in need of more careful and systematic study and has yet to be broadly highlighted as a health or public welfare concern.

One recent theory by Johnsen et al. [138] postulates that magnetoreception in animal species may be "noisy" — meaning that the magnetic signal is small compared to thermal and other receptor noise, for instance. They speculate that magnetoreception may serve as a redundant "as-needed" source of information, otherwise animal species would use it as their primary source of information. Many species, they note, preferentially exploit non-magnetic cues first if they are available despite the fact that the Earth's geomagnetic field is pervasive and ever-present. They speculate that magnetic receptors may thus be unable to instantaneously attain highly precise magnetic information, and therefore more extensive time-averaging and/or other higher-order neural processing of magnetic information is required. This may render "…the magnetic sense inefficient relative to alternative cues that can be detected faster and with less effort." Magnetoreception may have been maintained, however, they said by natural selection because the geomagnetic field may sometimes be the only available source of directional and/or positional information.

We already know that some species use various mechanisms to detect EMFs as noted throughout this paper. With new environmental factors from anthropogenic causes, such as artificial light-at-night, air/water pollution, climate change impacting visibility as environmental cues, and rising background RFR — all of which can obscure natural information — magnetoreception may, in fact, become *more* necessary as an evolutionary survival tool as time goes on, not less.

Other mechanisms of biological significance: DNA — direct and indirect effects (See Part 2, Supplements 1 and 2, for tables of ELF and RFR genetics studies)

A significant biological effect in any toxicology research involves the basic genetics of an exposed organism. Genetic effects consist mainly of gene expression, chromatin conformational changes, and genotoxicity. All such effects can influence normal physiological functions. Relevant to this paper is the fact that genetic effects are found at EMF levels similar to those in ambient environments, far below levels from communication devices and infrastructure (see Part 1, Supplement 1).

DNA, the fundamental building block of all life, is a molecular double helix that is coiled, twisted and folded within the nucleus of each living cell. It is essentially identical among species with variations only in number and specific genes along chromosomes on DNA's twisted chains that distinguish various species and their characteristics from one another. DNA damage repeatedly seen in one species can therefore be extrapolated to other species, although not all species react the same to external stimuli.

Many factors, both endogenous and exogenous, damage DNA which is then normally repaired by DNA enzymes. But an absence of adequate repair can result in the accumulation of damaged DNA, which will eventually lead to aging, cell death (apotosis) and/or cancer. DNA breaks occur as both single and double strand events; double strand breaks are difficult to repair correctly and can lead to mutations. DNA damage from endogenous factors can include free radical formation from mitochondrial respiration and metabolism; exogenous factors include chemicals, ionizing and nonionizing radiation, and ultra violet light among others [139]

In several early studies, Lai and Singh [140, 141] found both double and single strand DNA breaks in the brain cells of rats exposed to RFR for 2 h at 2,450 MHz, and whole body SAR levels of 0.6 and 1.2 W/kg. The effects were interestingly blocked by antioxidants [142] suggesting free radical involvement, which could indicate an indirect cause for DNA damage (see below). The low-intensity genetic effects listed in Part 2 Supplements 1 and 2 are at 0.1 W/kg and less. Therefore, the Lai and Singh [140, 141] RFR studies are not included in those Supplements. Very similar effects have also been found by Lai and Singh [143, 144] with 60-Hz magnetic field exposure.

There has also been much study of ELF genetic effects. As discussed in Phillips et al. [139], numerous studies found that ELF-EMF leads to DNA damage [143–158]. Two studies [159, 160] showed that ELF also affects DNA repair mechanisms. Sarimov et al. [161] found chromatin conformational changes in human lymphocytes exposed to a 50-Hz magnetic field at 5–20 μT. EMF-induced changes in cellular free radicals are also well studied [77, 162].

Others investigated DNA damage early on but without the availability of today's more sensitive assays. Sarkar et al. [163] exposed mice to 2,450-MHz microwaves at a power density of 1 mW/cm^2 for 2 h/day over 120, 150, and 200 days. They found DNA rearrangement in the testis and brain of exposed animals that suggested DNA strand breakage. Phillips et al. [164] were the first to use the comet assay to study two different forms of cell phone signals — multi-frequency time division multiple access (TDMA) and integrated digital enhanced network (iDEN) — on DNA damage in Molt-4 human lymphoblastoid cells using relatively low intensities of 2.4–26 W/g for 2–21 h. The authors reported seeming conflicting increases *and* decreases in DNA damage, depending on the type of signal studied, as well as the intensity and duration of exposure. They speculated the fields could affect DNA repair mechanisms in cells, accounting for the conflicting results.

In a recent literature review of EMF genetic effects by Lai [165], analysis found more research papers reporting effects than no effects. For RFR, 224 studies (65%) showed genetic effects while 122 publications (35%) found no effects. For ELF and static-EMF studies, 160 studies (77%) found effects while in 43 studies (23%) no effects were seen.

Research now points to the duration, signaling characteristics, and type of exposure as the determining factors in potential damage [164, 166], not the traditional demarcation between ionizing and nonionzing radiation. Long-term, low-level nonionizing radiation exposures common today are thought to be as detrimental to living cells as are short-term, high-intensity exposures from ionizing radiation. Effects may just take longer to manifest [167]. Nonionizing EMF at environmental levels does cause genetic damage. These have also been shown in humans exposed to environmental levels of EMF in both ELF and RFR ranges [168–171]. Conceivably, similar genetic effects could happen in other species living in similar environments.

This body of genetics work goes against the pervasive myth that low-level, low-intensity nonionizing radiation cannot cause detrimental genetic effects. That premise is in fact the bedrock belief upon which vested interests and government agencies rely in support of current exposure standards. But in fact, biological systems are far more complex than physics models can ever predict [6, 8, 172]. A new biological model is needed because today's exposures no longer fit that framework [173] for humans and wildlife. Enough research now indicates a reassessment is needed, perhaps including the very physics model used to back those traditional approaches (see Part 1).

Direct mechanisms: DNA as fractal antennas, cell membranes, ion channels

DNA as fractal antennas

There are several likely mechanisms for DNA damage from nonionizing radiation far below heating thresholds, both direct and indirect, intracellular, intercellular, and extracellular. Such mechanisms potentially apply to all wildlife. One direct mechanism theorizes that DNA itself acts as a fractal antenna for EMF/RFR [174], capable of receiving information from exogenous exposures.

According to Blank and Goodman [174], DNA has interesting electrical characteristics due to its unique structure of intertwined strands connected by rungs of molecules called nucleotides (also called bases), with each rung composed of two nucleotides (one from each strand) in bonded pairs. The nucleotides are held together by hydrogen bonds in close proximity that results in a strong attraction between the two strands. There are electrons on both molecular surfaces making the symmetrical nucleotides capable of conducting electron current along the entire DNA chain, a phenomenon called electron transfer. This makes DNA a most efficient electrical conductor, something not lost on nanotechnology researchers.

DNA may also act as an efficient fractal antenna due to its tightly packed shape within the cell nucleus. Blank and Goodman [174] characterized DNA properties in different frequency ranges, and considered electronic conduction within DNA's compact construction in the nucleus. They concluded that the wide frequency range of observed interactions seen with EMF is the functional characteristic of a fractal antenna, and that DNA itself possesses the two structural characteristics of fractal antennas — electronic conduction and self symmetry. They noted that these properties contribute to greater reactivity of DNA with EMF in the environment, and that direct DNA damage could account for cancer increases, as well as the many other biological effects seen with EMF exposures.

A fractal is a self-repetitive pattern of sometimes geometric shapes, marked by a larger originating design progressing to small identical designs with a potentially unlimited periphery. Each part of the shape looks like the whole shape. Fractal designs are quite common in nature, e.g., in snail/mollusk shells, some deciduous tree leaves and conifer needles, pine cones, many flowering plants, some reptile scales, bird feathers and animal fur patterns, snowflakes, and crystals forming on cold winter glass windows. Minerals — both inert and biological — can also be fractals.

The varying sizes within fractals are what make them inherently multi-frequency. By mimicking nature, repetitive fractal patterns are also designed into mechanical transceiver antennas that radiate in multiband frequencies with more or less efficiency [175]. Cell phones, WiFi, digital TV, and many other transceivers use fractal antennas to operate.

The complex twisted shape and coiled structure of DNA — small coils coiled into larger coils, or *coiled coils*, which Blank and Goodman [174] note that no matter how far you zoom in or out, the shape looks the same — is the exact structure of a fractal that maximizes the length of an antenna within a compact space while boosting multi-frequency signals. As such, DNA may be acting as a hidden intracellular biological fractal capable of interacting with exogenous EMF across a range of frequencies. In fact, one of DNA's fundamental functions may be specifically to interact with exogenous natural energy and as such may be more sensitive to EMF than other larger protein molecules within any living system. Once thought safely tucked away and protected within the nucleus, DNA may be acting as a most efficient electrical conductor at the nexus of all life. This interesting theory, unfortunately, has not been followed up by others to test its biological validity although fractals have been mimicked widely in technology.

Cell membranes/ion channels

Another direct effect from EMF is at the cell membrane itself. While DNA is life's fundamental building block, cells are DNA's complex electron-coherent architectural expression. The cell's membrane is far more than just a boundary. It is rather the most important ordering tool in the biological space between intracellular and extracellular activities, "… a window through which a unitary biological element can sense its chemical and electrical environment" [176]. And it is replete with microcurrent.

The cell's outer surface contains molecules that receive innumerable electrochemical signals from extracellular activities. Specific binding portals on the cell membrane set in motion a sequence leading to phosphorylation of specific enzymes that activate proteins for cellular 'work.' That includes everything from information processing in the central nervous system, mechanical functions such as muscle movements, nutrient metabolism, and the defense work of the immune system, among many others including the production of enzymes, hormones, antibodies, and neurotransmitters [177]. Complex microcurrent signaling pathways exist from the cell's outside to the inside via protein intramembraneous particles in the phospholipid plasma membrane. These convey information on external stimuli to the cell's interior to allow cellular function.

The cell membrane also has electrical properties. Microcurrent constantly moves from the interior to the exterior and vice versa of the cell membrane. According to Adey and Sheppard [176], some of these properties influence proteins that form voltage gated membrane channels, which is one way that cells control ion flow and membrane electromagnetic potential essential to life. There are specific windows that react according to frequency, amplitude, and duration differences, indicating a nonlinear and non-equilibrium character to exogenous exposures on cells [177–185].

Some pulsed fields are more biologically active than non-pulsed fields and different forms of pulsing also create different effects. As far back as 1983, Goodman et al. [186] found pulsed weak electromagnetic fields modified biological processes via DNA transcription when a repetitive single pulse and the repetitive pulse train were used. The single pulse increased the specific activity of messenger RNA after 15 and 45 min while the pulse train increased specific activity only after 45 min of exposure. Digital technology simulates pulsing and is the most common form of environmental exposure today.

Cellular calcium ion channels have long been of interest and may be particularly sensitive targets for EMFs due to possible increased calcium flux through the channels which can lead to secondary responses mediated through Ca^{2+}/calmodulin stimulation of nitric oxide synthesis, calcium signaling, elevated nitric oxide (NO), NO signaling, peroxynitrite, free radical formation, and oxidative stress — many with implications to DNA as hypothesized by Pall [187]. Calcium is essential to signal transduction between cells and is significant to everything from metabolism, bone/cell/blood regeneration, hormone production and neurotransmissions among many others. These cellular calcium responses to EMF indicate an artificial change in the signaling processes at the cell membrane — considered a switchboard for information between the exterior environment and intracellular activities that guide cell differentiation and control growth [188].

Pall [187] cited 23 studies of effects to voltage gated calcium channels (VGCC) and noted nonthermal mechanisms were the most likely since many studies showed effects were blocked by calcium channel blockers (widely prescribed for heart irregularities having nothing to do with thermal issues). Pall [189] noted that many other studies showed EMF changes in calcium fluxes and intracellular calcium signaling. He hypothesized that alterations in intracellular calcium activity may explain some of the myriad biological effects seen with EMF exposure, including oxidative stress, DNA breaks, some cancers, infertility, hormonal alterations, cardiac irregularities, and diverse neuropsychiatric effects. These end points need further study and verification.

There is much to be learned about calcium effects as studies are contradictory. Changes in free radicals (see below) also affect calcium metabolism. There are more studies showing EMF effects on free radicals than calcium changes. Calcium activates the nitric oxide free radical pathway but there are only a few studies of this pathway following EMF exposure — less than 5% of EMF-oxidative change studies are on nitric oxide mechanisms. Also of interest is the fact that power density and frequency windows were seen in early research at rising harmonic increments along the electromagnetic spectrum beginning in the ELF bands [190–195]. Observed effects were quite dramatic in what researchers described as calcium efflux or 'dumping' from cells. The most dramatic effects were seen at 180 Hz in the ELF range. This appears to contradict Pall's work [189] cited above as increased calcium efflux is the opposite of what Pall's hypothesis would predict, e.g., calcium *influx*. With more research both calcium influx and efflux effects may be found to be caused by different variables and/or EMF exposures.

In addition, exogenous signaling characteristics are also important to how cells react to both ELF and RFR ranges. Building on the work that demonstrated carrier waves of 50 and 147 MHz, when sinusoidally amplitude modulated at 16 Hz ELF in *in vitro* chick brain tissue [190, 191] and in live awake cat brain models [196] that created frequency windows for calcium efflux, Blackman et al. [194] additionally found that signaling *characteristics* were also significant. Research showed that calcium efflux occurred only when tissue samples are exposed to specific intensity ranges of an ELF-modulated carrier wave; unmodulated carrier waves did not affect ion efflux. Blackman et al. [194] further wrote that cells may be capable of demodulating signals. The authors reported that 16-Hz sinusoidal fields, in the absence of a carrier wave, altered the efflux rate of calcium ions and showed a frequency-dependent, field-induced enhancement of calcium-ion efflux within the ranges 5–7.5 V/m and 35–50 V/m (peak-to-peak incident field in air) with no enhancement within the ranges 1–2, 10–30, and 60–70 V/m. This body of work indicates that living cells interact with, and are capable of taking direction from, exogenous fields in far more complex ways than ever imagined, at intensities barely above background levels. This work may be particularly important to new technology that turns previously wired ELF frequencies into wireless applications, such as "wireless electricity" to charge electric cars.

Blackman et al. [197] found for the first time a link between the ELF/EMF being studied and the density of the natural local geomagnetic field (LGF) in the production of a biological response. Calcium efflux changes could be manipulated by controlling the LGF along with ELF and RF-EMF exposures. In a local geomagnetic field at a density of 38 µT, 15- and 45-Hz electromagnetic signals had been shown to induce calcium ion efflux from the exposed tissues, whereas 1- and- 30-Hz signals did not. Bawin and

Adey [190] found a reduction in efflux when using an electric field; Blackman et al. [194] found an increase when using an electromagnetic field, thus identifying/isolating for the first time the significance of the magnetic field component in exposure parameters. Building on the window ranges noted above, Blackman et al. [197] demonstrated that the enhanced calcium efflux field-induced 15-Hz signal could be rendered ineffective when the LGF is reduced to 19 µT with Helmholtz coils. In addition, the ineffective 30-Hz signal became effective when the LGF was altered to k25.3 µT or to +76 µT. *The results demonstrated that the net intensity of the local geomagnetic field is an important cofactor in biological response and a potentially hidden variable in research.* The results, they noted, appear to describe a resonance-like relationship in which the frequency of the electromagnetic field can induce a change in calcium efflux proportional to LGF density (see Liboff [198, 199] below for more detail).

The bottom line is that changes of this magnitude at the cellular level — be it directly to DNA within the nucleus or via voltage gated channels at the cell's membrane — can lead to direct effects on DNA within and across species. The evidence cited above illustrates the degree, likelihood, and variety of impacts from EMF directly on cellular physiology that are capable of affecting DNA in all living systems in myriad ways.

Indirect mechanisms: free radicals, stress proteins, resonance, Earth's geomagnetic fields

Free radicals

An indirect, or secondary, mechanism for DNA damage would be through free radical formation within cells, which is the most consistently reported with both ELF and RFR exposures under many different conditions in biological systems. According to Phillips et al. [139], free radicals may also interact with metals like iron [142, 151, 152, 158] and play a role in genotoxic effects from something called the Fenton effect — a process "…catalyzed by iron in which hydrogen peroxide, a product of oxidative respiration in the mitochondria, is converted into hydroxyl free radicals, which are very potent and cytotoxic molecules" [139].

The significance of free radical processes may eventually answer some questions regarding how EMF interacts with biological systems. There are about 200–300 papers showing EMF effects on free radicals [77, 168, 200]. Free radicals are important compounds involved in numerous biological functions that affect many species. Increases in free radicals explain effects from damage to macromolecules such as DNA, protein, and membrane lipids; increased heat shock proteins; neurodegenerative diseases; and many more.

Yakymenko et al. [168] published a review on oxidative stress from low-level RFR and found induced molecular effects in living cells, including significant activation of key pathways generating reactive oxygen species (ROS), activation of peroxidation, oxidative damage in DNA, and changes in the activity of antioxidant enzymes. In 100 peer-reviewed studies, 93 confirmed that RFR induced oxidative effects in biological systems and that their involvement in cell signaling pathways could explain a high pathogenic range of biological/health effects. They concluded that low-intensity RFR should be recognized as one of the primary mechanisms of biological activity of nonionizing radiation. In a follow-up study, Yakymenko et al. [200] investigated the oxidative and mutagenic effects of low intensity GSM 1,800 MHz RFR on developing quail embryos exposed *in ovo* (0.32 $\mu W/cm^2$, 48 s On, 12 s Off) during 5 days before and 14 days through the incubation period. They found statistically significant oxidative effects in embryonic cells that included a 2-fold increase in superoxide generation rate, an 85% increase in nitrogen oxide generation, and oxidative damage to DNA up to twice the increased levels of 8-oxo-dG in cells of 1-day old chicks. RFR exposure almost doubled embryo mortality and was statistically significant. They concluded that such exposures should be recognized as a risk factor for living cells, including embryonic integrity.

Lai [77] focused a review on static magnetic field ELF-EMF and found that changes in free radical activities are one of the most consistent effects. Such changes can affect numerous physiological functions including DNA damage, immune system and inflammatory response, cell proliferation and differentiation, wound healing, neural electrical activities, and behavior. Given that many species have proven sensitive to natural static geomagnetic fields and use such information in critical survival skills, some wildlife species may also be adversely affected via free radical alterations from anthropogenic exposures. But Lai [77] noted the inherent contradictions from EMF-induced changes in free radicals, particularly on cell proliferation and differentiation since those processes can affect cancer development as well as growth and development. Induced free-radical changes may therefore have therapeutic applications in killing cancer cells via the generation of the highly cytotoxic hydroxyl free radical by the Fenton Reaction (noted above), thereby creating a non-invasive low-side-effect cancer therapy.

Stress proteins

Another potentially indirect effect to DNA is via protein synthesis required by all cells to function. A living animal converts animal and plant proteins that it ingests into other proteins needed for life's activities — antibodies, for instance, are a self-manufactured protein. DNA is critical to protein synthesis and can create in humans about 25,000 different kinds of proteins with which the body can then create 2,000,000 types in order to fully function.

There are many different classes of proteins. These include stress proteins stimulated by potentially harmful environmental factors to help cells cope and repair damage due to factors like acute temperatures, changes in oxygen levels, chemicals/heavy metals exposure, viral/bacterial infections, ultraviolet light and other ionizing and nonionizing radiation exposures [124].

The presence of stress proteins indicates healthy repair action by an organism and is considered beneficial up to a point as a protective mechanism. According to Blank and Goodman [201], "The 20 different stress protein families are evolutionarily conserved and act as 'chaperones' in the cell when they 'help' repair and refold damaged proteins and transport them across cell membranes. Induction of the stress response involves activation of DNA." Stress proteins are also considered a yardstick to determine what living cells experience as stress that requires remediation in the first place — something not always obvious, especially with subtle environmental exposures like low-level EMF barely above natural background levels.

Whether an effect is thermal or nonthermal, adverse or simply observed biologically, has been subject to fierce debate for decades; thus tissue-heating DNA pathways are also central to this paper. Heat as a cellular stressor was first observed in the 1960s by Italian researcher Ferruccio Ritossa in fruit flies (*D. melanogaster*) when experimental temperatures were accidentally raised by a few degrees and he observed enlarged chromosomes at particular sites. (*Drosophilae* are often used in research because they only have four pairs of chromosomes, are relatively easy to work with, have a fast breeding cycle, and lay numerous eggs.) As cited in Blank [124], as Ritossa's observation became better understood, with effects subsequently seen over decades in animals, plants and yeast cells, it came to be called the "heat shock response." Extensive research established that the heat shock response lead to the formation of a unique protein class — heat shock proteins (HSP) that repair other proteins from potentially fatal temperature damage, as well as assist cells to be more thermo-tolerant. Research has gone on to prove that cells produce other similar proteins to various stressors, now generally called stress proteins but most are still categorized as "HSP" from the original demarcation.

Goodman and Blank [202, 203] found that EMF is a cellular stressor even at low intensities in the absence of elevated temperatures. They found the protein distribution patterns synthesized in response to ELF-EMF resembled those of heat shock with the same sequence of changes even though the energy of the two stimuli differed by many orders of magnitude. Their results indicated that ELF-EMF stimulates a similar gene expression pathway as that of thermal shock and is itself a cellular stressor. Of particular significance is the fact that over-expression of stress genes is found in a number of human tumors and is characteristic of a variety of neoplasia [202]. Increased stress proteins are seen in numerous animal model studies pertinent to wildlife.

Blank and Goodman [201] further noted that both ELF and RFR activate the cellular stress response despite the large energy difference between them; that the same cellular pathways respond in both frequency ranges; and that models suggest that EMF can interact directly with electrons in DNA. They note that low energy EMF interacts with DNA to induce the stress response while the increased energy in RFR can lead to DNA strand breaks. *As such, this makes the stress response a frequency-dependent direct and indirect cause of DNA damage — a significant finding.* They concluded that exposure standards should not be based on exposure intensity alone but on biological responses long before thermal thresholds are met or crossed.

Resonance and geomagnetic fields

There are other important direct and indirect ways that EMFs interact with and effect biological systems, including various forms of resonance — cyclotron, electron paramagnetic, nuclear, and stochastic — as well as through inherently produced biological materials such as magnetite found in bird brains and many other species (see below).

Resonance is the phenomenon that occurs when a certain aspect of a force (like a frequency wave) matches a physical characteristic (like a cell or whole living organism) and the power inherent in the force is transferred to the physical object causing it to resonate or vibrate. Within the object, the resonance is self-perpetuating. The classic example is of an opera singer hitting high C in the presence of a crystal goblet for a sustained period until it shatters.

Following the work of Blackman et al. [197] who found the Earth's local geomagnetic fields (LGF) could influence calcium ions moving through membrane channels (see above), Liboff [198, 199] proposed that cyclotron resonance was a plausible mechanism for coupling interactions between the LGM and living cells. Liboff found cyclotron resonance consistent with other indications that showed many membrane channels have helical configurations; that the model could apply to other circulating charged components within the cell; and that cyclotron resonance could lead to direct resonant electromagnetic energy transfer to selected cell compartments.

All resonance is based on a *relationship*. Cyclotron resonance is based on the relationship between a constant magnetic field and an oscillating (time-varying) electric or magnetic field that can affect the motion of charged particles such as ions, some molecules, electrons, atomic nuclei, or DNA in living tissue. Living systems are filled with charged particles necessary for life, including calcium, sodium, lithium, and potassium ions that all pass through the cell membrane and are capable of affecting DNA. Cyclotron resonance occurs when an ion is exposed to a steady magnetic field (such as the Earth's) which causes the ion to move in a circular orbit at a right angle to the field. The speed of the orbit is determined by the charge and mass of the ion and the strength of the magnetic field. If an electric field is added that oscillates at exactly the same frequency and that is also at a right angle to the magnetic field, energy will be transferred from the electric field to the ion causing it to move faster. The same effect can be created by applying an additional magnetic field parallel to the constant magnetic field. This is important because it provides a plausible mechanism for how living cells interact with both natural and artificial fields, and explains how vanishingly low levels of EMFs can create major biological activity when concentrated on ion particles. It also points to living systems' ability to demodulate — or take direction from — certain aspects of electromagnetic information from both natural and artificial exposures [7]. Resonance should not be underestimated. It applies to all frequencies and is not based on power density alone.

Another subtle energy relationship in biology is called stochastic resonance that has been determined to be significant in how various species interact with their natural environments, in some instances for their survival. Stochastic resonance is a phenomenon where a signal below normal sensing can be boosted by adding wide-spectrum white noise signals. The frequencies in the white noise that match the original signal's frequencies will resonate with each other and amplify the original signal while not amplifying the rest of the white noise. This increase in what is called the signal-to-noise ratio makes the original signal more prominent. Some fish, for instance, can "hear" predators better in the noise of running water than in still water due to stochastic resonance (see "Fish" below.).

The signal-to-noise ratio has been a prominent aspect of EMF research with some scientists long holding that energy exposures below the body's natural signal-to-noise ratio could not possibly damage living tissue. But the most recent research that finds effects to DNA from low intensity EMF indicates that many variables affect biological processes, often in nonlinear patterns far below the signal-to-noise ratio. Some of the most cutting edge research — with an eye toward treating human *in utero* birth defects and adult limb regeneration — is being done by manipulating the electric charge across cell membranes (called membrane potential) via intentional manipulation of genes that form ion channels. Pai et al. [204] found that by putting ion channels into cells to raise the voltage up or down, they could control the size and location of the brain in embryonic African clawed frogs (*Xenopus laevis*), thus demonstrating the importance of microcurrents on membrane potential in growth and development. The research group also studied endogenous bioelectricity on clawed frog brain patterning during embryogenesis, noting that early frog embryos exhibit a characteristic hyperpolarization of cells lining the neural tube. Disruption of this spatial gradient of the transmembrane potential (V_{mem}) diminished or eliminated the expression of early brain markers in frogs, causing anatomical mispatterning, including absent or malformed regions of the brain. This effect was mediated by voltage-gated calcium signaling and gap-junctional communication. The authors hypothesized that voltage modulation is a tractable strategy for intervention in certain classes of birth defects in humans but they did not make the leap to potential environmental damage to other species from such ambient exposures.

In general, whether direct, indirect, or synergistic, to understand ambient effects to wildlife, one also needs to know if effects are cumulative, what compensatory mechanisms a species may have, and when or if homeostasis will deteriorate to the point of no return [205]. In looking at environmental contaminants, we have historically focused on chemicals for both direct and indirect effects such as endocrine disruption. But primary biological manifestation is more physical than chemical since the only thing that distinguishes one chemical from another on the Periodic Table is the amount of electrons being traded up and down on the scale. Chemicals are actually secondary manifestations of initial atomic principles, not the other way around. Plus, the synergistic effects of the Earth's natural fields can no longer be dismissed as an interesting artifact that is not biologically active or relevant. All living systems are first and foremost expressions of biological energy in various states of relationship.

For a Table of more low-level effects studies on DNA, see Part 2, Supplements 1 and 2.

What the studies show

The literature is voluminous on EMF effects to nonhuman species, going back at least to the 1930s using modern methods of inquiry. We have, after all, been using animal, plant, and microbial models in experiments for decades. We may in fact know *less* about effects to humans than to other species.

In this paper, we focused on exposures common in today's environment. In Part 1, Rising Background Levels, we defined low level RFR as power density of 0.001 mW/cm^2 (1 μW/cm^2), or a SAR of 0.001 W/kg. Part 2 Supplements 3 and 4 contain extensive tables with pertinent studies that apply to fauna and flora, respectively. The sections that follow in Part 2 on individual species include selected studies of particular interest to how EMF couples with, and potentially affects, wildlife. In most studies, as illustrated in Part 2, Supplement 3, the intensity of the incident EMF was provided in μW/cm^2 or V/m. To be consistent throughout the paper, we converted intensity in the studies to μW/cm^2. However, such conversion (i.e. V/m to μW/cm^2) tends to overestimate the exposure level and does not represent the full picture. Therefore where studies provided the amount of energy absorbed, e.g., the specific absorption rate (SAR), they were also included in Supplement 3 (in W/kg). Very low levels of energy absorption have shown effects in all living organisms studied.

Levitt and Lai [167] reported numerous biological effects from RFR at very low intensities and SARs comparable to far-field exposures within 197–492 ft (60–150 m) from cell towers. Included were *in vivo* and *in vitro* low-intensity RFR studies. Effects included genetic, growth and reproductive changes; increased permeability of the blood brain barrier; changes in stress proteins; behavioral responses; and molecular, cellular, genetic, and metabolic alterations. All are applicable to migratory birds, mammals, reptiles, and other wildlife and to plant communities, and to far-field exposures in general. (An update of that table appears in Part 2 Supplement 3.) It is apparent that environmental levels of RFR can elicit biological/health effects in living organisms. Although there are not enough data on low-intensity effects of static ELF-EMF to formulate a separate table, some effects of low-intensity static ELF-EMF are also described throughout this paper. ELF genotoxic effects can be found in Part 2, Supplement 2 and ELF in flora are also listed separately in Part 2, Supplement 4.

Effects, however, do not easily translate from the laboratory to the field. Cucurachi et al. [31] reported on 113 studies with a limited number of ecological studies. The majority were conducted in laboratory settings using bird embryos or eggs, small rodents, and plants. In 65% of the studies, effects from EMF (50% of the animal studies and about 75% of the plant studies) were found at both high and low intensities, indicating broad potential effects. But lack of standardization among the studies and limited sampling size made generalizing results from organism to ecosystem difficult. The researchers concluded that due to the number of variables, no clear dose–response relationship could be determined. Nevertheless, effects from some studies were well documented and can serve as predictors for effects to wild migratory birds and other wildlife.

As noted elsewhere throughout this paper, living organisms can sense and react to very low-intensity electromagnetic fields necessary for their survival as seen, for instance, in studies by Nicholls and Racey [206, 207] on bats and many others. Bats are already in serious trouble in North America from white-nosed syndrome and commercial wind turbine blade collisions. Due to the increased use of tracking radars for bird and bat studies, impacts will likely only increase [22, 23]. Presence of low levels of RFR from tracking radars could adversely affect bat foraging activity, which in turn could affect the composition of insect populations in the vicinity. Many insects, including honey bees (*Apis mellifera* var) and butterflies also depend on the Earth's electromagnetic fields for orientation and foraging. Presence of exogenous RFR can disturb these functions. This is particularly relevant for pollinator insects, such as bees and butterflies. Pollinators are essential in producing commercial crops for human consumption, including almonds, apples, pears, cherries, numerous berry crops, citrus fruits, melons, tomatoes, sunflowers, soybeans, and much more. The strongest disruptive effect to insect pollinators occurs at 1.2 MHz known as the Larmor frequency [208] which is related to radical pair resonance and superoxide radical formation. This is an important indication that effects from RFR are frequency-dependent.

Lai [77], citing Shepherd et al. [209], noted that EMF can disrupt the directional sense in insects. The fact that many animals are able to differentiate the north and south poles of a magnetic field known as the polarity compass [68, 73, 134, 210, 211] indicates they are susceptible to having that important sense impaired. These polarity compass traits confer survival competitiveness to organisms but are of particular concern since directional cues can be easily disturbed by man-made EMF [69, 134, 212].

Bird migration also depends on proper sensing and orientation to natural electromagnetic fields. A study by Engels et al. [213] showed that magnetic noise at 2 kHz–9 MHz (within the range of AM radio transmission) could disrupt magnetic compass orientation in migratory European Robins (*Erithacus rubecula*). The disruption can occur at a vanishingly low level of 0.01 V/m, or 0.0000265 $\mu W/cm^2$. Similar effects of RFR interference on magnetoreception have also been reported in a night-migratory songbird [214] and the European Robin [126]. Migration is already a taxing and dangerous activity for birds; adding another potential negative impact to bird survival is troubling.

Lai [77] also noted that another consideration is the “natal homing behavior” exhibited in some animals that return to their natal birth places to reproduce. These include sea turtles [89] eels [90]; and salmon [91]. Newborns of these animals are imprinted with the memory of the intensity and the inclination angle of the local geomagnetic field, later used to locate their place of birth when they return to breed. There are indications that man-made EMF can distort this imprinting memory to locate the site (see “Fish” and “Turtles”below). This has important consequences to the survival of particular species since it interrupts their reproductive processes.

It is clear that biological effects can occur at levels of man-made RFR in our present environment, thereby conceivably altering delicate ecosystems from a largely unrecognized danger.

Mammals

The majority of EMF laboratory research, some going back to the 1800s, has been conducted on a variety of mammal species using mice, rats, rabbits, monkeys, pigs, dogs, and others. (The second and third most used models are on insects and yeast respectively.) Thus, with varying degrees of confidence, we know a significant amount about how energy couples with, and affects, laboratory mammalian species across a range of frequencies. However, this evidence does not automatically transfer at the same confidence level regarding how this vast body of research applies to wildlife, including mammalian species.

There is unfortunately a dearth of field research on EMF effects to wildlife. Referenced below, however, are many potential indicator studies. The effects seen include reproductive, behavioral, mating, growth, hormonal, cellular, and others.

Rodents

Rodents are the most frequently used mammalian species in laboratory research across a range of frequencies and intensities. While studies are inconsistent, there are enough troubling indications regarding potential EMF implications for wildlife.

In the RFR range, there have been several reviews of fertility and other issues in rodent models with citations too numerous to mention here — see La Vignera e al. [215] and Merhi [216] — but some stand out as potentially pertinent to wildlife.

Magras and Xenos [217] investigated effects of RFR on prenatal development in mice, using RFR measurements and *in vivo* experiments at several locations near an "antenna park," with measured RFR power densities between 0.168 and 1.053 $\mu W/cm^2$. Divided into two groups were 12 pairs of mice, placed in locations of different power densities, and mated five times. One hundred eighteen newborns were collected, measured, weighed, and examined macro- and microscopically. With each generation, researchers found a progressive decrease in the number of newborns per dam ending in irreversible infertility. However, the crown-rump length, body weight, and number of lumbar, sacral, and coccygeal vertebrae, was improved in prenatal development of some newborns. RFR was below exposure standards and comparable to far-field exposures that mice could experience in the wild.

Aldad et al. [218], in a laboratory setting, investigated cell phone RFR (800–1,900 MHz, SAR of 1.6 W/kg) exposures in *in-utero* mouse models and effects on neurodevelopment and behavior. They found significant adult behavioral effects in prenatally exposed mice vs. controls. Mice exposed *in-utero* were hyperactive, had decreased memory and anxiety, and altered neuronal developmental programming. Exposed mice had dose-response impaired glutamatergic synaptic transmission onto layer V pyramidal neurons of the prefrontal cortex. This was the first evidence of neuropathology in mice from *in-utero* RFR at cell phone frequencies, now the most prevalent in the environment. Effects persisted into adulthood and were transmissible to next generations. Such changes can affect survival in wild populations.

Meral et al. [219] looked at effects in guinea pigs (*Cavia parcels*) from 900 MHz cell phone frequency exposures on brain tissue and blood malondialdehyde (MDA), glutathione (GSH), retinol (vitamin A), vitamin D(3) and tocopherol (vitamin E) levels, as well as catalase (CAT) enzyme activity. Fourteen male guinea pigs were randomly divided into control and RFR-exposed groups containing seven animals each. Animals were exposed to 890- to-915 MHz RFR (217 Hz pulse rate, 2 W maximum peak power, SAR 0.95 W/kg) from a cellular phone for 12 h/day (11 h 45 min stand-by and 15 min spiking mode) for 30 days. Controls were housed in a separate room without cell phone radiation. Blood samples were collected through cardiac puncture; biochemical analysis of brain tissue was done after decapitation at the end of the 30-day period. Results found MDA levels increased ($p<0.05$), and GSH levels and CAT enzyme activity decreased, while vitamins A, E and D(3) levels did not change significantly in the brain tissue of exposed animals. In blood samples of the exposed group, MDA, vitamins A, D(3) and E levels, and CAT enzyme activity increased ($p<0.05$), while GSH levels decreased ($p<0.05$). They concluded that cell phone radiation could cause oxidative stress in brain tissue of guinea pigs but more studies were needed to determine if effects are harmful and/or affect neural functions.

Lai et al. [220] found that Sprague-Dawley rats exposed to RFR during water maze testing showed spatial working memory deficits compared to controls. But similar studies [221–223] did not find performance effects in spatial tasks or alterations in brain development after similar exposures. However, subsequent studies in the last two decades have shown memory and learning effects in animals and humans after RFR exposure [224].

Several studies also investigated RFR behavioral effects in rodent models on learning, memory, mood disturbances, and anxiety behaviors with contradictory results. Daniels et al. [225] found decreased locomotor activity, increased grooming and increased basal corticosterone levels in rats exposed to RFR for 3 h per day at 840 MHz, but no significant differences were seen between controls and test animals in spatial memory testing or morphological brain assessment. The researchers concluded that RFR exposure may lead to abnormal brain functioning.

Lee et al. [226, 227] looked specifically at effects on pregnant mice and rat testicular function from combined RFR mobile network signal characteristics used in wide-band code division multiple access (W-CDMA) or CDMA used in 3G mobile communications. Experiments showed no observable adverse effects on development, reproduction, or mutation in tested subjects. And no significant effects were seen by Poulletier de Gannes et al. [228] in *in-utero* and post-natal development of rats with wireless fidelity (WiFi) at 2,450 MHz. Also, Imai et al. [229] found no testicular toxicity from 1.95 GHz W-CDMA.

One extremely high frequency (EHF) study comparable to 5G on a mouse model by Kolomytseva et al. [230] looked at leukocyte numbers and the functional activity of peripheral blood neutrophils. In healthy mice, under whole-body exposures to low-intensity extremely-high-frequency electromagnetic radiation (EHF, 42.0 GHz, 0.15 mW/cm^2, 20 min daily) found that the phagocytic activity of peripheral blood neutrophils was suppressed by about 50% ($p<0.01$ as compared with the sham-exposed control) in 2–3 h after the single exposure. Effects persisted for 1 day and thereafter returned to normal within 3 days. But a significant modification of the leukocyte blood profile was observed in mice exposed to EHF for 5 days after exposure cessation. Leukocytes increased by 44% ($p<0.05$ as compared with sham-exposed animals). They concluded that EHF effects can be mediated via metabolic systems and further said results indicated whole-body low-intenstiy EHF exposure of healthy mice had a profound effect on the indices of nonspecific immunity. These low levels will be common near 5G infrastructure.

In well-designed non-rodent mammal field studies, Nicholls and Racey [206, 207], found that foraging bats showed aversive behavioral responses near large air traffic control and weather radars. Four civil air traffic control (ATC) radar stations, three military ATC radars and three weather radars were selected, each surrounded by heterogeneous habitat. Three sampling points were carefully selected for matched habitats, type, structure, altitude and surrounding land class at increasing distances from each station. Radar field strengths were taken at three distances from the source: close proximity (<656 ft/200 m) with a high EMF strength >2 V/m (1.06 μW/cm^2), an intermediate line-of sight point (656–1,312 ft/200–400 m) with EMF strength <2 V/m, and a control location out of radar sight (>1,312 ft/400 m) registering 0 V/m. Bat activity was recorded three times for a total of 90 samples, 30 within each field strength category. Measured from sunset to sunrise, they found that bat activity was significantly reduced in habitats exposed to an EMF greater than 2 V/m compared to 0 EMF sites, but such reduced activity was not significantly different at lower EMF levels within 400 m of the radar. They concluded that the reduced bat activity was likely due to thermal induction and an increased risk of hyperthermia. This was a large field study near commercial radar installations with mostly high intensity exposures but low-level effects cannot be excluded given known magneto-sensitivity in bats.

In another field study using a small portable marine radar unit significantly less powerful than their earlier measured field study, Nicholls and Racey [207] found the smaller signal could also deter bats' foraging behaviors. First, in summer 2007, bat activity was compared at 20 foraging sites in northeast Scotland during experimental trials with radar switched on, and in controls with no radar signal. After sunset, bat activity was recorded for a period of 30 min with the order of the trials alternating between nights. Then in summer 2008, aerial insects were sampled at 16 of the sites using two small light-suction traps, one with a radar signal, the other a control. Bat activity and foraging were found significantly reduced when the radar signal was unidirectional, creating a maximized exposure of 17.67–26.24 V/m (83–183 μW/cm^2). The radar had no significant effect on the abundance of insects captured by the traps despite reduced bat activity.

Balmori [231] also noted significantly reduced bat activity in a free-tailed bat colony (*Tadarida teniotis*) where the number of bats decreased when several cell towers were placed 262 ft (80 m) from the colony.

In the ELF range, Janać et al. [232] investigated ELF/MF effects — comparable to powerline and stray voltage ground current — on motor behavior patterns in Mongolian gerbils (*Meriones unguiculatus)* and found age-dependent changes in locomotion, stereotypy, and immobility in 3- and 10-month-old males. Animals were continuously exposed to ELF-MF (50 Hz; 0.1, 0.25 and 0.5 mT) for seven days with behavior monitored for 60 min in the open field after the 1st, 2nd, 4th, and 7th day (to capture immediate effects), as well as three days after exposure (to capture delayed effects). They found that exposure to 3-month-old gerbils increased motor behavior (locomotion and stereotypy), and therefore decreased immobility. In the 3-month old gerbils, ELF/MF also showed a delayed effect (except at 0.25 mT) on stereotypy and immobility. In 10-month-old gerbils, ELF/MF of 0.1, 0.25 and 0.5 mT induced decreased locomotion, a slight increase in stereotypy, and pronounced stimulation of motor behavior. Increased motor behavior was observed three days after exposure, indicating long lasting effects. Researchers concluded that in 3- and 10-month-old gerbils, specific temporal patterns of motor behavior changes were induced by ELF/MF due to age-dependent morpho-functional differences in brain areas that control motor behavior.

The above is a very small sample of rodent studies. See Part 2 Supplements 1 and 2 for more genetic effects to rodents, and Supplement 3 for additional studies.

Bovines

Due to domestication and easy accessibility, there are numerous studies of dairy cows (*Bos taurus*) which appear particularly sensitive to both natural and man-made EMFs. Fedrowitz [71] published a thorough review with citations too numerous to mention here. Noted in the review is the fact that bovines, although easily accessible, are difficult to study with precision due to their size, which creates handling and dosimetric complexities. Also noted are that bovines today are at their milk- and beef-production physiological limits, and that the addition of even a weak stressor may be capable of altering a fragile bovine physiological balance. It is clear in the Fedrowitz review that cows respond to environmental exposures from a broad range of frequencies and properties, even as some studies lack good exposure assessment. RFR exposure created avoidance behavior, reduced ruminating and lying times, and alterations in oxidative stress enzymes among other problems, while ELF-EMF found contradictory evidence affecting milk production, fat content, hormone imbalances and important changes in other physiological parameters. Cows have also been found sensitive to stray voltage and transient harmonics with problematic milk production, health, reproduction and behavioral effects.

The question is how much of this body of work could translate to other ruminants and large mammals on-field or in the wild such as deer/cervids — behaviorally, reproductively, and physiologically. Stray voltage and ELF-EMF near powerlines, and rural area RFR from both ground-based and satellite transmitters, for instance, may affect wild migratory herds and large ungulates in remote areas that go undetected.

Bovines and RFR

Loscher and Kas [233] observed abnormal behavior in a dairy herd kept in close proximity to a TV and radio transmitter. They found reduction in milk yield, health problems, and behavioral abnormalities. After evaluating other factors, they concluded the high levels of RFR were possibly responsible. They removed one cow with abnormal behavior to another stable 20 km away from the antenna, resulting in normalization of behavior within five days. Symptoms reappeared when the cow was returned to the stable near the antennas. In a later survey, Loscher [234] also found effects of RFR on the production, health and behavior of farm animals, including avoidance behavior, alterations in oxidative stress parameters, and ruminating duration.

Balode [59] obtained blood samples from female brown cows from a farm close to, and in front of, the Skrunda Radar – located in Latvia at an early warning radar system operating in the 156–162 MHz frequency range — and samples from cows in a control area. They found micronuclei in peripheral erythrocytes were significantly higher in the exposed cows, indicating DNA damage.

Stärk et al. [235] investigated short-wave (3–30 MHz) RFR on salivary melatonin levels in dairy cattle, with one herd at a farm located at 1,640 ft/500 m (considered higher exposure) and a second control herd located 13,123 ft/4,000 m from the transmitter (considered unexposed). The average nightly magnetic field strength readings were 21-fold greater on the exposed farm (1.59 mA/m) than on the control farm (0.076 mA/m). At both farms, after initially monitoring five cows' salivary melatonin concentrations at 2-h intervals during night dark phase for 10 consecutive days, and with the short-wave transmitter switched off during three of the 10 days (off phase), samples were analyzed using a radioimmunoassay. They reported that mean values of the two initial nights did not show a statistically significant difference between exposed and unexposed cows and concluded that chronic melatonin reduction was unlikely. But on the first night of re-exposure after the transmitter had been off for three days, the difference in salivary melatonin concentration between the two farms (3.89 pg/ml, CI: 2.04, 7.41) was statistically significant, indicating a two-to-seven-fold increase of melatonin concentration. They concluded that a delayed acute effect of EMF on melatonin concentration could not be excluded and called for further trials to confirm results.

Hässig et al. [95] conducted a cohort study to evaluate the prevalence of nuclear cataracts in veal calves near mobile phone base stations with follow-up of each dam and its calf from conception through fetal development and up to slaughter. Particular emphasis was focused on the first trimester of gestation (organogenesis). Selected protective antioxidants (superoxide dismutase, catalase, glutathione peroxidase [GPx]) were assessed in the aqueous humor of the eye to evaluate redox status. They found that of 253 calves, 79 (32%) had various degrees of nuclear cataracts, but only 9 (3.6%) of calves had severe nuclear cataracts. They concluded that a relationship between the location of veal calves with nuclear cataracts in the first trimester of gestation and the strength of antennas was demonstrated. The number of antennas within 328–653 ft (100–199 m) was associated with oxidative stress and there was an association between oxidative stress and the distance to the nearest base station. Oxidative stress was increased in eyes with cataract (OR per kilometer: 0.80, confidence interval 95 % 0.62, 0.93). But the researchers further concluded that it had not been shown that the antennas actually affected stress. Hosmer-Lemeshow statistics showed an accuracy of 100% in negative cases with low radiation, and only 11.11% accuracy in positive cases with high radiation. This reflected, in their opinion, that there are a lot of other likely causes for nuclear cataracts beside base stations and called for additional studies on EMF during embryonic development.

Hässig et al. [96] further examined a dairy farm in Switzerland where a large number of calves were born with nuclear cataracts after a mobile phone base station was erected near the barn. Calves showed a 3.5 times higher risk for heavy cataracts if born there compared to the Swiss average. All usual causes for cataracts could be excluded but they nevertheless concluded that the incidence remained unknown.

Bovines and swine: ELF-EMF, stray electric current

Bovines appear unusually sensitive to ELF-EMF from stray current caused by both normal industrial and faulty grounding methods near high tension transmission lines close to dairy farms. Stray current can cover large areas and occurs when current flows between the grounded circuit conductor (neutral) of a farm and the Earth through dairy housing equipment like metal grates. It typically involves small, steady power frequency currents [99], not high transient shocks, although that also can sometimes occur under wet weather conditions. According to Hultgren [236], dairy cattle can perceive alternating currents exceeding 1 mA between the mouth and all four hooves with behavioral effects in cows usually occurring above 3 mA. Stray current can act as a major physical stressor in cows and other animals [237]. This may also be happening in wild migratory species moving through such areas.

At the request of dairymen, veterinarians, and county extension agents in Michigan, U.S., Kirk et al. [238] investigated stray current on 59 Michigan dairy farms. On 32 farms, stray current sources were detected. Where voltage exceeded 1 V alternating current, increased numbers of dairy cows showed abnormal behavior in the milking facility and increased prevalence of clinical mastitis. Recovery from the stray current-induced abnormalities was related to the type of abnormality and the magnitude of the exposure voltage.

Burchard et al. [239] in a small but well-controlled alternating exposure study of non-pregnant lactating Holstein cows found a longer estrous cycle in cows exposed to a vertical electric field of 10 kV/m and a uniform horizontal magnetic field of 30 μT at 60 Hz, compared to when they were not exposed. Rodriguez et al. [240] also found that exposure to EMF may increase the duration of the bovine estrous cycle. Burchard et al. [241] evaluated effects on milk production in Holsteins exposed to a vertical electric field of 10 kV/m and a uniform horizontal MF of 30 μT at 60 Hz and found an average decrease of 4.97, 13.78, and 16.39% in milk yield, fat corrected milk yield, and milk fat, respectively in exposed groups, and an increase of 4.75% in dry matter food intake. And Buchard et al. [242] in two experiments investigated blood thyroxine (T4) levels in lactating pregnant and non-lactating non-pregnant Holstein cows exposed to 10 kV/m, 30 μT EMF and found a significant change depending on the time of blood sampling in exposed groups. They concluded that exposure of dairy cattle to ELF-EMF could moderately affect the blood levels of thyroxine.

Hillman et al. [93, 94] reported that harmonic distortion and power quality itself could be another variable in bovine sensitivity to stray current. They found behavior, health, and milk production were adversely affected by transients at the 3rd, 5th, 7th, and triplen harmonic currents on utility power lines after a cell tower was found charging the ground neutral with 10+ V, causing the distortion. After installing a shielded neutral isolation transformer between the utility and the dairy, the distortion was reduced to near zero. Animal behavior improved immediately and milk production, which had been suppressed for three years, gradually returned to normal within 18 months.

Swine (*Sus scrofa domesticus*) — like rats and mice — have demonstrated aversive behavior to ELF-EMF electric fields. Hjeresen et al. [243] found miniature pigs, exposed to 60-Hz electric fields (30 kV/m for 20 h/day, 7 days/week up to 6 months) preferred an absence of the field during a 23.5-h period by spending more time out of the electric field than in it during sleep periods. And Sikov et al. [244], as part of a broad study of Hanford Miniature swine on reproductive and developmental toxicology (including teratology) over three breeding cycles found a strong association between chronic exposure to a vertical uniform electric field (60-Hz, 30-kV/m, for 20 h/day, 7 days/week) and adverse developmental effects vs. control. They concluded that an association exists between chronic exposure to strong electric fields and adverse developmental effects in swine (75% malformations in exposed vs. 29% sham) in first generation with consistent results in two subsequent generations.

Avian

Birds are important indicators of ecosystem well-being and overall condition. Even subtle effects can be apparent due to their frequent presence in RFR areas. Their hollow feathers have dielectric and piezoelectric properties, meaning they are conductive and capable of acting as a waveguide directing external RFR energy directly and deeply into avian body cavities [245–249]. Their thin skulls have both magnetite and radical pair receptors (see "Mechanisms" above) and they are highly mobile — often traveling across great migratory distances of tens to as much as a hundred thousand kilometers round-trip per year, resulting in potential multi-frequency cumulative effects from chronic near, middle, and far-field exposures. Avian populations are declining worldwide, especially among migratory species. This means that birds may be uniquely sensitive to adverse effects from environmental RFR since their natural habitat is air and they often fly at lateral levels with infrastructure emissions, bringing them that much closer to generating sources.

Tower and building construction, as direct obstacles, are known hazards to birds. One tower at 150 feet (46 m) above ground level is thought to account for as many as 3,000 songbird deaths per month in migratory pathways during peak migration [250] and communication tower collisions have been documented to kill more than 10,000 migratory birds in one night at a TV tower in Wisconsin [251, 252]. It has been known for years that the songbird populations of North America and Europe are plummeting. Only recently were towers considered a significant factor. But is the problem solely due to obstacles in direct migratory pathways or is something else involved?

RFR from towers may be acting as an attractant to birds due to their singular physiology. Avian eyes and beaks are uniquely magnetoreceptive with both magnetite and cryptchrome radical pair receptors. One definitive study by Beason and Semm [253] demonstrated that the common cell phone frequency (900-MHz carrier frequency, modulated at 217 Hz) at nonthermal intensities, produced firing in several types of nervous system neurons in Zebra Finches (*Taeniopygia guttate*). Brain neurons of irradiated anesthetized birds showed changes in neural activity in 76% of responding cells, which increased their firing rates by an average 3.5-fold vs. controls. Other responding cells exhibited a decrease in rates of spontaneous activity. The Beason and Semm study [253] could explain why birds may be attracted to cell towers, a theoretical premise they previously observed with Bobolinks (*Dolichonyx oryzivorus*; [254]).

RFR may also act as an avian stressor/irritant. Early work by Wasserman et al. [255] in field studies on 12 flocks of migratory birds subjected to various combinations of microwave power density and duration under winter conditions at Monomet, MA, using birds from two additional flocks as controls, showed increased levels of aggression in some of the irradiated birds.

Other research indicated a range of effects capable of broad adverse environmental outcomes. Laboratory studies by Di Carlo et al. [256] found decreases in heat shock protein production in chick embryos. The researchers used 915-MHz RFR on domestic chicken embryos and found that exposure typical of some cell phone emissions reduced heat shock proteins (HSP-70) and caused heart attacks and death in some embryos. Controls were unaffected. In replicated experiments, similar results were found by Grigor'ev [257] and Xenos and Magras [258]. Batellier et al. [259] found significantly elevated embryo mortality in exposed vs. sham groups of eggs incubated with a nearby cell phone repeatedly calling a 10-digit number at 3-min intervals over the entire incubation period. Heat shock proteins help maintain the conformation of cellular proteins during periods of stress. A decrease in their production diminishes cellular protection, possibly leading to cancer, other diseases, heart failure, and reduction in protection against hypoxia and ultraviolet light.

Not all results are adverse. Tysbulin et al. [260, 261] investigated both short and prolonged GSM 900 MHz cell phone signal exposure on embryo development in Quail (*Coturnix coturnix japonica),* irradiating fresh fertilized eggs during the first 38 h and 14 days of incubation using a cell phone in connecting mode continuously activated through a computer system. Maximum intensity of incident radiation on the egg's surface was 0.2 mW/cm^2. Results found a significant ($p<0.001$) increase in differentiated somites in 38-h exposed embryos and a significant ($p<0.05$) increase in total survival of embryos in eggs after 14 days exposure. They also found the level of thiobarbituric acid (TBA) reactive substances was significantly (p 0.05–0.001) higher in the brains and livers of hatchlings from exposed embryos and hypothesized that a facilitating effect exists due to enhanced metabolism in exposed embryos via peroxidation mechanisms. They concluded low-level nonthermal effects from GSM 900 MHz to quail embryogenesis is possible and that effects can be explained via a hormesis effect induced by reactive oxygen species (ROS).

Signaling characteristics such as pulsing vs. continuous wave are also important. Berman et al. [262], in a multi-lab study of pulsed ELF magnetic fields found a highly significant incidence of abnormalities in exposed chick eggs vs. controls. And Ubeda et al. [263] found irreversible damage to chick embryos from weak pulsed ELF-EMF magnetic fields that are common in the environment today. Initial studies on freshly fertilized chicken eggs were exposed during the first 48 h of post-laying incubation to pulsed magnetic fields (PMFs) with 100 Hz repetition rate, 1.0 μT peak-to-peak amplitude, and 500 μs pulse duration. Two different pulse waveforms were used, with rise and fall times of 85 μs or 2.1 μs. A two-day exposure found significant increased developmental abnormalities. In follow-up research, after exposure, eggs were incubated for an additional nine days without PMFs. Embryos removed from eggs showed an excess of developmental anomalies in the PMF-exposed groups compared with the sham-exposed samples. There was a high rate of embryonic death in the 2.1 μs rise/fall time. Results indicate PMFs can cause irreversible developmental changes, confirming that a pulse waveform can determine embryonic response to ELF magnetic fields common today.

Between 1999 and 2005, Fernie et al. for the first time investigated various potential reproductive effects on a captive raptor species — the American Kestrel (*Falco sparverius*) — from ELF-EMF equivalent to that of wild nesting pairs on power transmission lines. In a series of studies, captive pairs were typically bred under control or EMF exposure over 1–3 breeding cycles. In 1999, Fernie et al. [264] investigated photo phasic plasma melatonin in reproducing adult and fledgling kestrels, finding that EMFs affected plasma melatonin in adult male kestrels, suppressing it midway through, but elevating it at the end of the breeding season. In long-term, but not short-term EMF exposure of adults, plasma melatonin was supressed in their fledglings too which could affect migratory success. Molt happened earlier in adult EMF-exposed males than in controls. EMF exposure had no effect on plasma melatonin in adult females. In avian species, melatonin is involved in body temperature regulation, seasonal metabolism, locomotor activity, feeding patterns, migration, and plumage color changes important for mate selection. Melatonin also plays a key role in the growth and development of young birds. The researchers concluded it is likely that the results are relevant to wild raptors nesting within EMF exposures.

In 2000 Fernie et al. [265] focused on reproductive success in captive American Kestrels exposed to ELF-EMF, again equivalent to that experienced by wild reproducing kestrels. Kestrels were bred one season per year for two years under EMF or controlled conditions. In some years but not others, EMF-exposed birds showed a weak association with reduced egg laying, higher fertility, larger eggs with more yolk, albumen, and water, but thinner egg shells than control eggs. Hatching success was lower in EMF pairs than control pairs but fledging success was higher than control pairs in one year. They concluded that EMF exposure such as what kestrels would experience in the wild was biologically active in a number of ways leading to reduced hatching success.

Also in 2000, Fernie et al. [266] further investigated behavioral changes in American Kestrels to ELF-EMF, again in captive birds comparable to nesting pairs that commonly use electrical transmission structures for nesting, perching, hunting, and roosting. The amount of EMF exposure time of wild reproducing American Kestrels was first determined at between 25 and 75% of the observed time. On a 24-h basis, estimated EMF exposure in wild species ranged from 71% during courtship, to 90% during incubation. Then effects of EMFs on the behavior of captive reproducing kestrels were examined at comparable exposures of 88% of a 24-h period. Additionally, captive kestrels were exposed to EMF levels experienced by wild kestrels nesting under 735-kV power lines. There appeared to be a stimulatory/stress effect. Captive EMF females were more active, more alert, and perched on the pen roof more frequently than control females during courtship. EMF females preened and rested less often during brood rearing. EMF-exposed male kestrels were more active than control males during courtship and more alert during incubation. The researchers concluded that the increased activity of kestrels during courtship may be linked to changes in corticosterone, but not to melatonin as found in earlier work [264], but said the behavioral changes observed were unlikely to result in previously reported effects in EMF-exposed birds as noted above. They added that behavioral changes of captive EMF-exposed kestrels may also be observed in wild kestrels, with uncertain results.

In 2001 Fernie and Bird [267] looked at ELF-EMF oxidative stress levels in captive American Kestrels using the same test parameters described above to see if ELF-EMF exposure elicited an immune system response. In captive male kestrels bred under control or EMF conditions equivalent to those experienced by wild kestrels, short-term EMF exposure (one breeding season) suppressed plasma total proteins, hematocrits, and carotenoids in the first half of the breeding season. It also suppressed erythrocyte cells and lymphocyte proportions, but elevated granulosa proportions at the end of the breeding season. Long-term EMF exposure (two breeding seasons) also suppressed hematocrits in the first half of the reproductive period. But results found that only short-term EMF-exposed birds experienced an immune response, particularly during the early half of the breeding season. The elevation of granulocytes and the suppression of carotenoids, total proteins, and melatonin [264] in the same kestrel species indicated that the short-term EMF-exposed male kestrels had higher levels of oxidative stress due to an immune response and/or EMF exposure. The researchers noted that long-term EMF exposure may be linked to higher levels of oxidative stress solely through EMF exposure. Oxidative stress contributes to cancer, neurodegenerative diseases, and immune disorders. And in 2005, Fernie and Reynolds [268] noted most studies of birds and EMF indicate changes on behavior, reproductive success, growth and development, physiology and endocrinology, and oxidative stress — with effects not always consistent or in the same direction under EMF conditions. The entire body of work by this research group has implications for all wild species that encounter a wide range of EMFs on a regular basis.

In field studies on wild birds in Spain, Balmori [269] found strong negative correlations between low levels of microwave radiation and bird breeding, nesting, roosting and survival in the vicinity of communication towers. He documented nest and site abandonment, plumage deterioration, locomotion problems, and death in Wood Storks (*Mycteria americana*), House Sparrows (*Passer domesticus*), Rock Doves (*Columba livia*), Magpies (*Pica pica*), Collared Doves (*Streptopelia decaocto)*, and other species. While these species had historically been documented to roost and nest in these areas, Balmori [269] did not observe these symptoms prior to construction and operation of the cell phone towers. Results were most strongly negatively correlated with proximity to antennas and Stork nesting and survival. Twelve nests (40% of his study sample) were located within 656 ft (200 m) of the antennas and never successfully raised any chicks, while only one nest (3.3%), located further than 984 ft (300 m) never had chicks. Strange behaviors were observed at Stork nesting sites within 328 ft (100 m) of one or several cell tower antennas. Birds impacted directly by the main transmission lobe (i.e., electric field intensity > 2 V/m) included young that died from unknown causes. Within 100 m, paired adults frequently fought over nest construction sticks and failed to advance nest construction (sticks fell to the ground). Balmori further reported that some nests were never completed and that Storks remained passively in front of cell site antennas. The electric field intensity was higher on nests within 200 m (2.36 ± 0.82 V/m; 1.48 $\mu W/cm^2$) than on nests further than 300 m (0.53 ± 0.82 V/m, 0.074 $\mu W/cm^2$). RF-EMF levels, including for nests <100 m from the antennas, were not intense enough to be classified as thermal exposures. Power densities need to be at least 10 mW/cm^2 to produce tissue heating of even 0.5 °C [270]. Balmori's results indicated that RFR could potentially affect one or more reproductive stages, including nest construction, number of eggs produced, embryonic development, hatching and mortality of chicks and young in first-growth stages.

Balmori and Hallberg [271] and Everaert and Bauwens [272] found similar strong negative correlations among male House Sparrows (*Passer domestics)* throughout multiple sites in Spain and Belgium associated with ambient RFR between 1 MHz and 3 GHz at various proximities to GSM cell base stations. House Sparrow declines in Europe have been gradual but cumulative for this species once historically well adapted to urban environments. The sharpest bird density declines were in male House Sparrows in relatively high electric fields near base stations, indicating that long-term exposure at higher RFR levels negatively affected both abundance and/or behavior of wild House Sparrows. In another review, Balmori [25] reported health effects to birds that were continuously irradiated. They suffered long-term effects that included reduced territorial defense posturing, deterioration of bird health, problems with reproduction, and reduction of useful territories due to habitat deterioration.

Birds have been observed avoiding areas with high and low-intensity EMF, in daylight as well as nocturnally. An early study by Southern in 1975 [273] observed that gull chicks reacted to the U.S. military's Project Sanguin ELF transmitter. Tested on clear days in the normal geomagnetic field, birds showed significant clustering with predicted bearing corresponding with migration direction, but when the large antenna was energized they dispersed randomly. He concluded that magnetic fields associated with such conductors were sufficient to disorient birds. Larkin and Sutherland [274] observed that radar tracking of individual nocturnal migrating birds flying over a large alternating-current antenna system caused birds to turn or change altitude more frequently when the antenna system was operating than when it was not. The results suggested that birds sense low-intensity alternating-current EMF during nocturnal migratory flight.

In a well-designed, multi-year avian study of magneto-disruption, Engels et al. [213] investigated environmental broadband electromagnetic 'noise' emitted everywhere humans use electronics, including devices and infrastructure. They found migratory birds were unable to use their magnetic compass in the presence of a typical urban environment today. European Robins (*E. rubecula),* exposed to the background electromagnetic 'noise' present in unscreened wooden huts at the University of Oldenburg campus, could not orient using their magnetic compass. But when placed in electrically grounded aluminum-screened huts, creating Faraday cages that attenuated electromagnetic 'noise' by approximately two orders of magnitude, their magnetic orientation returned. The researchers were able to determine the frequency range from 50 kHz to 5 MHz was the most disruptive. When grounding was removed, or additional broadband electromagnetic 'noise' was deliberately generated inside the screened and grounded huts, birds again lost magnetic orientation abilities. They concluded that RFR's magneto-disruption effects are not confined to a narrow frequency band. Birds tested far from sources of EMFs required no screening to orient with their magnetic compass. This work documented a reproducible effect of anthropogenic electromagnetic ambient 'noise' on the behavior of an intact vertebrate. The magnetic compass is integral to bird movement and migration. The findings clearly demonstrated a nonthermal effect on European Robins and serves as a predictor for effects to other migratory birds, especially those flying over urban areas. Such fields are much weaker than minimum levels expected to produce any effects and far below any exposure standards.

Intensity windows in different species have also been found where effects can be more extreme at lower intensities than at higher ones due to compensatory mechanisms such as cell apotosis. Panagopoulos and Margaritas [34] found an unexpected intensity window at thermal levels around 10 mW/cm^2 RFR — not uncommon near cell towers — where effects were more severe than at intensities higher than 200 mW/cm^2. This window appeared at a distance of 8–12 in (20–30 cm) from a cell phone antenna, corresponding to a distance of about 66–98 ft (20–30 m) from a base station antenna. This could be considered a classic nonlinear effect and would apply to far-field exposures. Since cell base station antennas are frequently located within residential areas where birds nest, often at distances 20–30 m from such antennas, migratory birds, non-migratory avifauna, and other wildlife may be exposed up to 24-h per day.

Concerns also apply to impacts from commercial radio signals on migratory birds. The human anatomy is resonant with the FM bands so exposure standards are most stringent in that range. High intensity (>6,000 W) commercial FM transmitters are typically located on the highest ground available to blanket a wider area. Low powered FM transmitters (<1,000 W) can be placed closer to the human population. High intensity locations, which can be multi-transmitter sites (colloquially called "antenna farms") for other services, also provide convenient perches and nest sites for migratory birds. FM digital signals, which simulate pulsed waves, pose additional health concerns to migratory birds. This creates a dangerous frequency potential for protected migratory birds such as Bald Eagles with wingspans that extend to about 6 ft (1.83 m) — a resonant match with the length of the FM signal — creating a potential full-body resonant effect for both humans and Bald Eagles. Birds could experience both thermal and non-thermal effects.

All migratory birds are potentially at risk, including Bald Eagles, Golden Eagles, birds of conservation concern [275], federal and/or state-listed bird species, birds nationally or regionally in peril, as well as birds whose populations are stable. Sadly, addressing these concerns — beginning with independent research conducted by scientists with no vested interest in the outcomes — has not been a priority for government agencies or the communications industry.

Insects and arachnids

Insects are the most abundant and diverse of all animal groups, with more than one million described species representing more than half of all known living species, and potentially millions more yet to be discovered and identified. They may represent as much as 90% of all life forms on Earth. Though some are considered pests to farm crops and others as disease vectors, insects remain essential to life and planetary health. Found in nearly all environments, they are the only invertebrates that fly, but adults of most insect species walk, while some swim.

Because of these different environmental adaptations, different species will encounter different EMF exposures in varying degrees. For instance, ground-based walking insects may be more susceptible to effects from 60 Hz stray current while flying insects may be more susceptible to wireless exposures. However, all species tested have been affected across a range of the nonionizing electromagnetic bands.

Most insects have an exoskeleton, three-part body consisting of a head, thorax, and abdomen, three pairs of jointed legs, compound eye structures capable to seeing many more colors, widths, and images than humans, and one pair of antennae capable of sensing subtle meteorological changes and Earth's geomagnetic fields. They live in close harmony with the natural environment for survival and mating purposes. The most diverse insect groups coevolved with flowering plants, many of which would not survive without them. Most insect species are highly sensitive to temperature variations and climate alterations as they do not dissipate heat efficiently.

Nearly all insects hatch from eggs that are laid in myriad ways and habitats. Growth involves a series of molts and stages (called instars) with immature stages greatly differing from mature insects in appearance, behavior, and preferred habitat. Some undergo a four-stage metamorphosis (with a pupal stage) and others a three-stage metamorphosis through a series of nyphal stages.

While most insects are solitary, some — like bees, termites and ants — evolved into social networks, living in "cooperative" organized colonies that can function as one unit as evidenced in swarming behaviors. Some even show maternal care over eggs and young. They communicate through various sounds, pheromones, light signals, and through their antennae such as during the bees' "waggle dance" (see below).

As far back as the 1800s, even though testing methods were primitive by today's standards, researchers were curious about electromagnetism's effect on insect development, particularly teratogenicity [276]. Research on EMF across frequencies and insect populations has been ongoing since at least the 1930s with an eye toward using energy as an insecticide and anti-contaminant in grain, typically at high intensity thermal exposures that would not exist in the natural environment. Mckinley and Charles [277] found that wasps die within seconds of high frequency exposure. But not all early work was strictly high intensity, or all effects observed due to thermal factors.

There were interesting theories introduced by early researchers regarding how energy couples with various insect species. Frings [278] found larval stages are more tolerant to heat than adult insects with appendages that can act as conducting pathways to the body, and that the more specialized the insect species, the more susceptible they appear to microwave exposure. Carpenter and Livingstone [279] studied effects of 10 GHz continuous-wave microwaves at 80 mW/cm^2 for 20 or 30 min, or at 20 mW/cm^2 for 120 min on pupae of mealworm beetles (*Tenebrio molitor*) — clearly within thermal ranges. In control groups, 90% metamorphosed into normal adult beetles whereas only 24% of exposed groups developed normally, 25% died, and 51% developed abnormally. Effects were assumed to be thermally induced abnormalities until they simulated the same temperature exposure using radiant heat and found 80% of pupae developed normally. They concluded that microwaves were capable of inducing abnormal effects other than through thermal damage.

Fruit flies

Insects at all metamorphic stages of development have been studied using RFR including egg, larva, pupa and adult stages. Much work has been done on genetic and other effects with fruit flies (*D. melanogaster*) because of their well-described genetic system, ease of exposure, large brood size, minimal laboratory space needed, and fast reproductive rates. Over several decades Goodman and Blank, using ELF-EMF on *Drosophila* models, found effects to heat shock proteins and several other effects ([201]; and see "Mechanisms" above). It is considered a model comparable to other insects in the wild approximating that size. *D. melanogaster* may be the most lab-studied insect on Earth, although honey and related bee species, due to their devastating losses over the last decade and significance to agriculture, are quickly catching up.

Michaelson and Lin [50] noted that RFR-exposed insects first react by attempting to escape, followed by disturbance of motor coordination, stiffening, immobility and eventually death, depending on duration of exposure and insect type. For example, *D. melanogaster* survived longer than 30 min while certain tropical insects live only a few seconds at the same field intensity. Also noted were concentration changes in many metabolic products and effects to embryogenesis — the period needed for a butterfly to complete metamorphosis — with accelerated gastrulation and larval growth [17]. Michaelson and Lin [50] cited several negative studies with *D. melanogaster* exposed with continuous-wave RFR between 25 and 2,450 MHz on larval growth [280, 281] and mutagenicity [282]. This was after Heller and Mickey [283] found a tenfold rise in sex-linked recessive mutations with pulsed RFR between 30 and 60 MHz. It was among the earliest studies that found pulsing alone to be a biologically active exposure.

As reported in Michaelson and Lin [50], Tell [284] looked at *D. melanogaster*'s physiological absorption properties and found that a group of 6-day old male wild-type flies, exposed to 2,450 MHz for 55 min at an intense field caused a dramatic 65% reduction in body weight. This was thought to be from dehydration. They then sought to calculate the fruit fly's absorption properties in relation to plane electromagnetic waves and found that a fly has only a 1/1,000th effective area of its geometric cross section and thus is an inefficient test species for absorbed microwave radiation. However, they concluded that fruit flies were responsive to absorbed energy at thermal levels as a black body resonator at a power density of 1.044×10^4 mW/cm^2, corresponding to a thermal flux density of 0.562×10^{-3} cal. These are levels found in close proximity to broadcast facilities and cell phone towers today.

More recent investigations of RFR by Weisbrot et al. [285] using GSM multiband mobile phones (900/1,900 MHz; SAR approximately 1.4 W/kg) on *D. melanogaster* during the 10-day developmental period from egg laying through pupation found that non-thermal radiation increased numbers of offspring, elevated heat shock protein-70 levels, increased serum response element (SRE) DNA-binding and induced the phosphorylation of the nuclear transcription factor, ELK-1. Within minutes, there was a rapid increase of hsp70, which was apparently not a thermal effect. Taken together with the identified components of signal transduction pathways, the researchers concluded the study provided sensitive and reliable biomarkers for realistic RFR safety guidelines.

Panagopoulos et al. [286] found severe effects in early and mid-stage oogenesis in *D. melanogaster* when flies were exposed *in vivo* to either GSM 900-MHz or DCS 1,800-MHz radiation from a common digital cell phone, at non-thermal levels, for a few minutes per day during the first 6 days of adult life. Results suggested that the decrease in oviposition previously reported [287–289] was due to degeneration of large numbers of egg chambers after DNA fragmentation of their constituent cells which was induced by both types of mobile phone radiation. Induced cell death was recorded for the first time in all types of cells constituting an egg chamber (follicle cells, nurse cells and the oocyte) and in all stages of early and mid-oogenesis, from germarium to stage 10, during which programmed cell death does not physiologically occur. Germarium and stages 7–8 were found to also be the most sensitive developmental stages in response to electromagnetic stress induced by the GSM and DCS fields. Germarium was also found to be more sensitive than stages 7–8. These papers, taken collectively, indicate serious potential effects to all insect species of similar size to fruit flies from cell phone technology, including from infrastructure and transmitting devices.

Fruit flies have also been found sensitive to ELF-EMF. Gonet et al. [290] found 50 Hz ELF-EMF exposure affected all developmental stages of oviposition and development of *D. melanogaster* females, and weakened oviposition in subsequent generations.

Savić et al. [291] found static magnetic fields influenced both development and viability in two species of *Drosophila* (*D. melanogaster and D. hydei*). Both species completed development (egg-to-adult), in and out of the static magnetic field induced by a double horseshoe magnet. Treated vials with eggs were placed in the gap between magnetic poles (47 mm) and exposed to the average magnetic induction of 60 mT, while control groups were kept far from the magnetic field source. They found that exposure to the static magnetic field reduced development time in both species, but only results for *D. hydei* were statistically significant. In addition, the average viability of both species was significantly weaker compared to controls. They concluded a 60 mT static magnetic field could be a potential stressor, influencing on different levels both embryonic and post-embryonic fruit fly development.

Beetles

Other insect species also react to both ELF-EMF and RF-EMF. Newland et al. [292] found behavioral avoidance in cockroaches (*Periplaneta americana*) to static electric fields pervasive in the environment from both natural and man-made sources. Such fields could exist near powerlines or where utilities ground neutral lines into the Earth. They found insect behavioral changes in response to electric fields as tested with a Y-choice chamber with an electric field generated in one arm of the chamber. Locomotor behavior and avoidance were affected by the magnitude of the electric fields with up to 85% of individuals avoiding the charged arm when the static e-field at the entrance to the arm was above 8–10 kV/m. Seeking to determine mechanisms of perception and interaction, they then surgically ablated the antennae and cockroaches were unable to avoid electric fields. They concluded that antennae are crucial in cockroach detection of electric fields that thereby helps them avoid such fields. They also noted that cockroach ability to detect e-fields is due to long antennae which are easily charged and displaced by such fields, not because of a specialized detection system. This leads to the possibility that other insects may also respond to electric fields via antennae alone.

Vácha et al. [208] found that cockroaches (*P. americana*) were sensitive to weak RFR fields and that the Larmor frequency at 1.2 MHz in particular had a "deafening effect" on magnetoreception. The parameter they studied was the increase in locomotor activity of cockroaches induced by periodic changes in geomagnetic North positions by 60°. The onset of the disruptive effect of a 1.2 MHz field was found between 12 and 18 nT whereas the threshold of a field twice the frequency (2.4 MHz) fell between 18 and 44 nT. A 7 MHz field showed no significant effect even at maximal of 44 nT. The results suggested resonance effects and that insects may be equipped with the same magnetoreception system as birds.

Prolić et al. [293] investigated changes in behavior via the nervous system of cerambycid beetles (*Morimus funereus*) in an open field before and after exposure to a 50 Hz ELF-MF at 2 mT. Experimental groups were divided into several activity categories. Results showed activity increased in the groups with medium and low motor activity, but decreased in highly active individuals. High individual variability was found in the experimental groups, as well as differences in motor activities between the sexes both before and after exposure to ELF-MF. They assumed activity changes in both sexes were due to exposure to ELF-MF. Only a detailed analysis of the locomotor activity at 1-min intervals showed some statistically significant differences in behavior between the sexes.

Ants

Ants are another taxa found sensitive to EMF. Ants comprise between 15 and 25% of the terrestrial animal biomass and thrive in most ecosystems on almost every landmass on Earth. By comparison, the total estimated biomass (weight) of all ants worldwide equates to the total estimated biomass of all humans. Their complex social organization in colonies, with problem-solving abilities, division of labor, and both individual and whole colony communication via complex behavioral and pheromone signaling may account for their success in so many environments. Some ant species (e.g., *Formica rufa*-group) are known to build colonies on active earthquake faults and have been found to change behavior hours in advance of earthquakes [294], thus demonstrating predictive possibilities. Ants can modify habitats, influence broad nutrient cycling, spread seeds, tap resources, and defend themselves. Ants co-evolved with other species which led to many different kinds of mutual beneficial and antagonistic relationships.

Ants (e.g., *Solenopsis invictus*) are long known to be sensitive to magnetic fields both natural and manmade [295]. Ants (e.g., *Atta colombica*), like birds, have been found to be sensitive to the Earth's natural fields and to use both a solar compass on sunny days as well as a magnetic compass when there is cloud cover [296]. Jander and Jander [297] similarly found that the weaver ant (*Oecophylla* spp*)* had a more efficient light compass orientation with a much less efficient magnetic compass orientation, suggesting that they switch from the former to the latter when visual celestial compass cues become unavailable. There is evidence from Esquivel et al. [298] that such magnetoreception is due to the presence of varying sized magnetite particles and paramagnetic resonance in fire ants (*Solenopsis* spp). But Riveros and Srygley [299] found a more complex relationship toward a magnetic compass rather than the presence of magnetite alone when leafcutter ants (*Atta columbica)* were subjected to a brief but strong magnetic pulse which caused complete disorientation regarding nest-finding. They found external exposures could interfere with ants' natural magnetic compass in home path integration, which indicated evidence of a compass based on multi-domain and/or super-paramagnetic particles rather than on single-domain particles like magnetite.

Acosta-Avalos et al. [300] found that fire ants are sensitive to 60 Hz alternating magnetic fields as well as constant magnetic fields, changing their magnetic orientation and magnetosensitivity depending on the relation between both types of magnetic fields. Alternating current had the ability to disrupt ant orientation, raising the question of effects to wild species from underground wiring and the common practice of powerline utility companies using the Earth as a neutral return pathway to substations, creating stray current along the way [99].

Camelitepe et al. [301] tested black-meadow ants' (*Formica pratensis*) response under both natural geomagnetic and artificial earth-strength static EMFs (24.5 μT). They found that under the natural geomagnetic field, when all other orientational cues were eliminated, there was significant heterogeneity of ant distribution with the majority seeking geomagnetic north in darkness while under light conditions ants did not discriminate geomagnetic north. Under artificial EMF exposure, however, ant orientation was predominantly on the artificial magnetic N/S axis with significant preference for artificial north in both light and dark conditions. This indicated EMF abilities to alter ant orientation.

Ants are also shown to react to RFR [302, 303]. Cammaerts et al. [304] found that exposures to GSM 900 MHz at 0.0795 $\mu W/cm^2$ significantly inhibited memory and association between food sites and visual and olfactory cues in ants (*Myrmica sabuleti*) and eventually wiped out memory altogether. Subsequent exposure, after a brief recovery period, accelerated memory/olfactory loss within a few hours vs. a few days, indicating a cumulative effect even at very low intensity. The overall state of the exposed ant colonies eventually appeared similar to that exhibited by honey bee (*Apis mellifera*) colony collapse disorder. Although the impact of GSM 900 MHz radiation was greater on the visual memory than on the olfactory memory, the researchers concluded that such exposures — common to cell phones/towers — were capable of a disastrous impact on a wide range of insects using olfactory and/or visual memory, including bees. Many ant species (e.g., *Lasius neglectus, Nylanderia fulva, Camponotus* spp, *Hymenoptera formicidae, Solenopsis invicta,* among others*)* are attracted to electricity, electronic devices, and powerlines, thereby causing short circuits and fires. One hypothesis [305] is that the accumulation of ants in electrical equipment may be due to a few foraging "worker ants" seeking warmth and finding their way into small spaces, completing electrical contacts which then causes a release of alarm exocrine gland pheromones that attract other ants, which then go through the same cycle. In their study, they found that workers subjected to a 120 V alternating-current released venom alkaloids, alarm pheromones and recruitment pheromones that elicited both attraction and orientation in ants as well as some other unknown behavior-modifying substances. But given how ants are affected by EMFs in general it is likely that an attractant factor is also involved, not just warmth and small spaces.

There is evidence that ants use their antennae as "antennas" in two-way electrochemical communications. Over 100 hundred years ago, Swiss researcher Auguste Forel [306] removed the antennae of different species of ants and put them together in one place. What would have normally evoked aggressive behaviors among the different species did not occur and they got along as if belonging to the same colony. To Forel this indicated an ability of ant antennae to help different ant species identify each other.

Two mechanisms in ants have long been known for chemical receptivity as well as electromagnetic sensitivity. Recently Wang et al. [307] found evidence that chemical signals located specific to antennae vs. other body areas drew more attention from non-nest mates. When cuticular hydrocarbons (CHCs) were removed by a solvent from antennae, non-nest mates responded less aggressively than to other areas of the body, indicating that antennae reveal nest-mate identity, conveying and receiving social signals. Regarding magnetoreception, magnetic measurements [308–310] found the presence of biogenic magnetite was concentrated in antennae and other body parts of the ant *Pachycondyla marginata*. De Oliveira et al. [311] also found evidence of magnetite and other magnetic materials imbedded in various locations of antennae tissue in *P. marginata* indicating that antennae function as magnetoreceptors. The amount of magnetic material appeared sufficient to produce a magnetic-field-modulated mechanosensory output and therefore demonstrated a magnetoreception/transduction sense in migratory ants.

Ticks

Ticks are members of the order Arachnida, shared with scorpions and spiders. Recent papers in a tick species (*Dermacentor reticulates*) mirrors an attraction to some frequencies but not others. Vargová et al. [312, 313] found that exposure to RFR may be a potential factor altering both presence and distribution of ticks in the environment. Studies were conducted to determine potential affinity of ticks for RFR using radiation-shielded tubes (RST) under controlled conditions in an electromagnetic compatibility laboratory in an anechoic chamber. Ticks were irradiated using a Double-Ridged Waveguide Horn Antenna to RF-EMF at 900 and 5,000 MHz; 0 MHz served as control. Results found that 900 MHz RFR induced a higher concentration of ticks on the irradiated arm of RST whereas at 5,000 MHz ticks escaped to the shielded arm. In addition, 900 MHz RFR had been shown to cause unusual specific sudden tick movements during exposure manifested as body or leg jerking [312]. These studies are the first experimental evidence of RFR preference and behavioral changes in *D. reticulates* with implications for RFR introduced into the natural environment by devices and infrastructure. In a further study, Frątczak et al. [314] reported that *Ixodes ricinus* ticks were attracted to 900 MHz RFR at 0.1 $\mu W/cm^2$, particularly those infected with Rickettsia (spotted fever).

RFR may be a new factor in tick distribution, along with known factors like humidity, temperature and host presence, causing concentrated non-homogenous or mosaic tick distribution in natural habitats. Tick preference for 900 MHz frequencies common to most cell phones has possibly important ecological and epidemiological consequences. Increasing exposures from use of personal devices and infrastructure in natural habitats where ticks occur may increase both tick infestation and disease transmission. Further studies need to investigate this work, given the ubiquity of ticks today, their northward spread due to climate change in the Northern Hemisphere, and the increasing and sometimes life-threatening illnesses they transmit to humans, pets, and wildlife alike.

Monarch butterflies

The American Monarch butterfly (*D. plexippus)* has fascinated researchers for over 100 years as it is the only insect known to migrate in multi-generational stages [315–319], with the ability to find their exact birthplace on specific milkweed plants (*Asclepias* spp.) at great distances across land and oceans.

Monarchs (*D. plexippus*), found across Southern Canada, the United States, and South America, are generally divided by the Rocky Mountains into eastern and western migratory groups. Their population has precipitously declined by 99.4% since the 1980s (85% of that since 2017) and by 90% in the past two decades in both western and eastern populations [13, 15]. These steep declines are from numerous anthropogenic causes and may have already crossed extinction thresholds, thereby leaving us bereft not only of their beauty and inspiration, but also the perfect model for long-distance animal migration study in general.

Monarch butterflies are among North America's most beloved invertebrates. They have for centuries navigated thousands of miles/kilometers in an iconic fall migration from southern Canada and the mid- and northeastern U.S. to a small area of about 800 square miles (2,072 square kilometers) in Central Mexico where they once wintered over in the millions in small remote oyamel fir forests. By the time they reach their final destination, some will have traveled distances exceeded only by some migratory seabird species. The monarch is the only insect known to migrate annually over 3,000 miles (4,828 km) at ~ 250 miles (402 km) per day in the fall from the Canadian border to Mexico, and in the springtime back again. Similar to some bird species, it is the only butterfly known to have a two-way migration pattern. Monarchs are only followed by army cutworm moths (*Euxoa auxiliaris*) which may migrate several thousand kilometers to high elevation sites in the Rocky Mountains to escape lowland heat and drought.

But monarchs are more interesting than for this one amazing migrational feat alone. How they do this is a long-standing mystery since their entire lifecycle, including their two-stage spring return migration, is multi-generational indicating genetic factors in directional mapping since the final return fall migration south cannot be considered "learned." Several multifaceted mechanisms must come into play, as well as little understood complexities in how those mechanisms cooperate and trade off with each other under different environmental circumstances. Monarchs also go from solitary insects during early developmental stages confined to specific locations, then exhibit social insect behaviors after the third generation has reached northern latitudes and turned south during the final fall migration. And all of this happens in a brain the size of a grain of sand.

Reppert et al. [320] published an excellent review in 2010 on the complexities of monarch migration, noting "… recent studies of the fall migration have illuminated the mechanisms behind the navigation south, using a time-compensated sun compass. Skylight cues, such as the sun itself and polarized light, are processed through both eyes and likely integrated in the brain's central complex, the presumed site of the sun compass. Time compensation is provided by circadian clocks that have a distinctive molecular mechanism and that reside in the antennae. Monarchs may also use a magnetic compass, because they possess two cryptochromes that have the molecular capability for light-dependent magnetoreception. Multiple genomic approaches are being utilized to ultimately identify navigation genes. Monarch butterflies are thus emerging as an excellent model organism to study the molecular and neural basis of long-distance migration." Reppert and de Roode [321] updated that information in 2018.

Although it has been known for some time that monarchs use a circadian rhythm time-compensated directional sun compass [316, 322–338], many questions remain about its dynamics and concerns regarding effects from radiation.

Monarch antennae are known to contain magnetite [339, 340] and cryptochromes [335, 336, 341, 342] — both understood to play a role in magnetoreception (see "Mechanisms"above). One early study by Jones and MacFadden [343] found magnetic materials located primarily in the head and thorax areas of dissected monarchs. More recently, Guerra et al. [16] found convincing evidence that monarchs use a magnetic compass to aid their longest fall migration back to Mexico. Those researchers used flight simulator studies to show that migrants possess an inclination magnetic compass to assist fall migration toward the equator. They found this inclination compass is light-dependent, utilizing ultraviolet-A/blue light between 380 and 420 nm and noted that the significance of light (<420 nm) for an inclination compass function had not been considered in previous monarch studies. They also noted that antennae are important for an inclination compass since they contain light-sensitive magnetosensors. Like some migratory birds, the presence of an inclination compass would serve as an orientation mechanism when directional daylight cues are impeded by cloudy or inclement weather or during nighttime flight. It may also augment time-compensated sun compass orientation for appropriate directionality throughout migration. The inclination compass was found to function at earth-strength magnetic fields, an important metric.

The question remains: Can the magnetic compass in monarchs be disrupted by anthropogenic EMF like it does with geomagnetic orientation in migratory birds [213]. There is some indication this is possible. Perez et al. [330] found monarchs completely disorient after exposure to a strong magnetic field (0.4-T MF for 10 s, or approximately 15,000 times the Earth's magnetic field) immediately before release vs. controls. This is a high exposure but within range of man-made exposures today very close to powerlines.

Bees, wasps, and others

Pollinators, bees in particular, are keystone species without which adverse effects would occur throughout food webs and the Earth's entire biome were pollinators to disappear. Because of their central role and accessibility for research, bee studies have created a wealth of information, including regarding anthropogenic EMFs.

Bees — especially honey and bumble bees — are another iconic insect species beloved for their role in pollination; honey, propolis, royal jelly and beeswax production; their critical importance to our food supply; and their crucial role in global ecological health and stability. Found on every continent except Anarctica wherever there are flowering plants requiring insect pollination, there are over 16,000 known species of bees in seven different biological families, consisting of four main branches. Some species live socially in colonies while others are solitary. The western honey bee (*Apis mellifera*) is the best known and most studied due in part to its central role in agriculture. Bees feed on nectar for energy and pollen for protein/nutrients, and have co-evolved with many plant species in astoundingly complex ways. They are also highly sensitive to both natural and anthropogenic EMFs. Beeswax itself has electrical properties [50].

Human apiculture has been practiced since the time of ancient Egyptian and Greek cultures and bees have been closely studied since the 1800s. Almost all bee species, including commercially raised and wild species, are under decades-long multiple assaults. These include from pesticides, herbicides, climate change, various bacterial/viral diseases, infestations from parasitic mite species — particularly *Apis cerana*, *Varroa destructor* and *Varroa jacobsoni* beginning in the mid-1980s — and predation from introduced species that attack bees directly (e.g., the invasive giant bee-eating hornet *Vespa mandarinia*), as well as alter plant ecology over time to adversely affect bee food supply. Some have suggested that vanishing bees may also have to do with premature aging due to environmentally caused shortened telomeres [344].

Whole colony collapse disorder (CCD) is the most dramatic manifestation of domesticated bee demise in which worker bees abruptly disappear from a hive without a trace, resulting in an empty hive with perhaps a remaining queen and a few worker bees despite ample resources left behind. Few, if any, dead bees are ever found near the hive. CCD was first described in the U.S. in 2006 in Florida in commercial western honey bee colonies. Van Englesdorp et al. [345] quantified bee losses across all beekeeping operations and estimated that between 0.75 and 1.00 million honey bee colonies died in the United States over the winter of 2007–2008. Up until that survey, estimates of honey bee population decline had not included losses occurring during the wintering period, thus underestimating actual colony mortality.

The same phenomenon had been described by beekeepers in France in 1994 [346] — later attributed to the timing of sunflower blooming and the use of imidacloprid (IMD), a chlorinated nicotine-based insecticide or "neonicotinoid" being applied to sunflowers for the first time there [347]. Similar to DDT but considered safer for mammals including humans, neonicotinoids are a slow-release class of neurotoxins that block insect nervous systems via acetylcholine receptors, interfering with neuronal signaling across synapses. Sublethal doses can interfere with bee navigation.

Since then similar phenomena have been seen throughout Europe [348] and some Asian countries. Causal hypotheses included all of the above factors with varying foci on pesticide classes like neonicotinoids and genetically modified crops, but no single agent adequately explains CCD. Bromenshenk et al. [349] however, identified pathogen pairing/co-infection with two previously unreported RNA viruses — *V. destructor*-1, and Kakugo viruses, and a new irridescent virus (IIV) (*Iridoviridae*) along with *Nosema ceranae* — in North American honey bees that were associated with all sampled CCD colonies. The pathogen pairing was not seen in non-CCD colonies. Later cage trials with IIV type-6 and *N. ceranae* confirmed that co-infection with those two pathogens was more lethal to bees than either pathogen alone. Still many questions remain.

There are two national surveying groups in the U.S. — the U.S. Department of Agriculture (USDA) which began surveying managed bee populations in 2015 but funding was cut in late 2019; and the Bee Informed Partnership (BIP), a non-profit that coordinates with research facilities and universities. Prior to USDA's funding cuts, managed colonies decreased from CCD by 40% [350] with an additional 26% over the same quarter in 2019 [351]. BIP's survey period for April 1, 2018 through April 1, 2019 found U.S. beekeepers lost an estimated 40.7% of their managed honey bee colonies. The previous year had similar annual losses of 40.1%. The average annual rate of loss reported by beekeepers since 2010–11 was 37.8% [352].

Also in the U.S., for the first time in 2016, seven species of Hawaiian yellow-faced bees (*Hylaeus anthracinus*, *Hylaeus longiceps*, *Hylaeus assimulans*, *Hylaeus facilis*, *Hylaeus hilaris*, *Hylaeus kuakea*, and *Hylaeus mana*) were added to the federal endangered species list, as well as the rusty patched bumble bee (*Bombus affinis*) which, prior to the late 1990s, had been widely dispersed across 31 U.S. states [353]. Mathiasson and Rehan [354] examined 119 species in museum specimens in New Hampshire going back 125 years and concluded that 14 species found across New England were on the decline by as much as 90%, including the lesser studied leafcutter and mining bees that nest in the ground, unlike honeybees that nest in commercial hives or in trees, shrubs, and rock crevices in the wild.

Worldwide, many bee and other pollinator populations have also declined over the last two decades. Managed honey bee (*Apis mellifera*) colonies decreased by 25% over 20 years in Europe and 59% over 58 years in North America, with many wild bumble bee populations in Europe and North America having gone locally extinct [355–358]. But while dramatic range contractions have been seen, not all bees in all places are declining; some populations are growing depending on opportunistic and species-adaptability factors. For many species data are still insufficient, of poor quality, or nonexistent [359]. In addition, bee declines can affect flora survival. Miller-Struttmann et al. [360] recorded flower declines of 60% with 40 years of climate warming in alpine meadows — areas largely protected from land-use changes. Insects are highly sensitive to temperature changes.

A comprehensive UK survey of pollinator species [361] found that of 353 wild bee and hoverfly species across Britain from 1980 to 2013, 25% had disappeared from the places they had inhabited in 1980. Further estimates found a net loss of over 2.7 million in 0.6 mi (1 km) grid cells across all species. Declining pollinator evenness suggested losses were concentrated in rare species. Losses linked to specific habitats were also identified, with a 55% decline among wild upland species while dominant crop pollinators increased by 12%, possibly due to agricultural business interventions. The general declines found a fundamental deterioration in both wider biodiversity and non-crop pollination services.

There is no question that the huge diversity of pollinator species across the planet is suffering and that losses could be catastrophic with an estimated 90% of wild plants and 30% of world crops in jeopardy [362].

There is a likelihood that rising EMF background levels play a role. Bees have been known for decades to have an astute sense of the Earth's DC magnetic fields [363, 364] and rely on that perception for survival. For centuries beekeepers had noticed curious movements in bee hives but Austrian ethologist Karl von Frisch finally interpreted that activity in the 1940s, winning the Nobel Prize in 1973 for what came to be known as the honey bee "waggle dance." Through complex circles and waggle patterns, bees communicate the location of food sources to other members of the hive, using the orientation of the sun and the Earth's magnetic fields as a gravity vector, "dancing" out a map for hive members to follow like nature's own imbedded GPS. Bees also detect the sun's direction through polarized light and on overcast days use the Earth's magnetic fields, likely through the presence of magnetite in their abdominal area, and employ complex associative learning and memory [365].

Building on the earlier work of Gould et al. [119], Kobayashi and Kirschvink [52] noted that biogenic magnetite in honey bees is located primarily in the anterior dorsal abdomen. When small magnetized bits of wire were glued over those areas, it interfered with bees' ability to learn to discriminate magnetic anomalies in conditioning experiments, while nonmagnetized wire used in controls did not interfere [366]. Kirschvink and Kobayashi [367] found that when pulse-remagnetization techniques were used on bees trained to exit from a T-maze, that north-exiting bees could be converted to a south-exiting direction similar to what was observed in magnetobacteria and artificial reorientation by Blakemore [113]. Honeybees could also be trained to respond to very small changes in the geomagnetic field intensity [368]. Valkova and Vacha [369] discussed the possibility that honey bees use a combination of both radical pair/cryptochromes and magnetite to detect the geomagnetic field and use it for direction like many birds.

Given these sensitivities, bees may be reacting negatively through muti-sensory mechanisms to numerous sources of anthropogenic multi-frequency interference. Bumble bees (*Bombus terrestris*), a solitary species, and honey bees (*Apis mellifera*), a social hive species, are known to detect weak electric fields in different behavioral contexts, using different sensory mechanisms. Bumble bee e-field detection is likely through mechanosensory hairs [370–372] while honey bees reportedly use their antennae [373] that are electro-mechanically coupled to the surrounding e-field, taking place in the antennal Johnston's organ. Greggers et al. [373] found that honey bee antennae oscillate under electric field stimulation that can then stimulate activity in the antennal nerve. The latter occurs due to bees being electrically charged, and thus subject to electrostatic forces. Erickson [374] found different surface potentials in bees when leaving or entering hives, and Colin et al. [375] found seasonal variability between positive and negative charges in resting bees. It has also been shown that honey bees with removed or fixed antennae are less able to associate food reward with electric field stimuli and that bees emanate modulated electric fields when moving their wings (at about 230 Hz) and body (at about 16.5 Hz) during the waggle dance [373].

Electro-ecological interplay between flowers and pollinators has also been known since the 1960s and is critical to pollen transfer from flowers to bees [376–378]. It is known that as bees fly through the air, they accumulate a positive charge. Flowers, on the other hand, which are electrically grounded through their root systems, tend to have a negative charge in their petals created by surrounding air that carries around 100 V for every meter above ground. The accumulating positive charge around the flower induces a negative charge in its petals which then interacts with the positive charge in bees. In fact, bees do not even need to land on flowers for pollen transfer to occur; pollen can "jump" from the flower to the bee as the bee approaches due to charge differentials between the two. Thus, it appears that bees and flowers have been "communicating" via electric fields all along [379]. Bees can also learn color discrimination tasks faster when color cues are paired with artificial electric field cues similar to those surrounding natural flowers, but did not learn as readily in an electrically neutral environment [370].

This evidence points to floral e-fields being used in a co-evolutionary symbiotic relationship with bees. Clarke et al. [370, 371] even found that bumblebees can distinguish between flowers that give off different electric fields as floral cues to attract pollinators. Like visual cues, floral electric fields exhibit complex variations in pattern and structure that bumblebees can distinguish, contributing to the myriad complex cues that create a pollinator's memory of floral food sources. And because floral electric fields can — and do — change within seconds of being visited by pollinators, this sensory ability likely facilitates rapid and dynamic "information exchange" between flowers and their pollinators. Bumblebees can even amazingly use electric field information to discriminate between nectar-rewarding and unrewarding flowers [370].

Bees, locusts: ELF-EMF

Bees are also known to be sensitive to anthropogenic ELF-EMF. In 1973,Wellenstein [380] found that high tension powerlines adversely affected honey bees in wooden hives. This in part prompted the Bonneville Power Administration, an American federal agency operating in the Pacific Northwest under the U.S. Department of Energy (U.S. DOE), to investigate in 1974 [381–384] the effects of transmission lines on people, plants, and animals, including honey bees. The industry group, Electric Power Research Institute, also followed up on bee research [385, 386]. Both of those studies confirmed that transmission line electric fields can affect honey bees inside wooden hives as wood is a poor insulator and current can be induced when hives are placed in electric fields whether metal is present or not. The strength of the current inside the hive was influenced by the electric field strength, hive height, and moisture conditions with effects noticeable when induced current exceeded 0.02–0.04 mA. Depending on hive height, this occurred in field strengths between 2 and 4 kV/m. Effects included increased motor activity with transient increase in hive temperature, excessive propolis production (a resinous material used by bees as a hive sealer), decreased colony weight gains, increased irritability and mortality, abnormal production of queen cells, queen loss, decreased seal brood, and poor over-winter colony survival [387]. Impacts were most likely caused by electric shocks inside the hives [386, 388]. Effects were mitigated with grounded metal screen/shielding of hives [385]; however, bees appeared unaffected by magnetic fields which permeate metal shielding. The authors concluded that the shielding results indicated that bees were unaffected by flying through an external electric field up to 11 kV/m but noted that the study design could not reveal if subtle effects were occurring.

A more recent study of electric fields by Migdał [389] focused on honey bee behavioral effects on walking, grooming, flight, stillness, contact between individuals, and wing movement. They found that the selected frequency, intensity, and duration of exposure effects bees' behavioral patterns. Bees were exposed for 1, 3 and 6 h to E-fields at 5.0 kV/m, 11.5 kV/m, 23.0 kV/m, or 34.5 kV/m (with controls under E-field <2.0 kV/m). Within the exposed groups, results showed that exposure for 3 h caused decreased time that bees spent on select behaviors as well as the frequency of behaviors, whereas after both 1 and 6 h, the behavioral parameters increased within the groups. The researchers concluded that a barrier allowing behavioral patterns to normalize for some periods was indicated although none of the exposed groups returned to reference values in controls which adhered to normal behavioral patterns. Bees may have compensatory windows that appear to be both time and intensity dependent for E-fields. The significance of this study is that bees must accomplish certain activities — like flight frequency and the honey bee 'waggle dance' noted above — that are critical for life expectancy and survival. Even slight sequential disturbances may have cascading effects.

In an early-1988 study, Korall et al. [390] also found effects to bees from magnetic fields (MF). Bursts comparable to some of today's pulsed exposures of artificial MF at 250 Hz — the frequency of buzzing during the waggle dance — were applied parallel to natural EMF field lines and induced unequivocal 'jumps' of misdirection by up to +10° in bees during the waggle dance. This alone could cause directional confusion in hives. Continuous fields of 250 Hz with bursts perpendicular to the static MF however caused no effects. They concluded that a resonance relationship other than classic resonance models was indicated (see "Mechanisms" above). This early work has implications for subsequent digital pulsing and all wireless broadband technology.

More recent work on honey bees and ELF-EMF by Shepherd et al. [209] in 2018 found that acute exposure to 50 Hz fields at levels from 20–100 μT (at ground level underneath powerline conductors), to 1,000–7,000 μT (within 1 m of the conductors), reduced olfactory learning, foraging flight success toward food sources and feeding, as well as altered flight dynamics. Their results indicated that 50 Hz ELF-EMFs from powerlines is an important environmental honey bee stressor with potential impacts on cognitive and motor abilities.

Some wasp species have also been found sensitive to ELF-EMF. Pereira-Bomfim et al. [391] investigated the magnetic sensitivity of the social paper wasp (*Polybia paulista*) by analyzing wasp behavior in normal geomagnetic fields and in the presence of external magnetic fields altered by either permanent magnets (DC fields) or by Helmholtz coils (AC fields). They evaluated the change in foraging rhythm and colony behavior, as well as the frequency of departing/homeward flights and the behavioral responses of worker wasps located on the outer nest surface. They found that the altered magnetic field from the DC permanent magnet produced an increase in the frequency of departing foraging flights, and also that wasps grouped together on the nest surface in front of the magnet with their heads and antennae pointing toward the perturbation source, possibly indicating a response to a potential threat as a defense strategy. Controls showed no such grouping behavior. The AC fields created by the Helmholtz coils also increased foraging flights, but individuals did not show grouping behavior. The AC fields, however, induced wasp workers to perform "learning flights." They concluded that for the first time, *P. paulista* demonstrated sensitivity to an artificial modification of the local geomagnetic field and that mechanisms may be due to both cryptochrone/radical pairs and magnetite.

Another flying insect model — desert locust (*Schistocerca gregaria*) — was found susceptible to entrainment by ELF-EMF. In a complex study, Shepherd et al. [392] analyzed acute exposure to sinusoidal AC 50 Hz EMF (field strength range: 10 to 10,000 μT) vs. controls on flights of individual locusts tethered between copper wire coils generating EMFs at various frequencies and recorded on high-speed video. Results found that acute exposure to 50 Hz EMFs significantly increased absolute change in wingbeats in a field-strength-dependent manner. Applying a range of ELF-EMF close to normal wingbeat occurance, they found that locusts entrained to the exact frequency of the applied EMF. They concluded that ELF exposure can lead to small but significant changes in locust wingbeats, likely due to direct acute effects on insect physiology (vs. cryptochrome or magnetite-based magnetoreception) and/or behavioral avoidance responses to molecular/physiological stress. Wyszkowska et al. [393] also found effects on locusts — exposure to ELF-EMF above 4 mT led to dramatic effects on behaviour, physiology and increased Hsp70 protein expression. Such higher exposures may be found near high tension lines.

Bees: RF-EMF

The effects of RF-EMF on bees is of increasing interest since that is the fastest rising EMF environmental exposure of the past 30 years [369]. Beginning in the early 2000s, studies of cell phones placed in the bottom of hives began to appear. Honey bees showed disturbed behavior when returning to hives after foraging and under various RFR exposures [394–396]. Early methodologies, however, were not well designed or controlled. For instance, Favre [397] found increased piping — a distress signal that honey bees give off to alert hive mates of threats and/or to announce the swarming process. Both active and inactive mobile phone handsets were placed in close proximity to honey bees with sounds recorded and analyzed. Audiograms and spectrograms showed that active phone handsets had a dramatic effect on bee behavior in induced worker piping. This study was criticized by Darney et al. [398] for using music in the active RFR exposure which may have introduced a variable capable of affecting bee piping in response to the added sound alone.

In a complex study, Darney et al. [398] tested high frequency (HF) and ultra high frequency (UHF) used in RFID technology in order to develop a method to automatically record honey bees going in and out of hives. They glued RFID tags onto individual bee dorsal surfaces that were detected at the hive entrance by readers emitting HF radio waves. They then looked for possible HF adverse effects on honey bees' survival. Eight-day-old honey bees were exposed to HF 13.56 MHz or UHF 868 MHz RFR for 2 h split into ON and OFF periods of different durations. Dead bees were counted daily with cumulative mortality rates of exposed and non-exposed honey bees compared seven days after exposure. Two out of five experimental conditions found increased mortality, once after HF and once after UHF exposure, with OFF duration of 5 min or more, after which they recommended limiting honey bee exposure to RFR to less than 2 h per day. They also curiously concluded that the RFID parameters they used for monitoring hive activity presented no adverse effects but the multifrequency peak exposures and RFID attachments need further study in light of other works on RFID effects (see Part 1 for discussion of RFID.)

In another study using an active cell phone attached to hive frames, Odemer and Odemer [399] investigated RFR effects on honey bee queen development and mating success. Control hives had an inactive cell phone attached. After exposing honey bee queen larvae to GSM 900 MHz RFR during all stages of pre-adult development (including pupation), hatching of adult queens was assessed 14 days after exposure and mating success after an additional 11 days. They found that chronic RFR exposure significantly reduced honey bee queen hatching; that mortalities occurred during pupation but not at the larval stages; that mating success was not adversely affected by the irradiation; and that after exposure, surviving queens were able to establish intact colonies. They therefore determined that mobile phone radiation had significantly reduced the hatching ratio but not mating success if queens survived, and if treated queens successfully mated, colony development was not adversely affected. Even though they found strong evidence of mobile phone RFR damage to pupal development, they cautioned its interpretation, noting that the study's worst-case exposure scenario was the equivalent of a cell phone held to a user's head, not at a level found in typical urban or rural hive settings. They concluded that while no acute negative effects on bee health were seen in the mid-term, they also could not rule out effects on bee health at lower chronic doses such as found in ambient environments, and urgently called for long term research on sublethal exposures present in major city environments.

Sharma and Kumar [400] found similar abnormalities in honey bee behavior when they compared the performance of honey bees in RFR exposed and unexposed colonies. Two of four test colonies were designated and each equipped with two functional cell phones — a high exposure — placed on two different hive side walls in call mode at GSM 900 MHz. The average RFR power density was measured at 8.549 μW/cm^2 (56.8 V/m, electric field). One control colony had a dummy phone; the other had no phone. Exposure was delivered in 15 min intervals, twice per day during the period of peak bee activity. The experiment was performed twice a week during February to April. It covered two brood cycles with all aspects of hive behavior observed, including brood area comprising eggs, larvae and sealed brood; queen proficiency in egg-laying rate; foraging, flight behavior, returning ability; colony strength including pollen storage; and other variables. Results included a significant decline in colony strength and egg laying and reduced foraging to the point where there was no pollen, honey, brood, or bees by the end of the experiment. One notable difference in this study was that the number of bees leaving the hive decreased following exposure. There was no immediate exodus of bees as a result of exposure — instead bees became quiet, still, and/or confused "…as if unable to decide what to do…" the researchers said. Such a response had not been reported before. The authors concluded that colony collapse disorder is related to cell phone radiation exposures.

Vilić et al. [401] investigated RFR and oxidative stress and genotoxicity in honey bees, specifically on the activity of catalase, superoxide dismutase, glutathione *S*-transferase, lipid peroxidation levels and DNA damage. Larvae were exposed to 900 MHz RFR at field levels of 10, 23, 41 and 120 V m^{-1} for 2 h. At a field level of 23 V m^{-1} the effect of 80% AM 1 kHz sinusoidal and 217 Hz modulation were also investigated. They found that catalase activity and the lipid peroxidation levels significantly decreased in larvae exposed to the unmodulated field at 10 V m^{-1} (27 μW/cm^2) compared to the control. Superoxide dismutase and glutathione *S*-transferase activity in honey bee larvae exposed to unmodulated fields were not statistically different compared to the control. DNA damage increased significantly in larvae exposed to modulated (80% AM at 1 kHz) field at 23 V m^{-1} (140 μW/cm^2) compared to control and all other exposure groups. Their results suggested that RFR effects in honey bee larvae manifested only after certain EMF exposure conditions. Interestingly, they found that increased field levels did not cause a linear dose-response in any of the measured parameters, while modulated RFR produced more negative effects than the corresponding unmodulated field. They concluded that while honey bees in natural environments would not be exposed to the high exposures in their experiments, the results indicated additional intensive research is needed in all stages of honey bee development since the cellular effects seen could affect critical aspects of bee health and survival.

Kumar et al. [402] also found biochemical changes in worker honey bees exposed to RFR. A wooden box was designed with glass on the front and back and wire gauze for ventilation on two sides for both exposed bees and controls. Cell phones (same make, model, and network connection) were kept in listen-talk mode for 40 min. At intervals of 10, 20 and 40 min, 10 exposed and 10 control bees were collected at the same times. Hemolymph was then extracted from the inter-segmental region of bee abdomens and analyzed. Results included increased concentration of total carbohydrates in exposed bees in the 10 min exposure period compared to unexposed bees. Increasing the exposure time to 20 min resulted in a further increase in the concentration, but exposure at 40 min had a reverse effect with declines in carbohydrate concentration although it was still higher than controls. Hemolymph glycogen and glucose content also showed the same exposure pattern — increase in content up to 20 min after which a slight decline that was still higher than controls. Changes in total lipids/cholesterol — the major energy reserves in insects — can affect numerous biological processes. Some lipids are crucial membrane structure components while others act as raw materials in hormones and pheromones. Changes in these parameters are significant to every biological activity, including reproduction. Also of interest in this study was that as exposure time increased, the bees appeared to have identified the source of disturbance. There was a large scale movement of workers toward the talk-mode (with higher RFR exposure during transmission function) but not the listening mode. Bees also showed slight aggression and agitation with wing beating. The researchers hypothesized that this increased activity could be responsible for increased energy use thereby accounting for the decrease in concentration of carbohydrates and lipids in the 40 min exposed sample. The researchers concluded that cell phone radiation influences honey bee behavior and physiology. Sharma [403] had also reported increased glycogen and glucose levels in exposed honey bee pupa.

It must be pointed out that the cell phone emission conditions used in some experiments are questionable, in particular where there was no detail regarding how the phones were activated to achieve emission.

Not all studies demonstrated adverse effects. Mall and Kumar [404] found no apparent RFR effects on brood rearing, honey production or foraging behavior in honey bees in hives with cell phones inside or near a cell tower; and Mixon et al. [405] also found no effects of GSM-signal RFR on increased honey bee aggression. They concluded that RFR did not impact foraging behavior or honey bee navigation and therefore was unlikely to impact colony health.

Although there are several anectodal reports of insect losses near communication towers, there are only a handful of ambient RFR field studies conducted on invertebrates thus far. In the first large survey of wild pollinating species at varying distances from cell towers, Lázaro et al. [406] found both positive and negative effects from RFR in a broad range of insects on two islands (Lesvos and Limnos) in the northeastern Aegean Sea near Greece. Measured ambient RFR levels included all frequency ranges used in cell communications; broadcast RFR is absent on the islands. RFR values did not significantly differ between islands (Lesvos: 0.27 ± 0.05 V/m; Limnos: 0.21 ± 0.04 V/m; v3 2 = 0.08, p=0.779) and did not decrease with the distance to the antenna, possibly, they hypothesized, because some sampling points near the antenna may have been outside or at the edge of the emission lobes. They measured RFR at four distances of 50, 100, 200 and 400 m (164, 328, 656, and 1,312 ft, respectively) from 10 antennas (5 on Lesvos Island and 5 on Limnos Island) and correlated RFR values with insect abundance (numbers of insects) and richness (general health and vitality) — the latter only for wild bees and hoverflies. The researchers conducted careful flowering plant/tree- and- insect inventories in several low-lying grassland areas, including for wild bees, hoverflies, bee flies, other remaining flies, beetles, butterflies, and of various types. Honey bees were not included in this study as they are a managed species subject to beekeeper decisions and therefore not a wild species. On Lesvos 11,547 insects were collected and on Limnos 5,544. Varied colored pan traps for both nocturnal and diurnal samples were used. Results found all pollinator groups except butterflies were affected by RFR (both positively and negatively) and for most pollinator groups effects were consistent on both islands. Abundance for beetles, wasps, and hoverflies significantly decreased with RFR but overall abundance of wild bees and bee flies significantly increased with exposure. Further analysis showed that only abundance of underground-nesting wild bees was positively related to RFR while wild bees nesting above ground were not affected. RFR effects between islands differed only on abundance of remaining flies. On species richness, RFR tended to only have a negative effect on hoverflies in Limnos. Regarding the absence of effects seen in butterflies, they hypothesized that the pan trap collection method is not efficient for collecting butterflies (butterflies accounted for only 1.3 % of total specimens), and that a different sampling method might produce a different result. They concluded that with RFR's negative effects on insect abundance in several groups leading to an altered composition of wild pollinators in natural habitats, it was possible this could affect wild plant diversity and crop production. They further said the negative relationship between RFR on the abundance of wasps, beetles and hoverflies could indicate higher sensitivity of these insects to EMFs. Potentially more EMF-tolerant pollinators, such as underground-nesting wild bees and bee flies, may fill the vacant niches left by less tolerant species, thus resulting in their population increases. Another possible explanation is that EMFs may have particularly detrimental effects on more sensitive larval stages, and if so, larvae developing above ground (many beetles, wasps, hoverflies) may be more vulnerable than those developing underground since the former could be exposed to higher radiation levels.

In another field study, Taye et al. [407] placed five hives from December to May at varying distances of 1,000, 500, 300, 200 and 100 m (3,280, 1,640, 984, 656 and 328 ft, respectively) from a cell tower in India to measure flight activity, returning ability, and pollen foraging efficiency in honey bees (*Apis cerana* F). They found most effects closest to towers with the least returning bees at 100 m distance from the tower. Maximum foraging and return ability to the colonies was seen at 500 m, followed by 1,000 m and in descending order at 300 and 200 m, with the fewest returning bees at 100 m from the tower. The study also found that if bees returned, the pollen load per minute was not significantly affected.

Vijver et al. [408] however challenged the accuracy of distance from towers that is often used as a proxy for EMF gradients such as the study above. In a field study in The Netherlands, the researchers tested exposure to RFR from a cell base station (GSM 900 MHz) on the reproductive capacity of small virgin invertebrates during the most sensitive developmental periods spanning preadolescent to mating stages when reproductive effects would most likely be seen. Careful RFR field measurements were taken to determine null points in order to see if distance from emitters is a reliable RFR exposure model in field studies. They exposed four different invertebrate hexapod species. Springtails (*Folsomia candida*), predatory 'bugs' (*Orius laevigatus)*, parasitic wasps (*Asobara japonica)*, and fruitflies (*D. melanogaster*) were placed in covered pedestal containers within the radius of approximately 150 m of a 900 MHz mobile phone base station for a 48-h period. Six control groups were placed within 6.6 ft (2 m) of the treatment groups and covered in Farady cages. After exposure, all groups were brought to the laboratory to facilitate reproduction with resulting fecundity and number of offspring then analyzed. Results showed that distance was not an adequate proxy to explain dose-response regressions. After complex data synthesis, no significant impact from the exposure conditions, measures of central tendency, or temporal variability of EMF on reproductive endpoints were found although there was some variability between insect groups. As seen in other studies, distance is often used to create a gradient in energy exposures in studies but this study found the intensity of the transmitter and the direction of transmission to be more relevant, as did Bolte and Eikelboom [409, 410]. The direction and tilt of the transmitter determines whether the location of interest in field studies is in the main beam. In some instances, the closer promixity to the transmitter provided lower readings than further away, which they found between two locations. They also noted that the organisms selected in the study were small in size; springtails have a body length on average of 2 mm; wasps are about 3 mm, insect sizes from 1.4 to 2.4 mm, with the largest organisms tested being female fruit flies at about 2.5 mm length and males slightly smaller. Due to size, limited absorption and little energy uptake capacity, none of these insects are efficient whole-body receptors for 900 MHz waves with a wavelength of approximately 13 in (33 cm). But they further noted that this was a linear regression study and that biological effects are often non-linear. However, finding no distinct effects did not exclude physiological changes. They concluded that because of RFR exposure's increasing ubiquity, urgent attention to potential effects on biodiversity is needed.

The issue of insect size, nonlinearity, and antenna tilt/direction are factors of critical importance with 5G radiation which will create extremely complex near- and- far-field ambient exposures to species in urban and rural environments alike, not only from a densification of small cell antennas close to the ground but also from increased satellite networks circling in low Earth orbits (see Part 1). The range of frequencies used for wireless telecommunication systems will increase from below 6 GHz (2G, 3G, 4G, and WiFi) to frequencies up to 120 GHz for 5G which, due to smaller wavelengths, is therefore a better resonant match for small insects. An alarming study by Thielens et al. [411], drawing on numerous robust studies of RFR's decades-long use as a thermal insecticide, modeled absorbed RFR in four different types of insects as a function of frequency alone from 2 to 120 GHz. A set of insect models was obtained using novel Micro-CT (computer tomography) imaging and used for the first time in finite-difference time-domain electromagnetic simulations. All insects showed frequency-dependent absorbed power and a general increase in absorbed RFR at and above 6 GHz, in comparison to the absorbed RFR power below 6 GHz. Their simulations showed that a shift of 10% of the incident power density to frequencies above 6 GHz would lead to an increase in absorbed power between 3–370% — a large differential of serious potential consequence to numerous insect species.

Using a similar approach, Thielens et al. [412] focused on the western honey bee (*Apis mellifera*) with RF-EMF, using a combination of *in-situ* exposure measurements near bee hives in Belgium and numerical simulations. Around five honey bee models were exposed to plane waves at frequencies from 0.6 to 120 GHz — frequencies carved out for 5G. Simulations quantified whole-body averaged RFR absorbed as a function of frequency and found that the average increased by factors of 16–121 (depending on the specimen) when frequency increased from 0.6 to 6 GHz for a fixed incident electric field strength. A relatively small decrease in absorption was observed for all studied honey bees between 12 and 120 GHz due to interior attenuation. RFR measurements were taken at 10 bee hive sites near five different locations. Results found average total incident RFR field strength of 0.06 V/m; those values were then used to assess absorption and a realistic rate was estimated between 0.1 and 0.7 nW. They concluded that with an assumed 10% incident power density shift to frequencies higher than 3 GHz, this would lead to an RFR absorption increase in honey bees between 390 and 570% — a frequency shift expected with the buildout of 5G.

The two previous studies alone should give pause regarding environmental effects to invertebrates in these higher 5G frequency ranges.

Kumar [413] noted that RFR should be included as causal agents of bee CCD and that test protocols need to be standardized and established. Standardization is critical since many studies conducted with cell phones in hives are of very uneven quality and only indicative of potential effects. Placing cell phones in hives and assuming that RFR is the only exposure is inaccurate and misleading. ELF-EMFs are always present in all telecommunications technology, using pulsed and modulated signals [414]. All of these characteristics have been found to be highly biologically active apart from frequency alone. Such studies are likely capturing ELF effects without identifying them. All aspects of transmission, including transmission engineering itself from towers, need to be considered to determine accurate exposures and delineate causative agents. Vibration and heat must also be considered — cell phones in transmission mode could raise hive temperature quickly and bees are highly temperature sensitive. Due to “waggle dance” specifics in creating foraging “roadmaps,” bees should not be artificially relocated from hives to determine return ability after EMF exposure. They may be confused by relocation alone, adversely affecting their return abilities. Such tests also involve only one stressor when there are multiple stressors on insect species today. Understanding such co-factors is critical in determining accurate data and outcomes [415, 416]. Translating laboratory studies to field relevance has always been problematic but understanding EMF effects to insects has become urgent with ever increasing low-level ambient exposure from devices and infrastructure, especially in light of the new 5G networks being built. There are numerous variables that studies have yet to factor in. All of the above indicates a critical need to standardize experimental protocols and to take electro-ecology far more seriously, especially regarding aerial species in light of 5G.

Aquatic environments

There are fundamental electrical differences in conductivity (how well a material allows electric current to flow) and resistivity (how strongly a material opposes the flow of electric current) between air and water. Through water, EMF propagation is very different than through air because water has higher permittivity (ability to form dipoles) and electrical conductivity. Plane wave attenuation (dissipation) is higher in water than air, and increases rapidly with frequency. This is one reason that RFR has not traditionally been used in underwater communication while ELF has been. Conductivity of seawater is typically around 4 S/m, while fresh water varies but typically is in the mS/m range, thus making attenuation significantly lower in fresh water than in seawater. Fresh water, however, has similar permittivity as sea water. There is little direct effect on the magnetic field component in water mediums; propagation loss is mostly caused by conduction on the electric field component. Energy propagation continually cycles between electric and magnetic fields and higher conduction leads to strong attenuation/dissipation of EMF [98].

Because of these essential medium differences, electroreceptor mechanisms in aquatic species may be very different than those previously described in aerial species since air is a less conductive and resistive medium with less attenuation. That is why RFR travels more easily and directly through air. In aquatic species electroreception may be a result of transmission via water directly to the nervous system through unique receptor channels called Ampullae of Lorenzini [371]. In frogs, amphibians, fish, some worm species and others, receptor channels may be through the skin as well as via mechanisms more common in aerial species such as in the presence of magnetite (see “Mechanisms” above). There can be great variation in electroreceptive sensitivities in species inhabiting the two fundamentally different environments. Some amphibian species, however, have physical characteristics that span both mediums and therefore varied magnetoreception mechanisms.

Amphibians: frogs, salamanders, reptiles: regeneration abilities

Amphibians are the class of animals that include frogs, toads, salamanders, newts, some reptiles, and caecilians. The common term 'frog' is used to describe thousands of tailless amphibian species in the Order *Anura*. There are over 6,300 anuran species recorded thus far, with many more likely disappearing today due to climate change and other factors before we even knew they existed. Informal distinctions are made between frogs (thin-skinned species) and toads (thick, warty skins) but such distinctions are not used for taxonomic reasons. While the greatest concentration of diverse frog species is in tropical rainforests, they are widely found all over the world from the tropics to subarctic regions. Most adult frogs live in fresh water and/or on dry land while some species have adapted to living in trees or underground. Their skin varies in all manner of colors and patterns, from gray/green and brown/black to bright reds/yellows.

Frog skin is smooth and glandular — something of concern given nascent 5G technology (see Part 1) — and can secrete toxins to ward off predators. Frog skin is also semi-permeable which makes them highly susceptible to dehydration and pollutants. With radical weather shifts due to climate change and unpredictable swings between abnormal droughts followed by flooding in previously weather-stable regions, environmentally sensitive amphibians like frogs are considered bell-weather species. Frequently, time may be insufficient for some local/regional species to regenerate in between radical weather cycles, leading to population collapse.

Since the 1950s, there has been a significant decline in frog populations with more than one third of species today considered threatened with extinction while over 120 species are already believed to have gone extinct since the 1980s [10, 417, 418]. This amphibian decline is considered part of an ongoing global mass extinction, with population crashes as well as local extinctions creating grave implications for planetary biodiversity [419]. Amphibian extinction results are from climate change [420–422]; habitat loss/destruction [423, 424]; introduced species [425]; pollution [426], parasites [423, 427]; pesticides, herbicides and fungicides [428–430]; disease [431–435]; and increased ultraviolet-B radiation [436–439] among others. Anthropogenic sound pollution may also affect amphibian call rates and therefore impact reproduction [440] and artificial night lights affect male green frog (*Rana clamitaus melanota*) breeding [441]. Nonionizing electromagnetic fields may also play a role [442].

McCallum [443] calculated that the current extinction rate of amphibians could be 211 times greater than their pre-anthropogenic natural "background extinction" rate with the estimate rising 25,000–45,000 times if endangered species are also included in the computation. Today, declining amphibian populations are seen in thousands of species across numerous ecosystems, including pristine forested areas [418] and declines are now recognized among the most severe impacts of the anthropocene era [417, 442].

In addition, the number of frogs with severe malformations often incompatible with survival has risen sharply. Deformities are a complex issue related to physiology, anatomy, reproduction, development, water quality, changing environmental conditions, and ecology in general. Any time deformities are observed in large segments of wildlife populations there are indications of serious environmental problems [442]. Amphibian malformations are presumed due to an aggressive infectious fungal disease called Chytridiomycosisy, caused by the chytrid fungi *Batrachochytrium dendrobatodis* and *Batrachochytrium salamandrivorans* [432–435], and by parasites like *Ribeiroia ondatrae* [427]. Chytridiomycosis has been linked to dramatic amphibian declines and extinctions in North, Central, and South America, across sections of Australia and Africa and on Caribbean islands like Dominica and Montserrat. First identified in the 1970s in Colorado, U.S., it continues to spread globally at an alarming rate. Some populations witness sporadic deaths while others experience 100% mortality. There is no effective measure to control the disease in wild populations. Herbicides like glyphosate used in Roundup™ and atrazine, an endocrine disruptor, have also been found to cause severe malformations in both aquatic and land amphibian species from farmland pesticide/herbicide/fungicide runoff [428–430].

Frogs are known to be highly sensitive to natural and manmade EMF. Much research into the electrophysiology of frogs has been conducted because they are good lab models for human nervous system research, readily available, and easily handled. As far back as 1780, the Italian physicist Luigi Galvani discovered what we now understand to be the electrical basis of nerve impulses while studying static electricity (the only kind then known) when he accidentally made frog leg muscles contract while connected to the spinal cord by two different metal wires [444]. Galvani thought he had discovered "animal magnetism" but had actually discovered direct current and what later became known as a natural "current of injury"—the process by which an injured limb, for instance, produces a negative charge at the injury site that will later turn to a positive charge at the same site in some species as discovered in the 1960s by Robert O. Becker [444–451]. The earliest curiosity about natural current continued throughout the 1800s on various aspects of EMF and later throughout the 1920s to 1940s in pioneering researchers Elmer J. Lund [452–454] and Harold Saxon Burr [455–457] who worked to establish the first unified electrodynamic field theory of life, using hydra, frog, and salamander models among several others because of their morphogenic properties [458]. While frogs do not regenerate limbs the way salamanders do, both are so similar in taxonomy that curiosity was high in the early pioneers cited above throughout the 1960s to 1990s about what fundamentally allowed limb regeneration in one species, by not the other. Much was learned in the process about amphibian electrophysiology and cellular microcurrent in wound healing, as well as the electrophysiological properties of cellular differentiation, and eventually dedifferentiation pertinent to all contemporary stem cell research. Today the implications of this early work have gained new interest and targeted research regarding endogenous microcurrent and limb regeneration potential in humans, as well as dediffentiation/stem cell/morphogenesis in general for cancer treatment and other healing modalities. For a thorough review of studies on morphogenesis see Levin [459].

Ubiquitous low-level ambient EMFs today match some of the natural low-level microcurrent found critical to the fundamental processes of amphibian growth, reproduction, morphogenesis, and regeneration, lending new meaning to the early research that defined amphibian electrophysiology. We just need to make far better use of it to understand what role, if any, today's ambient exposures may be contributing to amphibian losses. (To compare tables between rising ambient EMF levels and low level effects in wildlife, see Part 1, Supplement 1; and Part 2, Supplement 3.)

Amphibian and reptile magnetoreception

How amphibians perceive natural and manmade EMF is similar to other species reviewed above and for amphibian mechanism reviews see Phillips et al. [460, 461]. Like many bird and insect species, evidence indicates that amphibians perceive the Earth's geomagnetic fields by at least two different biophysical magnetoreception mechanisms: naturally occurring ferromagnetic crystals (magnetite), and light-induced reactions via specialized photo-receptor cells (cryptochromes) that form spin-correlated radical pairs. Like birds, both mechanisms are present in some amphibians. Cryptochromes provide a directional 'compass' and the non-light-dependent magnetite provides the geographical 'map.'

In a thorough discussion of many magnetoreception studies in anura and urodela species, Diego-Rasilla et al. [462] found evidence that Iberian green frog tadpoles (*Pelophylax perezi*) had a light-dependent magnetic compass, and Diego-Rasilla et al. [463] also found that tadpoles of the European common frog (*Rana temporaria*) are capable of using the Earth's magnetic field for orienting along a learned y-axis. In these studies, they investigated if this orientation is accomplished using a light-dependent magnetic compass similar to that found in the earlier experiments with other species of frogs and newts [460, 462–470] or from some other factor. They concluded that the magnetic compass provided a reliable source of directional information under a wide range of natural lighting conditions. They also compared their findings to studies [470] that showed the pineal organ of newts to be the site of the light-dependent magnetic compass, as well as to recent neurophysiological evidence showing magnetic field sensitivity located in the frog frontal organ which is an outgrowth of the pineal gland. They hypothesized this work could indicate a common ancestor as long ago as 294 million years.

To determine if orientation using Earth's magnetic fields changed according to seasonal migration patterns, Shakhparonov and Ogurtsov [471] tested marsh frogs (*Pelophylax ridibundus*) in the laboratory to see if frogs could determine migratory direction between the breeding pond and their wintering site according to magnetic cues. Adult frogs (n=32) were tested individually in a T-maze 127 cm long inside a three-axis Helmholtz coil system (diameter 3 m). Maze arms were positioned parallel to the natural migratory route and measured in accordance with the magnetic field. Frogs were tested in the breeding migratory state and the wintering state, mediated by a temperature/light regime. Frog choice in a T-maze was evident when analyzed according to the magnetic field direction. They moved along the migratory route to the breeding pond and followed the reversion of the horizontal component of the magnetic field. The preference was seen in both sexes but only during the breeding migratory state. They concluded that adult frogs obtained directional information from the Earth's magnetic field.

Diego-Rasilla et al. [472] found similar evidence in two species of lacertid lizards (*Podarcismuralis and Podarcis lilfordi*) that exhibited spontaneous longitudinal body axis alignment relative to the Earth's magnetic field during sun basking periods. Both species exhibited a highly significant bimodal orientation along the north-northeast and south-southwest magnetic axis. Lizard orientations were significantly correlated over a five-year period with geomagnetic field values at the time of each observation. This suggested the behavior provides lizards with a constant directional reference, possibly creating a spacial mental map to facilitate escape. This was the first study to provide spontaneous magnetic alignment behavior in free-living reptiles although studies of terrapins have also found such spontaneous magnetic alignment [92, 323, 473]. Nishimura et al. [474, 475] also found sensitivity to ELF-EMF (sinusoidal 6 and 8 Hz, peak magnetic field 2.6 μT, peak electric field (10 V/m) in a lizard species (*Pogona vitticeps*) as demonstrated by significant increased tail lifting — a reproductive behavior. Interestingly, this tail-lifting response to ELF-EMF disappeared when the parietal eye was covered, suggesting that the parietal eye contributes to light-dependent magnetoreception and that exposure to ELF-EMFs may increase magnetic-field sensitivity in the lizards. A further experiment [476] showed that light at a wavelength lower than 580 nm was needed to activate the light-dependent magnetoreception of the parietal eye.

Amphibians: RF-EMF

Most frogs spend significant time on land but lay eggs in water where they hatch into tadpoles with tails and internal gills. However, some species bypass the tadpole stage and/or deposit eggs on land. Frogs are thus subject to exposures from both land-based and aquatic environments. A frog's life cycle is complete when metamorphosis into an adult form occurs. Many adverse effects do not appear until after metamorphosis is completed but problems have been found throughout the entire life cycle after exposures to both ELF-EMF and RFR.

Most early research on frogs (other than the Becker et al. regeneration inquiries noted above) was conducted at high thermal levels rarely encountered in the environment but some are included here because they helped delineate amphibian electrophysiology with effects later supported in low-level research. Some early work did use frog models to investigate cardiac effects with lower intensity exposures. Levitina [477] found that intact frog whole-body exposure caused a decrease in heart rate, while irradiation of just the head caused an increase. Using VHF frequency RFR at a power density of 60 μW/cm^2, *A*=12.5 cm, Levitina attributed the cardiac changes to peripheral nervous system effects but according to Frey and Siefert [478], because of the wavelengths used in that study, little energetic body penetration would be expected. They said a skin receptor hypothesis was therefore reasonable.

Following on Levitina's work, Frey and Seifert [478] — using isolated frog hearts, UHF frequencies that penetrate tissue more efficiently and low intensity pulse modulation — found that pulsed microwaves at 1,425 GHz could alter frog heart rates depending on the timing of exposure between the phase of heart action and the moment of pulse action. Twenty-two isolated frog hearts were irradiated with pulses synchronized with the P-wave of the ECGs; pulses were of 10 s duration triggered at the peak of the P-wave. Two control groups were used without RFR exposures with no effects noted. They found heart rate acceleration occurred with pulsing at about 200 ms after the P-wave. But if the pulse occurred simultaneously with the P-wave, no increases were induced. Arrhythmias occurred in half the samples, some resulting in cardiac cessation. Clearly from this study, RFR affected frog heart rhythm and could cause death.

A more recent work by Miura and Okada [479] found severe vasodilation in frog foot webs from RFR. In a series of three experiments using 44 anesthetized frogs (*X. laevis*) at thermal and non-thermal intensities, researchers exposed foot webs to pulsed RFR in three parameters with the monitor coil set at 1 V peak-to-peak: 100 kHz 582-3 mG and 174.76 V cm^{-1}; 10 MHz 7.3 mG and 2.19 V cm^{-1}; 1 MHz 539 mG and 16.11 V cm^{-1}. They found not only dilated arterioles of the web which had already been re-constricted with noradrenaline, but also dilated arterioles under non-stimulated conditions. Vasodilatation increased slowly and reached a plateau 60 min after radiation's onset. After radiation ceased, vasodilation remained for 10–20 min before slowly subsiding. Vasodilation was optimum when pulsation was applied 50% of the total time at a 10 kHz burst rate at 10 MHz. Effects were non-thermal. The pattern of vasodilation induced by warm Ringer solution was different from the vasodilatory effect of weak RFR, involving the level of intracellular Ca^{2+}. They hypothesized that since Ca^{2+} ATPase is activated by cyclic GMP which is produced by the enzymatic action of guanylate cyclase, RF-EMF may activate guanylate cyclase to facilitate cyclic GMP production. They concluded the study indicates for the first time that RFR dilates peripheral resistance vessels by neither pharmacological vasodilator agents nor physical thermal radiation, but that the precise mechanisms of activation of guanylate cyclase by RFR at the molecular level required further study. Vasodilation and constriction affects every part of the body and can affect all organ systems.

Prior to this, Schwartz et al. [480] found changes in calcium ions in frog hearts in response to a weak VHF field that was modulated at 16 Hz. This would be an exposure common in the environment. Calcium ions are critical to heart function.

Balmori [24–30, 442] and Balmori and Hallberg [271] have focused widely on EMF effects to wildlife, with two papers on amphibians. Balmori [442], in a review, noted that RFR in the microwave range is a possible cause for deformations and decline of some amphibian populations, and Balmori [481] in 2010 found increased mortality in tadpoles exposed to RFR in an urban environment. In the 2010 study, tadpoles of the common frog (*Rana temporaria*) were exposed to RFR from several mobile phone towers at a distance of 459 ft (140 m). Two month exposures lasted through egg phase to advanced tadpole growth prior to metamorphosis. RF and MW field intensity between 1.8 and 3.5 V/m (0.86–3.2 μW/cm^2) were measured with three different devices. Results determined that the exposed group (n=70) had low coordination of movements and asynchronous growth that resulted in both large and small tadpoles, as well as a disturbing 90% high mortality rate. In the control group (n=70) a Faraday cage was used under the same conditions. Controls found movement coordination to be normal and development synchronous with mortality rate at a low 4.2%. These results indicated that RFR from cell towers in a field situation could affect both development and mortality of tadpoles. Prior to this study, Grefner et al. [482] also found increased death in tadpoles (*Rana temporaria* L.) exposed to EMF, as well as higher mortality rates, and slower less synchronous development.

Mortazavi et al. [483] found changes in muscle contractions in frogs exposed to 900-MHz cell phone radiation for 30 min; gastrocnemimus muscles were then isolated and exposed to a switched on/off mobile phone radiation for three 10-min intervals. The authors reported RFR-induced effects on pulse height and latency period of muscle contractions. SARs of the nerve-muscle preparation were calculated to be 0.66 (muscle) and 0.407 (nerve) W/kg.

Rafati et al. [484] investigated the effects of RFR on frogs from mobile phone jamming equipment emitting RFR in the same frequencies as mobile phones. (Although illegal in many countries, jammers are nevertheless used to interfere with signals and stop communication.) The study sought to follow up on reports of non-thermal effects of RFR on amphibians regarding alterations of muscle contraction patterns. They focused on three parameters: the pulse height of leg muscle contractions, the time interval between two subsequent contractions, and the latency period of frog's isolated gastrocnemius muscle after stimulation with single square pulses of 1 V (1 Hz). Animals in the jammer group were exposed to RFR at a distance of 1 m from the jammer's antenna for 2 h while the control frogs were sham exposed. All were then sacrificed and isolated gastrocnemius muscles were exposed to on/off jammer radiation for three subsequent 10 min intervals (SAR for nerve and muscle of the different forms of jammer radiation was between 0.01 and 0.052 W/kg). Results showed that neither the pulse height of muscle contractions nor the time interval between two subsequent contractions were affected, but the latency period (time interval between stimulus and response) was statistically significantly altered in the RFR-exposed samples. They concluded the results supported earlier reports of non-thermal effects of EMF on amphibians including the effects on the pattern of muscle contractions. Control sham exposed samples showed no effects.

Amphibians, reptiles: ELF-EMF

Amphibians are highly sensitive to ELF-EMF. An early-1969 study by Levengood [485] using a magnetic field probe found increased high rates of teratogenesis in frogs (*Rana sylvatica*) and salamanders *(Ambystoma maculatum*). Two identical probes using different field strengths were employed — both operated in the kilogauss region with high field gradients. Amphibian eggs and embryos were exposed at various stages of development with gross abnormalities found in developing larvae vs. control. At the hatching stage severe abnormalities were noted in both anuran and urodele larvae from probe-treated eggs. Hatching abnormalities included microcephaly, altered development, and multiple oedematous growths. In probe-treated frogs there was a delay in the appearance of a high percentage of malformations until the climax stage of metamorphosis. Until that stage, the larvae were of the same appearance as control specimens, thus camouflaging the damage after just a brief treatment of early embryos. The frog abnormalities at metamorphosis differed from those in the hatching tadpoles and consisted mainly of severe subepidermal blistering and leg malformations including formation of multiple deformed limbs incompatible with life. Over 90% of the morphological alterations at metamorphosis climax were also found to be associated with deformed kidneys. The gastrula stages of development appeared to be the most sensitive in the delayed-effects category. While this was a high-field exposure experiment, it is an intensity that is found in some environments today especially near high tension lines and in abnormal ground current situations.

Neurath [486] also found strongly inhibited early embryonic growth of the common leopard frog (*Rana pipiens*) by a high static magnetic field with a high gradient (1T) — an exposure sometimes found in the environment — while Ueno and Iwasaka [487] found abnormal growth and increased incidence of malformations in embryos exposed to magnetic fields up to 8T but exposures that high are typically near industrial sites and rarely found in nature.

Severini et al. [488] specifically addressed whether weak ELF magnetic fields could affect tadpole development and found delayed maturation in tadpoles. Two cohorts of *X. laevis laevis* (Daudin) tadpoles were exposed for 60 days during immaturity to a 50 Hz magnetic field of 63.9–76.4 μT rms (root mean square, average values) magnetic flux density in a solenoid. Controls were two comparable cohorts remotely located away from the solenoid. The experiment was replicated three times. Results showed reduced mean developmental rate of exposed cohorts vs. controls (0.43 vs. 0.48 stages/day, $p< 0.001$) beginning from early larval stages; exposure increased the mean metamorphosis period of tadpoles by 2.4 days vs. controls ($p < 0.001$); and during the maturation period, maturation rates of exposed vs. control tadpoles were altered. No increases in mortality, malformations, or teratogenic effects were seen in exposed groups. The researchers concluded that relatively weak 50 Hz magnetic fields can cause sub-lethal effects in tadpoles via slowed larval development and delays in metamorphosis. Such exposures are found in the environment today in some locations and even though the changes were small, coupled with climate change, such sub-lethal effects may impact some wildlife populations in some environments.

In similar followup work, Severini and Bosco [489] found sensitivity to small variations of magnetic flux density (50 Hz, 22-day continuous exposure, magnetic flux densities between 63.9 and 76.4 μT) in tadpoles exposed to a stronger field vs. controls exposed to a weaker field. A significant delay in development of 2.5 days was found in exposed vs. controls. They concluded the delay was caused by the slightly different magnetic flux densities with results suggesting a field threshold around 70 μT in controlling the tadpole developmental rate.

Schlegel in 1997 found European blind cave salamanders (*Proteus anguinus*) and Pyrenean newts (*Euproctus asper)* to be sensitive to low level electric fields in water [490]. And Schlegel and Bulog [491] in followup work found thresholds of overt avoidance behavior to electric fields as a function of frequency of continuous sine-waves in water. Nine salamanders from different Slovenian populations of the urodele (*P. anguinus)* that included three specimens of its 'black' variety (*P. anguinus parkelj*) showed thresholds between 0.3 mV/cm (ca 100 nA/cm^2) and up to 2 mV/cm (670 nA/cm^2), with the most reactive frequencies around 30 Hz. Sensitivity included a total frequency range below 1 Hz (excluding DC) up to 1–2 kHz with up to 40 dB higher thresholds. These are ranges that may be found in the wild near high tension lines and utility grounding practices near water, by some underwater cabling, and by some RFR transmitters.

Landesman and Douglas in 1990 [492] found some newt species showed accelerated abnormal limb growth when pulsed electromagnetic fields were added to the normal limb regeneration process. While normal limb regeneration found normal regrowth patterns in 72% of specimens, 28% were abnormal. Abnormalities included loss of a digit, fused carpals, and long bone defects which occurred singly or in combination with one another. When exposure to a PEMF was added for the first 30 days post-amputation, followed by a 3–4 month postamputation period, a group of forelimbs with unique gross defects increased by an additional 12%. Defects (singly or in combination) included the loss of two or more digits with associated loss of carpals, absence of the entire hand pattern, and abnormalities associated with the radius and ulna. The researchers offered no explanation. Exposure intensities were similar to those used to facilitate non-juncture fracture healing in humans.

Komazaki and Takano in 2007 [493] found accelerated early development growth rates with 50 Hz, 5–30 mT alternating current exposures in the fertilized eggs of Japanese newts (*Cynops pyrrhogaster*). The period of gastrulation was shortened via EMF-promoted morphogenetic cell movements and increased $[Ca^{2+}]_i$. They said their results indicated that EMF specifically increased the $[Ca^2]_i$ of gastrula cells, thereby accelerating growth. This study only observed through the larval stages and they did not see any malformations under EMF exposures, which they attributed to possible differences in the intensity and mode of EMF.

With amphibians and some reptiles demonstrating high sensitivity to natural background EMF for important breeding and orientation needs, amphibians living in aquatic, terrestrial, and aerial environments (i.e. tree frog species) may be affected from multi-frequency anthropogenic EMF in ways we do not fully understand. There are potential effects — especially from 5G MMW that couple maximally with skin — to all aspects of their development and life cycles, including secondary effects.

Fish, marine mammals, lobsters, and crabs

Aquatic animals are exquisitely sensitive to natural EMF and therefore potentially to anthropogenic disturbance. The Earth's dipole geomagnetic field yields a consistent though varying source of directional information in both land and aquatic species for use in homing behavior, orientation during navigation and migration. This information is used both as a 'map' for positional information as well as a 'compass' for direction [494–497]. Aquatic species are known to be sensitive to static geomagnetic fields, atmospheric changes and sunspot activities [498]. For recent comprehensive reviews on magnetic field sensitivity in fish and effects on behavior, see Tricas and Gill [36] and Krylov et al. [33]. Some biological 'magnetic maps' may be inherited [499]. And for a recent extensive discussion of the Earth's natural fields and magnetoreception in marine animals with a focus on effects from electromagnetic surveys that use localized strong EMFs to map petroleum deposits under seabeds, see Nyqvist et al. [498] and below.

As mentioned above, because of the difference in conductivity of water and other factors, the way some aquatic species sense EMF may rely on unique modes of physiological perception, as well as those employed by terrestrial animals. There may also be sensory combinations not yet understood in some aquatic and semi-aquatic species. For instance, what role does the neural conductivity of whiskers (vibrissae) in seals, sea lions and walrus play other than for food finding? Aquatic species' dense network of whiskers is larger with greater blood flow than terrestrial species and can contain 1,500 nerves per follicle vs. cats at 200 per follicle. Seal whiskers also vary geometrically from terrestrial species and the largest part of the seal brain is linked to whisker function. Seals use whiskers to map the size, shape and external structure of objects and can find prey even when blindfolded. Their whiskers are also sensitive to weak changes in water motion [100]. But are they also using them as a location or directional compass in relation to the geomagnetic field? That has yet to be studied.

Unique sensory differences in aquatic species have long been documented. Joshberger et al. [500] noted that in 1,678 Stefano Lorenzini [501] was the first to describe a network of organs in the torpedo ray that became known as the Ampullae of Lorenzini (AoL). Its purpose was unknown for 300 years until Murray [502] measured AoL's electrical properties in elasmobranch fish — sharks, rays and skates. Later work [101, 503–508] confirmed and greatly added to this knowledge. Researchers now know that AoL is likely the primary mechanism that allows elasmobranch fish to detect and map a potential prey's physiology via the very weak changes in electric fields given off by prey's muscle contractions.

Individual ampullae are skin pores that open to the aquatic environment with a jelly-filled canal leading to an alveolus containing a series of electrosensing cells. Within the alveolus, the electrosensitive cells of the ampullae communicate with neurons and this integration of signals from multiple ampullae is what allows elasmobranch fish to detect electric field changes as small as 5 nV/cm [503, 506, 509, 510]. The AoL jelly has been reported as a semiconductor with temperature-dependence conductivity and thermoelectric behavior [500, 509, 510], as well as a simple ionic conductor with the same electrical properties as the surrounding seawater [503, 506]. Josberger et al. [500] attempted to clarify what AoL's role is in electrosensing by measuring AoL's proton conductivity. They found that room-temperature proton conductivity of AoL jelly is very high at 2 ± 1 mS/cm — only 40-fold lower than some current state-of-the-art manmade proton-conducting polymers. That makes AoL the highest conductive biological material reported thus far. They suggested that the polyglycans contained in the AoL jelly may contribute to its high proton conductivity.

Other aquatic magneto-sensory mechanisms more in harmony with terrestrial animals include the presence of ferromagnetic particles in magnetite — tiny naturally produced magnets that align with the Earth's magnetic field, allowing for species' direction and orientation. Magnetite appears to transmit necessary information through a connection with the central nervous system [340, 497, 511]. A magnetite-based system is plausible for cetaceans [512, 513] as magnetite has been found in the meninges dura mater surrounding the brains of whales and dolphins [514, 515]. There is also evidence that local variations/anomalies in the geomagnetic field in certain underwater topographies may play a role in live cetacean strandings [516, 517] which indicates a magnetic compass based on magnetite. And free-ranging cetaceans have shown evidence of magnetoreception-based navigation, e.g., Fin whale migration routes have been correlated with low geomagnetic intensity [513].

Recently, Granger et al. [518] found correlations in data between 31 years of gray whale (*Eschrichtius robustus*) strandings and sunspot activity, especially with RF 'noise' in the 2,800 MHz range. The 11-year sunspot cycle strongly correlates with the intense releases of high-energy particles known as solar storms which can temporarily modify the geomagnetic field, and in turn may modify orientation in magnetoreceptive species. Solar storms also cause an increase in natural broadband RF 'noise'. They examined changes in both geomagnetic fields and RF 'noise' and found RF to be a determinant. Further, they hypothesized that increased strandings during high solar activity is more likely due to radical pair mechanisms which are more reactive with RFR than magnetite, which appears more reactive to ELF-EMF. Two previous studies also found correlations with cetacean strandings and solar activities [519, 520]. Both mechanisms may come into play under different circumstances or act in synergy.

Kremers et al. [512] investigated the spontaneous magnetoreception response in six captive free-swimming bottlenose dolphins (*Tursiops truncates*) to introduced magnetized and demagnetized devices used as controls. They found a shorter latency in dolphins that approached the device containing a strong magnetized neodymium block compared to a control demagnetized block identical in form and density and therefore indistinguishable with echolocation. They concluded that dolphins can discriminate on the basis of magnetic properties — a prerequisite for magnetoreception-based navigation. Stafne and Manger [521] also observed that captive bottlenose dolphins in the northern hemisphere swim predominantly in a counter-clockwise direction while dolphins in the southern hemisphere swim predominantly in clockwise direction. No speculation was offered for this behavior.

How salmon navigate vast distances — from their hatching grounds in freshwater river bottoms to lakes during juvenile growth, then the open ocean during maturity, and with a final return to their neonatal birthing grounds to spawn and die (for most anadromous salmonids) — has fascinated researchers for decades. Research indicates they may use several magneto-senses to accomplish this, including inherited mechanisms [522], imprinting [499, 522], a magnetic compass [499, 522, 523], and biomagnetic materials. Salmon have been found to have crystal chains of magnetite [524]. One recent study found that strong magnetic pulses were capable of disrupting orientation in salmon models [525], indicating a magnetite-based mechanism. In salmon, the migration process is complicated by the fact that the ability to sense geomagnetic fields can be altered by changes in salinity between fresh and salt water, thus pointing to multi-sensory mechanisms [499].

Speculation that salmon use the geomagnetic field in some capacity for their iconic migration goes back decades [526]. Quinn [527] found evidence that sockeye salmon (*Oncorhynchus nerka*) frey use both a celestial and magnetic compass when migrating from river hatching to lakes. Putman et al. [499], who have written extensively on this subject, focused on how salmon navigate to specific oceanic feeding areas — a challenge since juvenile salmon reach feeding habitats thousands of kilometers from natal locations. The researchers experimentally found that juvenile Chinook salmon (*Oncorhynchus tshawytscha*) responded to magnetic fields similar to latitudes of their extreme ocean range by orienting in directions that would lead toward their marine feeding grounds. They further found that fish use the combination of magnetic intensity and inclination angle to assess their geographic location and concluded that the magnetic map of salmon appears to be inherited since the fish had no prior migratory experience. These results, paired with findings in sea turtles (see below), indicate that magnetic maps are widespread in aquatic species and likely explain the extraordinary navigational abilities seen in long-distance underwater migrants [499].

It is less likely that light-sensing radical pair cryptochromes play much of a role in aquatic species though some hypothesize the possibility [528]. Krylov et al. [33], however, noted that there are no anatomical structures or neurophysiological mechanisms presently known for radical pair receptors in the brains of fish and that since light decreases with water depth and fish are capable of orienting in complete darkness using the geomagnetic field, their opinion was that it is too early to say fish have magnetoreception mechanisms based on free radicals, light-dependent or otherwise.

Fish, lobsters, crabs: ELF-EMF

For several reasons having to do with differences in conductivity in water vs. air (see above), RFR is of far less concern in aquatic environments at present than is ELF. With the ever-increasing number of underwater cables used for everything from transcontinental data/communications to power supplies for islands, marine platforms, underwater observatories, off-shore drilling, wind facilities, tidal and wave turbines among others, many new sources of both AC and DC electric current are being created in sea and freshwater environments alike. According to Ardelean and Minnebo writing in 2015 [529], almost 4,971 mi (8,000 km) of high voltage direct current (HVDC) cables were present on the seabed worldwide, 70% of which were in European waters, and this is only expected to grow dramatically as new sources of renewable energy are built to replace fossil fuels globally.

Curiosity about potential adverse effects from cable-generated ELF-EMF on all phases of fish life has also grown, especially in benthic and demersal species that spend significant time near cables in deeper bottom environments for egg laying, larvae growth, and development for most, if not all, of their adult lives.

Fey et al. [494, 495] and Öhman et al. [530] noted that there are two types of anthropogenic exposures created by cables: high voltage direct current (HVDC) that emits static magnetic fields, and three-phase alternating current (AC power transmission) that emit time-varying electromagnetic fields. The density of electric current near underwater cables on the sea floor can vary significantly depending on the type of cable and whether they are positioned on the sea bottom or buried [36, 530]. Noticeable magnetic field changes can occur within meters but generally not more than several meters from the cable. However, Hutchinson et al. [531], in a robust field study and extensive review, found surprisingly stronger and more complex exposures than anticipated (see below).

Since fish are highly sensitive to static magnetic fields (MF), it is important to delineate static fields from anthropogenic alternating current EMF in aquatic studies. In freshwater species under laboratory conditions, Fey et al. [494] found similar results to those of salmon studies (noted above) in northern pike (*Esox lucius*) exposed to a static magnetic field from DC cables (10 mT) during the embryonic phase and in the first six days of post-hatching. No statistically significant MF effect was seen on hatching success, larvae mortality, larvae size at hatching, and growth rate during the first six days of life. However, significant MF effects were seen on hatching time (one day earlier in a magnetic field than in control), yolk-sac size was smaller, and yolk-sac absorption rate was faster. They interpreted the faster yolk-sac absorption in a magnetic field as an indication of increased metabolic rate but added that even if some negative consequences were expected as a result, that the actual risk for increased northern pike larvae mortality seemed negligible. Though higher than 10 mT magnetic field values are hazardous for fish larvae, they added such values do not occur in the natural environment even along underwater cables.

But in follow-up work of longer duration the same general research group reached a different conclusion. Fey et al. [495] studied effects on eggs and larvae of rainbow trout (*Oncorhynchus mykiss*) exposed to a static magnetic field (MF) of 10 mT and a 50 Hz EMF of 1 mT for 36 days (i.e., from eyed egg stage to approximately 26 days post hatching). They found that while neither the static MF nor the 50-Hz EMF had significant effects on embryonic/larval mortality, hatching time, larval growth, or the time of larvae swim-up from the bottom, both fields did however enhance the yolk-sac absorption rates. While they said this was not directly related to a MF effect, it was shown that larvae with absorbed yolk-sacs by the time of swim-up were less efficient in taking advantage of available food at first feeding and gained less weight. They concluded that these exposures could negatively affect the yolk-sac absorption rate thereby hampering fish in important feeding activities needed for fast weight gain and increased survival. In an additional study, Fey et al. [532] observed that rainbow trout reared in a laboratory for 37 days and exposed to a static MF (10 mT) or a 50-Hz EMF (1 mT) showed defects in otolith of the inner ear which is responsible for hearing and balance in fish. The authors concluded that underwater construction and/or cables that emit a MF of 10 mT or higher can affect living organisms within a few meters distance, especially species like trout in settled life stages on the sediment bottom during early development.

Zebrafish (*Danio rerio*) are often used in EMF research in toxicology and developmental biology investigating effects on humans because the genomes are so similar. Li et al. [533] studied ELF-MF on the development of fertilized zebrafish embryos divided into seven groups. Embryos of experimental groups were continuously exposed to 50-Hz sinusoidal MF with intensities of 30, 100, 200, 400, or 800 μT for 96 h. The sham group was identical but without ELF-MF exposure. Results showed that ELF-MF caused delayed hatching and decreased heart rate at early developmental stages but no significant differences were seen in embryo mortality or abnormality. Acridine orange staining assays showed notable signs of apoptosis in the ventral fin and spinal column and transcription of apoptosis-related genes (caspase-3, caspase-9) was significantly up-regulated in ELF-MF-exposed embryos. They concluded that ELF-EMF demonstrated detrimental effects on zebrafish embryonic development, including on hatching, decreased heart rate, and induced apoptosis, although such effects were not a mortal threat. The lower range exposures of this study are found in some aquatic environments.

Sedigh et al. [534] investigated effects on zebrafish exposed to static magnetic fields. Exposures of 1-week acute and 3-week subacute exposures to different static magnetic fields at 2.5, 5, and 7.5 mT were measured on stress indices (cortisol and glucose), sex steroid hormones (17β-estradiol and 17-α hydroxy progesterone) and fecundity. They found a significant change in cortisol, glucose, 17β-estradiol (E_2) and 17-α hydroxy progesterone (17-OHP) levels with increased intensity and duration of exposure and concluded that static magnetic fields at higher intensities showed harmful effects on the reproductive biology of zebrafish during both acute and subacute exposures.

Recent laboratory research by Hunt et al. [535] used the transparent glass catfish (*Kryptopterus vitreolus*) found in slow moving waters in Southeast Asia as a model to investigate magnetoreception. The study used Y-maze chambers, animal tracking software and artificial intelligence techniques to quantify effects of magnetic fields on the swimming direction of catfish. They placed a permanent Neodymium Rare Earth Magnet (11.5 × 3.18 × 2.2 cm) with a horizontal magnetic flux of 577 mT at the magnet's surface at 10 cm from the end of one of the Y-maze arms and found that catfish consistently swam away from magnetic fields over 20 μT. The catfish also showed adaptability to changing magnetic field direction and location. The magnetic avoidance was not influenced by school behavior. Sham exposures produced no avoidance. Such exposures might be found near some underwater cables.

To further elucidate findings of species reactions near underwater cables and fill in knowledge gaps since the 2011 Tricas and Gill review [36], Hutchinson et al. [531] conducted both field and laboratory modeling studies of both AC and DC fields on the American lobster (*Homarus americanus*) and the little skate (*Leucoraja erinacea*). They noted that in previous studies, while behavioral responses had been seen, findings were unable to determine if significant biological effects (e.g., population changes) occurred. The American lobster was modeled because it is a magnetosensitive species [536] and concern existed that EMF from cables might restrict movements and/or migration. Lobsters may migrate up to 50 mi (80 km) one way from deep waters to shallow breeding grounds. The little skate was used as a model for the most electro-sensitive taxa of the elasmobranchs, which may be attracted by/to the EMF of cables, particularly for benthic species, thereby altering their foraging or movement behavior. Both models were therefore thought indicative of potential EMF impacts. In this robust field study, the researchers found that the American lobster exhibited a statistically significant but subtle change in behavioral activity when exposed to the EMF of the HVDC cable (operated at a constant power of 330 MW at 1,175 Amps). The little skate exhibited a strong behavioral response to EMF from a cable powered for 62.4% of the study with the most frequently transmitted electrical current at 16 Amps (at 0 MW, 37.5% of time), 345 Amps (100 MW, 28.6%) and 1,175 Amps (330 MW, 15.2%). They concluded that for both species, the behavioral changes have biological relevance regarding how they will move around and are distributed in a cable-EMF zone, but they noted that the EMF did not constitute a barrier to movements across the cable for either species.

Of interest in this study were the actual field readings near cables. Unexpected significant AC magnetic and electric fields did not match computer models and were observed to be associated with both of the DC power cables studied. The maximum observed AC values along the cable axis were 0.15 μT and 0.7 mV/m for the magnetic and electric fields respectively for one cable, and 0.04 μT and 0.4 mV/m respectively, for the other cable. Also, the cross section of the EMF peaks exhibited by the DC subsea power cables were broader than anticipated at both studied. The DC and AC magnetic fields reached background levels on either side of the cable on a scale of c.a.5 and 10 m from the peak observed value respectively, whereas the AC electric fields reached background on a scale of 100 m (328 ft) from the peak value. Peak observed values occurred almost directly above the cable axis location; there was an offset of 3.3 ft (<1 m) where the cable was twisted. The researchers noted that this observation of AC fields, with broad areas of EMF distortion being associated with DC cables, increased the complexity of interpreting the studies of EMF's biological effects from DC cables. The AC electric fields associated with the AC sea2shore cable (1–2.5 mV/m) were higher than the unanticipated AC electric fields produced by the DC cables (0.4–0.7 mV/m). The magnetic field produced by the AC sea2shore cable (range of 0.05–0.3 μT) was ~10 times lower than modeled values commissioned by the grid operator, indicating that the three-conductor twisted design achieves significant self-cancellation. This entire aspect of the study indicates the need for accurate field assessment, not just computer modeling, and well-designed systems since anomalies occur.

Nyqvist et al. [498] in a thorough review, focused on marine mammals and the use of underwater electromagnetic surveys that map petroleum deposits in seabeds via strong induced EMFs in varied directional applications. They found that EMFs created during such active surveying were within the detectable ranges of marine animals and the fields can potentially affect behavior in electro-perceptive species, but they noted that effects should be limited to within a few kilometers as the electric and magnetic fields created attenuate rapidly. They added that in migrating marine animals, exposures are of short duration and most are close to naturally occurring levels but cautioned that lack of studies is a concern, especially for the most sensitive elasmobranchs at highest risk for disturbance to electric fields. They also noted that with induced magnetic fields, animals using magnetic cues for migration or local orientation during certain time-windows for migration, orientation, or breeding, could be most affected by this surveying technology.

Taorimina et al. [537] studied both static and time-varying magnetic fields on the behavior of juvenile European lobsters (*Homarus gammarus*). Using two different behavioral assays, day-light conditions to stimulate sheltering behavior and exposures to an artificial magnetic field gradient (maximum intensity of 200 μT), they found that juvenile lobsters did not exhibit any behavioral changes compared to non-exposed lobsters in the ambient magnetic field. No differences were noted on the lobsters' ability to find shelter or modified their exploratory behavior after one week of exposure to anthropogenic magnetic fields (225 ± 5 μT) which remained similar to behavior in controls. They concluded that neither static nor time-varying anthropogenic magnetic fields at those intensities significantly impacted the behavior of juvenile European lobsters in daylight conditions, but they noted that evidence exists showing magnetosensitivity changes during different life stages in lobster species, and that since their modeling was on juveniles, their study was therefore an incomplete picture requiring further study.

Scott et al. [538] focused on ELF-EMF effects on commercially important edible/brown crab species (*Cancer pagurus*) and what they found was startling. In laboratory tanks, they simulated EMF (with Helmholtz coils, 2.8 mT evenly distributed, assessments during 24 h periods) that would be emitted from sub-sea power cables now commonly used at offshore renewable energy facilities. They measured stress related parameters ((L-lactate, D-glucose, haemocyanin and respiration rate) along with behavioral and response parameters (antennal flicking, activity level, attraction/avoidance, shelter preference and time spent resting/roaming). They found that although there was no EMF effect on haemocyanin concentrations, respiration rate, activity level or antennal flicking rate, there were significant changes in haemolymph L-lactate and D-glucose natural circadian rhythms, indicating alterations in hormones. Crabs also showed an unusually high attraction to EMF-exposed shelter areas (69%) compared to control shelter areas (9%) and significantly reduced their time roaming by 21%, with adverse implications for food foraging, mating, and overall health. They noted that EMF clearly altered behavior. Crabs spent less time roaming around the tank and more time in a shelter in direct contact with the EMF source, indicating natural roaming/food-or-mate-seeking behavior had been overridden by attraction to EMF. In fact, crabs consistently chose an EMF-exposed shelter over a non-exposed one and were always drawn to the EMF. The results appear to predict that in benthic areas surrounding EMF-emitting cables, there will be an increase in the abundance of *Cancer pagurus* present. They noted that such potential crab aggregation around benthic cables and the subsequent physiological changes in L-lactate and D-glucose levels caused by EMF exposure, is a concern regarding feeding rates, mating, and especially egg incubation directly in increased EMF environments. They concluded that long term investigations are needed regarding chronic EMF exposure, especially on egg development, hatching success and larval fitness, and added that EMF emitted in marine environments from renewable energy devices must be considered as part of the study of cumulative impacts during the planning stages.

Clearly ELF-EMF can affect myriad aquatic species at intensity levels found in proximity to underwater cables at environmental intensities.

Fish: RF-EMF

As mentioned, RFR is of minimal environmental concern for fish since aquatic environments, while highly conductive mediums, also highly attenuate EMF at higher frequencies. This may change in the near future as new technologies now exist that may surpass these obstacles [98], thereby introducing for the first time novel new RFR exposures underwater. Longer wave wireless ELF with expanded ranges are used in anthropogenic sonar (sound navigation ranging), primarily for military applications. These travel easily through water and are known to adversely affect cetaceans and other species that rely on their natural sonar for communication, migration, reproduction and food finding. But sound waves are not considered "EMF" in the strict sense of the term; since the focus of this paper is EMF, sound waves are tangential here. But acoustic damage, especially to cetaceans from military and commercial applications, is well documented and ELF cables used for underwater military submarine communications can have significant EMF exposures near cables. Just because this paper does not address impacts from sound waves in detail does not mean they are without serious effects.

There are, however, three recent studies of RFR on zebrafish included here because it is plausible that such exposures could exist near shallow aquatic environments under some circumstances. Nirwane et al. [539] studied 900-MHz GSM RFR effects on zebrafish (*D. rerio*) neurobehavioral changes and brain oxidative stress as a model for human exposures to cell phones. Exposures were applied daily for 1 h, 14 days, with SAR 1.34 W/Kg. They found 900-MHz GSM radiation significantly decreased socialization and increased anxiety as demonstrated by significant increased time spent in bottom areas, freezing behaviors, and duration and decreased distance travelled, as well as decreased average velocity and number of entries to the upper half of the tank. Exposed zebrafish spent less time in the novel arm of a Y-Maze indicating significant impaired learning compared to the control group. Exposure also decreased superoxide dismutase (SOD) and catalase (CAT) activities while increased levels of reduced glutathione (GSH) and lipid peroxidation (LPO) were encountered indicating compromised antioxidant defense. Post-exposure treatment with melatonin in the water, however, significantly reversed the induced neurobehavioral and oxidative changes.

Piccinettia et al. [540] investigated *in vivo* effects on embryonic development in zebrafish at 100 MHz thermal and nonthermal intensities via a multidisciplinary protocol. Results found 100 MHz RFR affected embryonic development from 24 to 72 h post fertilization in all the analyzed pathways. Most notably at 48 h post fertilization, reduced growth, increased transcription of oxidative stress genes, onset of apoptotic/autophagic processes and a modification in cholesterol metabolism were seen. EMF affected stress by triggering detoxification mechanisms. At 72 h post fertilization, fish partially recovered and reached hatching time comparable to controls. The researchers concluded that EMF-RFR unequivocally showed *in vivo* effects at non-thermal levels.

Dasgupta et al. [541] used embryonic zebrafish models at 3.5 GHz SAR ≈ 8.27 W/kg and exposed developing zebrafish from 6 to 48 h post fertilization, then measured morphological and behavioral endpoints at 120 h post fertilization. Results found no significant impacts on mortality, morphology or photomotor response but noted a modest inhibition of startle response suggesting some levels of sensorimotor disruptions. They concluded that exposures at low GHz levels are likely benign but nevertheless entailed subtle sensorimotor effects. Such effects can affect fish survival in various ways, including inhibited response time to predators, among others. This study was done with an eye toward potential human bioeffects at frequencies used in 4 and 5G technology. It was also conducted at intensities higher than the focus of this paper.

If new technology overcomes the conductivity/attenuation limitations of aquatic environments and introduces more RFR to aquatic species, studies like those cited above may soon have more environmental relevance, even at higher intensities than explored here.

Turtles

Oceanic sea turtle migration joins that of other renowned long-distance migratory species like salmon and over-land monarch butterfly treks, spanning thousands of kilometers and traversing multiple complex environments throughout their life cycles. Sea turtles have long been known to use geomagnetic fields for orientation [542, 543]. Freshwater species (e.g., *Chelydra serpentina*) have also been shown to have a magnetic sense capable of artificial disruption [92] as do terrestrial box turtles (*Terrapene carolina;* [544]).

Sea turtles demonstrate natal homing behavior — the ability to return over great distances to their exact birth location to reproduce [89] and because of anthropogenic disruptions of nesting grounds along beaches, this reproductive homing drive imperils them today. The underlying mechanism is still imperfectly understood but involves 'imprinting' of the intensity and inclination angle of the geomagnetic field at the birth location [545]. The information is then later used in maturity to return to their place of origin.

Sea turtles are by far the most studied models for turtle magnetoreception, especially by the Lohmann Laboratory at the University of North Carolina, U.S. [323, 546–558].

Irwin and Lohmann [559] discussed the advantages and disadvantages of various research approaches used to investigate magnetic orientation behavior in turtles. These include the use of large magnetic coil systems in laboratory settings to generate relatively uniform fields over large areas [560] which allow the magnetic field to be artificially altered and carefully controlled to determine changes in behavioral orientation. This approach, however, is unsuited for manipulating exposures around animals in natural environments or for studying localized body magnetoreceptors, which in turtles are still a mystery. Another approach is to attach a small magnet or electromagnetic coil to an animal to disrupt magnetic orientation behavior — a far easier approach in hatchlings than in juvenile or mature free-swimming species. They note that if the imposed field from an attached magnet or coil is strong enough to interfere with the Earth's field, behavioral orientation changes [116, 544, 561] and the performance of a conditioned response [367, 562] can be observed. This latter approach has been used in field studies for the purpose of blocking access to normal magnetic information [544, 561, 563–565] and to localize magnetoreceptors by disrupting the field around a specific terrapin body part [562]. This technique's disadvantage, however, is that fields rapidly change with distance from the source, making it difficult to quantify the fields that the animal actually experiences.

Most sea turtle studies have involved large magnetic coil systems but Irwin and Lohmann [559] attached small magnets greater in strength than the Earth's fields to two groups of loggerhead sea turtle hatchlings (*Caretta caretta* L.) under laboratory conditions in which turtles are known to orient magnetically [473, 546, 548–550]. They found that magnetic orientation behavior in hatchling turtles can be disrupted via small magnets attached to the carapace which then create exposures over the entire body. They concluded that such an approach can be used to finally determine local magnetoreceptors by varying the location of the magnet and using smaller, weaker magnets that alter the field only around specific anatomical target sites.

In loggerhead sea turtles, there is evidence of an inclination compass [473, 550] that is functionlly similar to the bird magnetic compass reported in European Robins [566, 567]. Lohmann and Lohmann [550] investigated an inclination compass in sea turtles and found it was a possible mechanism for determining latitude. Also investigated were detection of magnetic intensity [551]; natural regional magnetic fields used as navigational markers for sea turtles [557]; and sea turtle hatchlings' mapping abilities [545]. Sea turtles are also known to have magnetite in their heads [104, 568]. Studies with young sea turtles have shown that a significant portion of their navigational abilities involve magnetoreception following hatching [569] — imprinting with the Earth's magnetic field being one of several cues hatchlings use as they first migrate offshore [546, 554]. The magnetic fields that are unique to different areas at sea eventually serve as navigational markers to guide swimming direction to important migratory routes. As juveniles mature, they form topographical magnetic maps where they live that direct them to specific regions. But it has remained largely unknown if mature turtles, specifically nesting females, use such mechanisms in open-sea homing as this magneto-sense may change over time.

Field studies are notoriously difficult with large species at sea but Papi et al. [564] studied mature green turtles (*Chelonia mydas*) during their post-nesting migration over 1,243 mi (2,000 km) from their nesting grounds on Ascension Island in the middle of the Atlantic Ocean back to their Brazilian feeding grounds. They were investigating whether mature female turtles use an inclination compass and geomagnetic fields for direction, or by inference (once that sense is disturbed) by some other means as yet determined. Papi et al. [564] attached very strong DC magnets — significantly stronger than the Earth's fields — to disturb and overcome natural magnetoreception, and thereby determine if they could still navigate back to Ascension Island. Controls had nonmagnetic brass bars attached and some had transmitters glued to their heads. All had tracking devices that communicated with satellites, thus creating strong multi-frequency static and pulsed RFR exposures. Seven turtles were each fitted with six powerful static magnets that produced variable artificial fields surrounding the whole turtle, making reliance on a geomagnetic map impossible. The study's travel courses were very similar to those of eight turtles without magnets that had been tracked via satellite over the same period in the previous year. No differences between the magnetically exposed test turtles and untreated turtles were found regarding navigational performance and general course direction. They concluded that magnetic cues were not essential to turtles on the return trip and speculated that perhaps other factors such as smell or wave current direction may come into play.

Luschi et al. [563], like Papi et al. [564], also investigated the role of magnetoreception and homing in mature sea turtles but used a different design and found very different results. In a large field study in the Mozambique Channel, 20 mature pre-nesting green turtles were also equipped with both strong magnets and satellite tracking devices. The turtles were gathered at their nesting beach on Mayotte Island before egg-laying and transported to four open-sea sites 62–75 mi (100–120 km, respectively) away. There were five releases of four turtles each with three different treatments: turtles magnetically 'disturbed' only during transportation with magnets removed before release; those treated only during the homing trip with magnets attached just prior to release; and controls with nonmagnetic brass discs attached to their heads. Treated turtles had very strong moveable magnets attached to their heads to induce varying magnetic fields around them either at the nesting beach at the start of the relocation journey or on the boat just prior to release for the homing trip. All groups had satellite transmitters attached to their carapaces, thereby creating in the opinion of the authors of this paper, an additional exposure that was not considered as a variable. The researchers also included ocean currents in their assessments, estimated by using oceanographic remote sensing measurements. All but one turtle eventually returned to Mayotte to complete delayed egg-laying. But treated turtles, whether treated during transportation or homing, took significantly longer to reach the destination vs. controls — a surprising finding. Most homing routes showed very long circuitous curved and looping patterns before reaching their target. Control paths were direct. Both treated turtle groups were clearly impaired by the MF exposure, indicating significant recovery time needed between exposure and correcting positional behavior. The researchers hypothesized the existence of a navigational role for geomagnetic information being gathered by those turtles in the passive transportation group, as well as the possibility that magnetic disturbance during transportation may have persisted for some time after the removal of the magnets in that group, thus rendering the two treated groups functionally equivalent during their homing journeys. They also noted that exposures may have physically altered magnetite particles, thus creating a longer lasting effect but they said that since long-lasting after-effects of magnet application have not been described, this theory could neither be inferred nor dismissed.

Lohmann [323] reviewed both of the above studies and added that in addition to the two causal hypotheses of Luschi et al. [563] regarding their unexpected findings of turtle circuitous migration routes, another explanation would include the positioning of the satellite transmitters in the Papi et al. [564] study on turtle heads vs. on the carapace of the Luschi models. He added that since satellite transmitters also produce magnetic fields capable of disrupting magnetoreception, and since the Papi group also attached satellite transmitters on the heads of several control turtles, that re-analyzing the Papi study using only turtles with satellite transmitters placed on the carapace like the Luschi study could show evidence consistent with the hypothesis that adult turtles exploit magnetic cues in navigation. He concluded that sea turtles, like all other animals studied to date, likely exploit multiple cues for navigation since even with artificial magnetic disturbance causing impaired performance, the magnets in either study did not prevent turtles from eventually reaching their target beaches. This implies that turtles can also rely on other sources of information [570, 571] such as celestial compasses, wave direction [572], or olfactory cues like other species — a significant finding.

The sum total of the studies mentioned above is that sea turtle species are highly sensitive to Earth's fields and are capable of adapting to subtle anthropogenic disruption.

Turtles: RF-EMF

Turtles may also be senstitive to RFR, especially during incubation while on land, and/or initial hatchling stages if they are exposed to anthopogenic RF-EMF that could distort the imprinting memory they use in later life to locate their birthsite beaches again. For example, if a radar or communications base station is installed on or near the beach of a nesting site, could that affect the initial "imprinting" process? Perhaps augment imprinting and make return easier? Or conversely overwhelm the subtle imprinting process at the start and make return impossible? If the latter is valid, such technology could lead to extinction of sensitive species since it interrupts the reproduction process. In the very least, in sensitive species, disorientation might result as discussed above.

To characterize the underlying compass mechanisms in turtles, Landler et al. [92] studied freshwater juvenile snapping turtles' (*Chelydra serpentine*) ability for spontaneous magnetic alignment to the Earth's geomagnetic fields. Using exposure to low-level RFR near the Larmor frequency (1.2 MHz) that is related to free radical pair formation, turtles were first introduced to the testing environment without the presence of RFR ("RF off, RF off") and they were found to consistently align toward magnetic north. But when subsequent magnetic testing conditions were initially free of RFR, then included an introduced signal ("RF off, RF on"), they became disoriented. Thus, introduction of a RFR field could affect the turtles' alignment response to the natural magnetic field. The RFR field used was only 30–52 nT (1.43 MHz). In the following reverse scenario, when the turtles were initially introduced to the testing environment with RFR present but then removed ("RF on, RF off"), they became disoriented when tested *without* RFR. And with RFR on in both cases ("RF on, RF on"), they aligned in the opposite direction toward magnetic south. Clearly test turtles were affected by the exposures. The researchers concluded that the sensitivity of the spontaneous magnetic alignment response of the turtles to RFR was consistent with a radical pair mechanism (see "Mechanisms" above). In addition, they concluded that the effect of RFR appeared to result from a change in the pattern of magnetic input, rather than elimination of magnetic input altogether. Their findings indicated that turtles, when first exposed to a novel environment, form a lasting association between the pattern of magnetic input and their surroundings, and that they may form a larger internal GPS-like mapping ability when they meet any new magnetic reference framework based on natural magnetic cues, from multiple sites and localities.

They also showed that RFR at or near the Larmor frequency (1.2–1.43 MHz) had the ability to disrupt snapping turtle natural orientation, establish its own novel orientation, and completely reverse a natural orientation, leading back to the complex questions asked above regarding imprinting and possible reproductive disruption. Although the Landler et al. study [92] was conducted in a freshwater, non-homing species, snapping turtles are long-lived with a low reproduction success rate. Even small disruptions to this species from anthropogenic sources could have an outsized population effect over time. If this freshwater species is any indication of potential RFR effects, researchers need to further investigate RFR in long-distance migrating turtle species that imprint on land. We simply do not know the full range of possible effects across frequencies with which turtle species come in contact at vulnerable points throughout development and lifetimes.

Nematodes and smaller biota

There are reports of sensitivity to EMF in lesser taxa as well. EMF is known to affect numerous other species including: nematodes (Earth and aquatic worms), mollusks (snails), amoeba (single-celled organisms), molds, algae, protozoans, yeast, fungi, bacteria, and viruses (to a limited extent) — with ramifications for creation of antibiotic resistant bacteria strains. Below are some representative examples of observed effects.

Nematodes

Common soil-based nematode species like *C. elegans* serve as a useful whole-organism model for genetic and multicellular organism investigations. They are routinely used as a research model to investigate key biological processes including aging, neural system functioning, and muscle degeneration, to name a few. This species' genetic and phenotypic traits are extremely well documented and they can thus be used as important proxies for quantitative analyses [573]. Nematodes have a short lifespan, are hermaphrodites, and demonstrate effects quickly. As lab models they are used primarily for information that can be applied to humans but we can also glean important information and extrapolate to environmental exposures under certain circumstances. Healthy soil worm populations are critical to soil health upon which we all depend.

Hung et al. [574] investigated static magnetic field (SMF) effects on life span and premature aging in *C. elegans*. Nematodes were grown in SMFs varying from 0 to 200 mT. They found that SMF's accelerated development and reduced lifespan in wild-type nematodes. They also found increases in heat shock proteins that were selective and dose dependent.

Vidal-Gadea et al. [66] investigated magnetic orientation in *C. elegans* to identify magnetosensory neurons and found that they orient to the Earth's geomagnetic field during vertical burrowing migrations. Well-fed worms migrated up, while starved worms migrated down. Populations isolated from around the world were found to migrate at angles to the magnetic vector that would vertically translate to their native soil, with northern- and southern-hemisphere worms displaying opposite migratory preferences in conjunction with natural geomagnetic fields. They also found that magnetic orientation and vertical migrations required the TAX-4 cyclic nucleotide-gated ion channel in the AFD sensory neuron pair while calcium imaging showed that these neurons respond to magnetic fields even without synaptic input. They hypothesized that *C. elegans* may have adapted magnetic orientation to simplify their vertical burrowing migration by reducing the orientation task from three dimensions to one.

C. elegans have also demonstrated sensitivity to electric fields via electrotaxis (also known as galvanotaxis) which is the directed motion of living cells or organisms guided by an electric field or current and often seen in wound healing. Sukul and Croll [575] found that nematodes exposed to an electrical current (0.02–0.04 mA, potential differences 2–6 V) demonstrated a directional sensorily-mediated orientation toward the current at first, but at 2 mm from the electrode, individual worms increased reversing behaviors which then remained uniform as they moved in a constant direction parallel to the exposure. A few which did not reverse direction died (presumably from electrocution) at 6 V or 0.4 mA. They concluded that adult *C. elegans* move directionally at selected combinations of voltage and potential differences and that electrophoresis could be eliminated.

Gabel et al. [576] also investigated electric field effects on directionality on *C. elegans* with an eye toward better understanding how the nervous system transforms sensory inputs into motor outputs. They used time-varying electric fields modulated at 100 Hz across an agar surface with a defined direction and amplitude up to 25 V/cm. They found that the nematodes deliberately crawl toward the negative pole in an electric field at specific angles to the direction of the electric field in persistent forward movements with the preferred angle proportional to field strength. They also found that the nematodes orient in response to time-varying electric fields by using sudden turns and reversals (normal reorientation maneuvers). They also found that certain mutations or laser ablation that disrupt the structure and function of amphid sensory neurons also disrupted their electrosensory behavior and that specific neurons are sensitive to the direction and strength of electric fields via intracellular calcium dynamics among the amphid sensory neurons. This study showed that electrosensory behavior is crucial to how the *C. elegans* nervous system navigates and can be disrupted at some intensities found in the environment.

Maniere et al. [573] also found *C.elegans* was sensitive to electric fields and that when submitted to a moderate electric field, worms move steadily along straight trajectories. They hypothesized that imposing electric fields in research settings was an inexpensive method to measure worms' crawling velocities and a method to get them to self-sort quickly by taking advantage of their electrotactic skills.

An early RFR study of *C elegans* by Daniells et al. [577] found this species to be a useful model for investigating stress-responses. In the majority of investigations, they used 750 MHz with a nominal power of 27 dBm; controls were shielded and all temperatures were strictly controlled. Stress responses were measured in terms of beta-galactosidase (reporter) induction above control levels. Response to continuous microwave radiation showed significant differences from 25 degrees C in controls at 2 and 16 h, but not at 4 or 8 h. Using a 5 × 5 multiwell plate array exposed for 2 h, the 25 microwaved samples showed highly significant responses compared with a similar control array. Experiments in which the frequency and/or power settings were varied suggested a greater response at 21 than at 27 dBm, both at 750 and 300 MHz indicating a nonlinear effect, although extremely variable responses were observed at 24 dBm and 750 MHz. Lower power levels tended to induce greater responses — the opposite of simple heating effects. They concluded that microwave radiation causes measurable stress to transgenic nematodes via increased levels of protein damage within cells at nonthermal levels.

Tkalec et al. [578] found oxidative and genotoxic effects in earthworms (*Eisenia fetida*) exposed *in vivo* to RFR at 900 MHz, at 10, 23, 41 and 120 V m(-1) for 2 h using a Gigahertz Transversal Electromagnetic (GTEM) cell. All exposures induced significant effects with modulation increasing such effects. Their results also indicated antioxidant stress response induction with enhanced catalase and glutathione reductase activity, indicating lipid and protein oxidative damage. Antioxidant responses and damage to lipids, proteins and DNA differed depending on EMF level, modulation, and exposure duration.

Aquatic and semi-aquatic worm species also show sensitivity to EMF. Jakubowska et al. [579] investigated behavioral and bioenergetic effects of EMF at 50 Hz, 1 mT fields (comparable to exposures near underwater cables) in polychaete ragworms (*Hediste diversicolor)* that live and burrow in the sand/mud of beaches and estuaries in intertidal areas of the North Atlantic. While they found no attraction or avoidance behavior to EMF, burrowing activity was enhanced with EMF exposure, indicating a stimulatory effect. Food consumption and respiration rates were unaffected but ammonia excretion rate was significantly reduced in EMF-exposed animals compared to control conditions at only geomagnetic fields. The mechanisms remained unclear. The authors said this was the first study to demonstrate effects of environmentally realistic EMF values on the behavior and physiology of marine invertebrates.

Van Huizen et al. [67] investigated effects of weak magnetic fields (WMF) on stem-cells and regeneration in an *in vivo* model using free-swimming flatworms (*Planaria* ssp*)* that are capable of regenerating all tissues including the central nervous system and brain. This regeneration ability is due to the fact that about 25% of all their cells are adult stem cells (ASC). Injury is followed by a systemic proliferative ASC response that initially peaks at ~ 4 h, followed by ASC migration to the wound site over the first 72 h when a second mitotic peak occurs. Like salamander regeneration (see “Amphibians” above) this activity produces a blastema — a group of ASC cell growth that forms the core of new tissues. Full regeneration of damaged planaria tissues or organs occurs through new tissue growth and apototic remodeling/scaling of old tissues within 2–3 weeks. Following amputation above and below the pharynx (feeding tube), they exposed amputation sites to 200 μT WMF. At three days post-amputation, they found that 200 μT exposure produced significantly reduced blastema sizes compared to both untreated and earth-normal 45 μT field strength controls, indicating a WMF interference effect to regeneration. They also found that the 200 μT exposure was required early and had to be maintained throughout blastema formation to affect growth, and that shorter, single-day exposures failed to affect blastema size. In addition, they found weak magnetic fields produced field strength–dependent effects. These included significant reductions of blastema size observed from 100–400 μT, but conversely, a significant increase in outgrowth occurred at 500 μT. They hypothesized that WMF effects were caused by altered reactive oxygen species (ROS) levels, which peak at the wound site around 1-h post-amputation and are required for planarian blastema formation. This study shows that weak anthropogenic magnetic fields can affect stem cell proliferation and subsequent differentiation in a regenerative species, and that field strength can increase or decrease new tissue formation *in vivo*. This is a significant finding for regenerating species of all kinds, and may affect non-regenerating species as well. Sea lamprey eels (*Petromyzon marinus*), a fish species, are also known to regenerate even after multiple amputations [580].

Mollusks, amoeba, molds, algae, protozoans

Mollusks (marine versions are called chitons) are long known to manufacture magnetite in their teeth and to use fields weaker than the geomagnetic field for kinetic movement and direction [52, 117, 340, 524]. Lowenstam [118] first discovered that magnetite was the major mineral in the teeth of marine chitons, thought to give teeth their natural hardness. But Ratner [62] discovered chitons use magnetite as a magnetic compass when he found a number of chiton species have radulae (tongues) that are covered by ferro-magnetic (magnetite) denticles. The radulae of *Acompapleura granulata* and *Chiton squamosis* were also found to be ferro-magnetic but the shells were not. Live specimens of a chiton (*Chaetopleura apiculata*) that also have ferro-magnetic radulae were found to rotate more and move farther in a magnetic field weaker than in the Earth’s stronger geomagnetic field, indicating a nonlinear directionality. Ratner concluded that chitons are responsive to magnetic fields and demonstrate kinetic movements within them.

Some snails are sensitive to EMFs. Nittby et al. [581] observed analygesic effects in land snails (*Helix pomatia*) caused by GSM-1900 RFRs when snails lost sensitivity to pain on a hot plate test after nonthernal exposure to RFR.

Smaller organisms have also long shown effects from EMF. Goodman et al. [582] found delays in mitotic cell division in slime mold (*Physarum polycephalum*) with ELF-EMF exposures. Friend et al. [583] found perpendicular and parallel elongation of the giant amoeba Chaos chaos (*Chaos carolinensis*) in alternating electric fields over a wide frequency range (1 Hz–10 MHz) with characteristic changes as a function of frequency. Marron et al. [584] found effects on ATP and oxygen levels in another species of slime mold (*P. polycephalum*) after exposures to 60 Hz sinusoidal electric and magnetic fields. Luchien et al. [585] found a stimulating effect on the productivity of the algal biomass (*Chlorella sorokiniana*) for a magnetic field of 50 Hz but an inhibitory effect at 15 Hz in these microalgae.

Protozoans, thought to be more related to animals than microbes, also show sensitivity to EMF. Protozoans, as single-celled eukaryotes, are generally larger than bacteria which are classified as prokaryotes. The two organisms are structurally different: bacterial cells lack a nucleus while protozoa contain organelles such as mitochondria. Bacteria generally absorb nutrients through their cell walls while protozoa feed on bacteria, tissue, and organic matter and can be both infectious and parasitic. These protozoa include human parasites that cause diseases such as amoebic dysentery, malaria, giardiasis, leishmaniasis, trichomoniaisis, toxoplasmosis and others. Animal species are also affected by protozoans which can severely weaken and shorten their lifespans.

Rodriguez-de la Fuente et al. [586] tested ELF-EMF (60 Hz, 2.0 mT for 72 h) on two infectious protozoans, *Trichomonas vaginalis* and *Giardia lamblia*, and found growth alterations in both species which they attributed to alterations in cell cycle progression and cellular stress. Cammaerts et al. [587], used RFR (GSM 900-MHz at 2 W vs. control) on protozoans (*Paramecium caudatum*) and found individuals moved more slowly and sinuously than usual and that their physiology was affected. Paramecia became broader, pulse vesicles had difficulty expelling content to the outside of their cells, cilia moved less efficiently, and trichocysts became more visible — all effects that indicate poor functioning or cell membrane damage. They hypothesized that the first impact of RFR could be to cell membranes.

Clearly there are multiple effects at all levels documented in lower taxa from multi-frequency exposures that are now found in the environment.

Yeast and fungi

Yeast is often used in lab models, especially since 1996 when a complete genomic sequence of *Saccharomyces cerevisiae* was created. In fact it is now considered a "premier model" [588] for eukaryotic cell biology as well as having helped establish whole new fields of inquiry such as "functional genomics" and "systems biology" which focus on the interactions of individual genes and proteins to reveal specific properties of living cells and whole organisms.

EMF research is rich with studies using yeast models too numerous to fully analyze here. However we include a small sample of recent EMF research with potential significance to environmental exposures.

Lin et al. [589] investigated glucose uptake and transcriptional gene response to ELF-EMF (50 Hz) and RFR (2.0 GHz) on several strains of budding yeast (*S. cerevisiae*). Results determined that ELF-EMF and RFR exposure can upregulate the expression of genes involved in glucose transportation and the tricarboxylic acid (TCA) cycle, but not glycolysis pathways, thus showing that such exposures can affect energy metabolism which is closely related with cellular response to environmental stress. Glucose metabolism is fundamental to all living cells' need for energy, with related significance to many disease states including most cancers.

In a magnetic field study by Mercado-Saenz et al. [590], premature aging and cellular instability were found in yeast (*S. cerevisiae*) exposed to low frequency, low intensity sinusoidal magnetic fields (SMF continuous exposure at 2.45 mT, 50 Hz) and pulsed magnetic fields (PMF 1.5 mT, 25 Hz, 8 h/day). Chronological aging was evaluated during 40 days and cellular stability was evaluated by a spontaneous mutation count and the index of respiratory competence (IRC). They found exposure to PMF produced accelerated aging while SMF did not, and decreased mitochondrial mutation during aging was also seen with PMF. No alterations in respiratory competence were observed for either SMF or PMF exposures. They concluded that exposure to PMF accelerated chronological aging and altered the spontaneous frequency of mitochondrial mutation during the aging process, whereas the SMF used had no effect, thus showing abnormal effects on cell activity from pulsed exposures.

Because yeast cells are known to be sensitive to magnetic fields, some industrial and therapeutic applications to human health have been investigated. These investigations serve to illuminate what we know about yeast and fungal reactions to EMF in general, as well as specific uses. For industrial applications, Wang et al. [591] investigated low level static magnetic fields (SMF) on mold (*Aspergillus versicolor*) growth which can have high impacts on metal corrosion in environmental conditions conducive to mold growth. This is especially problematic in fine electronic circuit boards produced today. Using a

10 mT static magnetic field (SMF) perpendicular to the surface of printed circuit boards, they found the magnetic field inhibited mold growth and surface corrosion which were slowed down, unlike control boards without applied magnetic fields where mold formed a spore-centered corrosion pit that then led to macroscopic regional uniform corrosion. This demonstrated changes in cell/spore growth at a low intensity exposure that can be found in the environment.

Also with an eye toward commercial possibilities, Sun et al. [592] found that a polysaccharide of *Irpex lacteus* (a white-rot fungus found widely in the environment which breaks down organic materials but also is commercially used to treat nephritis in humans) was sensitive to low-intensity ELF-EMF as demonstrated by increased biomass and polysaccharide content, as well as induced malformed twists on the sample cell surfaces. Polysaccharides are carbohydrates with a large number of sugar molecules used as energy sources in living cells. They identified varying changes in multiple differentially expressed genes after exposure to alternating current EMF (50 Hz, 3.5 mT, 3 h per day, for 4 days). They found initial sharp increases in growth rates in exposed samples that were then marked by significant declines in EMF's influence over time, although there were also important lasting effects. Global gene expression alterations from EMF indicated pleiotropic effects (capable of affecting multiple proteins or catalyzing multiple reactions) were related to transcription, cell proliferation, cell wall and membrane components, amino acid biosynthesis and metabolism. Polysaccharide biosynthesis and metabolism were also significantly enriched in the EMF-exposed samples. They concluded that EMF significantly increased amino acid contents and was therefore deemed a suitable method for increasing fermentation of microorganisms, presumably for commercial use. However, the significance of this study to environmental exposures relates to the multiple ways that ELF alternating current common to electric power generation changed yeast gene expression. There is at least one clinical case of a different strain of *I. lacteus* taking on a rare infectious and dangerous quality in an immunocompromised human [593]. The question is: can now-ubiquitous ELF-EMF contribute to potentially emerging new forms of yeast contagion?

The same question arises with *Candida albicans* and other pathogenic yeasts that have rapidly developed resistance to antifungal medications. *C. albicans* can live harmlessly in human microflora, but certain lifestyle circumstances or immunosuppression can turn it into an opportunistic pathogen. It can also infect some non-human animals. While chronic mucocutaneous candidiasis can infect the skin, nails, and oral and genital mucosae, under high host immunodeficiency *C. albicans* can enter the bloodstream and induce systemic infections with mortality between 30 and 80% [594]. There has been increasing resistance of *C. albicans* to traditional antifungal agents, such as fluconazole and amphotericin B [595, 596]. Resistance mechanisms include overproduction of membrane drug efflux transporters and/or changes in gene expression [597].

Two investigations in search of new therapeutic strategies were conducted using EMF. Sztafrowski et al. [594] investigated the use of static magnetic fields (SMF, 0.5 T) on *C. albicans* cultures in the presence of two commonly used antifungal medications. Their aim was to assess whether SMF had any impact on general viability of *C. albicans* hyphal transition and its susceptibility to fluconazole and amphotericin B. They found reduction of *C. albicans* hyphal length in EMF-exposed samples. They also found a statistically significant effect on *C albicans* viability when SMF was combined with amphotericin B. They hypothesized that this synergistic effect may be due to the plasma membrane binding effects of amphotericin B and that SMF could influence domain orientation in the plasma membrane. They concluded, with caution, that the use of a SMF in antifungal therapy could be a new supporting option for treating candidas infections.

Novickij et al. [598] also focused on therapeutic possibilities given the multi-drug resistance and side effects to antifungal therapies. Their aim was to optimize the electroporation-mediated induction of apoptosis using pulses of varied duration (separately and in combination with formic acid treatment) and to identify yeast apoptotic phenotypes. They focused on nonthermal nanosecond pulsed electric fields (PEF 3 kV, 100 ns – 1 ms squarewave; and 250, 500, 750 ns duration 30 kV/cm PEF, 50 pulses, 1 kHz) as a therapeutic alternative and/or to enhance effects in combination with conventional treatments. In three yeast models, *S. cerevisiae* (as control) and drug resistant *Candida lusitaniae* and *Candida guilliermondii*, they found that nanosecond PEF induced apoptosis in all three strains. Combining PEF with a weak formic acid solution improved induced apotosis and inactivation efficacy in the majority of the yeast population. Yeast cells showed DNA breaks and other changes. They concluded that PEF could be a useful new non-toxic protocol to treat some fungal diseases and minimize tissue damage.

Choe et al. [599] studied ion transportation and stress response on a yeast strain (K667) to ELF-EMF (60 Hz, 0.1 mT, sinusoidal or square waves), specifically investigating internal ionic homeostasis via the cell membrane involving metal ions and cation transports (cations are ionic species of both atoms and molecules with a positive charge). They found significantly enhanced intracellular cation concentrations as ELF-EMF exposure time increased, as well as other changes. This study has implications for soil health as yeast can be an integral aspect of how healthy organic soil matter is formed. They concluded that EMF and yeast could also play a role in the bioremediation processes in metal-polluted environments.

Lian et al. [600] studied effects of ELF-EMF (50 Hz, 0–7.0 mT) and RFR (2.0 GHz, 20 V/m, temperature at 30 °C, average SAR single cell/0.12 W/kg) on two budding yeast strains (NT64C and SB34) and prion generation/propagation. They found under both EMF exposures that *de novo* generation and propagation of yeast prions (URE3) were elevated in both yeast strains. The prion elevation increased over time and effects were dose-dependent. The transcription and expression levels of heat shock proteins and chaperones were not statistically significantly elevated after exposure but levels of reactive oxygen species (ROS), as well as superoxide dismutase (SOD) and catalase (CAT) activities were significantly elevated after short-term, but not long-term exposure. This work demonstrated for the first time that EMF exposure could elevate the *de novo* generation and propagation of yeast prions, supporting the researcher's hypothesis that ROS may play a role in the effects of EMF on protein misfolding. ROS levels also mediate other broad effects of EMF on cell function. They concluded that effects of EMF exposure on ROS levels and protein folding may initiate a cascade of effects negatively impacting many biological processes.

The effects of EMF on protein folding cannot be overstated. Proteins must fold into proper three-dimensional conformations to carry out their specific functions — intact proteins are critical to the existence of all life. Misfolding not only impairs function but leads to disease. Folding inside of cells does not happen spontaneously but rather depends on molecular helpers called chaperones. Protein misfolding has been implicated in Alzheimer's, Parkinson's, and Huntington's diseases, among others. The devastating Creutzfeldt–Jakob disease is caused by prion misfolding in the brain, which causes abnormal signaling in neurons that eventually leads to paralysis and death. Wildlife can also suffer from prion diseases such as chronic wasting in deer, elk, and other cervids, and cattle can suffer from so-called "mad-cow" disease. The two studies from above [599, 600] have implications for how such diseases are spread through soil with possible links to environmental EMFs.

It is clear from the above that ELF-EMF and RF-EMF, using multiple signaling characteristics, are biologically active in both temporary and permanent ways in yeast/fungi species with wide environmental implications across numerous taxa.

Bacteria

Strains of bacteria are known to be magnetotactic and use geomagnetic fields for direction. Blakemore [63] was the first to suggest in 1973 that bacteria in North American saltwater marsh muds use magnetite as a sensor when he discovered not only that bacteria were highly attracted to an external magnet but they also had magnetite crystals that caused them to align with the lines of the Earth's magnetic fields. This was also discovered to be geolocation specific to the North Pole in northern samples and South Pole-seeking in southern species [52, 63, 511]. The bacteria showed "mud-up" and "mud-down" behavior along magnetic field gradients when mud was disturbed, indicating a magnetic compass. Since that early work, a whole new field called electromicrobiology has developed with discoveries that include some electro-active bacteria being responsible for magnetite formation, with others creating their own electric "wires" in mud flats with implications for new technologies [601].

Among the more troubling EMF effects are bacterial alterations with pressing implications for antibiotic resistance. Since the 1940s [602], nonthermal effects were documented in bacterial, viral, and tissue cultures with applied low-repetition 20-MHz pulses. Most studies spanning the 1940s though the 1980s focused on EMF's ability to kill microbes and fungi in human food sources at high intensity, consequently most research was focused on thermal intensities. That work still continues today as microwaves have been shown to be an efficient means for killing microbes [50]. But microbes also react to much lower nonlethal intensities and recent work finds effects from both ELF and RFR.

The common bacteria *Escherichia coli*, which can live harmlessly in the gut of humans and many other animal species, can also turn virulent and kill through food-borne illnesses. *E. coli* comes in many strains, is well studied, and now considered the most genetically and physiologically characterized bacterium. *E. coli* encounter varied and numerous environmental stressors during growth, survival, and infection, including heat, cold, changes in Ph levels, availability of food/water supplies, and EMF. Along with other bacteria, they respond by activating groups of genes and heat shock proteins (see "Mechanisms" above) which can eventually lead to stress tolerance for survival purposes. But induced stress tolerance can also lead to increased virulence, as well as enhanced tolerance to other stressors that confer cross-protection [603].

Salmen and colleagues [604, 605] published papers of EMF effects on bacterial strains documenting the growing investigation of microbes related to antibiotic resistance with many findings stressing responses to EMF [606–610]. Cellini et al. [611] investigated *E. coli*'s adaptability to environmental stress induced by ELF exposures to 50-Hz magnetic fields at low intensities (0.1, 0.5, 1.0 mT) vs. sham controls. They found exposed samples and controls displayed similar total and culturable counts, but increased cell viability was observed in exposed samples re-incubated for 24 h outside of the test solenoid compared to controls. Exposure to 50 Hz EMF (20–120 min) also produced a significant change in *E. coli* morphotype with a presence of coccoid cells aggregated in clusters after re-incubation of 24 h outside of the magnetic field-solenoid. Atypically lengthened bacterial forms were also noted, indicating probable alteration during cell division. Some differences in RNA-AFLP analysis were also seen for all intensities evaluated. They concluded that exposure to 50-Hz ELF-EMF is a bacterial stressor as evidenced by its immediate response in modifying morphology (from bacillary to coccoid) and inducing phenotypical and transcriptional changes. Despite this stressor effect, it was also seen that exposed samples significantly increased viability, suggesting the presence of VBNC cells. They concluded that further studies were needed to better understand ELF-EMF in bacterial cell organization. They did not extrapolate to the obvious — that *E. coli* was changed in an abnormal way but nevertheless strengthened in viability — a recipe for antibiotic resistance.

Crabtree et al. [612], in a small human study, investigated the biomic relationship of human bacteria exposed to both static magnetic fields (SMF) and RFR. Using laboratory culture strains and isolates of skin bacteria collected from the hand, cheek, and chin areas of four volunteers who had different (self-reported) cell phone use histories, they found varied growth patterns of *E. coli*, *Pseudomonas aeruginosa*, and *Staphylococcus epidermidis* under static magnetic fields on different bacterial species. Isolates of skin microbiota showed inconsistent growth among the test subjects, likely due to their differing cell phone usage histories (classified as heavy, medium and light) and other variables. The growth of *Staphylococci* was increased under RFR in certain individuals while in others growth was suppressed. This was complicated by the different body areas tested, some with higher chronic exposures such as the hands, as well as other variables when one test subject used an antibacterial face wash. Volunteers in the heavy use category showed less bacterial growth on the hands, possibly due to microbe habituation. Overall, and despite the small sample, they concluded RFR can disrupt the balance in skin microbiota, making it more vulnerable to infection by specific opportunistic and/or other foreign pathogens. They noted that both SMF and RF-EMFs have significant but variable effects on the growth of common human bacteria; that bacterial growth was either unaffected, increased, or suppressed depending on the species of bacteria; and that bacterial responses seemed to be determined by historic exposure to RF-EMF and life style. This study, even with inherent limitations, indicates changes in microbes with EMFs and may prove a novel way to study bacteria with significance for real-life exposures to humans and animals alike.

Salmen et al. [605] also found highly variable results from RFR (900 and 1,800 MHz) effects on DNA, growth rate, and antibiotic susceptibility in *Staphylococcus aureus*, *Staphylococcus epidermidis*, and *P. aeruginosa*. Using an active cell phone handset, they exposed bacteria to 900 and 1,800 MHz for 2 h, then injected samples into a new medium where growth rate and antibiotic susceptibility were evaluated. Regarding DNA, they found no differences in *S. aureus* and *S. epidermidis* when exposed to 900 and 1,800 MHz vs. controls, but *P. aeruginosa* showed changes in DNA band patterns following such exposures. Regarding growth rates, with the exception of a significant decrease after 12 h exposure to 900 MHz, no significant effects on growth of *S. aureus* and *S. epidermidis* were seen. But the growth of *P. aeruginosa* was significantly reduced following exposure for 10 and 12 h to 900 MHz, while no significant reduction in growth followed exposure to 1,800 MHz. Regarding antibiotic susceptibility, in the drugs studied (i.e., amoxicillin 30 mg, azithromycin 15 mg, chloramphenicol 10 mg, and ciprofloxacin 5 mg), with the exception of *S. aureus* treated with amoxicillin (30 mg), EMF-exposure had no significant effect on bacterial sensitivity to antibiotics. This study shows variability among bacterial species not only to different frequencies common in the environment today but also to changes in sensitivity to some antibiotics but not others. There may have been design problems with this study, however.

Several studies investigated WiFi signals on bacterial strains. Taheri et al. [610] assessed exposure to 900-MHz GSM mobile phone radiation and 2.4-GHz RFR from common WiFi routers to see if cultures of *Listeria monocytogenes* and *E. coli* resulted in altered susceptibility to 10 different antibiotics. They found narrow windows in which microbes became more resistant: For L. *monocytogenes* no significant changes in antibacterial activity between exposed and nonexposed samples — except for Tetracycline (Doxycycline) — were noted. For *E. coli*, however, there was a significant change in antimicrobial activities suggesting RFR exposures can influence antibiotic susceptibility of *E. coli* more than in *Listeria*. For window and pronounced effects, they found *L. monocytogenes* exhibited different responses to each antibiotic. For Doxycycline, the window occurred after 6 h exposure to WiFi and mobile phone-RFR. After 9 h of exposure to WiFi for Ciprofloxacin and Sulfonamide (Tremethoprin/sulfamethoxazole), bacteria tended to become more resistant. By contrast, the pattern for Levofloxacin and Penicillin (Cefotaxime/Deftriaxone) showed increased sensitivity. For *E.coli*, the pattern of the response to WiFi and mobile phone RFR was the same: maximum antibiotic resistance was seen between 6 and 9 h of exposure but after 12 h, a stress response lead to a return to preexposure conditions indicating an adaptive reaction. Taheri et al. [609] found similar nonlinear window effects and differences in growth rates in *Klebsiella pneumonia*, while Mortazavi et al. [613] found similar window effects in *E coli*. In addition, they saw significant increased growth rates after radiation exposures in both Gram-negative *E. coli* and Gram-positive *L. monocytogenes*. They concluded that such window effects can be determined by intensity and dose rate; that exposure to RFR within a narrow window can make microorganisms resistant to antibiotics; and that this adaptive phenomenon is a human health threat. The same can be inferred for many non-human species.

Said-Salman et al. [614] evaluated non-thermal effects of WiFi at 2.4 GHz for 24 and 48 h (using a WiFi router as the source) on the pathogenic bacterial strains *E. coli* 0157H7, *S. aureus, and S. epidermis* for antibiotic resistance, motility, metabolic activity and biofilm formation. Results found that WiFi exposure altered motility and antibiotic susceptibility of *E. coli* but there was no effect on *S. aureus and S. epidermis*. However, exposed cells (vs. unexposed controls) showed an increased metabolic activity and biofilm formation ability in *E. coli*, *S. aureus and S. epidermis*. They concluded that WiFi exposure acted as a bacterial stressor by increasing antibiotic resistance and motility of *E. coli*, as well as enhancing biofilm formation in all strains studied. They indicated the findings may have implications for the management of serious bacterial infections.

Movahedi et al. [615] also investigated antibiotic resistance, using short-term exposure to RFR from a mobile phone simulator (900 MHz, 24 h) on *P. aeruginosa* and *S. aureus* against 11 antibiotics. They found significant changes in structural properties and resistance to the numerous antibiotics studied. *P. aeruginosa* was resistant to all antibiotics after 24 h of exposure vs. non-exposed controls while *S. aureus* bacteria were resistant to about 50%. They also found structural changes in all exposed samples and increased cell wall permeability.

In a field study near cell towers, Sharma et al. [616] looked at changes in microbial diversity and antibiotic resistance patterns in soil samples taken near four different base stations with control samples taken >300 m away. *Stenotrophomonas maltophilia, Chryseobacterium gleum,* and *Kocuria rosea* were isolated and identified in soil samples collected near the exposed zones. They found greater antibiotic resistance in microbes from soil near base stations compared to controls, with a statistically significant difference in the pattern of antibiotic resistance found with nalidixic acid and cefixime when used as antimicrobial agents. They concluded that cell tower radiation can significantly alter the vital systems in microbes and make them multi-drug resistant.

Researchers have also investigated ELF-EMF effects on bacterial growth and antibiotic sensitivity. Segatore et al. [608] investigated 2 mT, 50 Hz exposures on *E. coli* ATCC 25922 and *P. aeruginosa* ATCC 27853 and found EMF significantly influenced the growth rate of both strains, notably at 4, 6, and 8 h of incubation. The number of cells was significantly decreased in exposed bacteria vs. controls. And at 24 h incubation, the percentage of cells increased (*P. aeruginosa* ~ 42%; *E. coli* ~ 5%) in treated groups vs. controls which suggested to the researchers a progressive adaptive response. However, they saw no remarkable change in antibiotic sensitivity. Potenza at al. [617] also found effects at high-intensity static magnetic fields at 300 mT on growth and gene expression in *E.coli* but that would be a high environmental exposure.

Viruses

There is a paucity of research on viral species and EMF, likely due to the fact that viruses lack ferromagnetic materials, are difficult to study, and don't make good general lab models other than to investigate their direct impact on specific *in vivo* end points. Virology research thrives in its own specialized niche and has not been used for basic modeling like so many other living life forms as noted throughout this paper. There is long-standing debate on whether viruses are even alive.

However, one wide-ranging discussion by Zaporozhan and Ponomarenko [618] hypothesized a possible complex mechanistic link between influenza pandemics, natural sun spot cycles, and non-thermal effects of weak magnetic fields via cryptochromes/radical pairs, gene expression pathways, and stress-induced host immunological alterations favorable to influenza epidemics. Noting that most — though not all — major influenza epidemics occurred in time intervals starting 2–3 years before and ending 2–3 years after maximum solar activity, they hypothesized that solar cycles are able to both regulate and entrain processes of biological microevolution in viral species (among others), as well as influence human biorhythms in synergistic ways that could lead to influenza epidemics. Although others have also noted links between influenza pandemics and sunspot activity — possibly based on changes in migratory bird patterns as viral vectors [619–621]— and some have linked sun spots with other adverse human health events, these effects remain of interest but are still hypothetical. UV radiation, which is not covered in this paper, is known to suppress cell-mediated immunity and is therefore capable of adversely affecting the course of a viral infection in some mammal species. Ambient EMF in lower frequency ranges may also be reducing immune viability across species which can theoretically foster opportunistic virulence. Far more EMF research needs to be conducted on viruses; one fruitful approach might be synergistic investigations in virus-infected plant species.

The previous studies of microbes show a pattern of sensitivity in microorganisms to EMF with associations that encompass a wide range of critical changes, including consistent stress responses, alterations in growth and viability, cell membrane alterations, and clear patterns of how easily antibiotic resistance forms in microbial life to now ubiquitous EMF levels.

Plants (see Part 2, Supplement 4, for a table of flora studies: ELF, RFR)

Plants have evolved in highly sensitive ways to natural and manmade EMF in all phases of germination, growth and maturation [31]. Magnetoreception, which is well documented in animals such as birds, has also been described in plants [622] and plant species can respond to subtle changes in EMF in the environment, including in whole plant communities [623]. They may even 'communicate' and gather various kinds of 'information' via electrical signals in neuron-like cells in root tips and elsewhere [624]. Some hypothesize [625] that a form of vibrational and acoustic sensitivity around 220 Hz may play a role in plant life, although not everyone agrees [626].

Almost all vegetation is subject to complex multi-frequency fields due to their soil-based root systems and high water content, plus above-ground ambient RFR exposures makes plants uniquely susceptible to effects near transmission towers [623, 627]. Many EMF studies have found both growth stimulation as well as dieback. The presence of numerous RFR-emitters in the German and Swiss Alps is thought to have played a role in the deforestation there [628]. The 'browning' of treetops is often observed near cell towers, especially when water is near tree root bases [25]. Treetops, with their high moisture content and often thick vegetative canopy, are known RFR waveguides. In fact, military applications utilize this capability in treetops for communication signal propagation in remote areas and for guidance of low-flying weapons systems [629].

How flora interacts with EMF is still a mystery but a clear pattern has emerged in researching the database for this paper: static ELF-EMF has largely been found beneficial to plant and seed growth [630] while RFR is detrimental. Plants clearly have magnetoreception in their stationary condition. The normal ground state of magnetic fields for plants is the relatively constant natural geomagnetic field that averages between 25 and 65 μT depending on location and seasonal variations [631]. Atmospheric changes, such as thunderstorms and lightning, can cause intermittent changes in ambient magnetic fields. These activities are also generally associated with rainwater critical to virtually all plant life. Plants can detect these changes and prepare for growth using the upcoming rainfall. Trees are seen extending their branches skyward long before rain actually occurs and such changes match alterations in tree polarities [632].

There are many studies showing an increase in the growth rate in plants, such as studies of seed germination exposed to alternating magnetic fields. Plants also respond similarly to high intensity static magnetic fields. This may mean that the physiological mechanism in plants that causes magnetic field-induced growth is finely tuned to a certain intensity of magnetic flux. Any variation in intensity or shape of the ambient magnetic field could activate or hinder this growth mechanism.

Lightning, for instance, generates fast and intense electromagnetic pulses (EMP). EMP has consistently been shown to cause biological effects [633] with just one pulse. Plants may have mechanisms so sensitive that they can detect the energy of EMP from kilometers away. The pulse causes a transient change in the environmental magnetic field that may be detected by one or more of the mechanisms mentioned in the "Mechanisms" section above, as well as discussed below. EMP has been closely investigated for military applications for its ability at high intensities to disable electronics. While much of the military-supported research finds no biological effects from EMP exposure, non-military supported research does show effects. This parallels the same findings in industry vs. non-industry research patterns [165, 634].

There is a long history on the study of effects of EMF exposure on plant growth, notably, the work of the Indian scientist Sir Jagadish Bose (1858–1937) who proposed the electric nature of plant responses to environmental stimuli and studied effects of microwaves on plant tissues and membrane potentials [635]. Interestingly, Bose investigated the effects of millimeter waves [636] now applicable to 5G technology. Bose, arguably, was a pioneer of wireless communication.

Another early pioneer in EMF effects on plants was Harold Saxon Burr (1889–1973) at Yale University who investigated the electric potential of trees in two tree species (a maple and an elm) located on one property and another maple tree for comparison growing 40 miles (64 km) away. Measurements of numerous parameters were taken using embedded electrodes that recorded hourly from 1953 to 1961 [637]. Simultaneous records of temperature, humidity, barometric pressure, sunlight, moon cycles, sunspot activity, weather conditions, atmospheric-potential gradients, earth-potential gradients, and cosmic rays were correlated with tree potentials. Burr also installed equipment that measured the potential between electrodes in the Earth (about 10 miles apart) and the potential gradient of the air, and found that the air and Earth potentials fluctuated exactly with the phase of the tree potentials although the trees were not always synchronous. Burr ultimately found that the electrical environment correlated closely with tree potentials in a kind of entrainment to diurnal, lunar and annual cycles. Meteorological parameters did not correlate in any immediate way other than when passing thunderstorms elicited anomalous behavior in the trees in direct parallel to measurements with the Earth electrodes. This follows the theory noted above that plants can sense EMP and take immediate information from it.

There are no other long-term field studies as detailed as Burr's of magnetic field effects on a plant species. However, another field study of RFR in Latvia [638] measured effects directly on trees near the Skrunda Radio Location Station, an early warning radar system that operated from 1971 to 1998. The system operated in the 156–162 MHz frequency range transmitting from four pulsed two-way antennas that had operated continuously for over 20 years by the time of the study. In permanent plots in pine forest stands, at varying distances from the radar station and in control areas, tree growth changes were measured and analyzed using retrospective tree ring data. They found a statistically significant negative correlation between the relative additional increment in tree growth and the intensity of the electric field with the radial growth of pine trees diminished in all plots exposed to RFR. The decreased growth began after 1970, which coincided with the initial operation of the station and was subsequently observed throughout the period of study. The effects of many other environmental and anthropogenic factors were also evaluated but no significant effects on tree growth were correlated. This may have been the first detailed field study of plants and RFR.

Many studies of EMF and plants are today conducted in laboratories and have often focused on growth promotion to create higher yields of food-producing plants. Effects of static EMF, pulsed EMF, ELF-EMF, and RF-EMF have been reported. There are, in fact, over 200 studies on plants and EMF alone — too numerous to review here. See Part 2, Supplement 4, for a Table of studies on plant seedlings and development based on the types of EMF's tested.

As noted in Supplement 4 and in Halgamuge [627], frequently static and ELF-magnetic fields generally improve plant growth whereas RFR retards it. This is the opposite of results from animal and animal-cell culture experiments in which ELF-MF usually produces the same effects as RFR. It is interesting to note that Hajnorouzi et al. [639] and Radhakrishma et al. [640] proposed that MF decreases environmental stress in plants whereas Vian et al. [641, 642] considered RFR as a systemic stressor. A major morphological difference between animal and plant cells is that plant cells have a cell wall that is an active physiological organelle which regulates growth and cell division and controls cellular communications. The cell wall contains a considerable amount of water [643]. Is it possible that absorption of RFR by cell-wall water causes a microthermal effect that adversely affects plant cell functions and even causes cell death, whereas thermal effects are not likely to occur with ELF-EMF exposure.

Some plant roots have been found sensitive to both ELF and RFR. Belyavskaya [644] found a strong cytochemical reaction in pea root cells after exposure to low level magnetic fields. Kumar et al. [645] found cyto- and genotoxicity in root meristems of *Allium cepa* with 900-MHz and 1,800-MHz RFR. Chandel et al. [646] studied cytotoxic and genotoxic activity on DNA integrity in root meristems of *A. cepa* using 2,100-MHz RFR and found exposure caused DNA damage with a significant decrease in HDNA accompanied by an increase in TDNA while TM and OTM did not change significantly compared to controls. Biological effects were dependent on the duration of exposure with maximum changes seen at 4 h.

In a series of studies, Stefi et al. [647–649] investigated the effects of long term RFR exposure from the base units of common cordless DECT phone systems (pulsed transmission mode 1,882 MHz, 24 h/day, 7 d/week) on various plant species (*Arabidopsis thaliana, Pinus halepensis, Gossypium hirsutum* respectively) and found structural and biochemical alterations. Compared to controls in Faraday cages, exposed plant biomass was greatly reduced and leaf structure was only half as thick. Leaves were thinner and possessed greatly reduced chloroplasts which contributed to overall reduced vitality. Root systems were also adversely affected. They concluded that RFR is a stressor and noxious to plant life. A study of similar design [650] did not find the same effects on maize (*Zea mays*) which they attributed to that plant's structural differences although chloroplasts were severely affected (see also Kumar et al. [651]).

Jayasanka and Asaeda [652] published a lengthy review that focused on microwave effects in plants. Studies indicate effects depend on the plant family and growth stage involved; and exposure duration, frequency, and power density, among other factors. They concluded that even for short exposure periods (<15 min to a few hours), nonthermal effects were seen that can persist for long periods even if initial exposures were very short. In addition, they noted that since base stations operate 24 h/day, neither short exposures nor recovery periods are possible in natural habitats as plants are continuously exposed throughout their life cycles. They said that variations in the power density and frequency of microwaves exert complex influences on plants, and that clearly diverse plant species respond differently to such factors. They concluded it is necessary to rethink the exposure guidelines that currently do not take nonthermal effects into consideration.

There are numerous reports of adverse RFR effects on mature flora. Waldman-Salsam et al. [653] reported leaf damage in trees near mobile phone towers/masts. In a detailed long-term field monitoring study from 2006 to 2015 in two German cities, they found unusual and unexplainable tree damage on the sides of trees facing the towers and correlated it to RFR measurements vs. control areas without exposures. They found that tree-side differences in measured values of power flux density corresponded to tree-side differences in damage. Controls, which consisted of 30 selected trees in low radiation areas without visual contact to any phone mast and power flux density under 50 μW/m^2, showed no damage. They concluded that nonthermal RFR from mobile phone towers is harmful to trees and that damage that affects one side eventually spreads to the whole tree.

Vian et al. [642] published a review of plant interactions with high frequency RFR between 300 MHz and 3 GHz and noted that reports at the cellular, molecular, and whole plant scale included: numerous modified metabolic activities (reactive oxygen species metabolism, α- and β-amylase, Krebs cycle, pentose phosphate pathway, chlorophyll content, and terpene emission among others); altered gene expression (calmodulin, calcium-dependent protein kinase, and proteinase inhibitor); and reduced growth (stem elongation and dry weight) after nonthermal RFR exposure. They said changes occur in directly exposed tissues as well as systemically in distant tissues and proposed that high-frequency RFR be considered a genuine environmental factor highly capable of evoking changes in plant metabolism.

Halgamuge [627] also published a review that found weak non-thermal RFR affects living plants. The author analyzed data from 45 peer-reviewed studies of 29 different plant species from 1996 to 2016 that described 169 experimental observations of physiological and morphological changes. The review concluded that the data substantiated that RFR showed physiological and/or morphological effects (89.9%, p<0.001). The results also demonstrated that maize, roselle, pea, fenugreek, duckweeds, tomato, onions and mungbean plants are highly sensitive to RFR and that plants appear more responsive to certain frequencies between 800 and 1,500 MHz (p<0.0001); 1,500 and 2,400 MHz (p 0.0001); and 3,500 and 8,000 MHz (p=0.0161). Halgamuge [627] concluded that the literature shows significant trends of RFR influence on plants.

There is particular concern for impacts to flora and 5G since millions of small antennas mounted on utility poles, transmitting in MMW and other broadband frequencies, already are — or will soon be — in very close proximity to vegetation, creating both near- and -far field exposures. As noted in Halgamuge [627], the following are some studies investigating GHz frequencies already in use or planned for 5G that found significant effects on plants: Tanner and Romero-Sierra [654] on accelerated growth of Mimosa plant (10 GHz, 190 mW/cm^2, 5–10 min); Scialabba and Tamburello [655] on reduced hypocotyls growth rate in radish (*Raphanus sativus*) (10.5 GHz, 8 mW or 12.658 GHz, 14 mW for 96 h); Tafforeau et al. [656] induced meristem (actively dividing group of cells) production in *Linum usitatissimum* (105 GHz for 2 h at 0.1 mW/cm^2); and Ragha et al. [657] (9.6 GHz, 30 min) found germination depended on exposure parameters on *Vigna radiata*, *Vigna aconitifolia*, *Cicer arietinum* and *Triticum aestivum* plants. This is an area in immediate need of further investigation given the results from the previous studies.

A thorough review of RFR effects to trees and other plants was published by Czerwinski et al. [622] who reported that ecological effects on whole plant communities could occur at a very low exposure level of 0.01–10 μW/cm^2 — certainly comparable to limits examined in this paper. They focused on frequencies between 0.7 and 1.8 GHz and included multiple complex indicators for plant types, biometrics, and environmental factors. It was the first comprehensive paper that extended beyond using narrower research methods. They noted that although the literature on the effects of RFR on plants is extensive, not a single field study had assessed the biological response at the level of a whole plant community, biome, or ecosystem, but rather focused mostly on short-term laboratory studies conducted on single species. They said, "…This dissonance is particularly striking in view of the fact that alterations in a plant community's structure and composition have long been considered to be well founded, sensitive and universal environmental indicators." The paper serves as a predictive model for complex future field studies on larger ecosystems.

Interesting EMF synergistic effects were found with static magnetic fields and bacteria in plants. Seeking nonchemical methods to improve seed germination after prolonged periods of storage when seed viability can deteriorate, Jovičić-Petrović et al. [658] studied the combined effects of bacterial inoculation (*Bacillus amyloliquefaciens* D5 ARV) and static magnetic fields (SMF, 90 mT, 5 and 15 min) on white mustard (*Sinapis alba* L.) seeds. Their results found that biopriming with the plant growth-promoting *B. amyloliquefaciens* increased seed growth by 40.43%. Seed response to SMF alone was dependent on treatment duration. While SMF at 5 min increased the germination percentage, exposure at 15 min lowered seed germination compared with the control. However, the negative effect at the longer exposure was neutralized when combined with the bacterial inoculation. Both germination percentages were significantly higher when SMF was combined with the bacteria (SMF, 5 min, + D5 ARV; and SMF, 15 min + D5 ARV; 44.68 and 53.20%, respectively) compared with control. They concluded that biopriming and SMF treatment gave better results than bacterial inoculation alone. The highest germination percentage — 53.20% of germinated seeds — was seen with the bacterium and 15 min exposure to 90 mT, demonstrating a synergistic effect. They concluded that such techniques can be used for old seed revitalization and improved germination.

Even aquatic plants have been found sensitive to artificial electric fields. Klink et al. [659] assessed electric field exposures on growth rates and the content of trace metals of *Elodea canadensis*. Plants were exposed in a laboratory to an electric field of 54 kV/m for seven days. Plant length and Fe, Mn, Ni, Pb, and Zn were measured. Results showed the applied electric fields slightly enhanced root growth. They also found changes in mineral absorption; Mn and Ni were significantly lower while Pb and Zn were significantly higher in exposed plants. Fe content did not differ between control and exposed plants. They concluded that electric fields had potential use for phytoremediation in trace metal contaminated waters. This study also has implications for long term aquatic plant health in general.

Also working with electric fields, Kral et al. [660] found fascinating regeneration in plant root tips in *Arabidopsis* at varying electric field exposures and time durations with the weaker exposures producing the most growth. They found that imposed electric fields can perturb apical root regeneration and that varying the position of the cut and the time interval between excision and stimulation made a difference. They also found that a brief pulse of an electric field parallel to the root could increase by up to two-fold the probability of its regeneration, perturb the local distribution of the hormone auxin, and alter cell division regulation with the orientation of the root towards the anode or the cathode playing a role.

While mechanisms are still unclear regarding how EMFs affect plants, oxidative effects appear to play a significant role. Oxidative changes have been reported in many studies in plants after exposure to EMF [578, 639, 661–671]. EMF-related stress has been proposed by Vian et al. [641, 642], Roux et al. [672, 673], and Radhakrishma et al. [640]. Other mechanisms affecting plants such as ferromagnetism, radical-pairs, calcium ions and cryptochromes have also been proposed [674, 675].

It is apparent that plant growth and physiology — with their root systems anchored in the ground while their 'heads' manifest in the air — are affected by exposure to EMF in complex synergistic ways and that they are susceptible to multi-frequency exposures throughout their life spans.

Conclusion

Effects from both natural and man-made EMF over a wide range of frequencies, intensities, wave forms, and signaling characteristics have been observed in all species of animals and plants investigated. The database is now voluminous with *in vitro, in vivo,* and field studies from which to extrapolate. The majority of studies have found biological effects at both high and low-intensity man-made exposures, many with implications for wildlife health and viability. It is clear that ambient environmental levels are biologically active in all non-human species which can have unique physiological mechanisms that require natural geomagnetic information for their life's most important activities. Sensitive magnetoreception allows living organisms, including plants, to detect small variations in environmental EMF and react immediately as well as over the long term, but it can also make some organisms exquisitely vulnerable to man-made fields. Anthropogenic EMF may be contributing more than we currently realize to species' diminishment and extinction. Exposures continue to escalate without understanding EMF as a potential causative and/or co-factorial agent. It is time to recognize ambient EMF as a potential novel stressor to other species, design technology to reduce exposures to as low as reasonably achievable, keep systems wired as much as possible to reduce ambient RFR, and create laws accordingly — a subject explored more thoroughly in Part 3.

Research funding: None declared.
Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission.
Competing interests: Authors state no conflict of interest.
Informed consent: Not applicable.
Ethical approval: Not applicable.

Part 2: supplements

Supplement 1: Genetic Effects of RFR Exposure
Supplement 2: Genetic Effects at Low Intensity Static/ ELF EMF Exposure
Supplement 3: Biological Effects in Animals and Plants Exposed to Low Intensity RFR
Supplement 4: Effects of EMF on plant growth

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Supplementary Material: The online version of this article offers supplementary material (https://doi.org/10.1515/reveh-2021-0050).

Part 2. Supplement 1.
Genetic Effects at Low Level RFR Exposure

RFR studies	**Power density/SAR (<0.1 W/Kg)**	**Effects observed**
Aitken et al. (2005)	Mice to 900-MHz RFR for 7 days at 12 h/day; SAR 0.09 W/kg	Mitochondrial genome damage in epididymal spermatozoa.
Akdag et al. (2016)	Male Wistar-Albino rats to 2400 MHz RFR from a Wi-Fi signal generator for a year; SAR 0.000141 (min)-0.007127 (max) W/kg	DNA damage in testes.
Alkis et al. (2019a)	Rats exposed to 900 MHz (brain SAR 0.0845 W/kg), 1800 MHz (0.04563 W/kg), and 2100 MHz (0.03957 W/kg) RFR 2 h/day for 6 months	Increased DNA strand breaks and oxidative DNA damage in brain.
Alkis et al. (2019b)	Rats exposed to 900 MHz, 1800 MHz, and 2100 MHz RFR 2 h/day for 6 months; maximum SAR over the rat 0.017 W/kg	DNA strand beaks and oxidative DNA damage in testicular tissue.
Atasoy et al. (2013)	Male Wister rats exposed to 2437 MHz (Wi-Fi) RFR; 24 h/day for 20 weeks; maximum SAR 0.091 W/kg	Oxidative DNA damage in blood and testes.
Beaubois et al. (2007)	Leaves of tomato plant exposed to 900-MHz RFR for 10 min at 0.0066 mW/cm^2	Increased expression of leucine-zipper transcription factor (bZIP) gene.
Belyaev et al. (2005)	Lymphocytes from human subjects exposed to GSM 915 MHz RFR for 2 h ; SAR 0.037 W/kg;	Increased condensation of chromatin.
Belyaev et al. (2009)	Human lymphocytes exposed to UMTS cell phone signal (1947.4 MHz, 5 MHz band	Chromatin affected and inhibition of DNA double-strand break.

	width) for 1 h; SAR 0.04 W/kg	
Bourdineaud et al. (2017)	Eisenia fetida earthworms exposed to 900 MHz for 2 h; SAR 0.00013-0.00933 W/kg	DNA genotoxic effect and HSP70 gene expressions up regulated.
Campisi et al. (2010)	Rat neocortical astroglial to CW 900 MHz RFR for 5, 10, or 20 min; incident power density 0.0265 mW/cm^2	Significant increases in DNA fragmentation.
Chaturvedi et al. (2011)	Male mice exposed to 2450 MHz RFR, 2 h/day for 30 days; SAR 0.03561 W/kg	Increased DNA strand breaks in brain cells.
Deshmukh et al. (2013)	Male Fischer rats exposed to 900 MHz (0.0005953 W/kg), 1800 MHz (0.0005835 W/kg), and 2450 MHz (0.0006672 W/kg) RFR for 2 h/day, 5 days/week for 30 days.	Increased DNA strand breaks in brain tissues.
Deshmukh et al. (2015)	Male Fischer rats exposed to 900 MHz (0.0005953 W/kg), 1800 MHz (0.0005835 W/kg), and 2450 MHz (0.0006672 W/kg) RFR for 2 h/day, 5 days/week for 180 days.	Increased DNA strand breaks in brain tissues.
Deshmukh et al. (2016)	Male Fischer rats exposed to 900 MHz (0.0005953 W/kg), 1800 MHz (0.0005835 W/kg), and 2450 MHz (0.0006672 W/kg) RFR for 2 h/day, 5 days/week for 90 days.	Increased DNA strand breaks in brain tissues.
Eker et al. (2018)	Female Wistar albino rats exposed to 1800-MHz RFR for 2 h/day	Caspase-3 and p38MAPK gene expressions increased in eye tissues.

	for 8 weeks; SAR 0.06 W/kg	
Furtado-Filho et al. (2014)	Rats of different ages (0-30 days) exposed to 950 MHz RFR for 0.5 h/day for 51 days (21 days of gestation and 6-30 days old): SAR pregnant rat 0.01-0.03 W/kg; neonate 0.88 W/kg, 6-day old 0.51 W/kg, 15-day old 0.18 W/kg, 30-day old 0.06 W/kg.	Decreased DNA strand breaks in liver of 15-day old and increased breaks in 30-day old rats..
Gulati et al. (2016)	Blood and buccal cells of people lived close (<400 meters) to a cell tower; 1800 MHz, Maximum power density (at 150 meters) 0.00122 mW/cm^2, some subjects lived in the area for more than 9 yrs	Increased DNA strand breaks in lymphocytes and micronucleus in buccal cells.
Gürler (2014)	Wistar rats exposed to 2450 MHz RFR 1 h/day for 30 consecutive days; power density 0.0036 mW/cm^2	Increased oxidative DNA damage in brain and blood.
Hanci et al. (2013)	Pregnant rats exposed 1 h/day on days 13-21 of pregnancy to 900-MHz RFR at power density 0.0265 mW/cm^2.	Testicular tissue of 21-day old offspring showed increased DNA oxidative damage.
He et al. (2016)	Mouse bone marrow stromal cells exposed to 900 MHz RFR 3 h/day for 5 days; SAR 4.1 x 10^{-4} W/kg (peak), 2.5 x 10_{-4} W/kg (average)	Increased expression of PARP-1 mRNA
Hekmat et al. (2013)	Calf thymus exposed to 940 MHz RFR for	Altered DNA structure at 0 and 2 h after exposure.

	45 min; SAR 0.04 W/kg	
Keleş and Süt (2021)	Pregnant rats exposed to 900-MH RFR at 0.0265 mW/cm2; 1 h/day from E13.5 until birth; thoracis spine of offspring examined.	Down regulation of H3K27me3 gene, am epigenetic modification to the DNA packaging protein Histone H3 in motor nerons.
Kesari and Behari (2009)	Male Wistar rats exposed to 50 GHz RFR for 2 h/day for 45 days; SAR 0.0008 W/kg	Increased in brain tissue DNA strand.
Kumar R. et al. (2021)	Male Wistar rats exposed to 900, 100, 2450 MHz RFR at SARs of 5.84×10^{-4} W/kg, 5.94×10^{-4} W/kg and 6.4×10^{-4} W/kg respectively for 2 h per day for 1-month, 3-month and 6-month	Microwave exposure with increasing frequency and exposure duration brings significant ($p < 0.05$) epigenetic modulations which alters gene expression in the rat hippocampus. Global DNA methylation was decreased and histone methylation was increased.
Kumar S. et al. (2010)	Male Wistar rats exposed to 10-GHz RFR for 2 h a day for 45 days, SAR 0.014 W/kg	Increased micronucleus in blood cells.
Kumar S. et al. (2013)	Male Wistar rats exposed to 10 GHz RFR for 2 h a day for 45 days; SAR 0.014 W/kg	Increased micronucleus in blood cells and DNA strand breaks in spermatozoa.
Marinelli et al. (2004)	Acute T-lymphoblastoid leukemia cells exposed to 900 MHz RFR for 2-48 h, SAR 0.0035 W/kg	Increased DNA damage and activation of genes involved in pro-survival signaling.
Markova et al. (2005)	Human lymphocytes exposed to 905 and 915 MHz GSM signals for 1 h; SAR 0.037 W/kg	Affected chromatin conformation and 53BP1/gamma-H2AX foci
Markova et al. (2010)	Human diploid VH-10 fibroblasts and human	Inhibited tumor suppressor TP53 binding protein 1 (53BP1) foci

	adipose-tissue derived mesenchymal stem cells exposed to GSM (905 MHz or 915 MHz) or UMTS (1947.4 MHz, middle channel) RFR for 1, 2, or 3 hr; SAR 0.037-0.039 W/kg	that are typically formed at the sites of DNA double strand break location.
Megha et al. (2015a)	Fischer rats exposed to 900 and 1800 MHz RFR for 30 days (2 h/day, 5 days/week), SAR 0.00059 and 0.00058 W/kg	Reduced levels of neurotransmitters dopamine, norepinephrine, epinephrine, and serotonin, and downregulation of mRNA of tyrosine hydroxylase and tryptophan hydroxylase (synthesizing enzymes for the transmitters) in the hippocampus.
Megha et al. (2015b)	Fischer rats exposed to 900, 1800, and 2450 MHz RFR for 60 days (2 h/day, 5 days/week); SAR 0.00059, 0.00058, and 0.00066 W/kg	Increased DNA damage in the hippocampus
Nittby et al. (2008)	Fischer 344 rats exposed to 1800 MHz GSM RFR for 6 h; SAR whole body average 0.013 W/kg, head 0.03 W/kg	Expression in cortex and hippocampus of genes connected with membrane functions.
Odaci et al. (2016)	Pregnant Sprague - Dawley rats exposed to 900 MHz RFR 1 h each day during days 13 - 21 of pregnancy; whole body average SAR 0.024 W/kg	Testis and epididymis of offspring showed higher DNA oxidation.
Pandey et al. (2017)	Swiss albino mice exposed to 900-MHz RFR for 4 or 8 h per day for 35 days; SAR 0.0054-0.0516 W/kg	DNA strand breaks in germ cells.
Pesnya and Romanovsky (2013)	Onion (Allium cepa) exposed to GSM 900-MHz RFR from a cell	Increased the mitotic index, the frequency of mitotic and chromosome abnormalities, and

	phone for 1 h/day or 9 h/day for 3 days; incident power density 0.0005 mW/cm^2	the micronucleus frequency in an exposure-duration manner.
Phillips et al. (1998)	Human Molt-4 T-lymphoblastoid cells exposed to pulsed signals at cellular telephone frequencies of 813.5625 MHz (iDEN signal) and 836.55 MHz (TDMA signal) for 2or 21 h. SAR 0.0024 and 0.024 W/Kg for iDEN and 0.0026 and 0.026 W/kg for TDMA)	Changes in DNA strand breaks
Qin et al. (2018)	Male mice exposed to 1800-MHz RFR 2 h/day for 32 days, SAR 0.0553 W/kg	Inhibition of testosterone synthesis might be mediated through CaMKI/RORα signaling pathway.
Rammal et al. (2014)	Tomato exposed to a 1250-MHz RFR for 10 days at 0.0095 mW/cm^2	Increased expression of two wound-plant genes.
Roux et al. (2006)	Tomato plants exposed to a 900-MHz RFR for 2-10 min at 0.0066 mW/cm^2	Induction of stress gene expression.
Roux et al. (2008)	Tomato plants exposed to a 900-MHz RFR for 10 min at 0.0066 mW/cm^2	Induction of stress gene expression.
Sarimov et al. (2004)	Human lymphocytes exposed to GSM 895-915 MHz signals for 30 min; SAR 0.0054 W/kg	Condensation of chromatin was observed.
Shahin et al. (2013)	Female mice (Mus musculus) exposed to continuous-wave 2.45 GHz RFR 2 h/day for 45v days; SAR 0.023 W/kg	Increased DNA strand breaks in the brain.

Sun Y. et al. (2017)	Human HL-60 cells exposed to 900 Hz RFR 5 h/day for 5 days; peak and average 0.00041 and 0.00025 W/kg, respectively.	Increased oxidative DNA damage and decreased mitochondrial gene expression.
Tkalec et al. (2013)	Earthworm (Eisenia fetida) exposed to comtinupus-wave and AM-modulated 900-MHz RFR for 2 - 4 h; SAR 0.00013, 0.00035, 0.0011, and 0.00933 W/kg	Increased DNA strand breaks.
Tsybulin et al. (2013)	Japanese Quail embryos exposed in ovo to GSM 900 MHz signal from a cell phone intermittently (48 sec ON/12 sec OFF) during initial 38 h of brooding or for 158 h (120 h before brooding plus initial 38 h of brooding): SAR 0.000003 W/kg	The lower duration of exposure decreased DNA strand breaks, whereas higher duration resulted in a significant increase in DNA damage.
Vian et al. (2006)	Tomato plants exposed to a 900-MHz RFR for 10 min at 0.0066 mW/cm^2	Induction of mRNA encoding the stress-related bZIP transcription factor.
Yakymenko et al. (2018)	Quail embryos exposed to GSM 1800 GHz signal from a smart phone (48 s ON/12 s OFF) for5 days before and 14 days during incubation, power density 0.00032 mW/cm^2	Increased DNA strand breaks and oxidative DNA damage.
Zong et al. (2015)	Mice exposed to 900 MHz RFR 4 h/day for 7 days; SAR 0.05 W/kg	Attenuated bleomycin-induced DNA breaks and repair,

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Table 1

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Part 2. Supplement 2.
Genetic Effects at Low Intensity Static/ELF EMF Exposure

Static and ELF EMF Studies	**magnetic flux density**	**Effects observed**
Agliassa et al. (2018)	Arabidopsis thaliana (thale cress) exposed to 0.00004 mT static magnetic field for 38 days after sowing	Changes in gene expression in leaf and floral meristem.
Baek et al. (2019)	Mouse embryonic stem cells exposed to hypomagnetic field (<0.005 mT) up to 12 days	Induced abnormal DNA methylation.
Bagheri Hosseinabadi et al. (2020)	Blood samples from thermal power plant workers; mean levels of exposure to ELF magnetic and electric fields were 0.0165 mT (±6.46) and 22.5 V/m (±5.38), respectively.	DNA strand breaks .in lymphocytes.
Baraúna et al. (2015)	Chromobacterium violaceum bacteria cultures exposed to ELF-EMF for 7 h at 0.00066 mT	Five differentially expressed proteins detected including the DNA-binding stress protein.
Belyaev et al. (2005)	Human lymphocytes exposed to 50 Hz magnetic field at 0.015 mT (peak) for 2 h (measurements made at 24 and 48 h after exposure).	Induced chromatin conformation changes.
Dominici et al. (2011)	Lymphocytes from welders (average magnetic field exposure from personal dosimeters 0.00781 mT (general environmental level 0.00003 mT)	Higher micronucleus frequency correlated with EMF exposure levels; decreased in sister chromatid exchange frequency.

Heredia-Rojas et al. (2010)	Human non-small cell lung cancer cells (INER-37) and mouse lymphoma cells (RMA E7) (transfected with a plasmid with hsp70 expression when exposed to magnetic field and contains the reporter for the luciferases gene) exposed to a 60-Hz magnetic field at 0.008 and 0.00008 mT for 20 min.	An increased in luciferase gene expression was observed in INER-37 cells.
Liboff et al. (1984)	Human fibroblasts dring the middle of S phaseexposed to 15 Hz-4 kHz sinusoidal MF	Enhanced DNA synthesis at between 5-25 μT
Sarimov et al. (2011)	Human lymphocytes exposed to 50-Hz magnetic field at 0.005-0.02 mT for 15-180 min	Magnetic field condensed relaxed chromatin and relaxed condensed chromatin.
Villarini et al. (2015)	Blood leukocytes from electric arc welders presumably exposed to 50-Hz EMF (mean 0.0078 mT; range: 0.00003-0.171 mT)	Decreased DNA strand beaks.
Wahab et al. (2007)	Human peripheral blood lymphocytes exposed to 50 Hz sinusoidal (continuous or pulsed) or square (continuous or pulsed) magnetic fields at 0.001 or 1 mT for 72 h.	Increase in the number of sister chromatid exchange/cell
Zendehdel et al. (2019)	Peripheral blood cells of male power line workers in a power plant. The median value of the magnetic	Increased in DNA strand breaks.

	field at the working sites was 0.00085 mT.	

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Part 2. Supplement 3
Biological Effects in Animals and Plants Exposed to Low-Intensity RFR

		SAR (W/kg)	Power density (μW/cm²)	Effects reported
Aitken et al. (2005)	Mice exposed to 900 MHz RFR, 12/day. 7 days	0.09		Genotoxic effect in sperm.
Akdag et al. (2016)	Rats exposed to 2400 MHz RFR from a Wi-Fi signal generator for a year	0.000141 (min)- 0.007127 (max)		DNA damage in testes.
Alimohammadi et al. (2018)	pregnant mice exposed to 915 MHz RFR; 8h/day, 10 days.		0.045	Offspring had increased fetal weight, enlarged liver and tail deformation
Alkis et al. (2019a)	Rtas exposed to 900; 1800; and 2100 MHz RFR; 2 h/day. 6 months	Brain SAR: 900 MHz - 0.0845; 1800 MHz- 0.04563; 210 MHz- 0.03957		DNA single strand break and oxidative damages in frontal lobe.
Alkis et al. (2019b)	Rats exposed to 900; 1800; and 2100 MHz RFR; 2 h/day. 6 months	maximum SAR over the rat body 0.017		DNA strand beaks and oxidative DNA damage in testicular tissue.
Atasoy et al. (2013)	Rats exposed to 2437 MHz (Wi-Fi) RFR; 24 h/day for 20 weeks	maximum SAR 0.091		Oxidative DNA damage in blood and testes.

Balmori et al. (2010)	Frog (Rana temporaria) exposed to 88.5 – 1873.6 MHz, cell phone base station emissions; 2 months from egg phase to tadpole		0.859-3.25 (1.5-3.8 V/m)	Retarded development and increased mortality rate.
Balmori et al (2015)	White stocks lived within 200 m of a Phone mast, GSM-900 MHz and DCS-1800 MHz signals		1.48	Affected reproduction rate.
Bartos et al. (2019)	Cockroach exposed to broadband RF noise		429 nT	Light-dependent slowing of circadian rhythm.
Beaubois et al. (2007)	Tomato plant exposed to 900-MHz RFR for 10 min		6.6	Increased expression of leucine-zipper transcription factor (bZIP) gene in leaves.
Bedir et al. (2018)	Rat exposed to 2100 MHz RFR, 6 or 19 h/day, 30 days	0.024		Oxidative stress-mediated renal injury.
Belyaev et al. (1992)	E. coli exposed to 51.62-51.84 and 41.25-41.50 GHz RFR, 5-15 min		1	Suppressed radiation-induced repair of genome conformation state.
Belyaev et al. (2005)	915 MHz GSM signal, 24 & 48 hr	0.037		Genetic changes in human white blood cells
Belyaev et al. (2009)	915 MHz, 1947 MHz; GSM, UMTS signals 24 & 72 hr	0.037		DNA repair mechanism in human white blood cells
Bourdineaud et al. (2017)	Earthworm (Eisenia fetida) exposed to 900 MHz RFR, 2 hr	0.00013-0.009		DNA modification.

Burlaka et al. (2013)	Japanese quail embryos exposed to GSM 900 MHz RFR; 158-360 hr		0.25	Oxidative DNA damage and free radical formation
Capri et al. (2004)	900 MHz, GSM signal, 1 hr/day, 3 days	0.07		Cell proliferation and membrane chemistry
Cammaerts and Johansson (2015)	Brassicaceae lepidium sativum (cress d'alinois) seed exposed to 900 and 1800 MHz RFR, 4, 7, and 10 days		0.007-0.01	Defect in germination.
Cammaerts et al. (2013)	Ants exposed to GSM signal for 180 h		0.1572	Affected food collection and response to pheromones.
Cammaerts et al. (2014)	Ants exposed to GSM signal for 10 min		0.5968	Affected social behavior.
Campisi et al. (2010)	Rat neocortical astroglial cells exposed to 50-Hz modulated 900 Mhz RFR, 5-20 min		26	Free radical production and DNA fragmentation.
Czerwinski et al. (2020)	Plant community exposed to cell phone base station radiation		0.01-0.1	Biological effects observed.
Chaturvedi et al. (2011)	Rat brain cells exposed to 2450 MHz RFR, 2 h/day for 30 days	0.03561		Increased DNA strand breaks.
Comelekoglu et al. (2018)	Rat sciatic nerve exposed to 1800 MHz RFR, 1 hr/day, 4 weeks	0.00421		Changes in electrical activity, increased catalase, and degeneration of myelinated fibers.

De Pomerai et al. (2003)	Protein exposed to 1 GHz RFR, 24 & 48 hr	0.015		Protein damages
Deshmukh et al. (2013)	Rats exposed to 900, 1800, and 2450 MHz RFR ; 30 days	0.0006-0.0007		DNA strand breaks in brain.
Deshmukh et al. (2015)	Rats exposed to 900, 1800, and 2450 MHz RFR; 180 days	0.0006-0.0007		Declined cognitive functions, increased brain HSP70 and DNA strand break.
Deshmukh et al. (2016)	Rats exposed 900, 1800, and 2450 MHz; 90 days	0.0006-0.0007		Declined cognitive functions, increased brain HSP70 and DNA strand break in rats
Dutta et al. (1984)	human neuroblastoma cells exposed to 915 MHz RFR, sinusoidal AM at 16 Hz	0.05		Increase in calcium efflux.
Dutta et al. (1994)	Escherichia coli cultures containing a plasmid with a mammalian gene for enolase were exposed for 30 min to 147 MHz RFR AM at16 or 60 Hz	0.05		Enolase activity in exposed cultures RFR at AM at 16 Hz showed enhanced activity enhanced, and AM at 60 Hz showed reduced activity. (Modulation frequencies. 16 and 60 Hz, caused similar effects.)
Eker et al. (2018)	Rats exposed to 1800 MHz RFR, 2 hr/day for 8 weeks	0.06		Increased caspase-3 and p38MAPK expressions in eye.
Fesenko et al. (1999)	Mice exposed to 8.15 – 18 GHz RFR, 5 hr to 7 days, direction of response depended on exposure duration		1	Changes in immunological functions.

Forgacs et al. (2006)	Mice exposed to 1800 MHz RFR, GSM- 217 Hz pulses, 576 µs pulse width; 2 hr/day, 10 days	0.018		Increase in serum testosterone.
Frątczak et al. (2020)	Ticks exposed to 900 MHz RFR		0.1	Ticks attracted to the RFR, particularly those infected with Rickettsia (spotted fever).
Friedman et al. (2007)	Rat and human cells exposed to 875 MHz RFR, 30 min		5	Activation of signaling pathways.
Furtado-Filho et al. (2014)	Pregnant rats exposed to 950 MHz RFR for 0.5 h/day for 51 days (21 days of gestation and 6-30 days old)	SAR pregnant rat 0.01-0.03 W/kg; neonate 0.88 W/kg, 6-day old 0.51 W/kg, 15-day old 0.18 W/kg, 30-day old 0.06 W/kg		Decreased DNA strand breaks in liver of 15-day old and increased breaks in 30-day old offspring.
Gandhi et al. (2015)	People who lived within 300 m of a mobile-phone base station.		1.15	Increased DNA damage in lymphocytes, more in female than in male subjects.
Garaj-Vrhovac et al. (2011)	Operators of two types of marine radars (3, 9.4, and 5.5 GHz); average time on job 2-16 yrs	0.0005-0.004 (time averaged)		Increased genetic damages in blood lymphocytes

Gremiaux et al. (2016)	Rose exposed to 900 MHz RFR, 3x 39min every 48 h at 2 stages of development	0.00072		Delayed and reduced growth.
Gulati et al. (2016)	People lived close (<400 meters) to a cell tower; 1800 MHz, , some subjects lived in the area for more than 9 yrs		Maximum power density (at 150 meters) 1.22	Increased DNA strand breaks in lymphocytes and micronucleus in buccal cells.
Gulati et al. (2020)	DNA damage in human lymphocytes	Cells exposed to UMTS signals at different frequency channels used by 3 G mobile phone (1923, 1947.47, and 1977 MHz) for 1 or 3 h; SAR 0.04 W/kg		DNA damage found only in cells exposed to 1977-MHz field.
Gupta et al. (2018)	Rtas exposed to 2450 MHz RFR; 1h/day 28 days	0.0616		Cognitive deficit, loss of mitochondrial functions, activation of apoptotic factors in hippocampus; affected cholinergic system.
Gurler et al. (2014)	Rats exposed to 2.45 GHz RFR, 1 h/day, 30 days		3.59	Increased DNA damage in brain.

Halgamuge et al. (2015)	Growth parameters of soybean seedlings	GSM 217 Hz-modulated (4.8×10^{-7}, 4.9×10^{-5}, and 0.0026 W/kg) SAR or CW (0.00039 and 0.02 W/kg) 900-MHz RFR for 2 h		Modulated and CW fields produced different patterns of growth effects. There was an amplitude effect and extremely low-level modulated field (4.8×10^{-7} W/kg) affected all parameters.
Hanci et al. (2013)	Pregnant rats exposed 1 h/day on days 13-21 of pregnancy to 900-MHz RFR		26.5	Testicular tissue of 21-day old offspring showed increased DNA oxidative damage.
Hanci et al. (2018)	Rats exposed to 900 MHz RFR, 1 h/day to postnatal day 60.	0.0067		Changes in morphology and increase in oxidative stress marker in testis.
Hassig et al. (2014)	Cows exposed to 916.5 MHz signal similar to GSM base station, 30 days 16 h 43 min per day		38.2	Changes in redox enzymes (SOD. CAT, GSH-px
He et al. (2016)	Mouse bone marrow stromal cells exposed to 900 MHz RFR 3 h/day for 5 days	2.5×10^{-4}		Increased expression of PARP-1 mRNA
Hekmat et al. (2013)	Calf thymus exposed to 940 MHz RFR, 45 min	0.04		Conformational changes in DNA.

Ivaschuk et al. (1997)	Nerve growth factor-treated PC12 rat pheochromocytoma cells 836.55 MHz TDMA signal, 20 min	0.026		Transcript levels for c-jun altered.
Ji et al. (2016)	Mouse bone-marrow stromal cells exposed to 900 MHz RFR, 4 hr/day for 5 days		120	Faster kinetics of DNA-strand break repair.
Keleş et al. (2019)	Rats exposed tp 900 MHz RFR; 1h/day, 25days	0.012		Higher number of pyramidal and granule neurons in hippocampus.
Kesari and Behari (2009)	Rats exposed to 50 GHz RFR; 2hr/day, 45 days	0.0008		Double strand DNA breaks observed in brain cells
Kesari and Behari (2010)	Rats exposed to 50 GHz RFR; 2 hr/day, 45 days	0.0008		Changes in oxidative processes and apoptosis in reproductive system.
Kesari et al. (2010)	Rats exposed to 2450 MHz RFR at 50-Hz modulation, 2 hr/day, 35 days	0.11		DNA double strand breaks in brain cells
Kumar et al. (2010a)	Rats exposed to 10 GHz RFR, 2h/day 45 days	0.014		Cellular changes and increase in reactive oxygen species in testes
Kumar et al. (2010b)	Rats exposed to 10 GHz RFR, 2 h/day, 45 days; or 50 GHz, 2h/day, 45 days	0.014 (10 GHz) 0.0008 (50 GHz)		Genetic damages in blood cells.

Kumar et al. (2013)	Rats exposed to 10 GHz RFR for 2 h a day for 45 days	0.014		Increased micronucleus in blood cells and DNA strand breaks in spermatozoa.
Kumar et al. (2015)	maize seedlings exposed to 1899 MHz RFR, 0.5-4 h		33.2	Retarded growth and decreased chlorophyll content.
Kumar et al. (2021)	Epigenetic modulation in the hippocampus of Wistar rats	Rats exposed to 900 MHz, 1800 MHz, and 2450 MHz RFR at a specific absorption rate (SAR) of 5.84×10^{-4} W/kg, 5.94×10^{-4} W/kg and 6.4×10^{-4} W/kg respectively for 2 h per day for 1-month, 3-month and 6-month periods.		Significant epigenetic modulations were observed in the hippocampus, larger changes with increasing frequency and exposure duration.
Kwee et al. (2001)	Transformed human epithelial amnion cells exposed to 960 MHz GSM signal, 20 min	0.0021		Increased Hsp-70 stress protein.
Landler et al. (2015)	Juvenile snapping turtle (c. serpentina) exposed to 1.43 MHz RFR, 20 min		20-52 nT	Disrupted magnetic orientation.

Lazaro et al. (2016)	50, 100, 200, 400 m from ten mobile telecommunication antennas		0.0000265 - 0.106	Distance-dependent effects on abundance and composition of wild insect pollinators
Lerchl et al. (2008)	383 MHz (TETRA), 900 and 1800 MHz (GSM) 24 hr/day, 60 days	0.08		Metabolic changes in hamster.
López-Martín et al. (2009)	Pulse-modulated GSM and unmodulated signals; 2 hr	0.03-0.26		c-Fos expression in brain of picotoxin-induced seizure-prone rats
Magras and Xenos (1997)	Mice in 'antenna park'-TV and FM-radio, exposure over several generations		0.168	Decrease in reproductive functions.
Marinelli et al. (2004)	Human leukemia cell exposed to 900 MHz CW RFR 2 - 48 hr	0.0035		Cell's self-defense responses triggered by DNA damage.
Makova et al. (2005)	human white blood cells exposed to 915 and 905 MHz GSM signal, 1 hr	0.037		Altered chromatin conformation.
Markova et al. (2010)	in human diploid VH-10 fibroblasts and human adipose-tissue derived mesenchymal stem cells exposed to GSM (905 MHz or 915 MHz) or UMTS (1947.4 MHz, middle channel) RFR for 1, 2, or 3 hr;	0.037-0.039		Inhibited tumor suppressor TP53 binding protein 1 (53BP1) foci that are typically formed at the sites of DNA double strand break location.

Megha et al. (2015a)	Rats exposed to 900 and 1800 MHz RFR for 30 days (2 h/day, 5 days/week)	0.00059 and 0.00058		Reduced levels of neurotransmitters dopamine, norepinephrine, epinephrine, and serotonin, and downregulation of mRNA of tyrosine hydroxylase and tryptophan hydroxylase (synthesizing enzymes for the transmitters) in the hippocampus.
Megha et al. (2015b)	Rats exposed to 900, 1800, and 2450 MHz RFR for 60 days (2 h/day, 5 days/week)	0.00059, 0.00058, and 0.00066		Increased DNA damage in the hippocampus.
Monselise et al. (2011)	Etiolated duckweed exposed to AM 1.287 MHz signal form transmitting antenna		0.859 (1,8-7.8 V/m)	Increased alanine accumulation in cells.
Navakatikian and Tomashevskaya (1994)	Rats exposed to 2450 MHz CW and 3000 MHz pulse-modulated 2 μs pulses at 400 Hz, Single (0.5-12 hr) or repeated (15-60 days, 7-12 hr/day)	0.0027		Behavioral and endocrine changes, and decreases in blood concentrations of testosterone and insulin. CW-no effect
Nittby et al. (2007)	Rats exposed to 900 MHz GSM signal, 2 hr/wk, 55wk	0.0006		Reduced memory functions.
Nittby et al. (2008)	Rats exposed to 915 MHz GSM signal, 6 hr	0.013 (whole body average); 0.03 (head)		Altered gene expression in cortex and hippocampus.

Novoselova et al. (1999)	Mice exposed to RFR from 8.15 -18 GHz, 1 sec sweep time-16 ms reverse, 5 hr		1	Changes in Functions of the immune system.
Novoselova et al. (2004)	Mice exposed to RFR from 8.15 -18 GHz, 1 sec sweep time-16 ms reverse, 1.5 hr/day, 30 days		1	Decreased tumor growth rate and enhanced survival.
Novoselova et al. (2017)	Mice exposed to 8.15 -18 GHz RFR, 1 Hz swinging frequency, 1 hr		1	Enhanced plasma cytokine.
Odaci et al. (2016)	Pregnant Sprague - Dawley rats exposed to 900 MHz RFR 1 h each day during days 13 - 21 of pregnancy	0.024		Testis and epididymis of offspring showed higher DNA oxidation.
Özsobacı et al. (2020)	Human kidney embryonic cells (HEK293) exposed to 3450 MHz RFR, 1 h		1.06	Changed oxidative enzyme activity and increased apoptosis.
Panagopoulos and Margaritis. (2010a)	Flies exposed to GSM 900 and 1800 MHz RFR, 6 min/day, 5 days		10	‘Window’ effect of GSM radiation on reproductive capacity and cell death.
Panagopoulos and Margaritis. (2010b)	Flies exposed to GSM 900 and 1800 MHz RFR, 1- 21 min/day, 5 days		10	Reproductive capacity of the fly decreased linearly with increased duration of exposure.
Panagopoulos et al. (2010)	Flies exposed GSM 900 and 1800 MHz RFR, 6 min/day, 5 days		1-10	Affected reproductive capacity and induced cell death.
Pandey et al. (2017)	Mice exposed to 900-MHz RFR for	0.0054-0.0516		DNA strand breaks in germ cells.

	4 or 8 h per day for 35 days			
Pavicic et al. (2008)	Chinese hamster V79 cells exposed to 864 and 935 MHz CW RFR, 1-3 hrs	0.08		Cell growth affected.
Perov et al. (2019)	Rats exposed to 171 MHz CW RFR, 6h/day, 15 days	0.006		Stimulation of adrenal gland activity.
Persson et al. (1997)	Rats exposed to 915 MHz RFR -CW and pulse-modulated (217-Hz, 0.57 ms; 50-Hz, 6.6 ms) 2-960 min.	0.0004		Increase in permeability of the blood-brain barrier. CW more potent.
Pesnya and Romanovsky (2013)	Onion exposed to GSM 900-MHz RFR from a cell phone for 1 h/day or 9 h/day for 3 days.		0.5	Increased mitotic index, frequency of mitotic and chromosome abnormalities, and micronucleus frequency.
Phillips et al. (1998)	Human leukemia cells exposed to 813.5625 MHz (iDEN); 836.55 MHz (TDMA) signals, 2 hr and 21 hr	0.0024		DNA damage observed.
Piccinetti et al. (2018)	Zebrafish exposed to 100 MHz RFR, 24-72 h post-fertilization	0.08		Retarded embroyonic development.
Postaci et al. (2018)	Rats exposed to 2600 MHz RFR, 1 h/day, 30 days	0.011		Cellular damages and oxidative damages in liver.

Pyrpasopoulou et al. (2004)	Rats exposed to 9.4 GHz GSM (50 Hz pulses, 20 µs pulse length) signal, 1-7 days postcoitum	0.0005		Exposure during early gestation affected kidney development.
Qin et al. (2018)	Mice exposed to 1800-MHz RFR, 2 h/day for 32 days	0.0553		Inhibition of testosterone synthesis.
Rafati et al. (2015)	Frog gastroenemius muscle exposed to cell phone jammers; 1 m away, 3x 10 min periods	For different jammers:0.01-0.05		Latency of contraction of prolonged.
Ranmal et al. (2014)	Tomato exposed to 1250-MHz RFR for 10 days.		9.5	Increased expression of two wound-plant genes.
Roux et al. (2006)	Tomatoes exposed to 900-MHz RFR for 2-10 min		6.6	Induction of stress gene expression in tomato.
Roux et al. (2008a)	Tomatoes exposed to 900 MHz RFR		6.6	Changes in Gene expression and energy metabolism.
Roux et al. (2008b)	Tomato plants exposed to 900 MHz RFR (>30 min)		6.6	Changes in energy metabolism in leave of tomato plant.
Salford et al. (2003)	Rats exposed to 915 MHz GSM, 2 hr	0.02		Nerve cell damage in brain.
Sarimov et al. (2004)	Human lymphocytes exposed to 895-915 MHz GSM signal, 30 min	0.0054		Chromatin affected similar to stress response.

Schwarz et al. (2008)	Human fibroblasts exposed to 1950 MHz UMTS signal, 24 hr	0.05		Changes in genes.
Shahin et al. (2013)	Mice exposed to 2450 MHz RFR, 2 h/day for 45 days	0.023		Increased DNA strand breaks in the brain.
Singh et al. (2012)	Hung beans exposed to 900 MHz RFR, 0.5-2 h		8.54	Reduced root length and number of roots per hypocotyls.
Sirav and Seyhan (2011)	Rats exposed to CW 900 MHz or 1800 MHz for 20 min	CW 900 MHz (0.00426 W/kg) or 1800 MHz (0.00146 W/kg)		Increased blood-brain barrier permeability in male rats, no significant effect on female rats.
Sirav and Seyhan (2016)	Rats exposed to pulsed-modulated (217 Hz, 517 µs width) 900 MHz or 1800 MHz 6 RFR for 20 min	0.02		In male rats, both frequencies increased blood-brain barrier permeability, 1800 MHz is more effective than 900 MHz; in female rats, only 900 MHz filed caused an effect.
Somosz et al. (1991)	Rat embryo 3T3 cells exposed to 2450-MHz 16-Hz square modulated RFR	0.024		Increased the ruffling activity of the cells, and caused ultrastructural alteration in the cytoplasm. CW was less effective.
Soran et al. (2014)	Plants exposed to GSM and WLAN signals		10 (GSM) 7 (WLAN)	Enhanced release of terpene from aromatic plants; essential oil contents in leaves enhanced by GSM radiation but reduced by WLAN radiation in some plants.

Stagg et al. (1997)	Glioma cells exposed to 836.55 MHz TDMA signal, duty cycle 33%, 24 hr	0.0059		Glioma cells showed significant increases in thymidine incorporation, which may be an indication of an increase in cell division.
Stankiewicz et al. (2006)	Human white blood cells exposed to 900 MHz GSM signal, 217 Hz pulses-.577 ms width, 15 min	0.024		Immune activities of human white blood cells affected.
Sun Y. et al. (2017)	Human HL-60 cells exposed to 900 Hz RFR, 5 h/day for 5 days	peak and average SAR 4.1×10^{-4} and 2.5×10^{-4} W/kg		Increased oxidative DNA damage and decreased mitochondrial gene expression.
Szymanski et al. (2020)	Human cells exposed to Pulse-modulated 900 MHz RFR, two 15-min exposure	0.024		Human blood mononucleus cells demonstrated high immunological activity of monocytes and T-cell response to concanavalin A.
Tkalec et al. (2013)	Earthorm exposed to continuous-wave and AM-modulated 900- MHz RFR for 2 - 4 h	0.00013, 0.00035, 0.0011, and 0.00933		Increased DNA strand breaks.
Tsybulin et al. (2012)	Japanese Quail embryos exposed to GSM 900 MHz signal during first 38 h or 14 days of fertilization		0.2	Enhanced development and survival in Japanese Quail embryos probably via a free radical-induced mechanism.
Tsybulin et al. (2013)	Japanese Quail embryos exposed to GSM 900 MHz signal, 48 sec on/12 sec off; 38 or 158 h	0.003		Decreased DNA strand break at 38 h and increased in 158h exposure in cells.

Vargová et al. (2017)	Ticks exposed to 900 MHz RFR		0.07	Ticks showed greater movement activity, with jerking movement of whole body or first pair of legs.
Vargová et al. (2018)	Ticks exposed to 900 MHz and 5000 MHz RFR		0.105	In a tube with half shielded for RFR, ticks exposed to 900 MHz concentrated on exposed side, and escaped to shielded side when exposed to 5000 MHz
Velizarov et al. (1999)	Human epithelial amnion cells exposed to 960 MHz GSM signal, 217 Hz square-pulse, duty cycle 12%, 30 min	0.000021		Decreased proliferation
Veyret et al. (1991)	Exposure to 9.4 GHz 1 μs pulses at 1000 pps, also with or without sinusoidal AM between 14 and 41 MHz, response only with AM modulation, direction of response depended on AM frequency	0.015		Changes in functions of the mouse immune system.
Vian et al. (2006)	Tomato plants exposed to 900 MHz RFR		6.6	Stress gene expression in plant.

Vilić et al. (2017)	Oxidative effects and DNA damage in honey bee (Apis mellifera) larvae		Honey bee larvae were exposed to 900-MHz at unmodulated field at 27 $\mu W/cm^2$ and modulated (80% AM 1 kHz sinusoidal) field at 140 $\mu W/cm^2$, for 2 hr.	Oxidative effect with exposure to unmodulated field. DNA damage increased after exposure to modulated field.
Waldmann-Salsam et al. (2016)	Mobile phone mast, long-term exposure		>0.005	Damages to trees
Wolke et al. (1996)	Heart muscle cells of guinea pig exposed to 900, 1300, 1800 MHz, square-wave modulated at 217 Hz; Also 900 MHz with CW, 16 Hz, 50 Hz and 30 KHz modulations	0.001		Changed calcium concentration in heart muscle cells.
Yakymenko et al. (2018)	Quail embryos exposed to GSM 1800 GHz signal from a smart phone (48 s ON/12 s OFF) for5 days before and 14 days during incubation		0.32	Increased DNA strand breaks and oxidative DNA damage.

Yurekli et al. (2006)	945 MHz GSM, 217 Hz pulse-modulation 7 hr/day, 8 days	0.0113		Free radical chemistry.
Zong et al. (2015)	Mice exposed to 900 MHz RFR, 4 h/day for 7 days	0.05		Attenuated bleomycin-induced DNA breaks and repair.

Author Note: *Many of the biological studies are acute, mostly one-time, exposure experiments, whereas exposure to ambient environmental man-made EMF is chronic. Acute and chronic exposures will likely end up with different consequences. Living organisms can compensate for the effect at the beginning of exposure and growth promotion in plants could be a result of over-compensation. After prolonged exposure, a breakdown of the system could occur, leading to detrimental effects. This sequence of response is basically how a living organism responds to stressors. The timeline of response depends on the physiology of an organism and also the intensity of exposure*

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Supplement 4. Effects of EMF on plant growth

	Experimental conditions	**Results**
STATIC MAGNETIC FIELD		
Abdani Nasiri et al.(2018)	medicinal sage;15-30 mT, 5 min	enhanced growth
Baghel et al. (2016)	soybean; 200 mT, 1h,	increased growth
Bahadir et al. (2018)	sweet pea *;* 125 mT, 24-72 h	promoted germination
Bhardwaj et al. (2012)	cucumber; 100-250 mT, 1-3 h	increased germination rate, length of seedling and dry weight
Ćirković et al. (2017)	wheat ; 340 mT, 16 h	increased growth rate
Florez et al. (2007)	maize;125 and 250 mT, 1 min to 10 days	increased growth rate
Jovičić-Petrović et al. (2021)	White mustard seed, 90 mT, 5 or 15 min	suppressed germination, but synergistic with a plant growth-promoting bacterial strain Bacillus amyloliquefaciens D5 ARV
Kataria et al. (2020)	soybean; 200 mT, 1 h	stimulated germination and promoted growth
Kim et al. (2016)	agricultural plants ; 130-250 mT, 4 days	increased stem and root lengths
Patel et al. (2017)	maize; 200 mT, 1 h	enhanced germination
Payez et al. (2013)	wheat; 30 mT, 4 days	promoted growth
Razmioo andAlinian (2017)	Cumin seed; 150, 250 500 mT or 1T for min	improved germination, growth and oil and essential contents
Shabrangy et al. (2021)	barley seeds, 7 mT, 1,3, or 6 h	Improved seed germination rate, root and shoot lengths, and biomass weight
Vashisth and Joshi (2017)	maize; 50-250 mT, 1-4 h	enhanced seed growth
Vashisth and Nagarajan (2008)	chickpea; 0-250 mT, 1-4 h	increased speed of germination, seedling length and dry weight
Xu et al. (2013)	rock cress, removal of the local geomagnetic field (~45 μT)	suppressed growth
PULSED MAGNETIC FIELD		

Bhardwaj et al. (2016)	green pea; 100 mT, 1 h, 6-min on/off	enhanced germination and growth
Bilalis et al. (2012)	corn; 3 Hz; 12.5 nT, 1 x 10^{-6} wave duration, 0-15 min	promoted plant growth and yield
Efthimiadou et al. (2014)	tomato; 3 Hz, 12.5 mT, 1 x 10^{-6} s duration, 0-15 min	enhanced plant growth
Radhakrishnan et al. (2012a)	soybean; 1 Hz, 1.5 µT, 5 h/day for 20 days	improved plant growth
Radhakrishnan et al. (2012b)	soybean; 10 Hz, 1.5 µT, 5 h/day for 20 days	improved plant growth
ELF MAGNET FIELD		
De Souza et al. (2008)	lettuce; 60-Hz, 120-160 mT, 1-5 min	enhanced growth and final yield
Fischer et al. (2004)	sunflower and wheat; 16.67 Hz; 20 µT, 12 days	increased fresh and dry weights and growth rate
Huang and Wang (2008)	Mung bean; 10-60 Hz modulated, 12 h, 6.38-16.20 µT	20 and 60 Hz, enhanced growth; 30, 40 and 50 Hz inhibited growth
Leelapriya et al. (2003)	cotton;10 Hz, 0.1 mT, 5 h/day for 20 days	enhanced germination
Naz et al. (2012)	okra; 50 Hz, 99 mT, 3 and 11 min	increased germination
Novitskii et al. (2014)	radish; 50 Hz, 500 µT,5 days	stimulated lipid formation
Shine et al. (2011)	soybean; 50 Hz, 0-300 mT, 30-90 min	improved germination parameters and biomass
Yano et al. (2004)	radish; 60 Hz, 50 µT plus a parallel 48-µT static magnetic field, 10-15 days	decreased CO_2 uptake , fresh and dry weights and leaf area
RFR		
Cammaerts and Johansson (2015)	Garden cress; 900 and 1800 MHz, 0.007-0.01 µW/cm^2, 10 days	decreased germination
Grémiaux et al. (2016)	rose, 900 MHz, 0.00072 W/kg, 3 hr once or 3 times, every 48 hr	delayed and reduced growth
Halgamuge et al. (2015)	Soybean seedling. 900 MHz GSM pulsed or CW, 0.45 mW/cm^2, 2 h	GSM radiation reduced outgrowth of epicotyls; CW exposure reduced outgrowth of roots and hypocotyls.
Kumar et al. (2015)	maize;1800 MHz, 0.5-4 h, 33.2 µW/cm^2	retarded growth and reduced chlorophyll content

Mildažienė et al. (2019)	sunflower seed; 5.28 MHz, 5, 10, 15 min 0.74 mT	changes in phytohormone balance, development and leaf protein expression
Payez et al. (2013)	wheat; 10 KHz, 4 days, 25 mW/cm^2	reduced water intake, increased speed of growth, reduced seeding vigor index I
Senavirathna et al. (2014)	Parrot feather (Myriophyllum aquaticum), 2000 MHz, 0.142 mW/cm^2, 1 h	Reduction in growth
Singh et al. (2012)	Mung bean; 900 MHz, 8.54 $\mu W/cm^2$, 0.5-2 h	reduced root length and number of roots per hypocotyls
Tkalec et al. (2009)	Onion; 400 and 900 MHz, 2h, 446 $\mu W/cm^2$	induced mitotic aberrations due to impairment of the mitotic spindle

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Review Article

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Effects of non-ionizing electromagnetic fields on flora and fauna, Part 3. Exposure standards, public policy, laws, and future directions

https://doi.org/10.1515/reveh-2021-0083
Received June 21, 2021; accepted September 1, 2021;
published online September 27, 2021

Abstract: Due to the continuous rising ambient levels of nonionizing electromagnetic fields (EMFs) used in modern societies—primarily from wireless technologies—that have now become a ubiquitous biologically active environmental pollutant, a new vision on how to regulate such exposures for non-human species at the ecosystem level is needed. Government standards adopted for human exposures are examined for applicability to wildlife. Existing environmental laws, such as the National Environmental Policy Act and the Migratory Bird Treaty Act in the U.S. and others used in Canada and throughout Europe, should be strengthened and enforced. New laws should be written to accommodate the ever-increasing EMF exposures. Radiofrequency radiation exposure standards that have been adopted by worldwide agencies and governments warrant more stringent controls given the new and unusual signaling characteristics used in 5G technology. No such standards take wildlife into consideration. Many species of flora and fauna, because of distinctive physiologies, have been found sensitive to exogenous EMF in ways that surpass human reactivity. Such exposures may now be capable of affecting endogenous bioelectric states in some species. Numerous studies across all frequencies and taxa indicate that low-level EMF exposures have numerous adverse effects, including on orientation, migration, food finding, reproduction, mating, nest and den building, territorial maintenance, defense, vitality, longevity, and survivorship. Cyto- and geno-toxic effects have long been observed. It is time to recognize ambient EMF as a novel form of pollution and develop rules at regulatory agencies that designate air as 'habitat' so EMF can be regulated like other pollutants. Wildlife loss is often unseen and undocumented until tipping points are reached. A robust dialog regarding technology's high-impact role in the nascent field of electroecology needs to commence. Long-term chronic low-level EMF exposure standards should be set accordingly for wildlife, including, but not limited to, the redesign of wireless devices, as well as infrastructure, in order to reduce the rising ambient levels (explored in Part 1). Possible environmental approaches are discussed. This is Part 3 of a three-part series.

Keywords: aeroecology; electroecology; International Council on Non-ionizing Radiation Protection (ICNIRP); Migratory Bird Treaty Act (MBTA); National Environmental Policy Act (NEPA); non-ionizing electromagnetic fields (EMFs); radiofrequency radiation (RFR); rising ambient levels; U.S. Federal Communications Commission (FCC).

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Introduction

This is Part 3 and concludes a three-part series on electromagnetic field (EMF) effects to wildlife.

Part 1 focused on measurements of rising background levels in urban, suburban, rural, and deep forested areas as well as from satellites. Discussed were different physics models used to determine safety and their appropriateness to current exposures. The unusual signaling characteristics and unique potential biological effects from 5G were explored. The online edition of Part 1 contains a Supplement Table of measured global ambient levels.

Part 2 is an in-depth review of species extinctions, exceptional non-human magnetoreception capabilities, and other species' known reactions to anthropogenic EMF exposures as studied in laboratories and in the field. All animal kingdoms are included and clear vulnerabilities are seen. Part 2 contains four Supplement Tables of extensive low-level studies across all taxa, including ELF/RFR genotoxic effects.

Part 3 discusses current exposure standards, existing federal, and international laws that should be enforced but often are not, and concludes with a detailed discussion of aeroecology—the concept of defining air as habitat that would serve to protect many, though not all, vulnerable species today.

Government exposure standards

Extremely Low Frequency (ELF)

In the U.S., there are no federal government exposure standards for humans, much less wildlife, for the extremely low frequency (ELF) bands between 0 and 300 Hz. Within this range are the 50–60 Hz exposures common to powerlines and electric utility wiring that continue to rise due to our increasing energy demands, as well as electric utility grounding practices that use the Earth itself as the return neutral for excess current back to substations. Today in many regions, rather than run additional neutral lines (at significant expense) on utility poles along roadways to handle the extra harmonic load that all of our new electronic and wireless devices place on the lines, utilities siphon off excess voltage every few poles apart directly into the ground. Earth itself becomes the neutral line, sometimes with significant accumulations near substations that can elevate contact currents in nearby homes and outdoor environments, affecting pets and urban wildlife, as well as on underground metal gas pipelines that can form dangerous corrosion and hotspots [1]. In addition, new technologies like "wireless electricity"—called wireless power transfer (WPT)—to charge electric vehicles, batteries, computers, and chargers are coming on the market, creating novel ambient wireless and DC power exposures that we have never seen before, spanning from ELF through the 9 kHz to 40 GHz frequency bands. The technology is in nascent stages but involves transmission of power via RFR, most likely in the microwave bands at 2.45 GHz, to a special receiver called a rectenna that then converts it back to DC power for use in an ELF ambient capacity. The goal is to get rid of wires. This is a completely new exposure to which many species of flora and fauna are sensitive (see Part 2). Such industrial-scale grounding practices and wireless ELF/RFR have never been studied as environmental factors for air, land-based, or underground wildlife. This includes potential damage to flora with vulnerable root systems in the ground while their primary growth is above ground level (AGL), making flora susceptible to both ELF and radiofrequency radiation (RFR) exposures. Standards-setting groups may soon turn attention to ELF in light of WPT that is coming on the market with virtually no environmental review.

The U.S. Federal Communications Commission

In the U.S., the Federal Communications Commission (U.S. FCC) has jurisdiction over the licensing of electromagnetic spectrum use between 100 kilohertz (kHz) and 100 gigahertz (GHz), which includes cable TV/Internet, amateur radio, AM/FM commercial broadcast stations, wireless cellular facilities, satellite communications, and all other communications devices/services (See Figure 1). There are adopted and enforceable exposure standards in the radiofrequency bands between 300 kHz and 100 GHz under FCC—a non-health agency that relies on other agencies and outside expert groups for advice regarding human exposures ([2, 3], and see Part 1). FCC's 1997 standards were reviewed and reaffirmed in 2020 with minimal changes [4].

The model for the FCC standards are human-centric, based on short-term, acute high-intensity exposures to RFR that are capable of heating tissue the way a microwave oven cooks food. Thermal heating effects were well-quantified decades ago and are reasonably easy to regulate while allowing technology to flourish. It is the ubiquitous lower intensity exposures that are problematic and unregulated (see Part 2, Supplement 3 for effects at very low intensity exposures).

It is important to understand that the FCC standards (and other similar models) are exposure limits, not emissions allowances from generating sources although the two are intricately linked. As such, the standards are distance related with accessibility to a generating source being the most important factor, and they are relevant only to locations that are accessible to workers and/or members of the public [2, 5, 6]. This means that despite safety factors built in to such standards, ambient levels are largely unregulated outside of built environments.

However, while standards by any group are derived with only humans in mind, all measurement factors are potentially relevant metrics to species in the wild. Thus the large body of research intended to help set exposure limits for humans are germane to determining new standards to protect wildlife, at least in some very broad ways. But in regulating for wildlife, factors involving rising ambient levels (see Part 1) must include both exposure and emission considerations, due to the increased sensitivity to EMF/RFR of many species (see Part 2) based on taxonomy, size, physiology, habitat, magnetoreception, seasonal

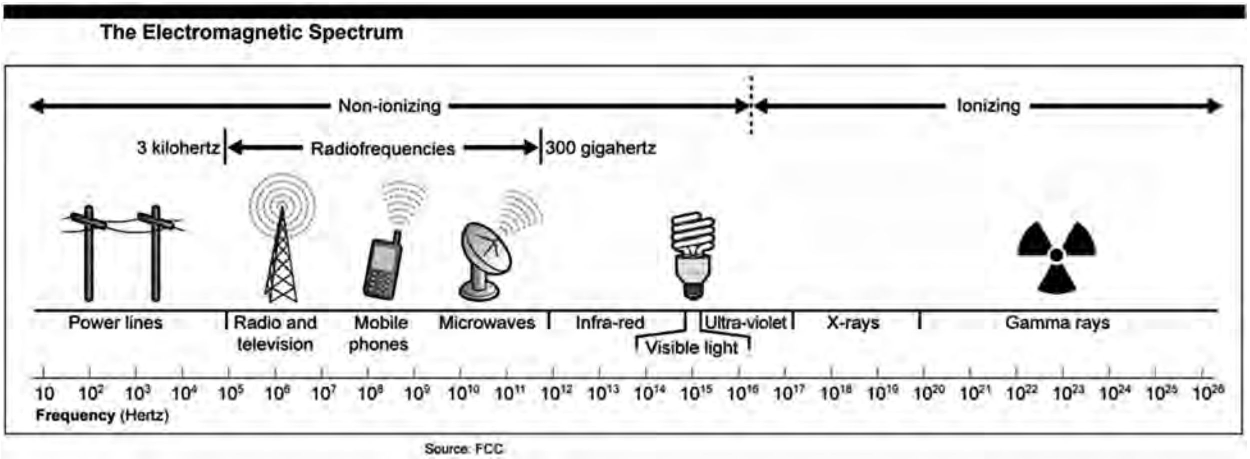

Figure 1: Illustration shows FCC area of regulatory responsibility between 100 kilohertz (kHz) up to the far microwave bands in the non-ionizing section of the spectrum. The frequency range for FCC limits cover from 300 kHz to 100 GHz. ([5] p. 3).

migration, and many other factors. Many airborne species, for example, have the ability to reach close proximities to antennas mounted on towers or buildings and routinely reach areas with detrimental levels of RFR even at some distance from transmitters. And several bird species fly at altitudes high enough to experience exposures from satellite systems that humans would never encounter. In essence, other species can experience both near-and-far-field exposures that humans rarely, if ever, experience and likely move in and out of such fields on a routine and/or seasonal basis.

Below is information on how governments regulate this subject regarding human exposures that point to possibilities for wildlife protection.

The U.S. FCC exposure standards are a two-tiered model based on recommendations from key regulatory agencies and two expert organizations: the National Council on Radiation Protection and Measurements (NCRP) report in 1986 [7, 8] and a subcommittee recommendation from 1992 to the American National Standards Institute (ANSI) by the International Electronics and Electrical Engineers (IEEE; [9]). The NCRP is a non-profit corporation chartered by the U.S. Congress to develop information and recommendations across many public and private sectors on radiation protection. The ANSI is a non-profit, privately funded, membership organization that coordinates the development of voluntary U.S. national standards used across all industry sectors. The IEEE is a non-profit, privately funded, technical, and professional/industry group that widely represents the technology sector with a membership of over 300,000 engineers and scientists worldwide; they have almost no biologists or members with medical backgrounds. ANSI, IEEE, and FCC are not health or environment-related entities, yet they play pivotal roles in non-ionizing radiation exposure regulation. NCRP does include human health expertise on their review panels. These various groups issue exposure guidelines. Once a government entity with enabling authority adopts such guidelines, they become enforceable and the government entity can require the private sector to abide by them as well as impose fines when they transgress. The FCC was given authority over RFR exposure standards adoption and enforcement by The Telecommunications (TCA) Act of 1996 [10].

At the impetus of the U.S. Environmental Protection Agency (U.S. EPA), the multi-agency Radiofrequency Interagency Working Group (RFIAWG) was formed in the 1990s. EPA, which has primacy over environmental radiation effects, was specifically defunded for non-ionizing radiation research and oversight in 1996 [11] just as the TCA was coming into effect. In lieu of EPA writing its own RFR exposure standards at the time—something they were poised to do and took criticism for not completing—EPA instead recommended a two-tiered exposure standard (see below) be adopted at FCC taken from recommendations by both NCRP and ANSI/IEEE, which FCC did in 1996. Subsequent to that, the RFIAWG also sent a letter in 1999 to the IEEE committee responsible for developing RF standards that listed 14 major topics and/or areas of concern related to any future revision of the IEEE standard [12]. Those concerns have yet to be addressed. The RFIAWG was comprised of key bioelectromagnetics scientists from seven or more U.S. federal regulatory agencies, representing health, the environment, and professional exposures (One of the authors of this paper was on RFIAWG representing the U.S. Fish and Wildlife Service). Although RFIAWG still exists on paper, it rarely meets, if at all, and is no longer the analytical advisory authority it once was to FCC. Consequently FCC regulates and issues rule-makings in an environmental vacuum, other than minimal comments provided by the Food and Drug Administration (U.S. FDA) which advises on devices like cell phones over which it has authority.

FCC is often now seen as an agency that is captured by the industries it is supposed to regulate [13] and because of cutbacks at key advisory agencies like EPA, FCC lacks the wider expertise upon which it relies to conduct thorough assessments regarding exposure safety [11].

What today's exposure standards measure

Most of the current guidelines used in Western countries are based on the specific absorption rate (SAR)—the rate of energy absorbed per unit mass of biological tissue with units expressed in watts per kilogram (W/kg) or milliwatts per kilogram (mW/kg) of tissue. Harmful effects from which the SAR was originally derived were based upon relatively few animal studies in the 1980s [14, 15] in which behavioral disruption was observed at approximately 4 W/kg when test animal body temperatures rose by about 1°C. Safety factors were built in to allow for unknown/unidentified effects and are reflected in the allowances noted below, but it is important to know that these additional margins are purely hypothetical. SARs are also studied on fluid-filled phantom laboratory models in the shape of human body parts, as well as cadavers which can never reflect the complexities of whole living electrodynamic organisms. SARs are extremely difficult, if not impossible, to measure in living models.

The FCC standards divide exposure allowances (based on the baseline or 4 W/kg) into two tiers legally defined as:

- **Occupational/controlled limits based on ANSI/IEEE:** Applies when people are exposed due to employment, provided they are fully aware of exposures and can exercise control over them. SAR is 0.4 W/kg, reflecting a safety factor of 10.
- **General population/uncontrolled limits based on NCRP:** Applies to when the general public may be exposed, or when people who are exposed as a consequence of employment may not be fully aware of potential exposure, or cannot exercise control over the exposure. SAR is 0.08 W/kg, reflecting a safety factor of 50.
- Limits are different for cell phone exposures when partial body exposure would be experienced and is derived by complicated methods of scaling from the whole body exposure. The SAR for partial body exposure is 1.6 W/kg measured over 1.0 g cube of tissue—a limit that all cell phones must meet in the U.S., and which is stricter than what is used in Europe as recommended by the ICNIRP guidelines (see below) at 2.0 W/kg averaged over 10 g of tissue. SAR evaluation continues to be required as the only acceptable compliance metric for portable devices below 6 GHz.
- In addition, there are whole-body SAR limits at 0.08 W/kg related to various factors including size, shape, and orientation toward a generating source, among other things. There are also higher SAR allowances for the body's extremities defined as hands, wrists, feet, and ankles, where the limit is 4 W/kg as averaged over any 10 g of tissue and where some peak allowances can be up to 8 W/kg over 1 g of tissue (it is assumed that extremities can absorb more energy without tissue heating [the ear—or pinna—was included as an extremity in 2013 – see discussion below]). There are also resonant SAR peaks for humans (maximum absorption rates) reflected in the illustration below. For whole-body human irradiation of a 6′ male, peak resonant SARs are reached in the bands between 70 and 100 Megahertz (MHz)—the middle of the FM radio band, where exposures are therefore most stringent (see Figure 2).

The frequency range for FCC limits covers from 300 kHz to 100 GHz and is dependent on frequency as defined in maximum permissible exposures (MPE). MPE's are given in terms of power density—milliwatts per centimeter squared (mW/cm^2)—or in field strength as volts per meter (V/m) or amperes per meter (A/m). Often far-field exposures from infrastructure are given in mW/cm^2 and MPE. (For a table of FCC MPE limits for occupational and general populations see reference [5], p. 15).

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) compared to the FCC

Countries throughout Europe and Canada have adopted standards based on recommendations by The International Commission on Non-Ionizing Radiation Protection (ICNIRP), a self-selecting group chartered in Germany in 1992 that functions as a collaborating non-state entity with the World Health Organization [16– 18]. ICNIRP is a

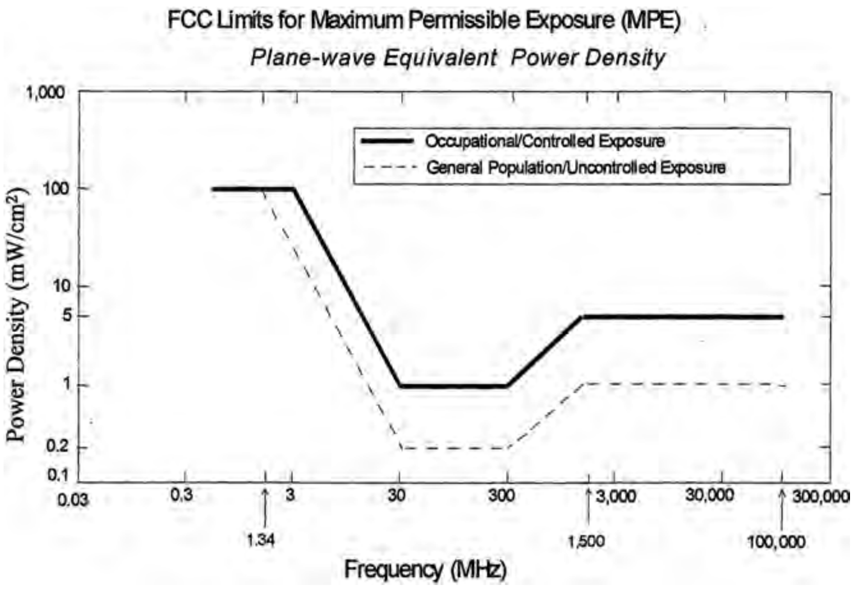

Figure 2: Worker limit is the solid line; general public is the dotted line.
Note that the strictest limit is in the 30–300 MHz range where human whole body resonance occurs. Standards-setting organizations have all made limits strictest in that region. Also note that higher limits are allowed on both sides of that area ([2] p. 69).

relatively new entity in standards setting, given that the ANSI-IEEE basic thermal exposure framework was first delineated and published in 1968 (at higher allowances) and the U.S. NCRP's basic reports on RF were published in 1986 and 1993 ([7, 8], respectively).

The FCC standards remain more stringent than ICNIRP's although in 2020 ICNIRP published an update of their 1998 allowances and adopted a few of FCC's measurements. Both remain two-tiered, human-centric, thermal-based models. ICNIRP differs in some exposure levels and averaging times, as well as allowances in some lower as well as upper frequency ranges that are more lenient than FCC. There is variation between countries that have adopted other standards, i.e., Italy and Switzerland use standards far below FCC and ICNIRP (see below).

By way of comparison: For power density (MPE) the U.S. standards are between 0.2 and 1.0 mW/cm^2 and for SAR between 0.08 and 0.40 W/kg of human tissue. For cell phones and uncontrolled environments, FCC SAR levels require hand-held devices to be at or below 1.6 W/kg averaged over 1.0 g cube of tissue. For whole body exposures in uncontrolled environments, the limit is 0.08 W/kg. Canada, which previously had used the ICNIRP standard, now uses the FCC's 1.6 W/kg averaged over any 1.0 g of tissue and for whole body exposures, the limit is 0.08 W/kg. The peak spatially-averaged SAR in the limbs, averaged over any 10 g of tissue, is 4 W/kg. In European countries and elsewhere where the ICNIRP standard is used, the SAR limit for hand-held devices is higher than FCC at 2.0 W/kg averaged over 10 g cube tissue mass (than measurement, which changed in 2020, used to be over any contiguous tissue). Whole body exposure limits are the same at 0.08 W/kg but until recently were averaged differently: in the FCC standards they are averaged over 30 min; ICNIRP used to be averaged over 6 min but has now gone to 30 min for whole body exposures too [19]. ICNIRP's local body-area SARs are still averaged over 6 min.

The 2020 ICNIRP revision made some other critical changes that many find troubling (see below). Hardell et al. [20] published a recent thorough review and analysis of why these standards are not as protective of public health as many assume.

Longstanding criticism of FCC and ICNIRP standards

The longstanding primary criticism of both the FCC and ICNIRP standards is that they are based on short-term acute exposures for tissue heating—unlike today's more realistic long-term chronic low-level exposures—and that the safety factors of 10 and 50 below that acute heating threshold are purely suppositional [21]. There are other flaws with how these standards are written, for instance the effect of time averaging diminishes the biological significance of peak intensity short-term exposures. And because real-life exposures can be quite organ-specific, such as a cell phone held against the head or carried in a pocket, partial body exposure guidelines for specific organs may not be accurate, especially after the FCC ruled in 2013 that the human ear (pinna) can be classified as an appendage like arms or legs [22, 23], thereby allowing cell phones to transmit at higher levels with higher SAR limits.

This reclassification only changes exposures to the ear. FCC standards are still 1.6 W/kg as averaged over 1 g of tissue, except for extremities where the limit is 4 W/kg as averaged over 10 g of tissue (For occupational exposures, the localized SAR limit is 8 W/kg as averaged over 1 g of tissue, except for within the extremities where it is limited to 20 W/kg as averaged over 10 g of tissue). The ear now fits that higher allowance even though the auricle is simply not an 'extremity.' The auricle is histologically very different from arms or legs and lacks bone, tendon, and skeletal muscle. It is also very close to the human brain and eyes. In addition auricle nerves are innervated by the vagus nerve which in turn innervates many other vital organs in the body, including the heart, GI-tract, and reproductive organs. The higher allowance may also affect the eyes as many now text and look directly into a cell phone screen. This entire new classification should be reconsidered. The eye is a highly conductive aqueous saline organ—the exact opposite of cartilage. The reclassification is inviting adverse effects to the ear, the brain, the eyes, and potentially other systems in the body [23]. It also exponentially increases ambient RFR levels with the number of active cell phones in operation at any given location. Health concerns over human eyes directly translate to species with eye structures similar to humans which includes most mammals. But in other species, effects are potentially more dire. Many insect species, for instance, have compound eye structures with sometimes thousands of lenses in addition to which insects do not dissipate heat efficiently. Their smaller size also makes them a resonant match with RFR's higher frequencies.

Given the scale of human cell phone use today, that technology's contribution alone to ambient levels is not insignificant (see Part 1). Yet people rarely understand that their cell phone may cause downstream effects to other species. Raising the power density output of cell phones may be an environmental factor in and of itself. In fact many of the fundamental criticisms of the human exposure standards may have consequences at the ecosystem level to wildlife species (see Part 2 and below).

In addition, no current exposure standards at FCC or ICNIRP take into consideration signal modulation, wave form, or cumulative exposures from multiple low-power devices transmitting simultaneously—all biologically important factors that have been found in numerous studies to be independent of frequency alone (see Parts 1 and 2). And both FCC and ICNIRP categorically exclude whole classes of low-power devices from review if they adhere to a certain transmission level around 1 mW effective radiated power (ERP).

In other words, there are multiple problems and significant deficits with the most widely adopted exposure standards as originally conceived, formulated, written, and defended. Both major entities have recently reinforced and justified their exposure parameters despite decades of recent research pointing to adverse effects from exposures far below heating thresholds. Both FCC and ICNIRP are actually dosimetry-based models—meaning a defined minimum exposure that will allow technology to function without causing gross short-term adverse heating effects—rather than true biological models based on thresholds where effects are seen [12].

Today a growing number of people, domestic pets, and urban and suburban wildlife are exposed to 24 h EMFs from individual devices, products, and infrastructure [21, 24–27]. Popular wireless devices such as baby monitors, smart grid/meters, home and industrial appliances, WiFi routers, remote controls, security systems, personal "assistants" like Amazon's Alexa and Apple's Siri, and some wireless laptop computers fall at, or below, the power density level of 1 mW ERP which qualifies them for categorical exclusion (CE, or CatEx) from licensing review. This can include CatEx for small cell infrastructure too but there is complex overlap in some situations.

There is a distinction between "no license required" for low-power individual consumer devices vs. "no environmental review pursuant to a CatEx" for low power infrastructure. Small cell networks do require FCC licensing because they use the spectrum, even though individual antennas can be categorically excluded as low-powered. And because issuing a license is a major federal action, NEPA should apply, even though under some circumstances, a CatEx can satisfy NEPA compliance—see below. Today, FCC CatExs include most consumer wireless products and the infrastructure for hundreds of thousands of individual 4G and 5G small cells. Exclusion criteria are based on such factors as type of service, antenna height, and operating power. CatExs are not exclusions from compliance itself, but rather exclusions from performing routine evaluations to demonstrate such compliance and therein lay problems because no one is monitoring. Qualifying for CatEx is based on manufacturer's declarations. According to FCC OET Bulletin 65 (2 p. 12), "… the exclusion itself from performing routine evaluation will be a sufficient basis for assuming compliance, unless an applicant or licensee is otherwise notified by the FCC or has reason to believe that the excluded transmitter or facility encompasses exceptional characteristics that could cause non-compliance …" In other words, much of this semi-regulated area is based on the honor system.

CatEx does not mean that significant exposures are unrealistic or unlikely, especially from cumulative exposures from many devices working simultaneously as is the case in most homes and workplaces today. Although infrastructure is the dominant contributor to outdoor pollution (see Part 1), cell phones and some domestic WiFi systems can be significant contributors to ambient exposures in indoor as well as outdoor environments at levels known to affect wildlife (see Part 2, Supplement 3). What are widely thought to be local indoor transmitters such as personal WiFi and home signal boosters, can and do penetrate walls to become outdoor exposures too. Every new application, though functioning within its own categorically excluded parameter, adds that much more to the aggregate, in essence creating a synergistic effect with the sum of exposures being greater than the individual effects of each component part. Although aggregate RFR levels are not supposed to exceed the FCC or ICNIRP regulations, no regulatory entity today measures, enforces, or attempts to mitigate for this [23] unless complaints are filed over interference issues with other systems. Each CatEx exists within its own technical realm, considered safe if kept under 1 mW ERP. Most such excluded devices and/or networks have considerable overlap, creating multiple exposures, and possible elevated effects. This is not a realistic, scientifically sound, or safe way to determine actual exposures to humans, domestic animals, or wildlife from aggregate, ambient radiation.

5G: changes at FCC and ICNIRP

5G is poised to bring radical changes to the ambient landscape from individual devices and especially infrastructure exposures, yet the major standards-setting groups have recently reinforced and justified their existing exposure allowances [3, 18, 19]. They continue to adhere to acute dosimetry-based frameworks rather than true biological models based on more sensitive thresholds where effects are seen. Plus, a most urgent area in need of clarification concerns how traditional standards have been written from the outset, which may, in fact, be based on a fundamental theoretical flaw. We may not even be using the correct physics model in today's standards setting (see Part 1) in light of actual exposures. The entire justification for adhering to thermoregulatory models rests on the classic physics theory of non-ionizing radiation not having enough energy to knock electrons off cellular orbits and thereby cause DNA damage. This may not be the most accurate model regarding biological reactions/interactions with low-level energy found in current exposures [28–32]. The classic theory is based on a mathematical calculation best suited to ionizing radiation and a narrow definition of a one-cell, one-photon concept whereas today's exposures are many simultaneous and often-overlapping streaming photons arriving at multiple cells from multiple angles at the same time in what behave more like photon wave "packets" rather than single photons [33–39] Our entire regulatory concept needs further attention if we are to truly understand and trust where we are headed with 5G's new technology.

To better accommodate 5G's buildout, all exposure limits at FCC and INCIRP may soon become more lenient. FCC has opened a new docket (Docket #19-226) to target the need for different regulations for 5G [40], even as they have stated their current regulations are adequate for 5G exposures [3]. The new FCC docket covers a wider frequency range from 3 kHz to 3 THz for permissible human exposures and has allocated certain applications in the millimeter (MMW) bands from 57.05 to 64 GHz for unlicensed use, meaning CatEx for some devices and infrastructure. FCC is also seeking comments on applying localized exposure limits above 6 GHz in parallel to the localized exposure limits already established below 6 GHz, as well as specifying new conditions and methods for averaging RFR for both time and exposure area. They are also seeking comment on new issues raised by WPT devices [3].

There have been numerous comments submitted to FCC regarding Docket 19-226 by citizens, organizations, and professional groups like the American Public Power Association (APPA) urging FCC not to further expand unlicensed operations in the 6 GHz bandwidth due to possible interference with present licensed systems, among many other issues. Numerous comments also center on health/environmental concerns [41].

There has been significant discussion at FCC and ICNIRP about changing SAR exposure categories that are now used for cell phones and other mobile/portable devices to a mW/cm^2 power density exposure measurement (MPE) for devices above 6 GHz, which 5G phones will be. FCC states that for portable devices operating at frequencies above 6 GHz, 'special frequency' considerations are necessary [2]. The localized SAR criteria used by the FCC only apply at operating frequencies between 100 kHz and 6 GHz. For portable devices that operate above 6 GHz (e.g., 5G millimeter-wave devices) they say that localized SAR is not an appropriate means for evaluating exposure; that at the higher frequencies, exposure from portable devices should be evaluated in terms of power density MPE limits instead of SAR, adding that power density values can be either calculated or measured, as appropriate, at a minimum distance of 5 cm from the radiator of a portable device to show compliance with FCC standards (2 p. 43–44). They do not elaborate on their reasons but it may have to do with the assumption that MMW do not penetrate skin deeply, which has been proven false (see Part 1 and below).

With 5G in mind, ICNIRP (2020) also addressed the subject of special "transition frequency" [19]—the frequency at which the measurement quantity changes—regarding local RF restrictions. Prior to 2020, the ICNIRP SAR was used up to 10 GHz (vs. FCC's 6 GHz), while power density was used above 10 GHz. They noted that the different quantities are used because SAR may underestimate superficial exposures at higher frequencies, whereas power density may underestimate deeper exposures at lower frequencies. As a pragmatic approach, ICNIRP reduced the transition frequency from 10 to 6 GHz to "… provide the most accurate account of exposure overall" [19].

ICNIRP's 2020 update [16–19] includes new allowances for 5G that many find disturbing [20, 42–45]. The new guidelines allow higher power densities above 6 GHz that replaced the SAR values, larger temperature increases in localized areas that may exceed thermal thresholds for both short and long periods of time, and divide skin into different types with different allowances (Type-1 tissue includes all tissues in the upper arm, forearm, hand, thigh, leg, foot, pinna and the cornea, anterior chamber and iris of the eye, epidermal, dermal, fat, muscle, and bone tissue. Type-2 tissue includes all tissues in the head, eye, abdomen, back, thorax, and pelvis, excluding those defined as Type-1 tissue). ICNIRP adheres to a thermal-effects-only model and now indicates assumed safety with increases to 5 °C in skin, the cornea and iris, and bones, as well as a 2 °C increase in brain temperatures on an indefinite basis. Their 1998 guidelines only allowed a 1 °C maximum increase for localized tissue and overall body temperature. Their rationale for the increased 2020 allowances stated that the 1998 safety margins were too conservative. For comparisons between ICNIRP's 1998 and 2020 allowances, see ICNIRP [19], and charts in Leszczynski [46] as well as Hardell et al. [20].

In the U.S., there has been significant longstanding pressure from industry over the years to harmonize FCC standards with ICNIRP—an action that FCC has resisted. As of this writing, which excludes any new standards pertinent to 5G being adopted, the current FCC standards are still more stringent in some frequency bands, exposures, and time allowances than ICNIRP's [47].

Other countries have adopted more stringent standards than FCC or ICNIRP based on different health criteria orientation—some more precautionary than others [25, 48]. There are calls to disband ICNIRP [49] as well as numerous lawsuits in various states of deposition against the U.S. FCC regarding NEPA enforcement (see below), federal preemptions in favor of industry over local/state infrastructure review and siting [50], and the adequacy of FCC's exposure standards [51]. A 2021 court ruling found that the FCC's decision terminating its inquiry into the adequacy of the RF health standards was unlawful [51]. There are other significant issues—such as the defunding of the U.S. EPA for nonionizing EMF research and oversight—that are mentioned in this 2021 case [11].

What wildlife may be experiencing

At a 100–200 ft (30.5–61 m) distance from a cell phone tower/base station (i.e., antennas or antenna arrays), a person or animal moving through the area can be exposed to a power density of 0.001 mW/cm^2 (i.e., 1.0 $\mu W/cm^2$). The SAR at such a distance can be 0.001 W/kg (i.e., 1.0 mW/kg) for a standing man. Throughout this three-part series, we defined low-intensity exposure where effects are seen to RFR for power density at 1 $\mu W/cm^2$ and a SAR of 0.001 W/kg. The reason for using such a very low level is to show that biological effects have been widely observed much lower than at the 4 W/kg used in standards setting. (For extensive tables of studies that match these low levels, see Part 2, Supplement Tables 1–4).

Many biological effects have been documented at low intensities comparable to what the population—and therefore wildlife—experience within 200–500 ft (61–152 m) of a cell tower [21]. These can include effects seen in *in vitro* studies of cell cultures and *in vivo* studies of animals after exposures to low-intensity RFR. Reported effects include: genetic, growth, and reproductive alterations; increases in permeability of the blood brain barrier; stress protein increases; behavioral changes; molecular, cellular, and metabolic alterations; and increases in cancer risk (see Part 2 Supplement 3 for broad animal effects and Supplement 4 for flora effects).

Unlike field research, *in vitro* and *in vivo* laboratory studies are conducted under highly controlled circumstances, often with immobilized test animals, typically at near-field exposure, for set durations, at specific frequencies and intensities. Extrapolations from laboratory research to species in the wild are difficult to make regarding uncontrolled far-field exposures, other than, for example, to seek possible correlations with laboratory-observed DNA, behavioral, or reproductive damage. In the wild, there is more genetic variation and mobility, as well as variables that confound precise data assessment. There are also numerous variables like orientation toward the generating source, exposure duration, animal size, species-specific physical characteristics, and genetic variation that also come into play. Assessments for wildlife may vary considerably depending on abundant factors.

It is highly likely that the majority of wildlife species are constantly moving in and out of varying artificial fields. Although precise exposure data are difficult to estimate, there is a growing body of evidence that finds damage to various wildlife species near communications structures, especially where extrapolations to, or measurements of, radiation exposure have been made [52–63].

The introduction of 5G broadband using frequencies in the mid-MHz through mid-GHz millimeter wave (MMW) bands—radiating from both land and satellite-based transmitters in urban, suburban, and rural/forested areas —has the ability to impact numerous species at very low intensities based on several mechanisms. These involve a plethora of unique magnetoreception factors in non-human species, depending on taxonomy, size, season, and habitat (see Part 2). Some of these include resonance factors and intense heating effects for some insect species as insects do not dissipate heat and therefore have no thermoregulatory compensatory responses; interference with orientation in some insect and bird species based on the presence of natural magnetite and cryptochrome in their physiologies that enable complex interactions with the Earth's geomagnetic fields and sunlight for all their life's activities; and adverse die-off effects in flora such as trees in close proximity to infrastructure like small cells, to name but a few (see Parts 1 and 2 and their Supplements for a more thorough analysis). 5G's effects on insects alone have the ability to create holes in critical food webs affecting all other species, and ultimately humans.

The exposure allowances used by FCC and ICNIRP are already higher in the MMW bands to be used in 5G. This is based on whole human body resonance factors and partly on efficient skin absorption—estimated at 90–95% MMW incident energy absorbed in human skin [64]. But this simplistic assessment does not factor in that skin tissue—human and some non-human species alike—contains critical structures like blood and lymphatic vessels, nerve endings, collagen, elastin fibers, and hair follicles, as well as sweat, sebaceous, and apocrine glands. MMW effects to skin have been found to be considerable in glandular tissue with multiple cascading effects throughout the human body even without deep penetration [65]. One study by Cosentino et al. [66] found effects to unilamellar vesicles made of phospholipid—or lipid vesicles—with decreased cell membrane water permeability and partial dehydration of the cell membrane, as well as cell membrane thickening/rigidity seen at 52–72 GHz at incident power densities of 0.0035–0.010 mW/cm^2. Human sweat ducts in particular may act as coiled helical antennas and propagate MMW energy as a waveguide deep into the body at these higher frequency exposures causing uniquely higher SARs [67] not reflected in today's standards. Where there are similar physical characteristics in other species, the above information would also apply.

Because of sub-millimeter depths of penetration in skin tissue with MMW, "superficial" SARs as high as 65–357 W/kg are possible. Eyes are of particular concern in all species. MMW frequencies penetrate less than 1/64 of an inch (0.4 mm)—about the thickness of three sheets of paper. That is thick enough to penetrate deeply into thin-skinned amphibian frog and salamander species, for instance, as well as most flora, and is more than half the depth of some small insects that are primary food sources for other species. The wavelength of MMWs is shorter (about 1/8th inch or 3.2–5 mm long) than microwaves used in cell phone/WiFi technology at 2.4 GHz (6.3 inch or 12.5 cm). The shorter the wavelength, the higher the energy density per wavelength unit. In this case, with MMWs it is about 25 times higher than with cell technology microwaves [68]. This means MMW are capable of resulting in significant damage throughout the biome, including possibly to all flora and fauna present, but effects are not due to wavelength alone. The multiple biological effects from intense energy absorption at very short wavelengths—e.g., in human skin cells or any thin-skinned species, and especially in insects that lack efficient heat dissipation—may cause intense heating with concomitant cellular destruction and organism death. Many of these effects are independent of power density, and therefore not covered by current regulations which are power-density and/or SAR-based. In other words, thermal exposure standards that may protect humans against heating have the ability to cause thermal damage to other species with more extreme consequences.

There are other interesting environmental characteristics regarding MMW. For instance, Betskii et al. [69] pointed out that MMW radiation, unlike other frequencies, is virtually absent from the natural environment due to strong absorption by the atmosphere. The authors hypothesized that low-intensity MMW may have broad nonspecific effects on biological organisms and that vital cell functions may be governed by coherent electromagnetic EHF waves. Their study results found alternating EHF/MMWs were used for interaction between adjacent cells, thereby interrelating and controlling intercellular processes in the entire organism. Other authors [70–73] expounded on the idea that because MMW are absent in the environment, living cells may make specific and dedicated use of them. While these ideas are theoretical, they may plausibly explain the high MMW sensitivity observed in biological subjects (see Part 1), especially in human therapeutic applications which have long been popular in Russia.

MMW below 100 GHz are maximally absorbed by water vapor (H_2O) at 24 GHz, and by oxygen (O_2) at 60 GHz [74–76], raising the possibility that 5G could destabilize the climate even more than current trends, especially from satellite transmission. Rain, foliage, and other things easily attenuate MMW signals so 5G must operate at higher power density, as well as utilize different modulation characteristics such as phasing to enhance signal propagation's penetration through physical objects like building walls. At 60 GHz, 98% of transmitted energy is absorbed by atmospheric oxygen. As far back as 1997, the FCC issued a report [74] on MMW propagation characteristics, noting that between 200 MHz and 95 GHz, there was significant signal loss at 40 GHz due to foliage (see Part 1), as well as resonant matches for atmospheric water vapor at 24 GHz and oxygen at 60 GHz.

Despite this, the FCC has already licensed the buildout of 5G in the 24, 28, 37, 39, and 47 GHz ranges thus far with higher bands extending above 95 GHz allocated for future use. FCC has also allocated MMW from 57.05 to 64 GHz for unlicensed use; ICNIRP may follow. Concerns include both land-based networks as well as satellite transmissions. By the time satellite transmissions reach the Earth's surface, the power density is low (see Part 1) but with 5G's phased array signals, the biologically active component is in the waveform, not power density alone. There is no research to predict how this will affect wildlife in remote areas but given what is known about extreme sensitivity to EMFs in many species, it is likely that effects will occur and likely go undetected. Even weak signals from satellites using phased array characteristics may be a significant contributor to species effects in remote regions (see Part 1 and Part 2, Supplement 3).

Much of the research on MMW and phased array with accompanying unusual biological effects—e.g., precursor formation capable of causing deep nonlinear body penetration (see Part 1)—has been done in lossy materials like water. We therefore have models to suggest that 5G may have particular effects not only on insect populations (due to resonance factors) and amphibians (due to thin membranes and deep body penetration) but also in some aqueous species since water is a highly conductive medium. Both aqueous environments and the high water content in living organisms may make MMW exposures particularly unique due to the way MMWs propagate though water with virtually no impedance [77–82].

In addition, Betskii and Lebedeva [83] described the complex hypothetical mechanism that stochastic resonance (see Part 2) may play in very sensitive water-containing biological species to very-low intensity EMF (in μm ranges) based on the generation of intrinsic resonance frequencies by water clusters that fall between about 50 and 70 GHz. When biological species are exposed to extremely weak EMF at these frequencies, their water-molecule oscillators can lock on to the external signal frequency and amplify the signal by means of synchronized oscillation or regenerative amplification. Since MMWs pass through aqueous media almost without loss but also with high absorption, in the process they are capable of deep penetration involving internal tissue and organ structures. The researchers summarized a long list of MMW effects that included EHF strong absorption by water and aqueous solutions of organic and inorganic substances; effects to the immune system; changes in microbial metabolism; stimulation of ATP (adenosine 5′-triphosphate) synthesis in green-leaf cells; increases in crop capacity (e.g., pre-sowing-seed treatment); changes in certain properties of blood capillaries; stimulation of central nervous system receptors; and the induction of bioelectric responses in the cerebral cortex. Biological effects were dependent on exposure site, power flux density, and wavelength in very specific ways. In addition, low-intensity MMWs were detected by 80% of healthy people, but perception was asymmetrical. Peripheral applications were found to affect the spatiotemporal organization of brain biopotentials, resulting in cerebral cortex nonspecific activation reactions. MMW-induced effects are perceived primarily by the somatosensory system with links to almost all regions of the brain. The authors also discussed water and aqueous environments' unique role on MMW effects, which induce convective motion in the bulk and thin fluid layers and may create compound convective motion in intra and intercellular fluid. This can result in transmembrane mass transfer and charge transport can become more active. EHF can also increase protein molecule hydration. The theory of stochastic resonance playing a mechanistic role in the effects noted in the above study deserves further investigation given its known function in non-human species perception abilities that are used for survival (see Part 2).

And then there's the role of unique wildlife magnetoreceptor cells. Akoev et al. [84] studied MMW effects to the specialized electroreceptor cells called Ampullae of Lorinzini in anesthetized rays (an elasmobranch fish) and found that the spontaneous firing in the afferent nerve fiber from the cells could be enhanced or inhibited by MMWs at 33–55 GHz continuous wave (CW). The most sensitive receptors increased firing rates at intensities of 1–4 mW/cm^2, which produced less than a 0.1 °C temperature increase. The authors emphasized they were not observing just a MMW bioeffect but rather a specific response to that frequency range by a unique electro-receptor cell. This one study points out the inadequacy of assuming that MMW's superficial skin penetration is enough to base exposure-standard extrapolations to nonhuman species (For an extensive reviews of other MMW studies pertinent to wildlife, see Parts 1 and 2).

In wildlife, especially small thin-membrane amphibians like frogs and salamanders, even at penetration less than 1/64 of an inch (0.4 mm), deep body penetration would result. In some insect species that would equal deadly whole body resonance exposure [85]. In a study, Thielens et al. [86], modeled three insect populations and found that a shift of just 10% of the incident power density to frequencies above 6 GHz would lead to an increase in absorbed power between 3 and 370% in some bee species, possibly leading to behavior, physiology, and morphology changes over time, ultimately affecting their survival. Insects smaller than 1 cm showed peak absorption at frequencies above 6 GHz. In a 2020 follow-up study of RFR, Thielens et al. [87] used *in-situ* exposure measurements near 10 bee hives in Belgium and numerical simulations in honey bee (*Apis mellifera*) models exposed to plane waves at frequencies from 0.6 to 120 GHz—frequencies carved out for 5G. They concluded that with an assumed 10% incident power density shift to frequencies higher than 3 GHz, this would lead to an RFR absorption increase in honey bees between 390 and 570%—resulting in possible catastrophic consequences for bee survival.

In birds, hollow feathers have piezoelectric properties that would allow MMWs to penetrate deep within the avian body cavity [88, 89]. 5G's complex phased MMWs may also be capable of disrupting crucial biological function in other species and critical ecosystems with broad effects throughout their entire food webs. In addition, the top end of these ranges reach infrared (IR) frequencies, some of which are actually visible to other species, especially birds, and could impede their ability to sense natural magnetic fields necessary for migration [90] as well as other crucial aspects of avian life.

Any assumed wildlife protection in exposure standards for humans is purely hypothetical at the ecosystem level. Chronic long-term, low-level ambient exposures to MMWs are yet to be studied but some extrapolations can be made based on the extensive database that does exist (see Parts 1 and 2, plus Supplements). FCC rules do not require an Environmental Assessment (EA) for new towers, for example, unless a proposed structure can be proven to negatively affect birds or other species federally listed as threatened or endangered (see below). EAs as currently applied can include effects from physical tower placement itself, but not typically RFR exposures. As a result, no one is required to assess ambient environmental EMF effects, let alone answer questions about impacts to other species from such technologies (see the Section "Discussion: synthesis of linear and nonlinear disciplines needed" below for some reasons why this situation exists at the federal level). There is a critical hole in our regulatory environmental apparatus when it comes to electroecology.

Regulations and laws pertinent to EMF

There are several significant U.S. federal environmental statutes and their implementing regulations intended to protect wildlife and their habitats. All potentially apply directly or indirectly to the impacts created by EMF if we choose to use these statutes in that capacity. In some cases, treaty protocols and international laws also extend to Canada, Mexico, Russia, and elsewhere. Some states, provinces, counties, and cities also have similar laws in place but space precludes detailed listing here. The focus of the sections below is on key U.S. federal laws and those of Canada and Europe that could incorporate EMF into assessment considerations.

The Endangered Species Act of 1973

While the Migratory Bird Treaty Act of 1918 (MBTA)—discussed in detail below—is the oldest U.S. environmental wildlife protection law, having been enacted over 100 years ago, the Endangered Species Act (ESA) of 1973 (16 U.S.C. 1531 et seq). [91] is considered the key U.S. environmental statute. The ESA is intended to recover plant and animal species from extinction, preventing further extinctions or extirpations, and provides subsequent protections including at ecosystem levels. ESA has been amended many times over the years[1] [92]. Somewhat like the MBTA, ESA was designed to implement an international protocol called the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) [93], which

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1 To view the entire contents of each section of the Endangered Species Act of 1973 as amended and to click on a section title below that corresponds with your interest see: https://www.fws.gov/endangered/laws-policies/esa.html. Many section pages include audio or slideshow summaries that provide a more general overview of that section. Or to download the entire Act or individual sections in PDF format from US FWS's document library, go to: https://www.fws.gov/endangered/esa-library/index.html.

itself was designed to protect plant and animal species worldwide through restrictions on such trade.

ESA was implemented to protect all plant and animal species listed as threatened or endangered, and to protect habitats designated as critical. ESA also contains provisions for designating species as *candidates* under Section 4(b)3(A) [94] for possible future threatened or endangered status—i.e., listings that may have been warranted but precluded for one reason or another, or are in need of additional population assessment before determinations can be made. While the process is supposed to be based strictly on sound scientific review and findings, politics have often impacted listing decisions. Nevertheless, since its passage in 1973, some 1,400 plant and animal species have been afforded protections, with many on the path to recovery (e.g., grizzly bears and gray wolves) or fully recovered (e.g., Bald Eagles and Peregrine Falcons). ESA is a longstanding highly successful environmental law.

The ESA is administered by two agencies: The U.S. Fish and Wildlife Service [95] and the U.S. National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) [96]. U.S. FWS maintains a worldwide ESA list of threatened and endangered species and is responsible for overseeing terrestrial and freshwater organisms, including four species of marine mammals—i.e., manatees, polar bears, walrus, and sea otters. The NMFS oversees all ESA listed marine wildlife, including large and small cetaceans, sea turtles, and anadromous and steelhead salmon, as well as some flora critical to marine wildlife survival such as Johnson's sea grass which is important for shelter and sea bottom nursery habitat.

All oversight agencies use the ESA as part of their enforcement toolkit.

The ESA regulations make it illegal to kill, harm or otherwise "take" a listed species. ESA definitions include:

- **"Take":** A "taking" under ESA is defined as to "… harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct."
- **Endangered:** A species is listed as: endangered if it faces a significant risk of extinction in the near foreseeable future throughout all or a significant portion of its range.
- **Threatened:** A threatened species is defined as at risk of becoming endangered in the near future.

The ESA and its implementing regulations include a detailed consultation process. Under Sections 7 and 10 [97, 98] the regulations can authorize "incidental or accidental take." Under Section 7, a federal agency must consult with either U.S. FWS or NMFS (depending on the species and/or habitat affected) and specifically provides that, "… each federal agency shall, in consultation with and with the assistance of the U.S. FWS or NMFS, insure that any action authorized, funded, or carried out by such agency is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat of such species which is determined to be critical" [97]. Further, the "action agency," meaning the agency that retains discretionary federal control and is responsible for its actions on the environment, must determine at the earliest possible time whether any listed species or critical habitat may be affected in any manner by the proposed action. In the case of RFR, the FCC is the action agency whose licensing effects from EMFs on ESA-listed migratory birds, for example, must be addressed. That includes radiation from any communications tower, device, or whole communications networks. More specifically, the action agency must consider the *potential* risks/impacts from RFR emitted from towers or other sources. Unfortunately, such determinations have yet to occur for wildlife at FCC. (For an inventory of listed species, see reference [99]).

Under Section 10 of the ESA, private landowners can develop their own habitat conservation plans, which must be approved by U.S. FWS. These may also allow for some level of "take" of listed species [100]. Under Section 11 [101], citizens can file lawsuits against U.S. FWS or NMFS for actions they deem illegal under the statute and such suits may proceed if litigants prove they have legal standing (For some examples of legal suits brought by the Department of Justice, see reference [102]).

For decades, the ESA—a most significant law—has been challenged by politicians, numerous industries, and some public segments, including Congressional attempts to defund the programs altogether. But the ESA is vitally worth protecting and has stood the test of time thus far.

The Migratory Bird Treaty Act (MBTA) of 1918

The Migratory Bird Treaty Act of 1918 [103], as amended, is over 100 years old and still among the most effective laws protecting avian species [26]. Migratory birds—those that migrate across U.S., Canadian, Mexican, and/or Russian borders, of which 1,093 species are currently protected in the United States [104]—are a public trust resource that belong to every U.S. citizen. Almost all native North American continental birds are protected by the MBTA. Exceptions include the Wild Turkey, Asian Pheasant, Lesser and Greater Prairie Chicken, other grouse species, European Starlings, English Sparrows, and Monk Parakeets (among others) which have been accidentally or intentionally introduced to the U.S. The ESA also addresses birds [105].

The MBTA implements/regulates bilateral protocols with Canada, Mexico, Japan, and Russia regarding the shared migratory bird resources of the U.S. and its treaty partners [26]. It is a strict *prima facia* liability statute, meaning that proof of criminal *intent* in the injury or killing of birds is not required by U.S. FWS or the Department of Justice for cases to be made. The statute currently protects migratory birds, their parts, eggs, feathers, and nests, with migratory bird nests protected during the breeding season, while eagle nests are protected year-round. A federal permit is required to “possess” a migratory bird and its parts, but the MBTA contains no provisions for the accidental or incidental “take” (i.e., causing injury or death) of a protected migratory bird, even where normal, legal business practices or personal activities are involved. Bird death, injury, and crippling loss are the only “takings” that matter under the MBTA, not the circumstances under which they occur, although those circumstances can certainly come under investigation.

When the MBTA was enacted, Congress was serious and intended the “take” of even one protected migratory bird to be a violation of the statute, sometimes backed by extensive fines and criminal penalties [26]. Examples include: the 1999 Moon Lake Electric Cooperative fined $100,000 for electrocuting migratory birds; the 2009 criminal settlement with PacifiCorp for $10,500,000 for electrocuting birds (the final settlement resulted in $400,000 in fines, $200,000 restitution to the State of Wyoming, and $1,900,000 to the National Fish and Wildlife Foundation for eagle conservation); and the 2012 settlement agreement with Duke Energy Wind Facility for $1,000,000 for bird deaths from wind turbine blade collisions. All of these settlements involved several years of probation for company executives, and required significant improvements to facilities (an author of this paper was involved with these criminal cases while at the U.S. FWS) [26].

Unfortunately there were recent potentially serious erosions of the legal interpretations involving MBTA. Up until 2017, companies could be fined under criminal misdemeanor provisions when steps to avoid or minimize “take” of birds were not implemented—especially if U.S. FWS’s Office of Law Enforcement had made requests to proponents to avoid/minimize dangers and such recommendations were ignored or minimally implemented. In late 2017, the former Trump Administration refused to enforce the MBTA for so-called “accidental or incidental take,” while only enforcing provisions for poaching (illegal harvest) and illicit trade in birds and their parts in its then new legal opinion (M-37050). But on March 8, 2021, under a new Administration, the U.S. Department of the Interior withdrew M-37050 after a U.S. District Court invalidated the rollback of the MBTA [106] (One of the authors of this paper was involved in these court cases).

The MBTA has no consultation process like that under ESA’s Section 7, and it does not authorize “incidental or accidental take” which ESA does under ESA Sections 7 and 10 [26, 97, 98]. Where “take” was likely to occur under MBTA, various agencies, entities, and individuals were working proactively with U.S. FWS (especially its Office of Law Enforcement, Ecological Service Field Offices, and Division of Migratory Bird Management) to implement all necessary and appropriate steps to avoid or minimize any future damage to birds. MBTA was intended to protect all migratory birds—no excuses accepted but solutions were appraised by U.S. FWS officials—while the ESA allowed some room to negotiate and remediate. But M-37050, as discussed above, until it was invalidated by the court and withdrawn by the Department of the Interior [106], completely upended that protective balance, demonstrating how fragile some of these longstanding effective laws can be due to political caprice. Both the ESA and MBTA could pertain to ambient EMF if applied that way.

Birds of Conservation Concern: how U.S. agencies track non-listed but imperiled migratory birds

There are two primary ways that U.S. federal agencies keep track of birds. In addition to ESA-listed birds, the U.S. FWS maintains the list of Birds of Conservation Concern (BCC) [107]. There are currently at least 147 species designated nationally of the 1,093 species now protected and the number grows with each BCC update [104]. When U.S. FWS regional lists are included in the overall tally, there are some 272 BCC species (>26% of all protected birds) designated in trouble [104]. BCC lists require periodic reviews/updates under provisions of the Fish and Wildlife Conservation Act (16 U.S.C. 2901–2912) [108]. The overall objective of the U.S. FWS is to maintain bird populations at stable or increasing numbers—a daunting challenge due to both direct and indirect impacts, including EMFs discussed in detail in Part 2. The BCC list is designed to serve as an early warning system of birds in trouble but not yet candidates for listing under the ESA [26]. A species designation on the BCC list could impact both infrastructure siting as well as potentially measured or modeled/projected rising ambient EMF levels in some regions (see Part 1).

Federally listed bird species are those protected under the ESA. On the List of Threatened and Endangered Species, there are currently 77 endangered and 15 threatened birds [104]. An endangered species faces significant risk of extinction in the near foreseeable future throughout all or a significant portion of its range, while a threatened species is at risk of becoming endangered in the near future. Extinction is irreversible and permanent.

Collectively, migratory birds are in decline, some precipitously (see Part 2), with numbers of both listed and BCC species increasing [26, 107]. With 272 BCC-designated species and 92 Federally Endangered and Threatened migratory birds, out of 1,093 protected migratory birds, at least 364 (>33%) species are in trouble. Those numbers continue to increase at a sizable rate and once a bird population is in trouble, reversing its decline is extremely difficult [26, 109, 110]. The MBTA has no provisions for acquiring and protecting bird habitats although there have been bilateral discussions between the U.S., Canada, Mexico, Japan, and Russia that have resulted in some bird habitat protection efforts.

Other protections: presidential Executive Order 13186—Migratory birds, and The Bald and Golden Eagle Protection Act

In January 2001, the Migratory Bird Executive Order 13186 [111] was signed by President Clinton. It stipulates that, "… each Federal agency taking actions that have, or are likely to have, a measurable negative effect on migratory bird populations …" is to develop and implement a Memoranda of Understanding (MOU) "… to promote the conservation of migratory bird populations." Simply put, if the actions of a federal agency are now, or will in the near future, impact bird populations, that agency is to sign and implement an MOU with the U.S FWS in an effort to protect migratory birds and their habitats [26]. While many of the previous Executive Orders in place from the Clinton, Bush, and Obama administrations were rescinded by the Trump Administration, E.O. 13186 was not among them. An executive order from the White House does not have the full force of a law implemented by the U.S. Congress, but in this case E.O. 13186 does have the force of the MBTA clearly backing it. E.O. 13186 provides specific opportunities for habitat protection, land management, and conservation planning. U.S. FWS has the responsibility under the E.O. to protect migratory birds and their habitats.

In addition to protections under the MBTA, the U.S. FWS is also responsible for maintaining stable and/or increasing breeding populations of Bald (*Haliaeetus leucocephalus*) and Golden (*Aquila chrysaetos*) Eagles under The Bald and Golden Eagle Protection Act [112, 113]. The definition of "take" under BGEPA is broader than under MBTA, and includes provisions against pursuit, shooting, poisoning, capturing, killing, trapping, collecting, molesting, and disturbing both species (ref. [112], 50 C.F.R. 22.3). Permits are required from U.S. FWS for "disturbance take" and "take resulting in mortality" (ref. [112], 50 C.F.R. 22.26), and for "take of nests" (ref. [112], 50 C.F.R. 22.27). Disturbing, injuring or killing eagles without an "eagle take" permit under BGEPA could result in criminal culpability. Any infrastructure-related EMF effects to Bald or Golden Eagles would be actionable under these regulations.

The National Environmental Policy Act: how it applies to environmental EMF and categorical exclusions

The second most iconic U.S. environmental law, after the ESA, is the 50 year old National Environmental Policy Act [114, 115]. Among the most effective laws ever passed, it was signed by President Nixon in 1970 and has become an important means for protecting wildlife in the face of large government actions. As such it is a constant target for various industries regulated by the government, most recently the telecommunications industry seeking exemptions from the FCC for any effects from their operations, including RFR [50].

NEPA has been applied to any major federal, state, or local project where a federal regulatory nexus or action is involved, including actions taken by federal agencies themselves. This includes:

- Where federal funding had been, is, or will be used.
- Where a permit has been issued by a federal agency.
- Where work or action by a federal agency has been contracted for a project [26].

Courts have also expanded the purviews of NEPA. In addition, the NEPA legislation established the Council for Environmental Quality (CEQ) which is housed within the U.S. Executive Office of the President to advise the President on the state of the environment and environmental policy.

The primary role of NEPA rules is to establish national environmental policy and to determine the regulations that require all federal agencies to prepare EAs, and/or Environmental Impact Statements (EISs) that accompany official reports and/or recommendations whenever they are submitted to Congress for funding. A vast array of federal agencies is involved in NEPA review/compliance, including agencies like the Environmental Protection Agency (EPA) and U.S. FWS.

Unlike MBTA and BGEPA, which are both strict liability statutes (see above), NEPA regulations have no criminal or civil penalties or sanctions. As such, all enforcement of NEPA must go through the courts which may order a federal agency to require a proponent to perform NEPA-compliant analysis and performance. This would include, for instance, compliance with the previously described bird protection laws where migratory birds could be impacted by EMF and other radiation exposures.

To effectively apply NEPA, an evaluation is required of the relevant environmental effects of a federal project. For instance, in the case of environmental EMFs, assessing the impacts of 5G on wildlife (including insects and migratory birds), NEPA review should be performed by the FCC before instituting any rulings that would facilitate 5G buildout, or an evaluation of an action mandated by NEPA where the "nexus" conditions apply. This process begins when an agency or commission, such as the FCC or the Federal Energy Regulatory Commission, develops a proposal that addresses the need to take an action. If that action is covered under NEPA, three levels of analysis are required by the action agency (i.e., the agency with responsibility for its action on the environment) for that action to be in compliance with NEPA. These include where applicable:

- Preparation of a CatEx.
- Preparation of an EA.
- The determination of either a Finding of No Significant Impact (FONSI) or …
- The preparation/release of an EIS if there will likely be significant impact to species or habitats.

Because NEPA allows public review and comment on these documents and the process, this provides a venue for litigation and possible court action.

A CatEx [116] is a list of actions that an agency has determined do not individually or cumulatively significantly affect the quality of the human environment ([116], 40 C.F.R. §1508.4). A lot of things can slip through the cracks with such exclusions. The "quality of the human environment" represents a key phrase in interpreting NEPA. As such, if a proposed action such as the use of 5G and its impacts on wildlife were to be included in an agency's CatEx—say by FCC and U.S. FWS—the agency must ensure that no extraordinary circumstances might cause the proposed action to affect the environment (in this case, humans and wildlife). Extraordinary circumstances include negative effects/impacts on endangered species, protected cultural sites, and wetlands. If the proposed action is not included in the description provided in the CatEx, an EA must be prepared and can be published in the *Federal Register*, which allows the public to comment, and if necessary, to litigate. (Notice of all EISs must be published in the Federal Register; some, but not all, agencies choose to also publish notice of EAs—no absolute requirements to do so exist. The Council of Environmental Quality [CEQ] regulations also do not mandate notice of EAs—only EISs).

The release of an EA and a FONSI represent specific public documents which include information on the need for a proposal, a list of alternatives, and a list of agencies and persons consulted in the drafting of the proposal. "The purpose of an EA is to determine the significance of the proposal's environmental outcomes and to look at alternatives for achieving the agency's objectives. An EA is supposed to provide sufficient evidence and analysis for determining whether to prepare an EIS, aid an agency's compliance with NEPA when no EIS is necessary, and it facilitates preparing an EIS when one is necessary." [115, 116].

If it is determined that a proposed federal action does not fall within a designated CatEx or does not qualify for a FONSI, then the responsible agency—which in the case of 5G buildout would involve the FCC with significant input from U.S. FWS—must prepare an EIS. The purpose of an EIS is to help public officials make informed decisions based on the relevant environmental consequences and the alternatives available.

From the information presented in Parts 1 and 2 of this paper and elsewhere, the environmental consequences of 5G and rising background levels of RFR could be catastrophic to some species. The drafting of an EIS includes public parties, outside parties, and other federal agency input concerning its preparation. These groups subsequently comment on the draft EIS. However, the FCC has systematically categorically excluded many devices and current technologies that use RFR, as well as ruling that their exposure standards extend to 5G exposures [4, 117], thus allowing their use/buildout to proceed without full NEPA/EIS review.

Even when NEPA has been applied to an RFR exposure situation, there have been problems. Part 1 included discussion of a U.S. military training proposal throughout a protected wilderness area that involved a lengthy, but ultimately inadequate, NEPA review with the U.S. FWS (see Part 1 for further details). What that case revealed was the necessity for environmental agencies to have their own inhouse bioelectromagnetics expertise with knowledge of nonionizing radiation effects to wildlife—something now lacking throughout regulatory agencies. In light of continuing new information, to do otherwise fosters large loopholes through which entire networks of low-power infrastructure can avoid larger environmental review.

It is important to note, as described above, that all small cells intended for 5G deployment, are categorically excluded by the FCC, thereby bypassing NEPA requirements despite significant studies (see Part 2) of adverse effects to all taxa that would apply for review under EAs, and EISs. Part 1 explored measured levels from the 1980s to today's measured rising background RFR that should also apply to NEPA review, given the expansion of a large new technology like 5G about to make its own significant contribution. Instead, FCC categorically excluded small cells from NEPA without any examination of the unique signaling characteristics of 5G that are new to broadband telecommunications technology in the built environment, or 5G's higher frequencies to be used widely at significant scale that may especially impact insects and birds (see above, "Government exposure standards"). Instead, FCC ruled that states and municipalities must streamline small cell network applications and buildouts without NEPA [117]—a position that was successfully challenged in U.S. courts [50].

At the moment, NEPA requirements still stand. But other suits challenging FCC's small cell streamlining without also updating their exposure standards were less successful [118]. Under the former Trump Administration, industry-friendly legislation was introduced [119] that would have excused the FCC from all NEPA review as a matter of course. No other federal agency with the ability to impact the environment had ever gotten such a pass. The bill did not succeed but such an attempt again demonstrates the fragility of these iconic environmental protections.

Canada's environmental laws and regulations: Species at Risk Act, and Migratory Birds Convention Act

In conjunction with U.S. laws that are observed across borders, Canada has some strong regulations of its own such as the Species at Risk Act and the Migratory Birds Convention Act (MBCA).

The Species at Risk Act, known as SARA [120], is similar in many respects to the U.S. ESA. SARA encourages the various government entities in Canada—e.g., Provincial, Federal, First Nations, territorial, county, city, town, and fort—to cooperate in protecting wildlife species in Canada. SARA also includes protocols for consultation and cooperation with Aboriginal/First Nations peoples which Canada views as essential to successfully implementing the statute.

Like the U.S. ESA, SARA can affect entities or individuals who own property or have a vested interest in land where a species at risk (designated in the List of Wildlife Species at Risk [121] is found at any time throughout the year. The statute also defines critical habitat, designated in the SARA Public Registry [122]. Like the purposes of the ESA, SARA is intended to prevent wildlife species in Canada from disappearing; to recover wildlife species extirpated (i.e., no longer found in the wild in Canada), endangered or threatened as a result of human activity; and to manage species of special concern so as to avoid threatened or endangered designation [123]. To accomplish these purposes and goals, SARA establishes how governments, organizations, and individuals in Canada should work together, and establishes guidelines for implementing a species assessment process to ensure the protection and recovery of species. Like the ESA, SARA incorporates penalties for violations; and like NGOs in the U.S. that support/publicize specific issues pertaining to threatened and endangered species, Canada also has NGOs doing the same thing [124].

Canada's Migratory Birds Convention Act (MBCA) of 1994

As with the U.S.'s MBTA, the vast majority of bird species in Canada are protected by the 1994 MBCA [125]. Passed in 1917 and updated in 1994 and 2005, MBCA implements the Migratory Birds Convention, a treaty signed with the United States in 1916. The Canadian Federal government is authorized to pass, implement, and enforce Migratory Bird Regulations [126] designed to protect the species included in the Convention. The lists of bird species protected by Canada and the U.S. may be different. Bird species that are not listed in Canada or the U.S., and/or defined under Article 1 of the MBCA, may or may not be protected by Provincial or territorial legislation, or by SARA, or the UN Convention on Biological Diversity [127] which is an international legal instrument for "… the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources" that has been ratified by 196 nations [128].

Persons, industries or other entities making any decisions (e.g., installing cell towers) that would impact the protected status of a bird species in Canada should also consult SARA. Environment and Climate Change Canada requires that three criteria be met to qualify for the list of bird species protected in Canada under the MBCA. They include:

(1) Birds designated in Article 1 of the MBCA as amended under the 1995 Protocol [128].
(2) Species native or naturally occurring in Canada noted under regulations.
(3) Species known to regularly occur in Canada. Although species that occur infrequently (i.e., "accidentals") and that meet criteria 1 and 2 are not included on this list, they continue to be considered as having protection under the MBCA any time they occur in Canadian territory.

While birds such as grouse, quail, pheasants, ptarmigan, and turkeys—which also in the U.S. are not migratory and/or have been introduced (e.g., pheasants)—are not protected under MBCA nor the MBTA, in Canada birds such as hawks, owls, eagles, falcons, cormorants, pelicans, crows, jays, kingfishers, and some species of blackbirds are also not protected under MBCA. This represents a significant difference between MBTA protection in the U.S., and eagle protection under the U.S. Bald and Golden Eagle Protection Act (discussed above) where all birds in the latter category are protected in the United States.

There are three introduced bird species that do not meet criterion 2 above, but continue to appear on the MBCA list. They include the Mute Swan (*Cygnus olor*), the Eurasian Collared-Dove (*Streptopelia decaocto*), and the Sky Lark (*Alauda arvensis*). Environment and Climate Change Canada [128] continues to consult with provincial and territorial governments, which share responsibility for the management of birds in Canada, regarding a proposal to remove these species from the list of MBCA birds. Until a decision is reached by the concerned parties, these three species will remain under MBCA protection. The list of birds protected under the MBCA follows the American Ornithologists' Union's Check-list of North American Birds, and its supplements to 2014, on matters of taxonomy, nomenclature, and sequence [129].

European environmental laws: European Union (EU) initiatives addressing endangered species and habitat protection

The EU, with its 27 member nations, has recently implemented a four-pronged approach to better address species protection, recovery, and restoration of imperiled plants and animals found on the continent [130, 131]. This includes:

- Species protection through a Birds Directive.
- Species protection under a Habitats Directive.
- Ensuring that plants and animals are not threatened by illegal and/or unsustainable international wildlife trade through stronger implementation of CITES—the Convention discussed above [93].
- Developing and implementing an EU pollinators initiative to reverse negative impacts to pollinators including effects from EMF/RFR [132].

The EU began an ambitious effort in 2011 to develop and implement a Biodiversity Strategy to institute the framework for this four-pronged approach above. The Strategy includes the following targets:

(1) Protect 100% more habitats and 50% more species above 2011 levels.
(2) Establish green infrastructure and restore at least 15% more ecosystems.
(3) Achieve more sustainable agriculture and forestry.
(4) Make fisheries more sustainable and the seas healthier.
(5) Combat invasive alien species.
(6) Help stop or reverse the global loss of biodiversity.

At this writing, the EU may still be on track to achieve their strategy, although progress calls for a much greater effort among all parties involved, and the transition from BREXIT is creating many difficulties, unknowns, and complexities [130–132].

It is clear that all industrialized Western countries are trying to address serious environmental issues with more and/or less success—depending on politics, funding, and the will to act. EMF as an environmental pollutant needs to be part of that effort.

Airspace as habitat: aeroecology

Birds, bats, insects, and other species that use airspace for critical life functions are of cornerstone significance to us all. Birds, for instance, provide key ecosystem functions that fuel multi-billion dollar industries through pollination and insect/weed/seed control in the agribusiness sector, as well as in the forestry industries. Without migratory birds, there would be untold problems and money spent globally for more pesticides, herbicides, and other chemicals. In addition, in the U.S. alone, feeding, photographing, and observing birds fuels a $32 billion annual recreation industry, representing 20% of the U.S. adult population engaging in these activities. Human/bird-related activities are reportedly more popular than golf [26, 133].

Birds also have spiritual significance to indigenous peoples. A number of migratory bird species—notably Bald and Golden Eagles, Common Ravens (*Corvus corax*), American Crows (*Corvus brachyrhynchos*), hawks, falcons, doves, owls, and hummingbirds—are revered and protected by the Tribal laws of several U.S. indigenous American Tribes and Canadian First Nation peoples. Some of these very species are at considerable risk from habitat disturbance/fragmentation, injury, and death, including from EMF and other radiation impacts which will undoubtedly increase exponentially without a change in human awareness.

We have a legal, moral, and ethical obligation to protect migratory species of every kind, the airborne included. Impacts from EMF may add to species declines and ultimately threaten their survival if we do not understand and respond appropriately because airspace is as critical a habitat as are water and soils for non-airborne species. Thus far we have failed to muster the macroscale vision of the air-as-habitat concept that also includes flora, which are exquisitely sensitive to the ELF of the Earth's geomagnetic fields with their root systems underground as well as to RFR with their primary stem and leaf growth in the air (see Part 2 and Part 2 Supplement 4). Humans have collectively done a poor job of addressing impacts to living organisms that use the airspace—most especially migratory birds, bats and beneficial insects—along with being negligent in protecting what is on, as well as below, the ground, and in aqueous environments. We need to understand EMF as a form of energetic air pollution, especially biologically active anthropogenic RFR that is endemic today in airspace.

Defining the habitat of airspace

The airspace used by plants and animals includes the space just above ground level (AGL) to ceilings in excess of 26,245 ft (8 km) AGL. These upper ranges are used, for example, by Demoiselle Cranes (*Grus virgo*) and other migratory bird species, as well as Golden Eagles which prey on the cranes and other quarry. But airspace should be considered as habitat for a variety of plants and animals too that use and depend on it during, and in some cases throughout, significant portions of their lives. These living organisms include, but are not limited to, flying insects, some arachnids, birds, bats, flying squirrels, flying fish, and some reptiles, as well as seeds, spores, vegetative plant parts, and forest canopies. Organisms use airspace for purposes of transport, dispersal, feeding, mating, territorial defense, escape, migration, daily movements, and for other reasons [134]. In most cases, unimpeded airspace is critical to mating, nesting, survival, food acquisition, territorial defense, daily movements, and migrations of birds and bats (including microchiropterans and megachiropterans) [27, 109, 110].

Impacts to species using airspace have been well documented, including of migratory birds and communication towers and their guy-wire support structures [135]—annual mortality now conservatively estimated at 6.8 million birds killed in the U.S. and Canada solely from collisions with communication structures [136–139]. However, the impacts to migratory birds, other wildlife, and plants generally do not include adequate cumulative effects analyses (cumulative biologically and under the legal mandates of NEPA). Cumulative effects under NEPA must consider and evaluate all impacts from all human-built structural sources including EMFs that they may emit and/or receive, where applicable.

Currently, environmental impacts from RFR on wildlife are not being assessed by the FCC, EPA, or the Department of Interior (DOI), nor is ELF-EMF being considered by the Department of Energy (DOE) regarding powerline exposures. However, it is important to note that precedent was set in 2014 when DOI publicly charged that the FCC's standards for RFR from cellular towers were outdated, based on narrow thermal heating effects, and inadequate to protect migratory birds and other wildlife [139]. A letter from DOI's Director of the Office of Environmental Policy and Compliance was sent in February 2014 to the National Telecommunications and Information Administration (NTIA), housed in the Department of Commerce [140]. The letter—and subsequent meetings with staff from the U.S. FWS—resulted in the initiation of an EIS process under NEPA by NTIA to begin an independent research study to address the impacts of radiation from cell towers on migratory birds using the airspace. Unfortunately, efforts languished and were completely suspended under the former Trump Administration with nothing similar initiated subsequent to that as of this writing. Under NEPA, cumulative effects must include impacts from all human-related sources that affect humans, wildlife, plants, and all living organisms that depend on/use airspace for survival. The effects of EMF on flora and fauna remain widely unassessed [27, 110].

Air as an actual habitat is a relatively new concept for many in the scientific community, including federal agencies such as U.S. FWS whose goal (including for wildlife that use the airspace) has been to "do no harm" [141]. Reducing harm to wildlife that use the airspace is a tall order because a lot of things occupy it—both permanently and on a temporary basis—but we do not generally think of it that way. Airspace interference and adverse effects to wildlife comes in many forms. For instance, in addition to the communication-tower bird-collision mortality estimates referenced by Longcore et al. [138] above, Manville [142] estimated that 440,000 protected migratory birds were killed annually by blade strikes at U.S. commercial wind energy facilities in 2008. Smallwood [143] increased that estimate to 573,000 bird fatalities per year (including 83,000 raptor deaths) based on increases in commercial wind turbines, and estimated that an additional 888,000 bats died in turbine blade collisions annually in the U.S. In addition, based on the variety of survey methods used, differences in survey detail, longevity of assessment, and robustness, as well as differences in infrastructures being investigated, Loss et al. [144] estimated between 8 and 57 million birds are killed annually by collisions with power distribution and transmission lines, and between 0.9 and 11.6 million birds die from wire and infrastructure electrocution each year in the U.S. This is not to mention the estimated 1.4–3.7 billion birds (median = 2.4 billion) killed annually in the U.S. by domestic and feral cats at ground level and/or near-ground while birds are in flight [145]; or the annual estimated 97.6–976 million U.S. bird deaths from building window collisions [146] which Klem and Saenger [147] later estimated was greater than any other source of human-associated bird mortality. Taken collectively, this is massive anthropogenic-caused avian mortality, all of which occurs within the airspace. There are reduction strategies for some of these—like keeping domestic cats indoors and/or placing bells on their collars, installing non-reflective window panes, and using vertical axis designs in wind turbines—but these do not substantially solve the problem. ELF and RFR problems can only be handled at the transmission source through use reduction. Approaches that use frequencies such as radar to repel birds only create an additional ambient source capable of affecting another species, such as insects, in a different way.

The staggering avian mortality rates noted above fail to include impacts from pesticides, contaminants, oil spills, disease, parasites, natural mortality, predators, entanglement, and other non-airspace related sources. Impacts to individual animal and plant species are cumulative. The potential role that EMF plays in adverse effects to animals that use the airspace should be added to the list as a growing concern based on evidence presented throughout this three-part series of papers, and elsewhere.

Aeroecology—a macrovision

The interdisciplinary field of aeroecology has evolved to encompass a variety of issues affecting airspace. The concept was founded around 2008 by Dr. T.H. Kunz, Professor of Biology and Director of the Center for Ecology and Conservation Biology at Boston University who sadly died from Covid-19 complications in April 2020. Kunz laid out an aeroecology vision that includes technological solutions for studying animals that use the aerosphere as well as the key questions that unite aeroecology. Frick et al. [148] wrote an excellent review of this emerging unifying discipline.

Aeroecology integrates domains that include atmospheric science, animal behavior, ecology, evolution, earth science, geography, computer science, computational biology, and engineering [134, 149, 150].

In 2008, Kunz and colleagues organized a symposium in San Antonio, Texas, entitled, “Aeroecology: Probing and Modeling the Aerosphere: the Next Frontier.” At that symposium and since, the concept evolved to define the field, including:

- The aerosphere comprises one of the three major components of our biosphere, yet it is one of the least understood substrata of the troposphere, especially in regard to how organisms interact with and are influenced by this highly variable and fluid environment [134].
- The biotic interactions and physical properties in the aerosphere provide significant selective pressures that influence the size and shape of organisms, as well as important influences affecting their behavioral, sensory, metabolic, and respiratory functions.
- While organisms that spend their entire lives on land or in the water tend to be less varied based on adaptive pressures, organisms that use the airspace can be immediately affected by the changing boundary layer conditions of the airspace.
- These conditions include winds, air density, oxygen concentrations, precipitation, air temperature, sunlight, polarized light, and moonlight, as well as geomagnetic and gravitational forces [134].

The authors of this paper would add to that growing list the impacts of ELF and RFR to organisms that use the airspace at varying durations and intensities.

The discipline of aeroecology allows us to better assess the impacts from anthropogenic factors affecting wildlife that use the airspace—ranging from nearly all, or significant portions of their lives, to minimal amounts of time. While no organism spends its entire life in the aerosphere, anthropogenic factors located within, or that directly or indirectly affect, the aerosphere can have significant impacts. These anthropogenic factors, for example, include skyscrapers, office buildings, homes, structural lighting, city/community lighting, power transmission and distribution wires and infrastructure, radio/television/cellular/emergency broadcast communication towers and structures, commercial wind turbines, industrial solar arrays (especially 'power' towers and large solar panel facilities), bridges, aircraft, air pollution, increases in greenhouse gases, climate change, and radiation emitted from communication structures and related devices, among others [26, 137]. Staff at U.S. FWS emphasized the importance of airspace as habitat, and garnered the attention of top service officials to respond through improved voluntary guidance addressing the various industries impacting airspace.

To study the impacts of communication structures on migratory birds (including from RFR), the U.S. Forest Service invited the Division of Migratory Bird Management at U.S. FWS, to design and develop a research protocol to study towers in several national forests in Arizona. While the protocol, which was written by one of the authors of this paper while at the U.S. FWS [151], would benefit from updating and peer-review, it nevertheless provides a framework for independent studies of EMF impacts to migratory birds, mammals, and other wildlife and plants in the field.

It is important that future studies be conducted by independent scientific sources without vested interests in the outcome. Such inquires clearly fall under the auspices of aeroecology. We first need the vision and will to move this forward.

Discussion: synthesis of linear and nonlinear disciplines needed

Nonionizing EMF is virtually uncontrolled as an environmental pollutant. This was observed as far back as the 1970s [152] and has only gotten progressively worse with each passing decade. There are several reasons for this, including the likelihood that in many regulatory agencies there is an assumption that the science is not robust or adequately developed upon which to base regulations, much less enforce them. There is also a pervasive attitude that risks to wildlife, if any, are minor compared to the human benefits of widespread wireless technology. Technology is seen as beneficial in many environmental circles for the information it can provide, for instance, via animal tracking devices (see Part 1), while potential adverse effects that create hidden variables from such devices rarely occur to environmental researchers. The need to study EMF effects is not obvious to many regulators or environmentalists. That may change once air is understood as 'habitat' and EMF is seen as an energetic pollution source.

Wildlife has also historically been considered resilient (despite much evidence to the contrary) and nonionizing radiation has been seen as relatively harmless beyond tissue heating and electric shock. If non-human species have been considered at all regarding EMF, broad but inaccurate assumptions have been made that protecting humans from the worst adverse effects also extend to other species. What has been lacking is the right government agency expertise with an understanding of how non-human species interact with exogenous EMFs, and at what intensities. There has never been funding in any agency to track or develop that area of interdisciplinary knowledge because the need was not obvious until recently. Other than at the FCC which is mostly staffed with engineers who lack knowledge of biology, civil scientists who are trained in bioelectromagnetics and/or biophysics are found throughout many regulatory agencies. Their work, however, is primarily focused on human health issues, not wildlife. Agencies tasked with wildlife protection have been completely defunded for such work—i.e., the U.S. FWS which does not have a bioelectromagnetics expert on staff, and most importantly the U.S. EPA which at one time had the world's foremost bioelectromagnetics basic research laboratory staffed with scientists who made groundbreaking discoveries (see Part 2, Mechanisms). Many agencies have simply not replaced what little bioelectromagnetics expertise they have had when those scientists retire and new ones have not been trained or hired. And it is only recently that environmental nonionizing radiation has increased to measurable levels high enough to warrant investigation to all living beings. Europe, for instance, is now taking an interest in potential 5G effects and developing standards that apply to wildlife protection [153].

One aspect of rising environmental EMF levels may, however, spur attention—the shadow role it could be playing in global climate change. Scientists know that what occurs in the ionosphere directly affects our weather patterns—of sudden importance given the dramatic increase in satellites being deployed globally for 5G telecommunications (see Part 1). Erratic weather and its consequences have grown to dangerous levels in most parts of the world. Thunderstorms increased 25% over

North America between 1930 and 1975, vs. between 1900 and 1930 [154]. That period directly parallels our first introduction of environmental EMFs along with other contaminants. As far back as 1975, a team of researchers at the Stanford University Radioscience Laboratories, then headed by Robert Helliwell, found evidence that powerline emissions are amplified within the magnetosphere [155], causing a veritable rain of electron precipitation into the ionosphere, which could theoretically lead to both highly localized as well as global changes in weather patterns. The technologies we have added since 1975—both ELF and RFR—which we assumed to be atmospherically benign, may not be as harmless as originally thought. The exponential growth planned for 5G broadband (including MMW) from satellites and millions of accompanying ground-based transmitters is certainly reason for caution. It is already well established that MMW bands at 60 GHz are maximally absorbed by atmospheric oxygen (O_2), as well as by H_2O at 24 GHz—ranges planned for 5G (see Part 1). Oxygen molecules readily absorb the 60 GHz frequency range and rain droplets easily attenuate signals [74–76, 156, 157]. In fact, at 60 GHz, 98% of transmitted energy is absorbed by atmospheric oxygen. This makes that frequency spectrum good for short-range transmission but no one understands how a large infusion of RFR in that band—or any other—may affect atmospherics. It could be highly destabilizing (see Part 1).

There is a need to re-integrate biology, which studies whole dynamic living systems, with the non-living sciences of physics and engineering that focus on how to create and make technology work. The latter have dominated EMF research and its applications in every way since the 1940s, including research protocols regarding human health and standards setting which are outside their areas of expertise. Today, physics and biology—although fundamentally very different disciplines with their own inherent cultures and biases—increasingly converge when it comes to environmental concerns. While we already understand how to make modern societies and accompanying technologies work, the most important questions now concern the potential effects to the living systems in the path of technology.

Electromagnetism is fundamental to life—indeed all living things function with biological microcurrent without which life would not exist. Technology, which also requires EMF to function, therefore speaks the same fundamental language as living cells. Yet biologists have consistently been left out of full participation in safety and environmental issues in anything other than cursory inclusion. If there is to be a better integration of physics and biology, it will need to be at the behest of the biology community. The physics/engineering disciplines have had the subject to themselves for decades and are somewhat territorial about it. Plus their inherent focus is on linear cause-effect dosimetry models in both technology design and exposure standards setting. They tend be less interested in the confounding complexities of biology which are mostly nonlinear and unpredictable.

The natural world typically demonstrates nonlinear dynamics, meaning that a small stimulus can result in a large, seemingly disproportionate outcome. The weather is nonlinear, for instance, as illustrated by the imagined "butterfly effect" in which a butterfly can theoretically flap its wings in Indonesia and cause a hurricane on the other side of the globe [158–160]. Some disease states are nonlinear, allergies being a prime example. A person with a severe peanut allergy can go into anaphylactic shock by merely being in the same room with the offending agent. Or someone with an allergy to bees, upon experiencing a sting, will react far out of proportion to the tiny amount of venom being injected by the insect. Physics and engineering, on the other hand, are highly linear—an exemplary asset in that realm. Humanity, after all, has no patience for machines or systems that don't work [161].

Until there is a synthesis between physics/engineering and biology, with an emphasis on nonlinear models, the potential environmental effects of our increasing EMF exposures will not be well understood. Each area has much to learn from the other. Biologists can benefit from the precision emphasized in physics and engineering while physicists and engineers can benefit for the savvy that biologists have acquired in environmental observation, measurement, quantification, hypothesis testing, and formulating policy in the face of scientific uncertainty.

Given the rising background levels in urban, rural, and some wilderness environments, EMF should be classified as an energetic air pollutant capable of adversely affecting wildlife and habitats as delineated throughout these papers. Cumulative effects should be taken into consideration from myriad sources, and continuing evidence should be evaluated by unbiased entities, including governments and NGO's. We can no longer presume that the status quo of ever-increasing EMF ambient levels is safe without much closer scrutiny.

Some solutions

Existing environmental laws in the U.S., Canada, and throughout Europe should be enforced. For example, in the U.S., NEPA and its EISs should be required each time a new broadly polluting EMF technology like 5G is introduced, not as the current policy is being interpreted through

"CatEx" or simple dismissal. EISs should be required for all new technologies that create pervasive ambient EMF such as 'smart' grid/metering, Distributed Antenna Systems (DAS), small cell networks, and the 5G "Internet of Things." Where wildlife species are affected, systems and networks that currently meet radiation levels for CatEx (and are therefore exempt from review) should be required to develop/implement NEPA and EIS reviews for cumulative exposures to wildlife from multi-transmission sources.

Efforts should begin to develop acceptable exposure and emissions standards for wildlife, which today do not exist. Setting actual exposure standards for wildlife will be an enormous challenge, and for some species there may be no safe thresholds, especially with 5G and MMW. We may simply need to back away from many wireless technologies altogether, especially the densification of infrastructure, and refocus on developing better dedicated wired systems in urban, suburban and rural areas. Environmentally sensitive wilderness areas should be considered off limits for wireless infrastructure. Once air is seen as 'habitat,' there may come a time when a cell phone call voluntarily *not made* will be understood as removing something detrimental from air's waste-stream, the way we now see plastic bags regarding terrestrial/aquatic pollution.

There are some reasonably simple things that can be done in the ELF ranges that would benefit insect, bird, and many wild mammal and ruminant species. For example, high-tension electric utility corridors can be built or changed to cancel magnetic fields with different wiring configurations. This is already widely done in the industry for other reasons but it also coincidentally eliminates at the source at least the magnetic field component for wildlife. There are other approaches too but further discussion is beyond the scope of this paper.

Research into the long-term, low-level ambient exposures to humans and wildlife is imperative given the picture that is emerging. There is a likelihood that low-level ambient EMF is a factor, or co-factor, in some of the adverse environmental effects we witness today—many previously discussed in this series of papers. There is currently no research in any industrialized country that looks to the broader implications to all flora and fauna from these rising background levels, even as effects to individual species are observed. This is an important, emerging environmental issue that must be addressed.

Conclusions

In this broad three-part review, we sought to clarify if rising ambient levels of EMF were within the range of effects observed in *in vitro, in vivo*, and field studies in all animal phyla thus far investigated. We further discussed mechanisms pertinent to different animal physiology, behavior, and unique environments. The intention was to determine if current levels have the ability to impact wildlife species according to current studies. The amount of papers that find effects at today's EMF levels to myriad species is robust. Some unusual patterns did emerge, including broadly in flora that react beneficially to static EMF but adversely to AC-ELF and especially to RFR.

There is a very large database supporting the hypothesis that effects occur in unpredictable ways in numerous species in all representative taxa from modern ambient exposures. Associations are strong enough to warrant caution. New enlightened public policies are needed, as well as existing laws enforced, reflecting a broader understanding of non-human species' interactions with environmental EMF. Emerging areas, such as aeroecology, help define airspace as habitat and bring better awareness of challenges faced by aerial species—including animals and plants. But we are in the nascent stages of understanding the full complexity and detailed components of electroecology—the larger category of how technology affects all biology and ecosystems.

Historically, control over the realm of nonionizing radiation has been the purview of the physics and engineering communities. It is time that the more appropriate branches of biological science, specializing in living systems, stepped up to fill in larger perspectives and more accurate knowledge. We need to task our technology sector engineers to create safer products and networks with an emphasis on wired systems, and to keep all EMF exposures as low as reasonably achievable.

Acknowledgments: The authors wish to thank the excellent reviewers who made this series of papers far better.
Research funding: None declared.
Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission.
Competing interests: Authors state no conflict of interest.
Informed consent: Not applicable.
Ethical approval: Not applicable.

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Changes of Clinically Important Neurotransmitters under the Influence of Modulated RF Fields—A Long-term Study under Real-life Conditions

Klaus Buchner and Horst Eger

This follow-up of 60 participants over one and a half years shows a significant effect on the adrenergic system after the installation of a new cell phone base station in the village of Rimbach (Bavaria).
After the activation of the GSM base station, the levels of the stress hormones adrenaline and noradrenaline increased significantly during the first six months; the levels of the precursor dopamine decreased substantially. The initial levels were not restored even after one and a half years. As an indicator of the dysregulated chronic imbalance of the stress system, the phenylethylamine (PEA) levels dropped significantly until the end of the study period.
The effects showed a dose-response relationship and occurred well below current limits for technical RF radiation exposures. Chronic dysregulation of the catecholamine system has great relevance for health and is well known to damage human health in the long run.

Keywords: cell phone base station, long-term study, stress hormones, radiofrequency radiation, GSM transmitter, far-field radiation

Introduction

Despite the distribution of numerous wireless transmitters, especially those of cell phone networks, there are only very few real-life field studies about health effects available. In 2003, the Commission on Radiation Protection was still noticing that there are no reliable data available concerning the public's exposure to UMTS radiation near UMTS base stations (1).

Since the 1960s, occupational studies on workers with continuous microwave radiation exposures (radar, manufacturing, communications) in the Soviet Union have shown that RF radiation exposures below current limits represent a considerable risk potential. A comprehensive overview is given in the review of 878 scientific studies by Prof. Hecht, which he conducted on behalf of the German Federal Institute of Telecommunications (contract no. 4231/630402) (2, 3).
As early as the 1980s, US research projects also demonstrated in long-term studies that rats raised under sterile conditions and exposed to "low-level" RF radiation showed signs of stress by increased incidences of endocrine tumors (4, 5).

Concerned by this "scientific uncertainty" about how radiofrequency "cell tower radiation" affects public health, 60 volunteers from Rimbach village in the Bavarian Forest decided to participate in a long-term, controlled study extending about one and a half years, which was carried out by INUS Medical Center GmbH and Lab4more GmbH in

Original study in German: BUCHNER K, EGER H (2011) Umwelt-Medizin-Gesellschaft 24(1): 44-57.

Zusammenfassung

Veränderung klinisch bedeutsamer Neurotransmitter unter dem Einfluss modulierter hochfrequenter Felder - Eine Langzeiterhebung unter lebensnahen Bedingungen

Die vorliegende Langzeitstudie über einen Zeitraum von eineinhalb Jahren zeigt bei den 60 Teilnehmern eine signifikante Aktivierung des adrenergenen Systems nach Installation einer örtlichen Mobilfunksendeanlage in Rimbach (Bayern).

Die Werte der Stresshormone Adrenalin und Noradrenalin steigen in den ersten sechs Monaten nach dem Einschalten des GSM-Senders signifikant; die Werte der Vorläufersubstanz Dopamin sinken nach Beginn der Bestrahlung erheblich ab. Der Ausgangszustand wird auch nach eineinhalb Jahren nicht wieder hergestellt. Als Hinweis auf die nicht regulierbare chronische Schieflage des Stresshaushalts sinken die Werte des Phenylethylamins (PEA) bis zum Ende des Untersuchungszeitraums signifikant ab. Die Effekte unterliegen einem Dosis-Wirkungs-Zusammenhang und zeigen sich weit unterhalb gültiger Grenzwerte für technische Hochfrequenzbelastung. Chronische Dysregulationen des Katecholaminsystems sind von erheblicher gesundheitlicher Relevanz und führen erfahrungsgemäß langfristig zu Gesundheitsschäden.

Schlüsselwörter: Mobilfunk-Basisstationen, Langzeituntersuchung, Stresshormone, Mobilfunkstrahlung, Fernfeld

in cooperation with Dr. Kellermann from Neuroscience Inc.[1].

Common risk factors such as external toxic agents, parameters of the catecholamine system (6) were determined prior to the activation of the GSM transmitter and followed up in three additional tests for a period of more than 18 months. The informed consent of all participants included the condition that the data were to be published anonymously.

-------------------------------- Materials and Methods

Study Setting and Selection of Study Subjects

In spring 2004, a combined GSMD1 and GSMD2 cell transmitter (900 MHz band) was installed on Buchberg mountain in D-93485 Rimbach (Lower Bavaria) with two sets of antenna groups each. The installation height of the antennas for both systems is 7.9 m; the horizontal safety distance along the main beam direction is 6.3 or 4.3 m, respectively. At the same tower, there is also a directional antenna at 7.2 m (7).

1) INUS Medical Center, Dr. Adam-Voll Str. 1, 93437 Furth im Wald, Tel.: 09973/500 5412, www.inus.de; Lab4more GmbH, Prof. Dr. W. Bieger, Paul-Heyse-Straße 6, 80336 München, Tel.: 089/54321 730, info@lab4more.de; NeuroScience Inc., Dr. Kellermann, 373 280th Street - Osceola, WI 54020 - USA, Tel.: +1/715/294-2144, www.neuroscienceinc.com.

Shortly after it had become known that the wireless transmitters were to be installed, all inhabitants of Rimbach had been asked to participate in a mass screening. The municipality has approximately 2,000 inhabitants. In 60 volunteers (27 male, 33 female) aged between 2 and 68, the levels of adrenaline, noradrenaline, dopamine, and PEA (phenylethylamine)—which cannot be consciously regulated—were determined in their urine at the end of January/beginning of February 2004 (shortly before the activation of the antennas and the RF emissions beginning) as well as in July 2004, in January 2005, and in July 2005.

Most of these study participants signed up immediately after an informational gathering in late January 2004, at which the course of action by the cell phone service providers was criticized. Others signed up following a call for participation in the local paper. Since Rimbach is a small municipality, mouth-to-mouth propaganda also played a role. Participation was made attractive to the volunteers because a lab test that usually would be very expensive was offered for a small fee. Since the study required to show the status of the biological parameters over a given time period, only those study subjects participating in all four tests are included.

The data presented below come primarily from volunteers who have a certain interest in the life of their community and their health. Other persons joined the stress hormone investigation because of the recommendation of, or request by, their fellow citizens. This does not meet the requirements for a random sample. The result of this study, however, is hardly affected because Rimbach is a very small municipality. Therefore, the social contacts that lead to participation are very important. Most probably they do not affect the blood parameters. Furthermore, numerous large families participated as a whole whereby the health status of the individual family members did not play any role. For this reason, but especially because of the population structure, the study includes many children but only a few adolescents and young adults: there are hardly any opportunities for occupational training in Rimbach. In contrast, the municipality is attractive to young families with many children.

Sample Collection

The second morning urine was collected at INUS Medical Center on Mondays between 9:00 and 11:00 a.m. We made sure that each participant's appointment was always scheduled for the same time and that the time of breakfast or the state of fasting was the same for each participant at all tests. On the same day, the samples were sent by express to *Labor Dr. Bieger* in Munich where they were processed. In addition, samples were also sent to a laboratory in Seattle for control analyses (8-11).

Medical History

Medical doctors of the INUS Medical Center took a thorough medical history of each participant. At the initial test, the following data were also gathered: exact address, average time spent at home, indoor toxins, stress due to heavy-traffic roads, and the number of amalgam fillings. The latter number also included fillings that had already been removed. A nine-year-old child was noted to be electrosensitive to the effects of household wiring and connected appliances. All other study participants declared themselves to be not electrosensitive.

When taking their medical history, participants were also questioned about subjective symptoms and chronic diseases at the start of the study and during its course; if overweight, this was also noted. In this study, overweight in adults is defined as a weight greater than the "body height in cm minus 100 plus 5 kg tolerance."

Consistency checks for the parameter "overweight," however, indicate that—especially with regard to children—different criteria have been applied during the taking of the medical history. These data, therefore, can only serve as a reference point. They are listed here anyhow since they can provide suggestions for further studies.

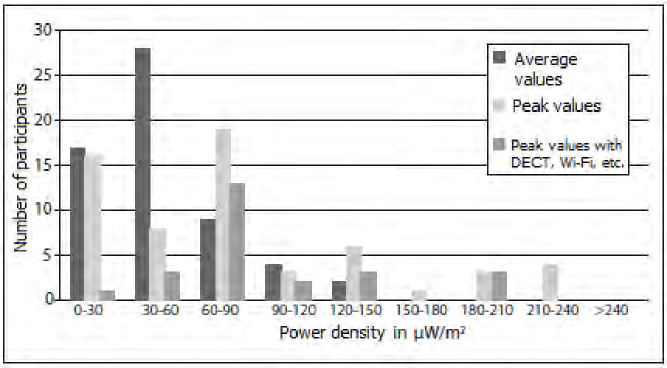

Fig. 1: Classification of participants based on average or peak value of the GSM power density level

All atopic disorders such as:

1. Hay fever, neurodermatitis, allergies, asthma, eczema are referred to as "chronic disorders;" as well as
2. All chronic inflammations such as interleukin- or COX-2-mediated problems;
3. All autoimmune diseases such as rheumatism, multiple sclerosis (MS);
4. All chronic metabolic disorders such as diabetes, liver diseases, intestinal diseases, kidney diseases.

Out of the 16 chronically affected participants 12 had allergies.

It was also asked whether there were DECT, Wi-Fi, or Bluetooth devices in the house or apartment during the study period from late January 2004 until July 2005. Also included were those devices present only for part of the study period, but not those turned off at night.

Exposure Level Measurements

For the most part, Rimbach municipality is located at one side of a narrow V-shaped valley. The cell phone base station is situated almost right across from the village center on the other side. RF radiation levels were measured at the outside of the residences of all study participants, wherever possible with direct line of sight of the transmitter. Because the municipality is located on a slope, great differences were noted inside homes—depending on whether or not a line of sight to the transmitter existed. In three cases, it was possible to measure the exposure levels at the head end of the bed. In these cases, the peak value of the power density was lower by a factor of 3.5 to 14 compared to measurements in front of the house with direct line of sight to the transmitter. The exact location of DECT, Wi-Fi, and Bluetooth base stations (if present) as well as possible occupational exposures, etc. were not determined by most participants.

At first, the measurements were taken with a broadband RF meter HF38B of Gigahertz Solutions, for which the manufacturer guarantees an error margin of max. ±6 dB (+ 7 decimal places; but this error can be mostly eliminated by selecting the appropriate measurement range). However, an inspection revealed that the error margin was less than ±3 dB. In addition, the broadband RF meter HF59B (±3 dB, ±5 decimal places) was used at several points. With this RF meter, relevant frequencies can be analyzed with variable filters, the ELF modulation frequencies via fast Fourier analysis.

By using broadband RF meters, the testing effort and expense are reduced compared to spectrum analyzers. Thus, it was possible to take measurements at a greater number of points, and as a result, it was easier to determine the maxima and minima of the power density levels. Furthermore, the accuracy of high-quality broadband RF meters is similar to that of spectrum analyzers.

In this study, only cell phone signals are considered: not DECT, Wi-Fi, or Bluetooth devices inside homes or emissions from broadcast or TV stations at *Hohenbogen*, a mountain above Rimbach. For the most part, the emissions from the latter transmitters remained stable during the study period, whereas the focus of this study is on changes in exposure levels. For almost all sample measurements, the portion of the exposure due to the transmitter at *Hohenbogen* was at maximum 35 µW/m^2 (peak value). It was higher in the residences of only two study participants: 270 µW/m^2 (average) or 320 µW/m^2 (peak), respectively. At these residences, the GSM exposure was approximately 10 µW/m^2.

For the assessment, the peak values of the signals are used because, in the case of GSM radiation, they are less dependent on the usage level than average values. The peak value of the power density for all study participants from Rimbach was on average 76.9 µW/m^2 (Tab. 1).

In Figure 1 the exposure of the participants is given as power density levels in increments of 30 µW/m^2.

Classification of Participant Group and Exposure Levels

Sixty persons participated in the study; their age distribution is shown in Figure 2 according to year groups. In order to capture the effect of the cell phone base station, other environmental factors must be excluded as much as possible. It is vitally important to ensure that no major differences between high-exposure and low-exposure persons influenced the results.

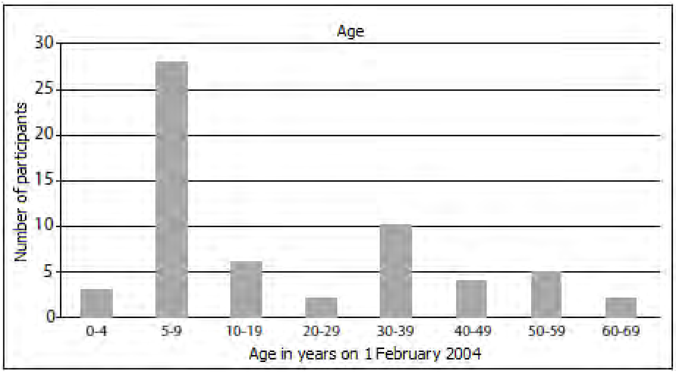

Fig. 2: Age distribution of study participants on 1 February 2004

	All	<=60 μW/m²	60-100 μW/m²	>100 μW/m²
Participants	60	24	20	16
Power density, avg (μW/m²)	76.9	21.7	68.1	170.7
Healthy adults	20	9	5	6
Sick adults	9	6	2	1
Healthy children	24	9	7	8
Sick children	7	0	6	1
Overweight	14	7	3	4
Amalgam number	12	5	3	4
Evaluation of amalgam/person	120	76.4	32.7	240
Street	8	0	8	0
Indoor toxins	17	7	6	4
DECT, Wi-Fi, Bluetooth	25	4	14	7

Tab. 1: Data on the 60 study participants who are classified into exposure groups 0 - 60 μW/m², 60 - 100 W/m², and above 100 μW/m², based on relevant peak values of GSM exposure in front of their residence.

Additional information:

Power density, avg (μW/m²) means: average peak value of GSM exposure level in the relevant category;
Healthy adults: adults without chronic diseases. Participants who were born after 1 February 1994 are referred to as children, all others as adults;
Sick adults: adults with chronic diseases;
Healthy children: children without chronic diseases;
Sick children: children with chronic diseases;
Overweight: see text;
Amalgam number: number of participants who had at least one amalgam filling (which may have been removed prior to the study period);
Evaluation of amalgam/person: For each tooth with an amalgam filling of a participant, the size of the filling (values from 1 to 3) is multiplied with the number of years this filling has been placed prior to the date of the initial test of this study (rounded up to the nearest whole number). The value in the table is the sum of these numbers for all amalgam fillings of a person in the respective category divided by the number of participants with amalgam fillings (= "amalgam number");
Street: number of participants who live at a busy street;
Indoor toxins: number of participants who have had contact with toxins, varnishes, preservatives, etc. at home or at work;
DECT, Wi-Fi: number of persons who had DECT, Wi-Fi, Bluetooth or the like at home at the end of January 2004 or later.

As shown in Table 1, the group with exposure levels greater than 100 μW/m² included fewer chronically ill persons and fewer residences at heavy-traffic roads, but considerably higher amalgam exposures by dental fillings compared to the average of the participants. These differences, however, cannot explain the observed development of the blood parameters as will be shown further below. It should also be noted that the number of children in the group of <= 60 μW/m² is considerably lower than in the other two groups.

Statistics

Because of the large individual differences in blood values, their asymmetrical distribution, and because of the many "outliers," the assessment presented here focuses on the following problem: "Did the level of a given substance predominantly increase (or decrease, respectively) in the test subjects?" For this problem, the so-called signed-rank paired Wilcoxon test (12) is applied. How to determine the confidence intervals of medians is described in an easy-to-understand form in (13).

Due to the rather large differences in individual values, we refrained from carrying out additional statistical analyses, especially those with parametric methods.

-- Results

1 Clinical Findings

Adrenaline, noradrenaline, and dopamine as well as phenylethylamine (PEA) levels were determined at the time when the medical history was taken at INUS Medical Center. Out of the 60 participants, eleven had sleep problems until the end of 2004. During the study period (until July 2005), eight additional cases with these problems were reported. At the end of January 2004, only two participants complained about headaches; eight additional cases were reported thereafter. For allergies, there were eleven cases in the beginning and 16 later; for dizziness five and eight; and for concentration problems ten and fourteen. Due to the limited number of participants, no meaningful statements can be made about changes during the study period regarding the conditions tinnitus, depression, high blood pressure, autoimmune diseases, rheumatism, hyperkinetic syndrome, attention deficit hyperactivity disorder (ADHD), tachycardia, and malignant tumors. (Tab. 2)

Symptoms	Before activation of transmitter	After activation of transmitter
Sleep problems	11	19
Headache	2	10
Allergy	11	16
Dizziness	5	8
Concentration problems	10	14

Tab. 2: Clinical symptoms before and after activation of transmitter

2 Adrenaline

The adrenaline level trends are shown in Figure 3. After the activation of the transmitter from January until July 2004, a clear increase is followed by a decrease. In participants in the exposure category above 100 μW/m^2, the decrease is delayed.

Since the distribution of the adrenaline levels is very asymmetrical as shown in Figure 4, the median values are better suited for evaluation than the average values. However, there is no significant difference between the trend of the median and the trend of the average values (Tab. 3). But it stands out that, in the lowest exposure group with a power density below 60 μW/m^2, median values do not decrease between July 2004 and January 2005.

The statement "The adrenaline values of study subjects increased after the activation of the transmitter, i.e. between January and July 2004" is statistically confirmed ($p<0.002$), as well as the statement "The adrenaline level of the study participants decreased from July 2004 to July 2005" ($p<0.005$). In the lowest exposure group, the increase is the smallest. Until the end of the study period, these values do not drop.

A certain dose-response relationship can be observed for the increase in adrenaline levels from January 2004 until July 2004. The increase in medians was 2.3 μg/g creatinine for all subjects. At an RF radiation level up to 60 μW/m^2, creatinine was 1.0 μg/g, and by contrast, for power density levels between 60-100 μW/m^2 it was 2.6 μg/g.

For subjects in the exposure group above 100 μW/m^2, creatinine levels were found to be 2.7 μg/g, i.e. this value did not increase. We refrain from any additional statistical analysis because, as shown further below, the increase in adrenaline levels was mainly observed in children and chronically ill participants whose numbers were not sufficient to be broken down into further subgroups.

		January 2004	July 2004	January 2005	July 2005
All	Average	8.56	10.79	8.84	9.14
	Median	7.44	9.75	8.40	7.45
	CI	5.9 - 8.4	6.6 - 11.7	6.1 - 10.0	6.5 - 9.6
0-60 μW/m^2	Average	8.9	10.3	7.7	9.0
	Median	6.4	7.4	7.8	7.4
	CI	3.8 - 10.3	4.6 - 13.2	3.4 - 9.4	5.5 - 11.1
60-100 μW/m^2	Average	7.9	10.4	8.4	9.0
	Median	7.4	10.2	8.1	7.2
	CI	5.3 - 10.0	6.6 - 12.8	5.0 - 11.2	6.4 - 9.7
>100 μW/m^2	Average	8.9	12.0	11.1	9.6
	Median	8.2	10.9	10.6	8.6
	CI	5.3 - 10.9	5.7 - 19.6	5.8 - 15.2	4.9 - 13.4

Tab. 3: Results for adrenaline levels in μg/g creatinine
CI = 95% confidence interval of median

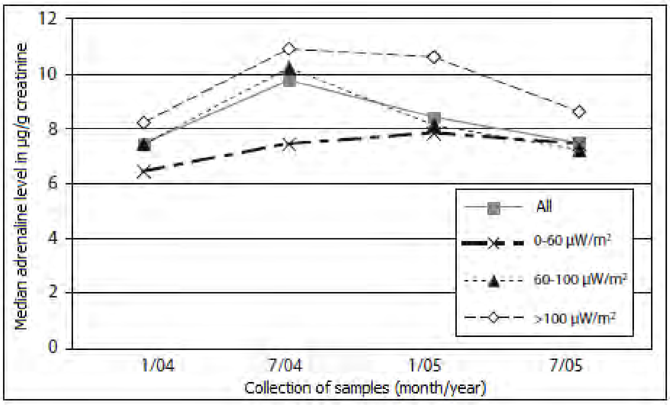

Fig. 3: Median adrenaline levels for all participating citizens of Rimbach whose cell phone base station exposure was above 100 μW/m^2, between 60 and 100 μW/m^2, or up to 60 μW/m^2. The power density levels refer to peak values of the GSM radiation exposure in front of a given residence.

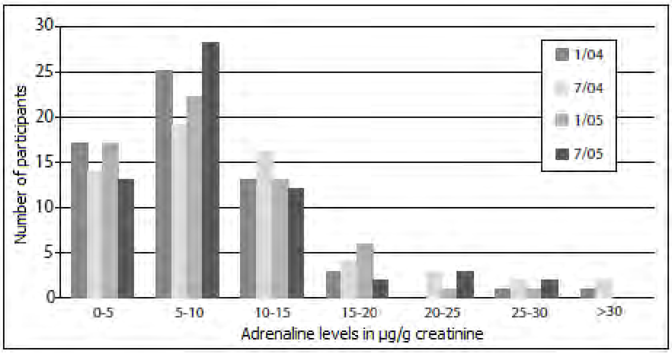

Fig. 4: Distribution of adrenaline levels in μg/g creatinine

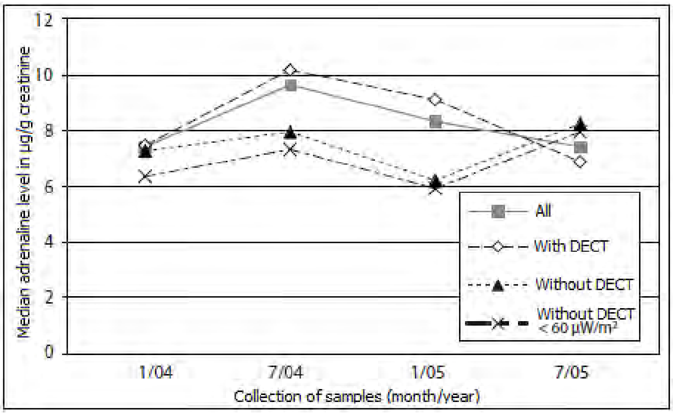

Fig. 5: Median adrenaline levels for all participating citizens of Rimbach who have a DECT phone, Wi-Fi, Bluetooth, or similar device, for those who do not have such wireless devices, and for the lowest exposure group without indoor wireless transmitters and with a GSM power density level up to 60 μW/m^2.

The impact of indoor wireless devices such as DECT, Wi-Fi, and Bluetooth (the latter are not specifically mentioned in the graphs) are shown in Fig. 5. Within the first year after the activation of the GSM transmitter, i.e. until and including January 2005, the group with indoor wireless devices shows the strongest responses.

Original study in German: BUCHNER K, EGER H (2011) Umwelt-Medizin-Gesellschaft 24(1): 44-57.

It is possible that in the less exposed subjects seasonal fluctuations or other factors such as "overshooting" of the values could have played a role.

It should be noted here that both the average as well as the median adrenaline values increased after the activation of the transmitter and decreased again after one year. This, however, only applies to exposure levels >60 µW/m². Chronically ill subjects and children showed especially strong responses; except for some "outliers," no effect was observed in healthy adults.

The adrenaline level of overweight subjects and those with an amalgam burden hardly changed during the study period (Fig. 6). In contrast, chronically ill subjects showed especially strong responses above average. In fact, the increase in the median values between January and July 2004 for all study subjects was predominantly caused by children and chronically ill subjects; adults without any chronic disease show a flat curve. During this period, an increased adrenaline level between 5 and 10.3 was measured in three healthy adults. Because of these "outliers," the average values for healthy adults clearly increased in contrast to the median values.

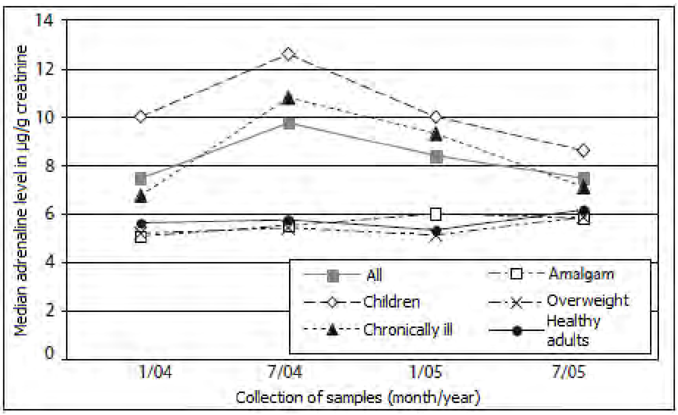

Fig. 6: Median adrenaline levels for participating children, for chronically ill subjects, for those with amalgam burden, and overweight subjects in Rimbach in comparison to the median levels of all study subjects and adults without chronic disease

The lower sensitivity of subjects with an amalgam burden can be explained by the fact that the effect occurs more often in children and that children according to our definition are younger than 10 years. They have hardly any fillings with amalgam.

3 Noradrenaline

The results for noradrenaline are similar to those for adrenaline (Tab. 4, Fig. 7). The statement that individual noradrenaline levels from January to July 2004 increased is statistically well supported with $p<0.001$. The fact that the levels dropped between July 2004 and July 2005 is also well supported with $p<0.0005$. Like in the case of adrenaline, the period under investigation is July 2004 to July 2005 to take the delayed decrease in the high exposure group into consideration. According to Table 4, the median of all noradrenaline levels increased from January to July 2004 for 11.2 µg/g creatinine; for exposures up to 60 µW/m², there were 2.2 µg/g creatinine, at 60-100 µW/m² 12.4 µg/g creatinine, and above 100 µW/m² 12.3 µg/g creatinine. As in the case of adrenaline, the increase for the last two groups is almost the same. Again, it is not possible to statistically verify a dose-response relationship. In Figure 7, a dose-response relationship

		January 2004	July 2004	January 2005	July 2005
All	Average	55.8	64.9	57.7	55.7
	Median	49.8	61.0	52.2	53.5
	CI	44.3-59.1	53.3-72.2	45.0-60.3	41.9 -60.5
0-60 µW/m²	Average	54.7	59.3	56.5	53.5
	Median	45.2	47.4	48.7	48.1
	CI	35.1-67.8	36.3-75.6	40.1-60.0	36.3-65.6
60-100 µW/m²	Average	51.4	63.6	49.1	55.9
	Median	47.5	59.9	45.8	54.8
	CI	38.0-59.1	53.1-74.8	40.5-58.4	34.9-66.5
>100 µW/m²	Average	62.9	74.9	70.1	58.8
	Median	58.8	71.1	71.6	56.3
	CI	49.9-87.3	54.9-91.6	48.7-89.1	36.9-81.6

Tab. 4: Results for the noradrenaline levels in µg/g creatinine
CI = 95% confidence interval of the median

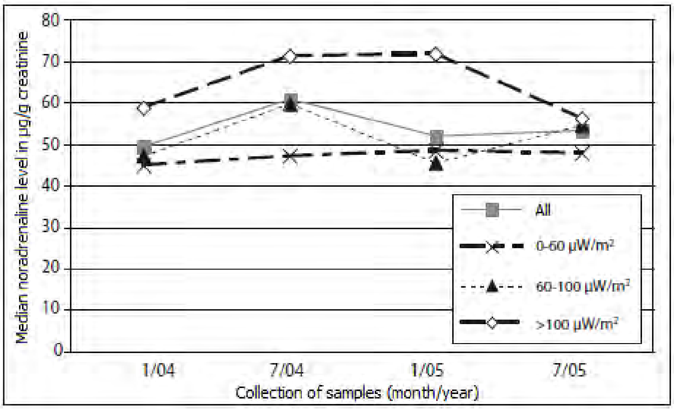

Fig. 7: Median noradrenaline levels in all participating citizens of Rimbach as a function of GSM power density levels (peak values)

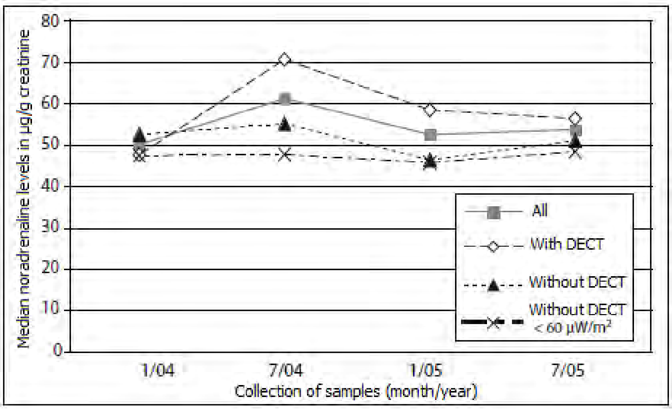

Fig. 8: Median noradrenaline values for subjects who had a DECT phone or other wireless devices at home, for those without indoor wireless devices, as well as for subjects without indoor wireless devices and with a GSM radiation exposure up to 60 µW/m² (peak value measured in front of residence)

is seen, whereby the dot-dashed line serves as reference for persons with very low exposures. It stands out that the "recovery period," i.e. the decrease in values in 2005, drags on for longer in subjects in the exposure group with GSM radiation levels above 100 μW/m². This also corresponds with the behavior of the adrenaline levels.

In comparison with adrenaline, noradrenaline plays a somewhat greater role in residences where wireless devices existed before the beginning of this study (Fig. 8).

The trend in Figure 9 shows that children and chronically ill subjects in contrast to overweight subjects express strong responses to cell tower radiation. The ratios, however, are not as clearly visible as with adrenaline. Especially in overweight subjects, they indicate a slow response to GSM radiation.

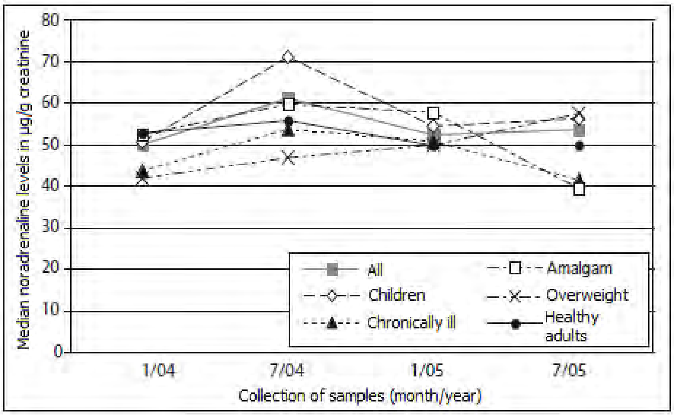

Fig. 9: Median noradrenaline levels of children, chronically ill subjects, those with amalgam burden and overweight subjects in Rimbach in comparison to the median values of all study subjects and healthy adults

Noradrenaline and adrenaline, however, responded very similarly.

4 Dopamine

For dopamine, inverse effects to those for adrenaline and noradrenaline were observed. The median dopamine levels decreased from 199 to 115 μg/g creatinine between January and July 2004 (Tab. 5). The fact that the dopamine levels of the study subjects decreased during this period is highly significant ($p<0.0002$). Thereafter, the median increased again: In January 2005, it was at 131 μg/g creatinine, in July of this year 156. This increase is also significant (for increase between July 2004 and July 2005 $p<0.05$).

This, too, is a dose-response relationship: from January to July 2004, the median for all subjects decreased for 84 μg/g creatinine, in the exposure group up to 60 μW/m² for 81, in the exposure group above 100 μW/m² even 153 μg/g (see Tab. 5 and Fig. 10). This dose-response relationship is statistically significant based on the signed-rank Wilcoxon test (12) with $p<0.025$. The following statement applies: "The decrease in dopamine levels for exposure levels up to 100 μW/m² is smaller than at exposure levels above 125 μW/m²."

In subsequent laboratory tests, the dopamine levels do not return to the same level as in January 2004. From Figure 11, it is obvious that the correlation with prior exposures to indoor wireless devices is small.

		January 2004	July 2004	January 2005	July 2005
All	Average	233	158	138	164
	Median	199	115	131	156
	CI	168-273	86-160	111-153	145-175
0-60 μW/m²	Average	217	183	130	148
	Median	189	108	116	147
	CI	142-273	80-254	90-157	129-167
60-100 μW/m²	Average	242	161	140	178
	Median	223	150	131	175
	CI	137-335	94-168	93-164	126-207
>100 μW/m²	Average	244	115	147	170
	Median	244	91	151	156
	CI	139-316	48-202	117-169	138-209

Tab. 5: Results for dopamine levels in μg/g creatinine
CI = 95% confidence interval of median

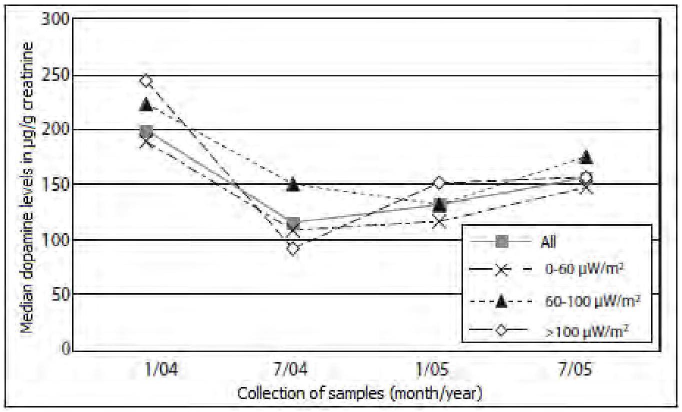

Fig. 10: Median dopamine levels for different GSM power density levels

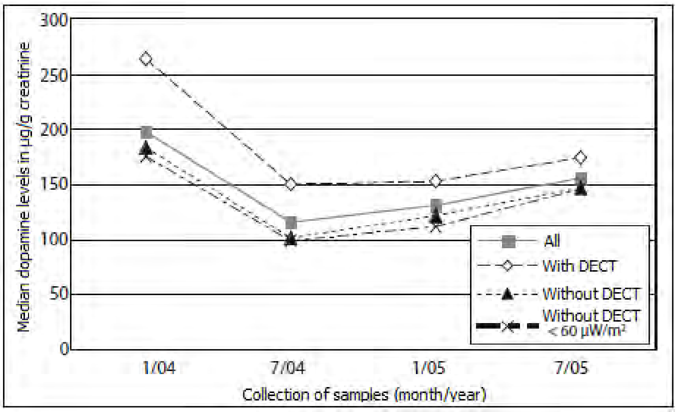

Fig. 11: Median dopamine levels for all participating citizens of Rimbach, for those with and without DECT phone, Wi-Fi, or Bluetooth, and for those without indoor wireless devices who had a GSM exposure level below 60 μW/m² (peak value).

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It is to be emphasized that the lowest exposure group without such indoor wireless devices and with a GSM power density level < 60 µW/m² responds almost as strongly as all other study subjects. This is consistent with the data in Figure 10: the data suggest that the effect of the radiation on the dopamine levels can already be observed at very low power density levels; however, it still can increase at levels above 100 µW/m².

Figure 12 shows that the radiation effect is somewhat more pronounced in children compared to the average, i.e. the gradient of the curves between the first two data points is somewhat greater. However, the difference is far too small to be statistically significant.

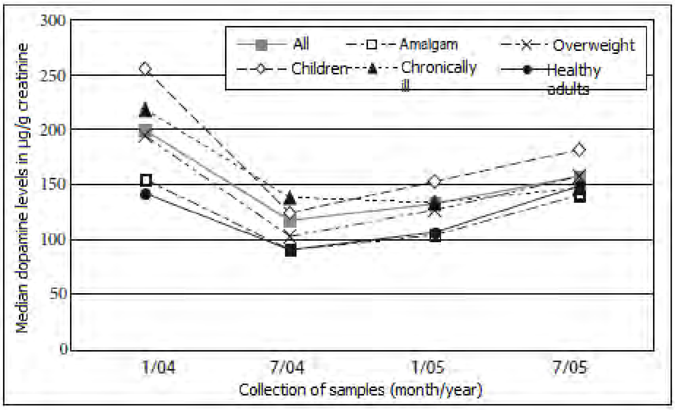

Fig. 12: Median dopamine levels of children, the chronically ill, with amalgam burden, overweight subjects, and healthy adults in Rimbach

In summary, dopamine levels decreased after the activation of the GSM transmitter and were not restored to the initial level over the following one and a half years. A significant dose-response relationship is observed. In children, the decrease is somewhat more pronounced than in adults.

5 Phenylethylamine (PEA)

Phenylethylamine (PEA) levels respond more slowly to the radiation compared to the substances investigated so far (Tab. 6, Fig. 13). Only in the exposure group above 100 µW/m² GSM radiation do the PEA levels decrease within the first six months. Thereafter, hardly any differences can be discerned between PEA values of the various power density levels investigated here.

The decrease of PEA levels between July 2004 and July 2005 is highly significant ($p<0.0001$)

Similar to adrenaline and noradrenaline, a previous exposure to indoor wireless devices intensifies the effect of the GSM radiation (see Fig. 14). The subjects of the low-exposure groups without indoor wireless devices do respond in a time-delayed fashion, but after six months they respond just as clearly as the subjects of the highest exposure group. In this regard, the PEA levels behave like those of dopamine in contrast to adrenaline and noradrenaline, which only respond to stronger fields.

		January 2004	July 2004	January 2005	July 2005
All	Average	725	701	525	381
	Median	638	671	432	305
	CI	535 -749	569 - 745	348 - 603	244 - 349
0-60 µW/m²	Average	655	678	523	329
	Median	604	653	484	243
	CI	477 - 835	445 - 835	279 - 675	184 - 380
60-100 µW/m²	Average	714	699	535	451
	Median	641	678	426	330
	CI	492 - 746	569 - 790	310 - 804	293 - 438
>100 µW/m²	Average	843	739	514	371
	Median	780	671	413	305
	CI	451 - 1144	334 - 822	338 - 748	157 - 513

Tab. 6: Results for phenylethylamine (PEA) levels in ng/g creatinine
CI = 95% confidence interval of median

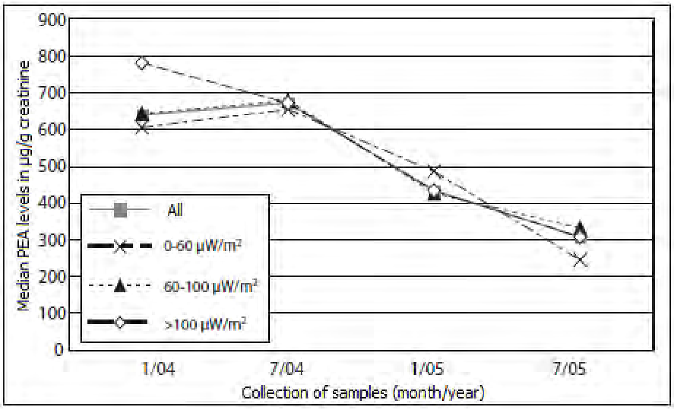

Fig. 13: Median phenylethylamine (PEA) levels for various GSM power density levels

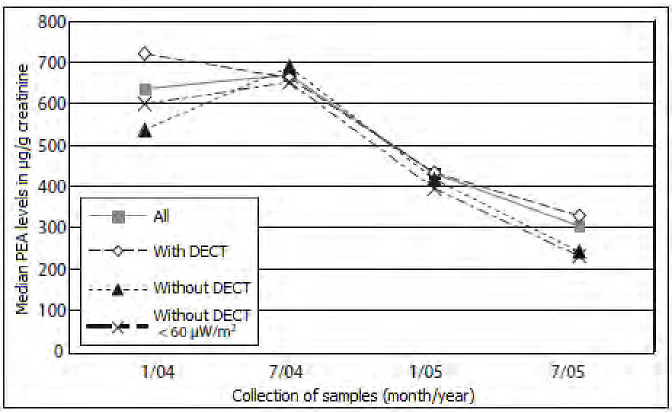

Fig. 14: Median phenylethylamine (PEA) concentrations in µg/g creatinine of subjects with and without indoor wireless devices at home and subjects without indoor wireless devices with a GSM power density level below 60 µW/m²

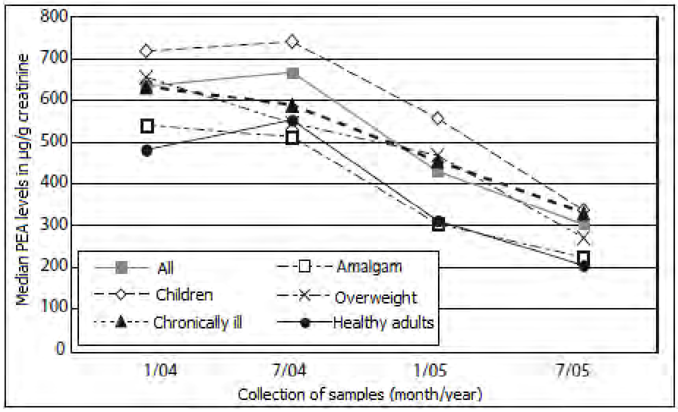

Fig. 15: Median phenylethylamine (PEA) concentrations in µg/g creatinine of children, the chronically ill, with amalgam burden, and overweight subjects, as well as health adults in Rimbach

In children, the effect of GSM radiation on their PEA levels is no greater than in the average of the study subjects; healthy adults also do not respond substantially differently. In contrast to the other substances looked at so far, the group of overweight subjects does respond particularly rapidly to PEA.

------------------------------------ Summary of Results

Adrenaline and noradrenaline levels increase during the first six months after the GSM transmitter had been activated; thereafter, they decrease again. After an exposure period of one and a half years, the initial levels are almost restored. Only at power density levels above 100 µW/m^2 is this decrease delayed for several months. In contrast, dopamine levels decrease substantially after the exposure begins. Even after one and a half years, the initial levels are not restored. Six months after the activation of the transmitter, PEA levels decrease continuously over the entire exposure period. Only in the exposure group above 100 µW/m^2 is this effect observed immediately. All findings were observed well below current exposure limits (14).

Wireless devices used at home such as DECT, Wi-Fi, and Bluetooth amplify the effect of the GSM radiation. In the case of adrenaline and noradrenaline, almost exclusively children and chronically ill subjects (here mostly subjects with allergies) are affected. However, the response of chronically ill subjects to dopamine and the response of children to PEA are very similar to those found in the average of the study subjects. Except for PEA, overweight subjects show only very weak responses to GSM radiation.

-- Discussion

Catecholamine System and Phenylethylamine (PEA)

The survival of mammals depends on their ability to respond to external sources of stress. An established, well-researched axis of the human stress system represents the catecholamine system (6, 15, 16). It can be activated by psychic or physical stressors. Impulses mediated by nerves are responsible for an induction of the catecholamine biosynthesis at the level of tyrosine hydroxylase as well as dopamine beta-hydroxylase, whereby the effect is based on an induction of both enzymes. Many biochemical regulatory mechanisms tightly control catecholamine synthesis (8, 15, 17). Chronic dysregulation always leads to health problems in the long run. The development of high blood pressure under continuous stress serves as a clinical example; so-called "beta blockers" directly block the action of adrenaline and noradrenaline on the target receptors, and it is impossible to imagine medication-based therapy without them (15).

PEA can be synthesized from the essential amino acid phenylalanine either via tyrosine, dopamine, noradrenaline, and adrenaline or via a direct biochemical path (15) (Fig. 16). The sympathetic-mimetic effect of PEA was first described by Barger in 1910 (18).

PEA is also synthesized from phenylalanine and is considered a superordinate neuromodulator for the regulation of catecholamine synthesis (19-22).

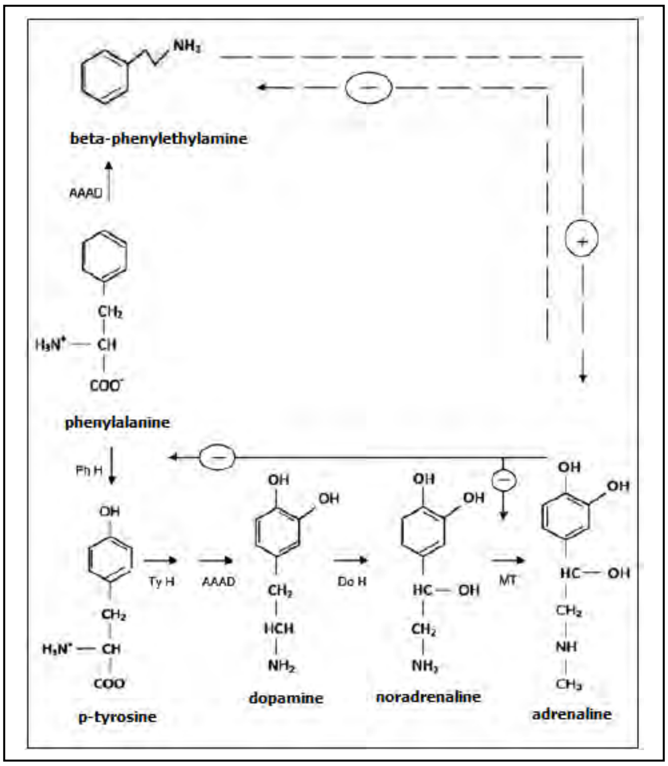

Fig. 16: Chemical structure of derivatives of the essential amino acid phenylalanine and the simplified synthesis pathways of catecholamines or phenylethylamine, respectively, simplified according to Löffler (15).

Abbreviations
AAAD: aromatic l-amino acid decarboxylase,
DoH: dopamine beta-hydroxylase,
PhH: phenylalanine hydroxylase,
MT: n-methyltransferase,
TyH: tyrosine hydroxylase
—(—)— ---- known feedback loop, - - (---) - - postulated feedback loop

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In 1976, Zeller described the physiological relationships (23) and points out that PEA is released by the brain via electrical stimulation (24).

The effect mechanism of PEA in the catecholamine system is the center of current pharmaceutical research efforts. In molecular biological terms, intracellular TAAR (trace amine-associated receptor) G-protein-coupled receptors that mediate modulatory effects of PEA are verified (20).

For high nanomolar to low micromolar PEA concentrations, in vivo studies have shown amphetamine-like effects. During an increase of PEA, an increased amount of noradrenaline and dopamine is also released and the reuptake of these substances is impaired (25, 26).
According to Burchett, the following effects of PEA amplifying the catecholamine effect are assumed to be known: Direct agonist action via increased release of transmitters, reuptake inhibition, and stimulation of transmitter synthesis as well as inhibition of monoamine oxidase (MAO) (19). PEA's high lipophilia—a prerequisite for the permeability of membrane barriers such as the blood-brain barrier—is of note here; PEA levels in the brain, serum, and urine correlate quite well (10, 21, 25, 27).

The clinical relevance of changed PEA levels is well documented for mental illnesses. Endogenous depression is associated with lowered PEA levels, whereby the transition from depression to maniac episodes is accompanied by an increase in PEA levels (28-32).

The therapeutic increase in the PEA level has a positive impact on the course of the disease. Phenylalanine improves the effectiveness of antidepressants; PEA by itself is a good antidepressant—effective in 60% of the cases of depression.

In persons with ADD/ADHD (attention deficit hyperactivity disorder), PEA levels are substantially lower; the ADHD treatment with methylphenidate (Ritalin®) normalizes PEA excretion in the urine of responders (33, 34).

Contributing Factors

Laboratory tests of catecholamine have been established for years. Increased values are found in disorders such as pheochromocytoma, neuroblastoma, and arterial hypertension, whereby it is impossible for a subject to consciously regulate these values. Especially urine tests offer a sufficient level of sensitivity and specificity because urine contains 100 to 1000 times higher levels than blood plasma. The intraindividual variation coefficient ranges from 7% to 12% from one day to another; stored under appropriate conditions, the stability of the samples can be guaranteed without problems (8).

In Rimbach, urine samples were always collected at the same time of the day so that a circadian dependence could be ruled out. Other contributing factors such as increased physical activity as well as large meals were also ruled out by collecting the urine in the morning. Seasonal factors of the samples collected twice in winter and summer should have been reflected as undulating levels in the testing results. Only in the adrenaline levels of the lower exposure groups (Fig. 5) can such a corresponding correlation be found. All other data did not indicate any seasonal influences.

In the study presented here, the selection of the participating citizens of Rimbach was not based on random assignment, but on self-selection. We can assume that the subjects, especially the adults, had informed themselves about the issue of cell tower radiation. However, because it is impossible to consciously regulate these levels, this self-selection should not make any difference in this study.
Especially in children below age ten, it is not thought possible to maintain a chronic state of anxiety for one and a half years due to an abstract term such as cell tower radiation.

This study limits itself to the following type of questions: "Did the level of a given substance predominantly increase or decrease during the study period?" Independent of each model, this question can be clearly answered with the Wilcoxon test and the indication of the confidence interval. The corresponding results are statistically very well supported. Any statements beyond this—e.g. the dependence of levels on certain parameters—cannot be made because with 60 study subjects the number of cases is too small to establish the same type of statistical significance.

The great advantage of the "Rimbach data" is that prior to January 2004 the exposure levels were very low because there was no cell phone tower and because only a few citizens had installed DECT, Wi-Fi and similar devices. In addition, due to the testing equipment with a measurement accuracy of less than ± 3 dB combined with repeated control measurements, the classification of the exposure groups can be considered to be verified.

For the stress hormones adrenaline and noradrenaline, the increase occurred only after the installation and activation of the transmitter, and thereafter, levels continued to decrease but did not fully normalize.
For dopamine, significant differences in the dose-response relationship according to exposure group could be shown after the activation of the new cell tower antenna. Also, the consistently decreasing levels of the hypothetically superordinate regulatory PEA do not support the hypothesis that the stress factor for the observed changes in the adrenergic system would exclusively be found in the realm of psychological factors.

Mode of Action of Microwave Radiation

There is a wide range of evidence to interpret the newly emerging microwave exposures as an invisible stressor.

Microwaves are absorbed by living tissue. The frequencies used for cell phone technologies have a half-life penetration depth of several centimeters, whereby cell membranes constitute no obstacle (35).

Microwaves cause enzymes to malfunction directly by, for example, monomerization (36). Thus, it is conceivable that enzymes of the catecholamine system could be affected directly.

Intracellular processes are changed, and cellular mitosis is disturbed by forces acting on the cellular spindle apparatus (37, 38). The human body is required to provide a higher level of repair services that is comparable to a chronic state of stress. A decrease in adenosine triphosphate (ATP) due to microwave exposure could be demonstrated by Sanders in intracerebral tissue already in 1980 (39).

Within current exposure limits, Friedman could show the stress caused by microwaves in the cell membranes of a cell model (40). The oxygen radicals formed by NADH have an activating effect on subsequent intracellular cascades that amplify the membrane effect by a factor of 10^7, which in turn substantially change intracellular processes (17). Even reproductive impairments due to microwaves are mediated by the formation of free radicals (41).

In industry, more and more microwave devices are being used for chemical peptoid syntheses, which allow for a 100 times faster and more precise production even without any measurable heating (42). The toxic effects of free radicals formed by microwaves are used in such technical applications as water purification (43).

In several studies, the chronic symptoms of residents near cell tower antennas were described (44-48). Interestingly, the expansion of wireless networks corresponds with the increase in prescription expenses for methylphenidate, a drug whose chemical structure is related to PEA and which is indicated in cases of attention deficit disorder (ADD) (49).

Long-term studies over five years suggested an increased cancer incidence due to microwave exposure (50, 51). Since the catecholamine system is directly linked with the nervous system within the psychoneuroimmunological framework beside its organ-specific effects, the observed increase in cancer incidence can now also be understood from a pathophysiological perspective (6, 15, 52, 53).

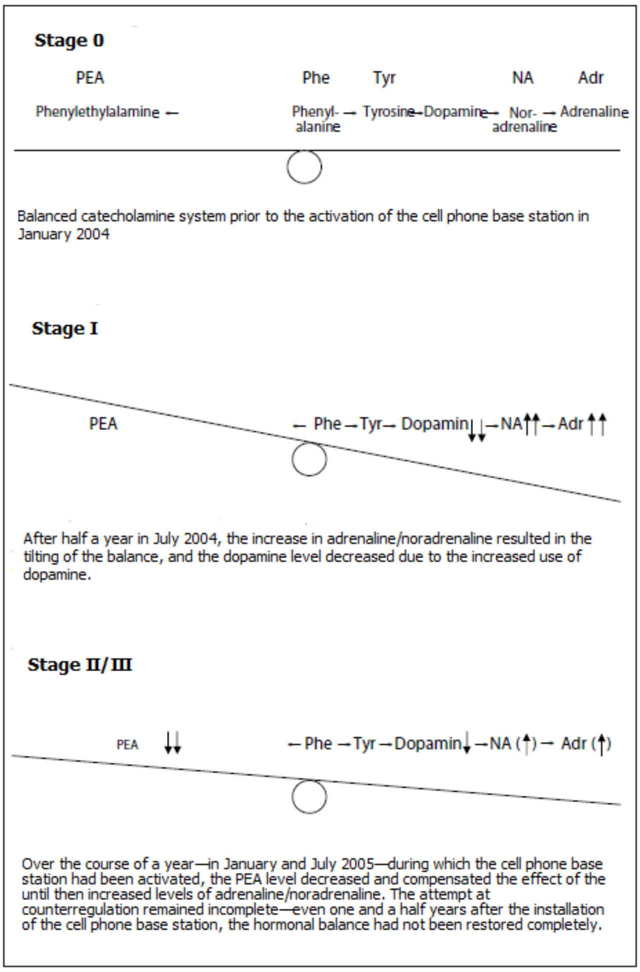

Fig. 17: Stage-like course of the stress response in Rimbach

Hypothesis of the Course of the Stress Response in Rimbach

Significant research on the stress-response axis was carried out in the 1950s. Selye established the nowadays generally accepted theory of the general adaptation syndrome of the human body to a stressor (16). He distinguished between three stages in the stress response, which can be found again in the description of the microwave syndrome according to Hecht (2, 3). Thus, after the stages of alarm and resistance, the last stage of exhaustion sets in (Fig. 17). The parameters investigated in the Rimbach study follow this pattern.

STAGE I—Activation Stage

The results of the long-term study presented here show an immediate activation of the adrenergic system. After the activation of the cell phone base station under investigation, the parameters adrenaline and noradrenaline increase significantly within a period of one and a half years. Because of the increased production of the final hormones noradrenaline/adrenaline, the use of dopamine increases, and as a result, the dopamine level decreases. The decrease in the dopamine level is the more pronounced, the higher the GSM radiation exposure level is at the residence of the individual participants.

STAGE II—Adaptation Stage

After this sympathicotonic activation stage, the body tries to compensate the increase in adrenaline and noradrenaline. In order to inhibit the overshooting catecholamine production and to ensure a stable regulation, the phenylethylamine level (PEA level) decreases. Here the decrease in PEA starts in the highest exposure group first.

STAGE III—Premorbid Stage

According to our hypothesis, the effects of adrenaline and noradrenaline are inhibited by feedback mechanisms at the expense of a chronically, over six continuous months, lowered PEA level. However, the attempt at counterregulation remains incomplete—even one and a half years after the installation of the cell phone base station; the hormonal balance had not been restored completely. The PEA level remains at a low level, which is to be interpreted as evidence for the beginning of exhaustion.

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Conclusion

Thus, the following hypothesis is proposed: Although participants maintained their usual lifestyle, they developed chronic stress with a primary increase in adrenaline/noradrenaline and a subsequent decrease in dopamine in response to the microwave exposure from the newly installed cell phone base station. During the stage of counterregulation, the "trace amine" PEA decreases and remains decreased.
This is of considerable clinical relevance because psychiatric symptoms also exhibit altered PEA levels. In Rimbach, the increase in sleep problems, cephalgia, vertigo, concentration problems, and allergies could be clinically documented after the cell phone base station had been activated. The newly developed symptoms can be explained clinically with the help of disturbances in the humoral stress axis (53).

After having exhausted the biological feedback mechanisms, major health problems are to be expected. The possible long-term consequences of remaining caught in the exhaustion stage have already been described by Hecht and Selye (3, 16).

Thus, the significant results presented here not only provide clear evidence for health-relevant effects in the study subjects of Rimbach after a new GSM base station had been installed there, but they also offer the opportunity to carry out a causal analysis. This has already been successfully done in the "shut-down study" of Schwarzenburg, Switzerland (54). In Rimbach, the documented levels should return to normal once the relevant base station is shut down.

Epidemiological Evidence

There is current epidemiological evidence for the considerable clinical relevance of the dysfunction of the humoral stress axis with its endpoints of PEA decrease and adrenaline increase, as documented by us.

1. Decreased PEA levels can be found in a large portion of ADD/ADHD patients. As therapy methylphenidate is used, a substance that is structurally related to PEA. Between 1990 and 2004, the boom time of cell phones, prescription costs for this medication had increased by a factor of 86 (49, 55).

2. As part of the German Mobile Telecommunication Research Programme, approximately 3000 children and adolescents were studied in Bavaria for their individual cell phone radiation exposure levels in relation to health problems. Among the various data sets, the data set regarding behavioral problems showed a significant increased risk for both adolescents (OR: 3.7, 95%-CI: 1.6-8.4) and also children (OR: 2.9, 95%-CI: 1.4-5.9) in the highest exposure group (56). For the first time, the "Rimbach Study" provides a model of explanation in biochemical terms.

3. Pheochromocytomata are adrenaline- and noradrenaline-secreting tumors of the adrenal gland (57). This type of tumor due to microwave exposure has already been demonstrated in animal experiments in 1985 (5). The increase of this disease in the US population is highly significant. Concurrent with the increase in local microwave exposures due to an increased number of base stations and use of wireless communication technologies, the number of cases have increased from 1,927 to 3,344 between 1997 and 2006 (58, 59).

It is a physician's responsibility—not bound by directives—to work toward the preservation of the natural basis of life regarding human health (60). Now it is the duty of the responsible agencies (public health department, Bavarian State Ministry of the Environment and Public Health as well as other federal ministries) to investigate the current situation.

Note
For the data collection, financial and personnel support was provided by INUS Medical Center and the two laboratories Lab4more GmbH and Neuroscience Inc.
The above-listed institutions were so kind to provide clinical examinations as well as the laboratory tests for the evaluation without external funding.

Acknowledgement
Many thanks to the Rimbach participants as well as the staff of the supportive clinics and laboratories, without whose efforts this study would not have been carried out. For the deciphering of cryptic handwriting, we owe Christina Panchyrz our gratitude.

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Editor's Note

The above paper is identified as an original scientific paper and it was subject to a special peer-review process in cooperation with the Scientific Advisory Board.

The Editorial Team

Translation
By Katharina Gustavs and authorized by the authors and publisher
Original publication: BUCHNER K, EGER H. (2011): Veränderung klinisch bedeutsamer Neurotransmitter unter dem Einfluss modulierter hochfrequenter Felder - Eine Langzeiterhebung unter lebensnahen Bedingungen (Wissenschaftlicher Originalbeitrag). Umwelt-Medizin-Gesellschaft 24(1): 44-57.

(Submitted: 9 July 2010)
(Revised version accepted: 13 December 2010)

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The FCC Must Ensure Review of Recent Studies That Show Wireless Radiation Impacts Fertility and Reproduction
The FCC must immediately initiate a full environmental impact assessment of 5G, 4G and wireless networks.

We are presenting several critical studies published in the last 4 months that the FCC must ensure are properly reviewed by U.S. health and regulatory medical and public health experts. These studies clearly indicate that FCC limits are not protective to humans nor wildlife. The FCC must ensure a complete review of all the research and the development of new safety limits based on up to date research.

The FCC must also immediately launch a full environmental review of the 5G deployment in the USA. The FCC must be compliant with NEPA.

The 2022 review "The role of non-ionizing electromagnetic radiation on female fertility: A review" published in the International Journal of Public Health Research states, "To date, in vitro and in vivo studies unveiled that exposure to non-ionizing radiations brings about harmful effects on oocytes, ovarian follicles, endometrial tissue, estrous cycle, reproductive endocrine hormones, developing embryo, and fetal development in animal models" and concludes that non-ionizing radiation can "also affect other female reproductive parameters that might lead to infertility."

Jangid P, Rai U, Sharma RS, Singh R. The role of non-ionizing electromagnetic radiation on female fertility: A review. Int J Environ Health Res. 2022 Feb 8:1-16. doi: 10.1080/09603123.2022.2030676. Epub ahead of print. PMID: 35132884.

A 2022 systematic review found non-ionizing electromagnetic field (EMF) radiation during pregnancy is associated with miscarriages and fluctuations in the fetal temperature and heart rate variability. Adult EMF exposure was linked to hormonal, thermal, and cardiovascular changes. The researchers concluded by calling for more research on pregnant women and highlighted how health practitioners could use the scientific evidence to encourage pregnant women to decrease their risk by decreasing their cell phone radiation exposure.

El Jarrah I, Rababa M. Impacts of smartphone radiation on pregnancy: A systematic review. Heliyon. 2022 Feb;8(2):e08915. doi: 10.1016/j.heliyon.2022.e08915. Epub 2022 Feb 8. PMID: 35155842; PMCID: PMC8823972.

ENVIRONMENTAL HEALTH TRUST

Numerous reviews by scientists from various countries repeatedly documenting a mounting body of science showing cell phone radiation harms sperm.

The 2021 University of Delhi, India study Association between reproductive health and nonionizing radiation exposure," published in the journal Electromagnetic Biology and Medicine concludes, "cell phone radiation harms male fertility by affecting the different parameters like sperm motility, sperm count, sperm morphology, semen concentration, morphometric abnormalities, increased oxidative stress along with some hormonal changes."

Negi P, Singh R. Association between reproductive health and nonionizing radiation exposure. Electromagn Biol Med. 2021 Jan 2;40(1):92-102. doi: 10.1080/15368378.2021.1874973. Epub 2021 Jan 20. PMID: 33471575.

A 2021 Pusan National University Republic of Korea review published in Environmental Research concludes that, "accumulated data from in vivo studies show that mobile phone usage is harmful to sperm quality."

Kim S, Han D, Ryu J, Kim K, Kim YH. Effects of mobile phone usage on sperm quality - No time-dependent relationship on usage: A systematic review and updated meta-analysis. Environ Res. 2021 Nov;202:111784. doi: 10.1016/j.envres.2021.111784. Epub 2021 Jul 30. PMID: 34333014.

A 2021 systematic review by Chinese scientists published in Environmental Pollution concludes that "mobile phone RF-EMR exposure could suppress sperm motility and viability."

Yu G, Bai Z, Song C, Cheng Q, Wang G, Tang Z, Yang S. Current progress on the effect of mobile phone radiation on sperm quality: An updated systematic review and meta-analysis of human and animal studies. Environ Pollut. 2021 Aug 1;282:116952. doi: 10.1016/j.envpol.2021.116952. Epub 2021 Mar 30. PMID: 33862271.

A 2021 systematic review by Malaysian scientists found that wireless can decrease testosterone.

Maluin SM, Osman K, Jaffar FHF, Ibrahim SF. Effect of Radiation Emitted by Wireless Devices on Male Reproductive Hormones: A Systematic Review. Front Physiol. 2021

Sep 24;12:732420. doi: 10.3389/fphys.2021.732420. PMID: 34630149; PMCID: PMC8497974.

We highlight the peer-reviewed research on the impact of wireless radiation with Malka N. Halgamuge of the University of Melbourne Australia Department of Electrical and Electronic Engineering includes a 2020 published review "A meta-analysis of in vitro exposures to weak radiofrequency radiation exposure from mobile phones" which documented effects in faster-growing cell types such as human sperm. As the paper "Proteomic impacts of electromagnetic fields on the male reproductive system," indicates, there is proteomic experimental and clinical evidence that electromagnetic fields "act as a male-mediated teratogen and contributor to infertility."

We call on the FCC to share with the public a list of simple steps to reduce cell phone radiation including:

- Use speakerphone instead of holding the phone to your head
- Do not sleep with the cell phone.
- Do not carry the cell phone in a pocket or bra.
- Text instead of talk or video calls.
- Keep the cell phone at a distance from the body, instead of close to your chest, abdomen or lap
- Prefer a corded landline instead of a cell phone at home and work if possible.
- Set airplane mode on with Wi-Fi/Bluetooth/Cellular off more often.
- Minimize your overall wireless phone use.

Additional research the FCC must ensure is evaluated.

A 2021 study published in Journal of Pharmaceutical Research International exposed 40 male Wistar Albino rats to mobile phones connected with Wi-Fi for eight weeks and found significant damage to the rat pancreas. Link to PDF

Sibghatullah, H., Sangi, S. M. A., Ahmedani, E. I., Alqahtani, A., Bawadekji, A. and Nagaraja, S. (2021) "Amelioration of Cell Phone and Wi Fi induced Pancreatic Damage and Hyperglycemia (Diabetes Mellitus) with Pomegranate and Vit E in Rats", *Journal of Pharmaceutical Research International*, 33(54B), pp. 204-215. doi: 10.9734/jpri/2021/v33i54B33781.

A 2021 study published in the Journal of the Veterinary Sciences Brno Czech Republic on rats exposed to 2.45 GHz (the frequency used in Wi-Fi) ; mean power density of 2.8 mW/cm^2) daily for 2 h, throughout their pregnancy found impacts to the liver including changes in the shape and number of microvilli at the vascular pole of hepatocytes, and formation of vesicles of various shapes and sizes. The endothelial cells were swollen with larger fenestrations compared to the control group. The spaces of Disse were irregular and dilated. The authors conclude that, “Even though these changes were only mild, further studies are needed to determine the effect of EMR and clarify its potential risk during pregnancy.”

Katarína Holovská1, Viera Almášiová1, Sandra Andrašková1, Zuzana Demčišáková1, Enikő Račeková2, Viera Cigánková, **Effect of electromagnetic radiation on the liver structure and ultrastructure of *in utero* irradiated rats, ACTA VET. BRNO 2021, 90: 315–319; https://doi.org/10.2754/avb202190030315**

The 2022 study Low Intensity Electromagnetic Fields Act via Voltage-Gated Calcium Channel (VGCC) Activation to Cause Very Early Onset Alzheimer’s Disease: 18 Distinct Types of Evidence concludes “that smarter, more highly pulsed "smart" wireless communication may cause widespread very, very early onset Alzheimer's Disease in human populations.”

Abstract: Electronically generated electromagnetic fields (EMFs) including those used in wireless communication such as cell phones, Wi-Fi and smart meters, are coherent, producing very high electric and magnetic forces which act on the voltage sensor of voltage-gated calcium channels to produce increases in intracellular calcium [Ca2+]i. The calcium hypothesis of Alzheimer’s disease (AD) has shown that each of the important AD-specific and nonspecific causal elements are produced by excessive [Ca2+]i. [Ca2+]i acts in AD via excessive calcium signaling and the peroxynitrite/oxidative stress/inflammation pathway which are each elevated by EMFs. An apparent vicious cycle in AD involves amyloid-beta protein (A) and [Ca2+]i. Three types of epidemiology each suggest EMF causation of AD including early onset AD. Extensive animal model studies show that low intensity EMFs cause neurodegeneration including AD, with AD animals having elevated levels of A, amyloid precursor protein and BACE1. Rats exposed to pulsed EMFs every day are reported to develop universal or near universal very very very early onset neurodegeneration including AD; these findings are superficially similar to humans with digital dementia. EMFs producing modest increases in [Ca2+]i can also produce protective, therapeutic effects. The therapeutic pathway and peroxynitrite pathway inhibit each other. A summary of 18 different findings is provided, which collectively provide powerful evidence for EMF causation of AD. The author is concerned that smarter, more highly pulsed “smart” wireless communication may cause widespread very, very early onset AD in human populations.

L Pall M. Low Intensity Electromagnetic Fields Act via Voltage-Gated Calcium Channel (VGCC) Activation to Cause Very Early Onset Alzheimer's Disease: 18 Distinct Types of Evidence. Curr Alzheimer Res. 2022 Feb 2. doi: 10.2174/1567205019666220202114510. Epub ahead of print. PMID: 35114921.

A new study published in the journal Environmental Research finds levels of radiofrequency (RF) radiation are increasing from the proliferation of cell antennas mounted close to the ground on buildings and poles. The researchers created heat maps of (cell tower antenna) RF radiation measurements in Stockholm and summarized the results of several recent studies on health effects. “These risks are relevant to those people working or living in the highly exposed places – in this study they are 1) people living in the apartments across the street from the antennas, 2) workers of the shops across the street and beneath the antennas.”

The team of international experts- Tarmo Koppel PhD, Mikko Ahonen PhD, Michael Carlberg MSc and Lennart Hardell MD, PhD -recommend antennas positioned as far as possible from the general public, like locations at the high elevations or remote areas, where the antenna targeted area is not regularly/frequently visited by the members of the public. For city environments they recommend lower power and less density to avoid RF hotspots.

Koppel T, Ahonen M, Carlberg M, Hardell L. Very high radiofrequency radiation at Skeppsbron in Stockholm, Sweden from mobile phone base station antennas positioned close to pedestrians' heads. Environ Res. 2022 May 15;208:112627. doi: 10.1016/j.envres.2021.112627. Epub 2022 Jan 4. PMID: 34995546.

A 2022 study published in Bioelectromagnetics exposing guinea pigs to 3500 MHz RF-EMFat SARs of 0, 2, 4, or 10 W/kg for 72 h. found the malondialdehyde levels of auditory cortex were increased ($P < 0.05$), and catalase (CAT), superoxide dismutase (SOD), and glutathione peroxidase (GSH-px) activities were decreased ($P < 0.05$) in the exposure groups compared to the sham group. Ultrastructural changes of auditory cortex (ACx), including swollen mitochondria and layered myelin sheaths. The researchers concluded that “these results suggest that oxidative stress is an important mechanism underlying the biological effects of RF-EMR, which can induce ultrastructural damage to the ACx and cell apoptosis through a mitochondria-dependent mechanism.”

ENVIRONMENTAL HEALTH TRUST

Abstract **Abstract**

Numerous studies have shown that radiofrequency electromagnetic radiation (RF-EMR) may negatively affect human health. We detected the effect of 3500 MHz RF-EMR on anxiety-like behavior and the auditory cortex (ACx) in guinea pigs. Forty male guinea pigs were randomly divided into four groups and exposed to a continuous wave of 3500 MHz RF-EMF at an average specific absorption rate (SAR) of 0, 2, 4, or 10 W/kg for 72 h. After exposure, malondialdehyde (MDA) levels, antioxidant enzyme activity, anxiety-like behavior, hearing thresholds, cell ultrastructure, and apoptosis were detected. Our results revealed that hearing thresholds and basic indexes of animal behavior did not change significantly after exposure (P > 0.05). However, the MDA levels of ACx were increased (P < 0.05), and catalase (CAT), superoxide dismutase (SOD), and glutathione peroxidase (GSH-px) activities were decreased (P < 0.05) in the exposure groups compared to the sham group. Ultrastructural changes of ACx, including swollen mitochondria and layered myelin sheaths, were observed. Cytochrome-c relocalization, caspase-9, and cleaved caspase-3 activation were detected in the exposure groups. In conclusion, these results suggest that oxidative stress is an important mechanism underlying the biological effects of RF-EMR, which can induce ultrastructural damage to the ACx and cell apoptosis through a mitochondria-dependent mechanism. Moreover, oxidative stress, apoptosis induction and ultrastructural damage increase in a SAR-dependent manner. However, RF-EMR does not increase hearing thresholds or induce anxiety. Bioelectromagnetics. 43:106-118, 2022. © 2021 Bioelectromagnetics Society.

Yang H, Zhang Y, Wu X, Gan P, Luo X, Zhong S, Zuo W. Effects of Acute Exposure to 3500 MHz (5G) Radiofrequency Electromagnetic Radiation on Anxiety-Like Behavior and the Auditory Cortex in Guinea Pigs. Bioelectromagnetics. 2022 Feb;43(2):106-118. doi:

A 2022 scientific literature review published in the International Journal of Environmental Research and Public Health regarding EMF exposure assessment on occupational/military settings, with particular focus on wireless RF exposure found the major uses of RF in the military environment are communication devices, localization/surveillance devices, jammers, and EM directed-energy weapons.

They found there were only occasional situations of overexposure, whereas in most of the conditions, the exposure was below the worker exposure limits. However, exposure assessment of the EMF generated by jammer devices and wearable devices is still limited or, as in case of the EM directed-energy weapons, completely lacking. The authors state the findings summarized in the paper are not conclusive, and “it is recommended to conduct further studies on military exposure assessment to these specific military devices."

Regarding 5G, " In fact, when a soldier is on mission, he will need to communicate accurately to the headquarter his position, the images of the environment and other strategic data. This amount of information is impossible to transmit with the current technologies whereas it will be possible to use the 5G technology. The introduction of this innovation will complicate even more the current EMF exposure scenario, increasing its variability and uncertainty, due to the involved innovation technologies (i.e., the use of mm-wave working frequencies, of MIMO antenna, of 3D beamforming techniques). All these aspects are not yet been studied in the military environment and it is therefore necessary to conduct promptly an exposure assessment, considering the new antenna technologies and frequencies involved."

Gallucci S, Fiocchi S, Bonato M, Chiaramello E, Tognola G, Parazzini M. Exposure Assessment to Radiofrequency Electromagnetic Fields in Occupational Military Scenarios: A Review. Int J Environ Res Public Health. 2022 Jan 14;19(2):920. doi: 10.3390/ijerph19020920. PMID: 35055741; PMCID: PMC8776107.

Electromagnetic hypersensitivity close to mobile phone base stations – a case study in Stockholm, Sweden

Lennart Hardell, Tarmo Koppel. Electromagnetic hypersensitivity close to mobile phone base stations – a case study in Stockholm, Sweden. Reviews on Environmental Health. Mar 2, 2022. doi: 10.1515/reveh-2021-0169.

Abstract

A previously healthy worker developed symptoms assigned to electromagnetic hypersensitivity (EHS) after moving to an office with exposure to high levels of anthropogenic electromagnetic fields (EMFs). These symptoms consisted of e.g. headache, arthralgia, tinnitus, dizziness, memory loss, fatique, insomnia, transitory cardiovascular abnormalities, and skin lesions. Most of the symptoms were alleviated after 2 weeks sick leave. The highest radiofrequency (RF) field level at the working place was 1.72 V/m (7,852 μW/m^2). Maximum value for extremely low frequency electromagnetic field (ELF-EMF) from electric power at 50 Hz was measured to 285 nT (mean 241 nT). For electric train ELF-EMF at 16.7 Hz was measured to 383 nT (mean 76 nT). Exposure to EMFs at the working place could be the cause for developing EHS related symptoms. The association was strengthened by the symptom reduction outside the working place.

Conclusions

This investigation established three possible reasons for developing health symptoms associated with the EMF exposure, including the following.

1. The working room was right below the mobile phone base station antenna, located on the roof of the building. The close proximity to these antennas caused significantly high RF radiation exposure in the working area.
2. The working room is also positioned close to lower radiofrequency transmitter (TETRA emergency services), located on the neighboring roof of the same building.
3. The working room was positioned within 20 m from the electric train railroad. 16 Hz magnetic field from the railroad power cable was on some instances the highest ELF MF component in the room, exceeding even the power grid 50 Hz MFs. Also, railroad power cable induced a fluctuating magnetic field in the office due to the coming and passing electric trains. As trains come and go, this introduces a change in the electric power supplied by the railroad electric cable. Consequently the magnetic field also changes in great amplitude.

In conclusion, there are at least three types of electromagnetic fields present in the working room, which cause a long term exposure to the workers. Exposure to multiple source electromagnetic fields could be the cause for developing EHS related symptoms. However, the person had been exposed to ELF-EMF also at other locations in the building, so exposure to RF-EMF seems to be the most probable cause to her developed health problems.

Open access paper:
https://www.degruyter.com/document/doi/10.1515/reveh-2021-0169/html

Attributes of non-ionizing radiation of 1800 MHz frequency on plant health and antioxidant content of Tomato (Solanum Lycopersicum) plants

Chandni Upadhyaya, Trushit Upadhyaya, Ishita Patel. Attributes of non-ionizing radiation of 1800 MHz frequency on plant health and antioxidant content of Tomato (Solanum Lycopersicum) plants. Journal of Radiation Research and Applied Sciences. 15(1):54-68. 2022. doi: 10.1016/j.jrras.2022.02.001.

Abstract

The Globe is marching towards the development of the telecommunication field which leads to increment of non-ionizing radiation in the environment which affects all living beings including plants grown nearby to communication base stations. The present

research was focused on physiological and biochemical alterations of tomato plants exposed to high-frequency radiation. The overall plant health was analyzed by physiological changes viz., plant height, size of leaves, length to the root system, and rate of germination upon exposure of radiation and shown significant reduction ($p < 0.05$) compared to control. Consecutively, radiation also negatively affects the photosynthetic pigment content of leaves which has shown significant reduction. Yet another confirmation of stress on exposed plant tissue was reported by obtaining higher H2O2 content within exposed plant leaf than the control. The morphological alterations viz. curling of leaves, discoloration, and size reduction became more prominent with an increase in the exposure time. The significant outcomes denoted according to 95% confidence limit. There was a significant decline in total phenolic content (37.06%), flavonoid content (71.38%), Vitamin C content (72.45%), and DPPH (59.32%) as well as total antioxidant assays (71.89%) which revealed significant deteriorative effects on such waves on secondary metabolites and the antioxidant potential of tomato plants. The lycopene content was continuously increasing up to 73.13% upon radiation of 120 h and such raise was the direct indication of harmful effect on fruit skin and release of lycopene due to softening of the fruit tissue. Thus, the presented findings illustrated the negative effects of such waves on the quality of tomato plants. The limited insight of metabolic pathways involved in plant responses to such non-ionizing radiation makes such investigation worth in agricultural application. Additionally, mobile communication agencies should be informed and installation of base stations for mobile communication towers should be prohibited at agricultural lands.

Excerpts

The ambient field in the greenhouse was as low as 1.1–1.5 V/m....

With an exposure of continuous wave (CW) electromagnetic field of 8 V/m, the SAR value was found to be 3.16×10^{-2} W $kg^{-1}$and 0.15 W kg^{-1} for leaves and fruits samples respectively....

Conclusion

The presented investigation discovered that all measured physiological parameters revealed deterioration with increase in electromagnetic exposure. However, the transient improvement in rate of seed germination and plant growth parameters can be considered as positive effect of short-term (12–24 h) exposure. The prolonged exposure effect on antioxidant content and activity interpreted the harmful effects of such radiation. Although, exposure of 12–24 h gave positive results for phenolic and flavonoid content assays and in the range of 1–10% for both fruit and leaf samples and indicated stimulation of plant defense system. The most significant outcomes in terms of deterioration were observed in the assays from fruit tissues viz. 36.97, 71.38, 72.45% decline in phenolic compounds, flavonoids, vitamin C content respectively. The throughout increase of lycopene in fruits (73.13%) indicated softening of skin and release of lycopene. There was a brief increase in enzymatic antioxidants POD and PPO activity upon 24–48 h of exposure which was followed by a constant decline with an increase in exposure time and revealed weakening of the defense system and plant health. The quality of exposed tomato fruits also deteriorated upon prolonged exposure. As there is constant advancement in electronics and communication and our march towards 5G frequency, the consequences of exposure to such radiation on plants should be investigated thoroughly.

https://www.sciencedirect.com/science/article/pii/S168785072200125X

Healthy disorders by WLAN-exposure

von Klitzing L. Healthy disorders by WLAN-exposure.J Clin Images Med Case Rep 2022; 3 (2): 1-3. doi:10.52768/2766-7820/1639

Abstract

By a diagnostic routine of a "burn-out"-patient, additionally claiming an electrosensitivity, there was tested the activity of the autonomic nervous system by electromyogram (EMG). Analyzing the frequency we found an artificial 10 Hz-component like those of WLAN-emitters as a dominant signal. By the following anamnestic discussion, the patient told about a longtime exposure to an active WLAN-equipment in office. Testing other patients using this communication-technique, there was a great number with the same 10 Hz-artifact in EMG. Additionally, some of these patients point out an artificial ECG. These data demonstrate the conflicts with the ICNIRP safety guidelines for this type of electromagnetic exposures.

Open access paper: http://www.jcimcr.org/pdfs/JCIMCR-v3-1639.pdf

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Simultaneous effect of gamma and Wi-Fi radiation on gamma-H2Ax expression in peripheral blood of rat: A radio-protection note

Ehsan Khodamoradi, Shima Afrashi, Karim Khoshgard, Farshid Fathi, Soodeh Shahasavari, Rasool Azmoonfar, Masoud Najafi. Simultaneous effect of gamma and Wi-Fi radiation on gamma-H2Ax expression in peripheral blood of rat: A radio-protection

note. Biochemistry and Biophysics Reports. Volume 30, 2022. doi: 10.1016/j.bbrep.2022.101232.

Abstract

Introduction Nuclear medicine patients are isolated in a room after the injection of a radiopharmaceutical. They may be active Wi-Fi option of its smartphone mobile or other environmental radiofrequency waves. The hypothesis of this study was the evaluation of increased biological effects of the simultaneous exposure to gamma-ray and the Wi-Fi waves by measuring the level of the increased double strand-breaks DNA in peripheral blood lymphocyte in the rat.

Materials and methods Fifty male Wistar rats were exposed for 2, 24, and 72 h only by Wi-Fi, 99m Tc, and simultaneously by Wi-Fi and 99m Tc. The power density levels of Wi-Fi emitter at 15 cm was 4.2nW/ cm2. An activity of 100 μCi of 99m Tc was injected intraperitoneally. Blood samples were taken by cardiac puncture following general anesthesia. Mononuclear cells are extraction by Ficoll-Hypaque density gradient centrifugation. The number of gamma-H2AX foci per nucleus was counted by flow cytometry. The statistical differences between experimental groups at 2, 24, and 72 h were determined with a repeated measure's analysis of variance. The significant difference between groups at the same time was analyzed with the Kruskal-Wallis Test.

Results The manner of gamma-H2AX expression was not the same for three groups in time. The number of gamma-H2AX foci between the three groups was a significant difference after 72 h.

Conclusion Simultaneous Wi-Fi and gamma-ray exposures can increase the number of double-strand break DNA in peripheral blood lymphocytes to exposure of gamma-ray to 72 h after technetium injection in the rat.

Open access paper:
https://www.sciencedirect.com/science/article/pii/S2405580822000334

Corneal opacity in Northern Bald Ibises (Geronticus eremita) equipped with radio transmitters

Alfonso Balmori. Corneal opacity in Northern Bald Ibises (Geronticus eremita) equipped with radio transmitters. Electromagnetic Biology and Medicine. 2022 Feb 27;1-3. doi: 10.1080/15368378.2022.2046046.

Abstract

ENVIRONMENTAL HEALTH TRUST

This note is intended to try to shed light on the discoveries made entitled "Biologging is suspect to cause corneal opacity in two populations of wild living Northern Bald Ibises (Geronticus eremita)". In this article, researchers participating in a reintroduction program for this endangered species in Europe document the unilateral corneal opacity that took place after birds were equipped with solar radio transmitters fixed on their upper-back position. The authors propose several possible effects caused by the device to explain the problem, and they conclude that the most parsimonious explanation for the symptomatology is a repetitive slight temperature rise in the corneal tissue due to electromagnetic radiation by the Global System for Mobile Communications (GSM) module of the device. The proposal of this communication is that these effects do not necessarily have to be thermal, but they can be non-thermal and thus more subtle and insidious. These effects may be caused by electromagnetic radiation at low levels but in long-term exposure.

https://pubmed.ncbi.nlm.nih.gov/35220839/

Health impact of 5G

STUDY

Panel for the Future of Science and Technology

EPRS | European Parliamentary Research Service

Scientific Foresight Unit (STOA)

PE 690.012 – July 2021

EN

Health impact of 5G

Current state of knowledge of 5G-related carcinogenic and reproductive/developmental hazards as they emerge from epidemiological studies and in vivo experimental studies

The upcoming deployment of 5G mobile networks will allow for significantly faster mobile broadband speeds and increasingly extensive mobile data usage. Technical innovations include a different transmission system (MIMO: use of multiple-input and multiple-output antennas), directional signal transmission or reception (beamforming), and the use of other frequency ranges. At the same time, a change is expected in the exposure to electromagnetic fields (EMF) of humans and the environment. In addition to those used to date, the 5G pioneer bands identified at EU level have frequencies of 700 MHz, 3.6 GHz (3.4 to 3.8 GHz) and 26 GHz (24.25 to 27.5 GHz). The first two frequencies (FR1) are similar to those used for 2G to 4G technologies and have been investigated in both epidemiological and experimental studies for different end points (including carcinogenicity and reproductive/developmental effects), while 26 GHz (FR2) and higher frequencies have not been adequately studied for the same end points.

The International Agency for Research on Cancer (IARC) classified radiofrequency (RF) EMF as 'possibly carcinogenic to humans' (Group 2B) and recently recommended RF exposure for re-evaluation 'with high priority' (IARC, 2019). Since 2011 a great number of studies have been performed, both epidemiological and experimental. The present review addresses the current knowledge regarding both carcinogenic and reproductive/developmental hazards of RF as exploited by 5G. There are various *in vivo* experimental and epidemiological studies on RF at a lower frequency range (450 to 6000 MHz), which also includes the frequencies used in previous generations' broadband cellular networks, but very few (and inadequate) on the higher frequency range (24 to 100 GHz, centimetre/MMW).

The review shows: 1) 5G lower frequencies (700 and 3 600 MHz): a) limited evidence of carcinogenicity in epidemiological studies; b) sufficient evidence of carcinogenicity in experimental bioassays; c) sufficient evidence of reproductive/developmental adverse effects in humans; d) sufficient evidence of reproductive/developmental adverse effects in experimental animals; 2) 5G higher frequencies (24.25-27.5 GHz): the systematic review found no adequate studies either in humans or in experimental animals.

Conclusions: 1) cancer: FR1 (450 to 6 000 MHz): EMF are probably carcinogenic for humans, in particular related to gliomas and acoustic neuromas; FR2 (24 to 100 GHz): no adequate studies were performed on the higher frequencies; 2) reproductive developmental effects: FR1 (450 to 6 000 MHz): these frequencies clearly affect male fertility and possibly female fertility too. They may have possible adverse effects on the development of embryos, foetuses and newborns; FR2 (24 to 100 GHz): no adequate studies were performed on non-thermal effects of the higher frequencies.

AUTHOR

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The scoping review search was performed by Dr Daria Sgargi, PhD, Master in Biostatistics, and Dr Andrea Vornoli, PhD in Cancer Research, Ramazzini Institute, Bologna.

Acknowledgments

The author thanks Dr Daniele Mandrioli, MD, PhD, Ramazzini Institute, Bologna (Italy), who advised and reviewed the methodology; Prof. Carlo Foresta, MD, and Prof. Andrea Garolla, MD, Professors of Endocrinology and Andrology, University of Padua (Italy), who critically reviewed the results on reproductive adverse effects in humans; Prof. Fausto Bersani, Physicist, Consultant, Rimini (Italy), who assisted her in the interpretation of papers regarding the exposure scenario.

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LINGUISTIC VERSION

Original: EN

Manuscript completed in July 2021.

PE 690.012
ISBN: 978-92-846-8030-6
doi: 10.2861/657478
QA-09-21-134-EN-N

http://www.europarl.europa.eu/stoa (STOA website)
http://www.eprs.ep.parl.union.eu (intranet)
http://www.europarl.europa.eu/thinktank (internet)

Executive summary

1. Background

Recent decades have seen an unparalleled development of technologies known as information and communications technologies (ICT), which include wireless communication used for mobile telephones and, for example, Wi-Fi using radiofrequency (RF) electromagnetic fields (EMF).

The first generation of handheld mobile phones was available in the late 1980s. Subsequently, the second (2G), third (3G) and fourth (4G, long-term evolution = LTE) generations dramatically increased their penetration rates in society, so that today in Europe there are more devices than inhabitants. In addition, Wi-Fi and other forms of wireless data transfer have become ubiquitous and are globally available. Nevertheless, there are new inequalities in terms of access to high-speed internet (even within high-income countries) and control by authoritarian regimes shows risks for democracy and European values.

The introduction of the next generation of RF, 5G, has begun on mobile networks. 5G is not a wholly new technology, but an evolution of already existing G1 to G4 technologies. 5G networks will work within several different frequency bands, the lower frequencies of which are being proposed for the first phase of 5G networks. Several of these frequencies have been or are currently being used for earlier mobile communication generations. There are also plans to use much higher radio frequencies at later stages of the 5G technology evolution. The new bands are well above the ultra high frequency (UHF) range, having wavelengths in the centimetre (3–30 GHz) or millimetre ranges (MMW) at 30-300 GHz. These latter bands have traditionally been used for radar and microwave links and very few have been studied for their impact on human health.

2. Methodology

This review of the currently available scientific evidence focuses on both the carcinogenic and the reproductive/developmental effects of RF from mobile phone telecommunications systems using 2G-5G networks, based on both in vivo animal studies and human epidemiological studies. The studies evaluated have been divided into two groups:

1) studies evaluating health effects due to RF at the lower frequency range (FR) (FR1: 450 to 6 000 MHz), which also includes the frequencies used in the existing 2-4 generations of the broadband cellular network. The current evidence from 2G-4G studies is the best evidence currently available. The studies were evaluated using *narrative* methods;

2) studies evaluating health effects due to RF at the higher FR (FR2: 24 to 100 GHz - MMW). The higher frequencies are new, not previously used for mobile communication and specific to the new 5G technology, which has particular physical characteristics and interactions with biological matter (lower penetration, higher energy, etc.): they were considered separately using a scoping review method.

Narrative review (FR1) will be distinguished from scoping review (FR2), but the selection and assessment criteria indicated for scoping reviews were adopted for both searches and for including/excluding studies on the cancer and reproductive/developmental biological end points.

In finally assessing the results of both epidemiological and experimental study, and of cancer and reproductive/developmental outcomes, consideration was given to the parameters indicated in the IARC Monograph Preamble (2019), tailored to the needs of the present report, and valid for both end points (i.e. cancer and reproductive/developmental effects):

Sufficient evidence: a causal association between exposure to RF-EMF and the specific adverse effect has been established. That is, a positive association has been observed in the body of evidence on exposure to the agent and the specific adverse effect in studies in which chance, bias, and confounding factors were ruled out with reasonable confidence.

Limited evidence: a causal interpretation of the positive association observed in the body of evidence on exposure to RF-EMF and the specific adverse effect is credible, but chance, bias, or confounding factors cannot be ruled out with reasonable confidence.

No evidence: there are no data available or evidence, suggesting lack of adverse effects (to be specified).

The overall evaluation for both cancer and reproductive/developmental effects was obtained by the integration of the human/animal evidence as follows:

Evidence in humans	Evidence in experimental animals	Evaluation based on strength of evidence
Sufficient	Not necessary	Clear association between exposure and the adverse effect
Limited	Sufficient	Probable association between exposure and the adverse effect
Limited	Less than sufficient	Possible association between exposure and the adverse effect
Inadequate	Inadequate or limited	Not classifiable

3. Exposure assessment

The question of exposure assessment with the introduction of 5G is complicated, above all concerning the monitoring of the continuous changes in activity of both base stations (BS) and user equipment (UE) related to MIMO (multiple input, multiple output) technology. Furthermore, the technical approach to exposure assessment in the future scenario, relating to 1G, 2G, 3G, 4G and 5G concurrent emissions, is still being formulated and is hence uncertain.

4. Non-thermal effects

The harmful effects of non-thermal biological interaction of RF-EMF with human and animal tissues have not been included in the determination of the ICNIRP 2020 guidelines (ICNIRP 2020a), despite the huge amount of available scientific publications demonstrating the harmfulness or potential harmfulness of those effects. Athermal bioresponses exist, and indeed some frequencies are being used for therapeutic purposes in a number of branches of medicine. Any drug, as we well know, even the most beneficial, may also entail some adverse effects. So, thermal as well as non-thermal effects of RF-EMF have to be considered in risk assessment.

5. State of the art of the research on RF-EMF

The introduction of wireless communication devices that operate in the RF region of the electromagnetic spectrum (450 to 6 000 MHz, lower frequencies) has triggered a considerable number of studies focusing on health concerns. These studies encompass studies on humans (epidemiological), on animals (rodent experimental studies), and on in-vitro cellular systems.

5G networks will increase the number of wireless devices, necessitating a lot more infrastructure, so as to allow for a higher mobile data volume per geographic area. Moreover, it is necessary to build up increased network density, as the higher frequencies required for 5G (24 to 100 GHz, MMW) have shorter ranges. The studies available on these frequencies are few in number and of mixed quality.

This raises thee questions as to whether these higher frequencies would have health and environmental effects different from those at lower ferquencies. Worldwide, assessments of RF safety have been performed at different levels, with the publication of scientific and policy papers.

With regard to cancer, the IARC 2011 analyis of the literature reviewed up to 2011 (Baan, 2011), published in 2013, and cited throughout as IARC (2013), defined RF-EMF in the frequency range from 30 kHz to 300 GHz as 'possibly carcinogenic' to humans, based on 'limited evidence of carcinogenicity' in human and in experimental animals. The studies available in 2011 examined RF in the range we here call FR1, that is from 450 to 6 000 MHZ. The FR2 frequencies (24 to 100 GHz) lie in the MMW range.

The IARC 2011 analysis evaluated RF-EMF. While there were no studies on 5G, some studies on high frequency occupational radar and microwave exposures were included.

The new MMW frequencies (FR2: 24 to 100 GHz) will be added to the lower frequencies already in use including in part by 5G. It follows that, for 5G in the range 450 to 6 000 MHz (FR1) there are many studies, many collected in the IARC Monograph in relation to cancer, while for 26 GHz and other MMW frequencies in general there is little literature exploring the possible adverse effects on health. The simple reason for this is that hitherto these frequencies have never been used for mass communication and hence there were few suitable populations exposed to these frequencies to study; there are likewise very few adequate studies on non-thermal effects on laboratory animals.

6. Results of the present review

Using PubMed and the EMF Portal database, and applying the scoping review methodology to our research, we found 950 papers on the carcinogenicity of RF-EMF in humans, and 911 papers on experimental rodent studies, totalling 1 861 studies. Regarding reproductive/developmental studies, we found 2 834 papers for epidemiology and 5 052 studies for experimental rodent studies, totalling 7 886 studies. From the present review of the literature and the considerations reported above, we come to the following conclusions:

6.1 Cancer in humans

FR1 (450 to 6 000 MHz): there is limited evidence for carcinogenicity of RF radiation in humans. Updating the results of the overall 2011 evaluation to 2020, positive associations have again been observed between exposure to radiofrequency radiation from wireless phones and both glioma (tumour of the brain) and acoustic neuroma, but the human evidence is still limited.

FR2 (24 to 100 GHz): no adequate studies were performed on the effects of the higher frequencies.

6.2 Cancer in experimental animals

FR1 (450 to 6 000 MHz): there is sufficient evidence in experimental animals of the carcinogenicity of RF radiation. New studies following the 2011 IARC evaluation showed a positive association between RF-EMF and tumours of the brain and Schwann cells of the peripheral nervous system, the same type of tumours also observed in epidemiological studies.

FR2 (24 to 100 GHz): no adequate studies were performed on the higher frequencies.

6.3 Reproductive/developmental effects in humans

FR1 (450 to 6 000 MHz): there is sufficient evidence of adverse effects on the fertility of men. There is limited evidence of adverse effects on fertility in women. There is limited evidence of developmental effects in offspring of mothers who were heavy users of mobile phones during pregnancy.

FR2 (24 to 100 GHz): no adequate studies were performed on the higher frequencies.

6.4 Reproductive/developmental effects in experimental animals

FR1 (450 to 6000 MHz): there is sufficient evidence of adverse effects on male rat and mouse fertility. There is limited evidence of adverse effects on female mouse fertility. There is limited evidence of adverse effects on the development in offspring of rats and mice exposed during embryo life.

FR2 (24 to 100 GHz): no adequate studies on non-thermal effects were performed on the higher frequencies.

7. Overall evaluation

7.1 Cancer

FR1 (450 to 6 000 MHz): these FR1 frequencies are probably carcinogenic to humans.

FR2 (24 to 100 GHz): no adequate studies were performed on the higher frequencies.

7.2 Reproductive/developmental effects

FR1 (450 to 6000 MHz): these frequencies clearly affect male fertility. They possibly affect female fertility. They possibly have adverse effects on the development of embryos, foetuses and newborns.

FR2 (24 to 100 GHz): no adequate studies were performed on non-thermal effects of the higher frequencies.

8. Policy options

8.1 Opting for novel technology for mobile phones that enables RF-EMF exposures to be reduced

The sources of RF emissions that seem at present to pose the greatest threat are mobile phones. Though transmitting installations (radiobase masts) are perceived by some people as providing the greatest risk, actually the greatest burden of exposure in humans generally derives from their own mobile phones, and epidemiological studies have observed a statistically significant increase in brain tumours and Schwann cell tumours of the peripheral nerves, mainly among heavy cell-phone users.

Accordingly, action is needed to ensure that safer and safer telephone devices are manufactured, emitting low energy and if possible only working when at a certain distance from the body. The cable earpiece solves much of the problem but is inconvenient and hence puts users off; on the other hand, it is not always possible to use speakerphone mode. The option of lowering RF-EMF exposure as much as possible in connection with telephones still applies whatever the frequencies being used, from 1G to 5G. Countries such as the US and Canada, which enforced stricter mobile phone SAR limits than in Europe, were still able to build efficient 1G,2G, 3G, 4G communications

(Madjar, 2016). Since 5G aims to be more energy-efficient than the previous technologies, adopting stricter limits in the EU for mobile phone devices would be at once a sustainable and a precautionary approach.

8.2 Revising exposure limits for the public and the environment in order to reduce RF-EMF exposure from cell towers

Recently, EU policies (European Commission, 2019) have promoted the sustainability of a new economic and social development model that uses new technologies to constantly monitor the planet's state of health, including climate change, the energy transition, agro-ecology and the preservation of biodiversity. Using the lowest frequencies of 5G and adopting precautionary exposure limits such as those used in Italy, Switzerland, China, and Russia among others, which are significantly lower than those recommended by ICNIRP, could help achieve these EU sustainability objectives.

8.3 Adopting measures to incentivise the reduction of RF-EMF exposure

Much of the remarkable performance of the new wireless lower frequency 5G technology can also be achieved by using optic-fibre cables and by adopting engineering and technical measures to reduce exposure from 1-4G systems (Keiser, 2003; CommTech Talks, 2015; Zlatanov, 2017). This would minimise exposure, wherever connections are needed in fixed sites. For example, optic fibre cables could be used to connect schools, libraries, workplaces, houses, public buildings, and all new buildings etc., and public gathering places could be 'no RF-EMF' areas (along the lines of no-smoking areas) so as to avoid the passive exposure of people not using a mobile phone or long-range transmission technology, thus protecting many vulnerable elderly or immune-compromised people, children, and those who are electro-sensitive.

8.4 Promoting multidisciplinary scientific research to assess the long-term health effects of 5G and to find an adequate method of monitoring exposure to 5G

The literature contains no adequate studies that would rule out the risk that tumours and adverse effects on reproduction and development may occur upon exposure to 5G MMW, or to exclude the possibility of some synergistic interactions between 5G and other frequencies that are already being used. This makes the introduction of 5G fraught with uncertainty concerning both health issues and forecasting and or monitoring the actual exposure of the population: these gaps in knowledge justify the call for a moratorium on MMW of 5G, pending completion of adequate research.

In light of these uncertainties, one policy option is to promote multidisciplinary team research into various factors concerning exposure assessment and also into the biological effects of 5G MMW at frequencies between 6 and 300 GHz, both on humans and on the flora and fauna of the environment, e.g. non-human vertebrates, plants, fungi, and invertebrates.

MMW will only be brought in with the final 5G protocol, i.e. not until three to five years' time. Given this time frame, one option is to study their effects before exposing the whole world population and environment.

Implementing MMW 5G technology without further preventive studies would mean conducting an 'experiment' on the human population in complete uncertainty as to the consequences. To restrict our scope to Europe, this could occur within a field like that of chemistry, currently governed by REACH (EC, 1907/2006).

REACH aims to improve the protection of human health and the environment through better and earlier identification of the intrinsic properties of chemical substances. EU REACH regulates the registration, evaluation, authorisation, and restriction of chemicals. It also aims to enhance the innovation and competitiveness of the EU chemicals industry. EU REACH is based on the principle of 'no data, no market', placing responsibility on industry to provide safety information on substances.

Manufacturers and importers are required to gather information on the properties of their chemical substances, which will allow their safe handling, and to register the information in a central database in the European Chemicals Agency (ECHA). One policy option can be to apply the same approach to all types of technological innovation.

The results of these studies could form the basis for developing evidence-based policies regarding RF-EMF exposure of human and non-human organisms to 5G MMW frequencies. Further studies are needed to better and independently explore the health effects of RF-EMF in general and of MMW in particular.

8.5 Promoting information campaigns on 5G

There is a lack of information on the potential harms of RF-EMF. The information gap creates scope for deniers as well as alarmists, giving rise to social and political tension in many EU countries. Public information campaigns should therefore be a priority.

Information campaigns should be carried out at all levels, beginning with schools. People should be informed of the potential health risks, but also the opportunities for digital development, what infrastructural alternatives exist for 5G transmission, the safety measures (exposure limits) taken by the EU and Member States, and the correct use of mobile phones. Only with sound and accurate information can we win back citizen trust and reach a shared agreement over a technological choice which, if properly managed, can bring great social and economic benefits.

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1G , 2G, 3G, 4G, 5G	First-fifth generation of telecommunication
2-ME	2-methoxyethanol
3β HSD	3β-Hydroxysteroid dehydrogenase
17 β HSD	17β-Hydroxysteroid dehydrogenases
3GPP	3rd Generation Partnership Project
ABCD	Amsterdam-born children and their development study
AKR/J	mouse strain
ANSES	French Agency for Food, Environmental and Occupational Health and Safety
AOR	covariate-adjusted odds ratio
APD	annual power density
AR	acrosome reaction
ASP	annual summarised power
AUDIPOG	assessment of neonatal growth (score expressed as a percentile)
B6C3F1/N	mouse strain
BALB/c	mouse strain
BAX	Bcl-2-associated X
BCL-2	B-cell lymphoma 2
BCL-XL	B-cell lymphoma-extra large
BLL	blood lead level
BMI	body mass index
BS	base stations
C3H/HeA	transgenic mouse
C57BL/6	mouse strain
CANULI	From the danish 'cancer og social ulighed' (cancer and socal inequality), cohort study
CAT	catalase
CEFALO	multicentre case-control study
CERENAT	multicentre case-control study
CDF	cumulative distribution function
CDMA	code division multiple access
CGRP	calcitonin gene-related peptide
CI	confidence interval
CNS	central nervous system
CRP	C-reactive protein
CW	continuous wave
DECT	digital enhanced cordless telecommunications

DFI	DNA fragmentation index
DNA	neoxyribonucleic acid
DNBC	Danish national birth cohort
ECHA	European Chemicals Agency
EARTH	Environment and Reproductive Health Study
EMF	electromagnetic field
ENU	N-ethyl-N-nitrosourea
EPM	elevated-plus maze
EPRS	European Parliamentary Research Service
Erα	estrogen receptor alpha
Erβ	estrogen receptor beta
EU	European Union
Eμ-Piml	transgenic mouse
F	female
FCC	Federal Communications Commission
FOEN	Federal Office for the Environment
FOMA	freedom of mobile multimedia access
FR1	lower frequency band (450 MHz- 6 GHz)
FR2	higher frequency band (24 - 100 GHz)
FST	forced swimming test
GA	gallic acid
GADD45	growth arrest and DNA damage 45
GBD	global burden of diseases, injuries and risk factors
GD	gestational day
GERoNiMO	generalised EMF research using novel methods
GFAP	glia fibrilliary acidic protein
GHz	giga hertz
GIS	geographical information systems
GSH	glutathione
GSH-Px	glutathione peroxidase
GSM	global systems for mobile communications
GR	γ-radiation
H2O2	hydrogen peroxide
HSP70 (or 25, or 32): 70 (or 25, or 32)	kilodalton heat shock proteins
IARC	International Agency for Research on Cancer
IATPF	International Academy of Toxicologic Pathology Fellow
ICNIRP	International Commission on Non-Ionizing Radiation Protection

ICR	mouse strain
ICT	information and communications technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEMFA	International EMF Alliance
IL-6 (or 10, or 32)	interleukine-6 (or 10, or32)
ILO	International Labour Organization
INMA	Spanish Environment and Childhood Project
INTERPHONE	a set of international case-control studies
INTEROCC	international case-control study
IoT	internet of things
ISTISAN	Italian National Institute of Health (Istituto Superiore di Sanità) report
IRR	incidence rate ratio
ITA	Austrian Institute fur Technickfolken
IT'IS	Foundation for Research on Information Technologies in Society
JECS	Japan Environment and Children Study
kHz	kilohertz
LH	luteinising hormone
LTE	long-term evolution
M	male
MARHCS	Male Reproductive Health in Chongqing College students cohort study
MDA	malondialdehyde
MDI	mental development index
MEL	melatonin
MHz	megahertz
MIMO	multiple-input and multiple-output antennas
MMP2 (or 14)	matrix metallopeptidase 2 (or 14)
MMW(s)	millimeter wave(s)
MoBa	prospective population-based pregnancy cohort study
MOCEH	Korean Mothers and Children's Environmental Health Study
MOE	moringa extract
MPBS	mobile phone base stations
MW	millimeter waves
MWM	Morris water maze
NéHaVi	cohort study
NIR	non-ionising radiation
NMRI	mouse strain

NO	nitric oxide
NOS	nitric oxide synthase
NTP	national toxicology programme
NTP TR	national toxicology programme technical report
OECD	Organisation for Economic Co-operation and Development
OFT	open field test
OR	odd ratio
OSI	oxidative stress index
PARP	poly (ADP-ribose) polymerase
P21	cyclin-dependent kinase inhibitor 1
P450scc	cholesterol side-chain cleavage enzyme
P53	tumour protein P53
PCNA	proliferating cell nuclear antigen
PD	power density
PDI	psychomotor development index
PECO	population, exposure, comparator and outcome
PEM	personal exposure meter
PGE2	prostaglandin E2
PND	postnatal day
PRISMA-ScR	preferred reporting items for systematic reviews and meta-analyses extension for scoping reviews
REACH	registration, evaluation, authorisation and restriction of chemicals
RF	radiofrequency
RFR	radiofrequency radiation
RF-EMF	radiofrequency electromagnetic field
RL	reference level
ROS	reactive oxygen species
RR	relative risk
RWTH	Rheinisch-Westfälische Technische Hochschule Aachen
SAR	specific absorption rate
SCENIHR	European Commission Scientific Committee on Emerging and Newly Identified Health Risks
SCHEER	Scientific Committee on Health, Environmental and Emerging Risks
SDQ	strengths and difficulties questionnaire
SEM	source-exposure matrix
SF1	splicing factor 1
SOD	superoxide dismutase
SPOCK3	PARC (osteonectin), cwcv and kazal-like domains proteoglycan 3

SSM	Swedish Radiation Safety Authority
SR	scoping review
StAR	steroidogenic acute regulatory protein
STOA	European Parliament's Panel for the Future of Science and Technology
TAC	total antioxidant capacity
TETRA	terrestrial trunked radio
TSC	total sperm count
TST	tail suspension test
UE	user equipment
UHF	ultra-high frequencies
UMTS	universal mobile telecommunications system
UK	United Kingdom
V/m	volt/meter
VEGF	vascular endothelial growth factor
W/kg	watt/kilogram
WHO	World Health Organization

1. Introduction

1.1 Background

Recent decades have experienced an unparalleled development of technologies known as Information and Communications Technology (ICT), which include wireless communication used for mobile telephones and, for example, Wi-Fi using electromagnetic fields (EMF). The first generation of handheld mobile phones were available in the late 1980s. Subsequently, the second (2G), third (3G), and fourth (4G, Long-Term Evolution = LTE) generations dramatically increased their penetration rates in society, so that today there are more devices than inhabitants in Europe. In addition, Wi-Fi and other forms of wireless data transfer have become ubiquitous, and are globally available. At present we are starting to introduce the next generation of RF, 5G, on mobile networks. 5G is not new technology, but an evolution of already existing G1 to G4 technologies.

1.2 The exposure scenario

1.2.1 Present scenario of exposure

The different exposure situations that may occur with the intensive deployment of telecommunications was well described in Monograph 102 of the International Agency for Research on Cancer (IARC, 2013). Monograph 102 is concerned with non ionising radiation in the RF range of the electromagnetic spectrum, i.e. between 30kHz and 300 GHz, thus including the frequencies relevant to the present review.

The corresponding wavelengths (the distance between successive peaks of RF waves) range from 10 Km to 1mm, respectively. EMF generated by RF sources couple with the human body, which results in induced electric and magnetic fields and associated currents inside body tissues (IARC, 2013). Human exposures to radiofrequency electromagnetic fields (RF-EMF) can occur from use of personal devices (e.g. mobile telephones, cordless phones, Bluetooth, and amateur radios), from occupational sources (e.g. high-frequency dielectric and induction heaters, and high-powered pulsed radars), and from environmental sources such as mobile-phone base stations, broadcasting antennas, and medical applications.

For workers, most exposure to RF-EMF comes from near-field sources, whereas the general population receives the highest exposure from transmitters close to the body, such as handheld devices like mobile telephones. Exposure to high-power sources at work might involve higher cumulative RF energy deposited in the body than exposure to mobile phones, but the local energy deposited in the brain is generally lower.

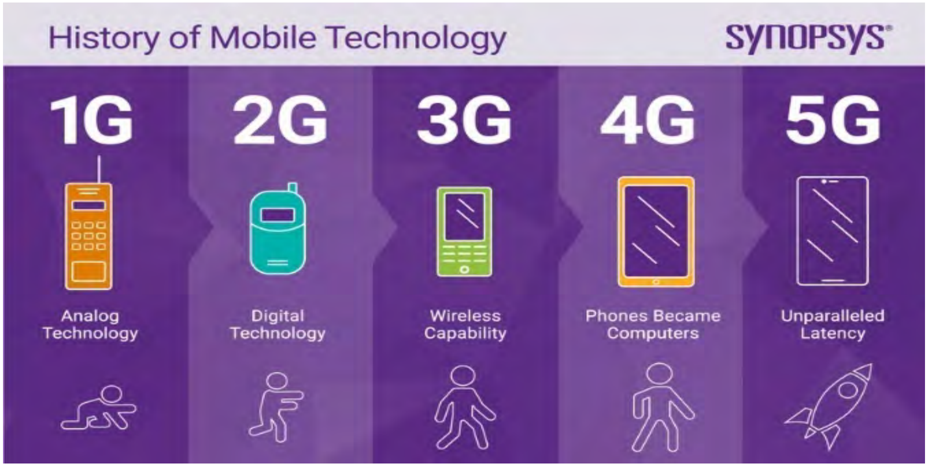
Typical exposures ofthe brain from rooftop or tower-mounted mobile-phone base stations and from TV and radio stations are several orders of magnitude lower than those from global systems for mobile communications (GSM) handsets. The average exposure from use of digital enhanced cordless telecommunications (DECT) phones is around five times lower than that measured for GSM phones, and third-generation (3G) phones emit, on average, about 100 times less RF energy than GSM phones, when signals are strong. Similarly, the average output power of Bluetoothwireless hands-free kits is estimated to be around 100 times lower than that of mobile phones.

EMFs generated by RF sources couple with the body, resulting in induced electric and magnetic fields and associated currents inside tissues. The most important factors that determine such induced fields are the distance of the source from the body and the output power level (IARC, 2013). The near field and far field are regions of the EMF around an object, such as a transmitting antenna, or the result of radiation scattering off an object. Non-radiative near-field behaviours dominate close to the antenna or scattering object (mobile phone), while electromagnetic radiation far-field behaviours dominate at greater distances (BC Center for Disease Control, 2013).

Additionally, the efficiency of coupling, and resulting field distribution inside the body, strongly depends on the frequency, polarisation, and direction of wave incidence on the body, and anatomical features of the exposed person, including height, bodymass index, posture, and dielectric properties of the tissues. Induced fields within the body are highly non-uniform,varying over several orders of magnitude, with local hotspots. Holding a mobile phone to the ear to make a voice call can result in high specific RF energy absorption-rate (Specific Absorption Rate = SAR) values in the brain, depending on the design and position of the phone and its antenna in relation to the head, how the phone is held, the anatomy of the head, and the quality of the link between the base station and phone. When used by children, the average RF energy deposition is two times higher in the brain and up to ten times higher in the bone marrow of the skull, compared with mobile phone use by adults. Use of hands-free kits lowers exposure to the brain to below 10% of the exposure from use at the ear, but it might increase exposure to other parts of the body (IARC, 2013).

1.2.2 The 5G scenario of exposure

Figure 1 – History of mobile technology



With the upcoming deployment of 5G mobile networks, significantly faster mobile broadband speeds and increasingly extensive mobile data usage will be ensured. Technical innovations include a different transmission system (MIMO: multiple-input and multiple-output antennas), directional signal transmission or reception (beamforming), and the use of other frequency ranges. This is made possible by the use of additional higher frequency bands (millimetre waves = MMW). 5G is intended to be the intersection of communications, from virtual reality to autonomous vehicles to the industrial internet and smart cities. In addition, 5G is considered the basic technology for the Internet of Things (IoT), where machines communicate with machines. At the same time, a change is expected in the exposure to EMF of humans and the environment (Figures 1 and 2).

Figure 2 – 3G vs 4G vs 5G

	3G	4G	5G
Deployment	2004-05	2006-10	2020
Bandwidth	2mbps	200mbps	>1gbps
Latency	100-500 milliseconds	20-30 milliseconds	<10 milliseconds
Average Speed	144 kbps	25 mbps	200-400 mbps

The 5G networks will work within several different frequency bands, of which the lower frequencies are being proposed for the first phase of 5G networks. Several of these frequencies (principally below 1 GHz - Ultra-High Frequencies, UHF) have been or are currently being used for earlier mobile communication generations. Furthermore, much higher RF are also planned to be used at later stages of the evolution of the technology.

The operating frequencies at low and mid bands can overlap with the current 4G band at 6 GHz or below. The biological effects of RF radiations at these lower-frequency bands are thus likely to be comparable to 2G, 3G or 4G. However, the scenarios of high band 5G, especially for 24 GHz to 60 GHz in the MMW region for high-capacity, short-range wireless data communications, are relatively recent new arrivals, and pose considerable challenge to health-risk assessment (Lin, 2020). These latter bands have traditionally been used for radar and microwave links (Simkò and Mattsonn, 2019) and very few have been studied for their impact on human health.

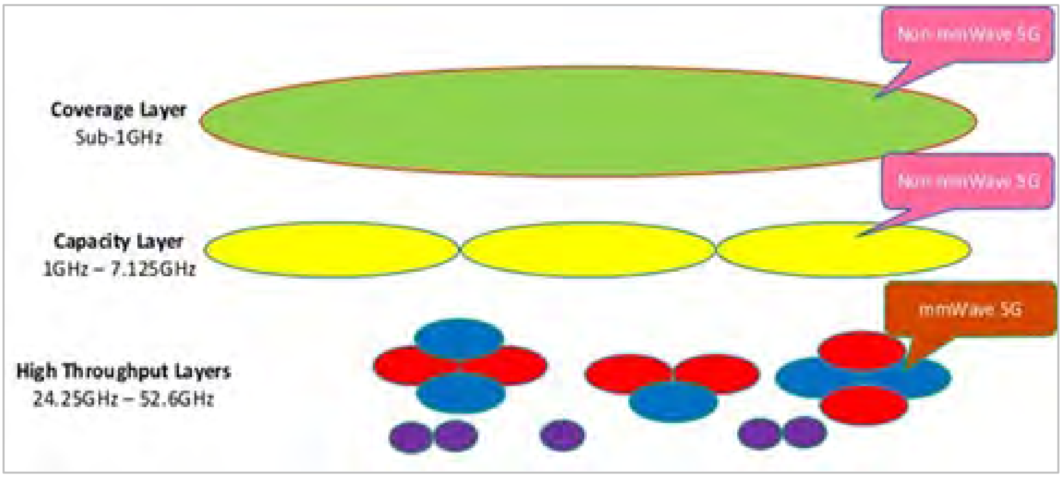
1.2.3 5G: beam forming and MIMO

The recent increase in cell-phone traffic over the microwave frequency band has shifted attention towards the broad MMW spectrum, which has hitherto been under-used. Up until 4G technology, cellular communication used frequencies below 3GHz and the idea that higher frequencies (greater than 3 GHz) incur more attenuation by physical obstacles tended to make the lesser frequencies seem more reliable. However, intelligent beamforming is improving the coverage and cutting interference to a minimum. The technique of dynamic radio masts employing beamforming, combined with multi-user MIMO (MU-MIMO), forms the basis of 5G NR (New Radio); working together they will enable over 1,000 more devices per square metre to be supported than with 4G, sending many more users ultra-fast data with high precision and low latency.

MIMO was originally developed for Single-User (SU-MIMO) applications so as to improve the efficiency of LTE (4G) networks. It was soon realised that such technology could be extended to Multi-User applications with a view to reducing or avoiding the problem of interference within a cell. This led to a series of solutions known as MU-MIMO (David and Viswanath, 2005). On the other hand, implementation of these inevitably raised queries as to the health impact. The European Parliament tackled the issue in a 2019 document concerning the state of advancement of 5G distribution in Europe, the US and Asia:

"Significant concern is emerging over the possible impact on health and safety arising from potentially much higher exposure to radiofrequency electromagnetic radiation arising from 5G. Increased exposure may result not only from the use of much higher frequencies in 5G but also from the potential for the aggregation of different signals, their dynamic nature, and the complex interference effects that may result, especially in dense urban areas. The 5G radio emission fields are quite different to those of previous generations because of their complex beamformed transmissions in both directions – from base station to handset and for the return. Although fields are highly focused by beams, they vary rapidly with time and movement and so are unpredictable, as the signal levels and patterns interact as a closed loop system. This has yet to be mapped reliably for real situations, outside the laboratory" (Blackman and Forge, 2019).

Figure 3 – 5G needs different frequency bands



Source: Qualcomm, 2020

5G will use a broad range of radio spectra (Fig.4). They divide into three distinct levels according to user need:

- the "*coverage layer*", with frequencies lower than 1GHz, provides broad outdoor coverage and deep indoor coverage. It basically consists of a frequency band used by digital television that performs well in penetrating obstacles. This system does not use beamforming, and in terms of management is similar to Radio Base Stations (RBS) using 4G technology, though possibly applying a corrective factor (peak power reduction coefficient) which takes account of the mean power used by the transmitting system;

- the "*coverage and capacity layer*", between 1GHz and 6GHz, is one of the major novelties of 5G. It uses the Massive – MIMO system to ensure an optimum compromise between coverage and capacity, i.e. the speed of data transfer per unit of frequency. It includes the band C spectrum, around 3.5 GHz. This non-millimetre frequency band operates in beamforming mode so as to concentrate most of the radiated power upon the target terminal;

- the "*super data layer*", from 6GHz up to MMW frequencies of 30 GHz and over, offers the breadth of band and data speeds required by the top-performing International Telecommunication Union Radiocommunication Sector (ITU-R) of the International Mobile Telecommunications (IMT)-2020 standard. This frequency band also uses the beamforming technique.

The main frequency bands for 5G standards taken up globally5G technology will not just be geared to communication among people, but also to interconnected automated systems (Internet of Things) using electromagnetic waves on a frequency belonging to the band 26.5-27.5 GHz. The frequency of such electromagnetic waves is so high that they are unable to penetrate buildings or get past obstacles. So ‘solving’ that difficulty calls for installation of many small cells of sizes ranging from about 10 metres (indoor) to several hundred metres (outdoor) - greatly inferior in range to the macro-cells of previous technologies which may extend for several kilometres. In Europe, the general picture might be summarised as reported in Fig. 4, 5 and 6 (Source: Qualcomm, 2020).

Figure 4 – 5G spectrum status by dashboard and auctions in Europe

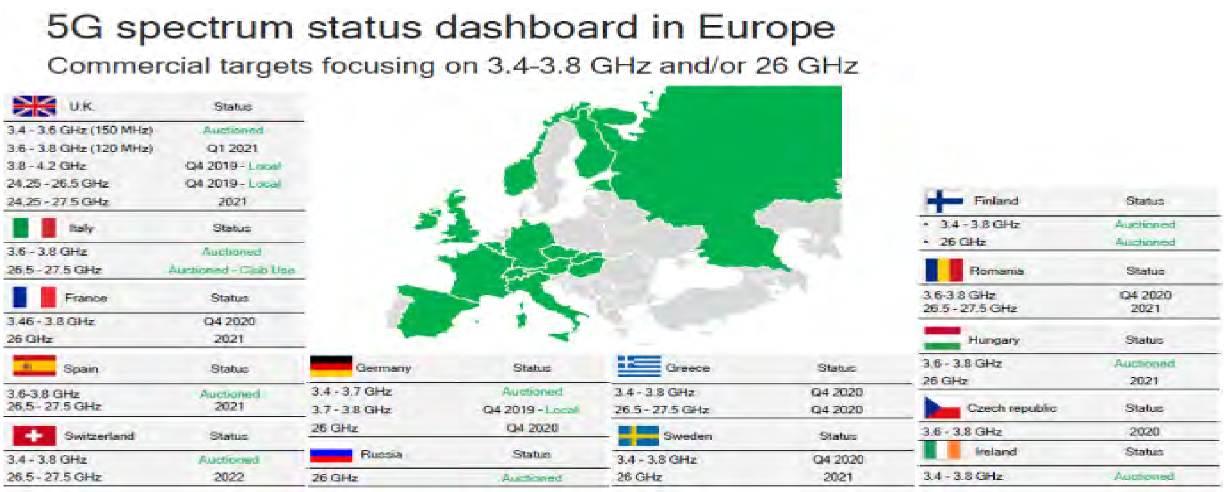


Figure 5 – 5G spectrum status by auctions in Europe (FR1: 700 MHz)

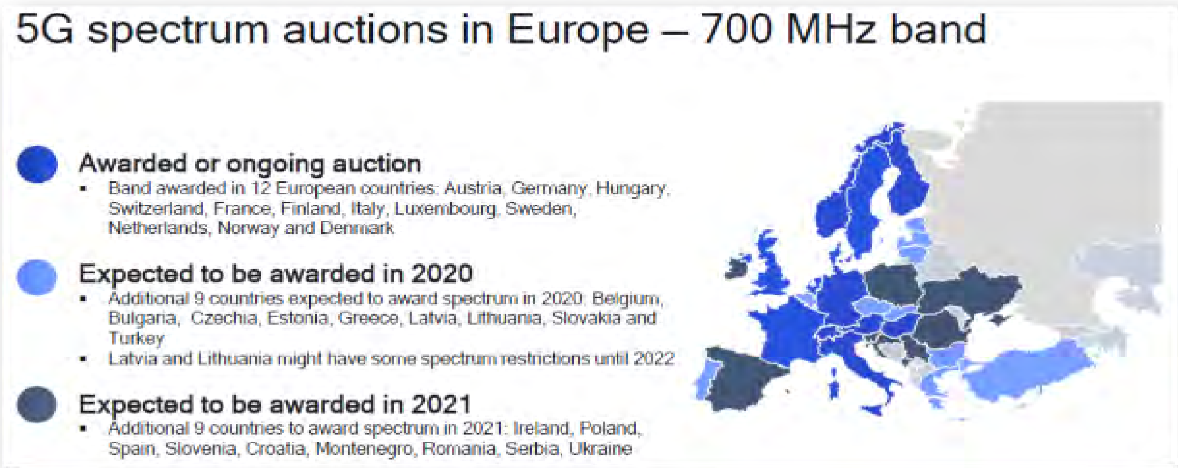


Figure 6 – 5G spectrum status by auctions in Europe (FR1: 3.4 -3.8 GHz)

Nasim and Kim (2017) simulates the possible exposure scenario to RF after 5G deployment using beamforming technology. The authors consider that at MMW frequencies, at which future mobile telecommunications systems will most likely operate, two changes that are likely to occur may increase concern as to the exposure of human users to RF fields. First, larger numbers of transmitters will operate. More base stations (BSs) will be deployed due to proliferation of small cells (Rappaport et al., 2013; Agiwal, 2016; Al-Saadeh, 2017) and mobile devices accordingly. This will increase the likelihood of human exposure to RF fields. Second, narrower beams will be used as a solution for the higher attenuation in higher frequency bands (Shakib, 2016; Zhang et al., 2017; Akdeniz et al., 2014). Very small wavelengths of MMW signals combined with advances in RF circuits enable very large numbers of miniaturised antennas. These multiple antenna systems can be used to form very high gains. The authors declare that their paper is motivated by the fact that previous works have not sufficiently addressed such a potential increase in risk. In their conclusions, the authors state*:*
"This paper has highlighted the significance of human RF exposure issue in downlink of a cellular communications system. This paper measured the exposure level in terms of PD and SAR, and compared them to those calculated in Release 9 as a representative of the current mobile communications technology. Unlike previous works that studied uplinks only, this paper has found that the downlinks of a 5G also yield significantly higher levels of PD and SAR compared to Release 9 [the present scenario of exposure]. Our results emphasized that the increase stems from two technical changes that will likely occur in 5G: (i)more access points (APs) due to deployment of smaller cells and (ii) morehighly concentrated RF energy per downlink RF beam due to use of larger phased arrays. As such, unlike prior work, this paper claims that RF fields generated in downlinks of 5G can also be dangerous inspite of far-field propagation. Therefore, the authors call for design of cellular communications and networking schemes that forcean AP to avoid generation of RF fields if pointed at a human user at an angle yielding a dangerous level of PD and SAR. To this end, the paper identifies as a future work developing the idea of techniques that reduce human exposure to RF fields in 5G downlinks" (Imtiaz and Seungmo, 2017).

It is noteworthy that this paper (Imtiaz and Seungmo, 2017) only referred to the 5G frequency of 28 GHz, one of the pioneer ones, with the simulation of only one user device connected, using the whole frequency band in static and stationary conditions.

Another paper (Baracca et al., 2018) from the Nokia group, taking into account massive MIMO base station (BSs), proposes a statistical approach for assessing the RF exposure conditions around massive MIMO BSs based on the 3D spatial channel model developed by the Third Generation Partnership Project (3GPP) and evaluates how the power is focused in a practical system when realistic assumptions regarding user equipment (UE) distribution and traffic models are taken into account. The methodology consists in performing system simulations that take into account realistic deployment scenarios in terms of installation height, user equipment, device distribution, and traffic, to evaluate the cumulative distribution function (CDF) of the BS actualtransmission power. "*The proposed statistical approach contributes to improve the calculation methods already defined by the International Electrotechnical Commission (IEC, 2017) and support the deployment of massive MIMO BSs for 5G and beyond cellular networks".*As a concluding remark, the Authors highlight that*: "All the statistical approaches including our own, although based on realistic assumptions, anyhow require complementary techniques, based for instance on power control and beamforming adaptation (*Sambo et al., 2015*), to ensure that the EMF constraints are met at the BSs for all the possible actual configurations*".

Regarding exposure assessment, Neufeld and Kuster (2018) issued a warning in a paper in Health Physics, urging that existing exposure standards be revised with shorter averaging times to address potential thermal damage from short and strong pulses: "*Extreme broadband wireless devices operating above 10 GHz may transmit data in bursts of a few milliseconds to seconds. Even though the time- and area-averaged power density values remain within the acceptable safety limits for continuous exposure, these bursts may lead to short temperature spikes in the skin of exposed people. ... [Our] results also show that the peak-to-average ratio of 1,000 tolerated by the ICNIRP guidelines may lead to permanent tissue damage after even short exposures, highlighting the importance of revisiting existing exposure guidelines*" (Neufeld and Kuster, 2018).

Kenneth Foster of the University of Pennsylvania, countered that their claims do not hold up: "*Because real-world communications technologies produce pulses of much lower fluence than the extreme pulses considered by Neufeld and Kuster, the resulting thermal transients from them will be very tiny in any event*" (Foster, 2019).

The Istituto Superiore di Sanità (Italian National Institute of Health) in the ISTISAN 2019 Report (available only in Italian) recognises that (translation by the author) : *"(…) on the basis of the technical characteristics of [5G] base stations, in order to correctly monitor the exposure, the mean value of measurements of electromagnetic fields should not be considered alone, but together with the maximum levels reached for short periods of exposure. This aspect calls for an updating of the national law which, up to now, has not considered short time exposures, but only continuous exposure as mean values within 6 minutes [20 V/m, occasional exposure] or 24 hrs [6V/m,residential/occupational exposure for more than 4hrs/day)"* (ISTSAN 19/11, 2019).

Uncertainty on exposure assessment remains unresolved. The above mentioned papers, shows that the question of exposure assessment with the introduction of 5G is complicated, above all concerning the monitoring of the continuous changes in activity of both base stations (BSs) and users (UEs) related to MIMO technology, while the technical position on exposure in the new scenario related to 2G, 3G, 4G, 5G emissions, is still being formulated and is hence uncertain. Exposure assessment constitutes a central matter of discussion before MMW and MIMO technology is disseminated all over the planet.

1.3 Overview of the policy action internationally and in Europe

1.3.1 International organisations

The International Agency for Research on Cancer (Baan et al., 2011; IARC, 2013) classified RF-EMF as "*possibly carcinogenic to humans*" (Group 2B).

The World Health Organization (WHO) recently relaunched a call for expressions of interest for systematic reviews (2020). The WHO is undertaking a health risk assessment of RF-EMF, to be published as a monograph in the Environmental Health Criteria Series. This publication will complement the monographs on static fields (2006) and extremely low frequency fields (2007), and will update the monograph on RF fields published in 1993 (WHO, 1993).

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) in March 2020 published new guidelines covering several new technologies, including 5G (ICNIRP, 2020a). The new guidelines introduce new and revised restrictions concerning 5G. On the ICNIRP website there is extensive information on the new guidelines and differences between the 1998 and 2020 guidelines. The guidelines refer only to thermal effects caused by 6 minutes and 30 minutes of exposure to RF-EMF, so the guidelines concern only short-term exposure. Safety guidelines for the currently deployed of 5G technology have been established though insufficient scientific research has yet been performed, while peer-reviewed science on non-thermal effects of RF already in use has not been evaluated in all ICNIRP guidelines (ICNIRP, 2020c).

1.3.2 European organisations and governments (by year)

The Council of Europe Resolution 1815 highlights that: "*The independence and credibility of the scientific expertise employed is crucial for a transparent and balanced assessment of possible negative effects on human health and environment. The resolution recommends: taking all reasonable measures to reduce exposure to EMF (especially from mobile phones) and particularly to protect children and young people who seem to be most at risk of developing head tumours; reconsidering the scientific basis for the present standards on exposure to electromagnetic fields set by the International Commission on Non-Ionising Radiation Protection, which have serious limitations; distributing information and awareness-raising campaigns on the risks of potentially harmful long-term biological effects on the environment and on human health, especially targeting children, teenagers and young people of reproductive age; giving preference to wired internet connections (for children in general and particularly in schools), and strictly regulating the use of mobile phones by schoolchildren on school premises; increasing public funding of independent research to evaluate health risks.*" (European Parliament Assembly, 2011)

The French Agency For Food, Environmental And Occupational Health and Safety (ANSES) in 2013, "(...) *issues recommendations for limiting exposure to radio frequencies limited levels of evidence do point to different biological effects in humans or animals. In addition, some publications suggest a possible increased risk of brain tumour, over the long term, for heavy users of mobile phones. Given this information, and against a background of rapid development of technologies and practices, ANSES recommends limiting the population's exposure to radiofrequencies – in particular from mobile phones – especially for children and intensive users, and controlling the overall exposure that results from relay antennas. It will also be further developing its work on electro-sensitive individuals, specifically by examining all the available French and international data on this topic that merits closer attention. Therefore, to limit exposure to radiofrequencies, especially in the most vulnerable population groups, the Agency recommends: - for intensive adult mobile phone users (in talk mode): use of hands-free kits and more generally, for all users, favouring the purchase of phones with the lowest SAR [values;- reducing the exposure of children by encouraging only moderate use of mobile phones; continuing to improve characterisation of population exposure in outdoor and indoor environments through the use of measurement campaigns; that the development of new mobile phone network infrastructures be subject to prior studies concerning the characterisation of exposures, and an in-depth study be conducted of the consequences of possibly multiplying the number of relay antennas in order to reduce levels of environmental exposure; - documenting the conditions pertaining at those existing installations causing the highest exposure of the public and investigating in what measure these exposures can be reduced by technical means; - that all common devices emitting electromagnetic fields intended for use near the body (DECT telephones, tablet computers, baby monitors, etc.) display the maximum level of exposure generated (SAR, for example), as is already the case for mobile phones; finally, in order to resolve the various uncertainties it identified when conducting this work, and in addition to the research projects already undertaken under the National Plan for Research on Environmental and Occupational Health, the Agency is also making a series of research recommendations"* (ANSES, 2013).

The European Commission Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) had a mandate to evaluate the risks of EMF and periodically reviews the scientific evidence available to assess whether it still supports the exposure limits proposed in Council Recommendation 1999/519/EC. In its latest opinion of January 2015, SCENIHR suggested that there is a lack of evidence that EMF radiation affects cognitive functions in humans or contributes to an increase of the cases of cancer in adults and children (SCENIHR, 2015). However, the International EMF Alliance (IEMFA) suggested that many members of SCENIHR could have a conflict of interests, as they had professional relationships with or received funding from various telecom companies.

Consequently, the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER), replacing the former SCENIHR, indicated a preliminary estimate of the importance of 5G as high, in a statement in December 2018. Furthermore, it evaluates the scale, urgency and interactions (with ecosystems and species) of possible hazard as high. It suggested that there could be biological consequences from a 5G environment, due to the fact that there is a lack of "*(...) evidence to inform the development of exposure guidelines to 5G technology*" (SCHEER, 2018).

In a briefing of June 2017, the European Parliamentary Research Service stated: *"Finally, little research has been performed on the health impacts of 5G, as most of the studies to date relate to previous generation of mobile technology. According to one recent study, this could prove a further bottleneck should 5G pose health risks owing to, 'its urban concentration and dense cellular structure, its use of much higher microwave frequencies and its highly directional concentration'. In the USA a 2016 government-funded study raised concern, as in its preliminary results it found significantly greater rates of rare tumours of the brain and heart in rats exposed to wireless radiation. Other 2017 research and publications also suggest that long-term mobile phone use could increase brain cancer risk. However the latest opinion published by the Commission's expert group in 2015 and research by the World Health Organization do not recognise a direct link. In France, meanwhile, a review of wireless radiation has concluded that there is a need to evaluate all wireless devices for their impact on children's health and recommends only moderate and supervised use by children. This complex issue therefore remains controversial while further research is ongoing"* (EPRS, 2017).

A more recent EPRS document stated that: *"The recent academic literature illustrates that continuous wireless radiation seems to have biological effects especially considering the particular characteristics of 5G: the combination of MMW, a higher frequency, the quantity of transmitters and the quantity of connections. Various studies suggest that 5G would affect the health of humans, plants, animals, insects, and microbes – and as 5G is an untested technology, a cautious approach would be prudent" (EPRS, 2020).*

The Federal Office for Radiation Protection of Germany published a report, where is stated that: *"In a few years, 5G will lead to higher frequencies. However, the effects of these have not yet been well researched. The Federal Office for Radiation Protection advises a prudent expansion of 5G and will further explore the effects of the new frequency bands"* (FORPG, 2019).

In 2020, the EMF scientific council of the Radiation Safety Authority in Sweden (SSM), published its 14th report. This is a consensus report, which means that all members of the Scientific Council agree with the report in toto. Despite the fact that no health risks with weak EMF have been established to date, the Authority considers that: "*Further research is important, in particular regarding long-term effects as the entire population is exposed. One key issue here is to further investigate the relationship between radio wave exposure and oxidative stress observed in animal studies and to establish whether and to what extent it may affect human health. There is also a need to further investigate the observed decreased sperm counts, sperm viability and decreased serum testosterone due to radio wave exposure of testes in animal studies before any conclusions concerning the possible implications for human health can be drawn*" (SSM, 2020).

The Austrian Institute of Technology (AIT) states: "*1) Electromagnetic fields have already been considered a potential health risk with previous generations of mobile radio communication. In 2011, the International Agency for Research on Cancer (IARC) classified mobile phone radiation as "possibly carcinogenic". To this day, experts continue to discuss this topic with much controversy. 2) 5G, the latest generation of mobile phone networks, promises to transmit larger amounts of data with lower latency. Industry 4.0, augmented reality games or the Internet of things rely on such higher performance. 3) The assessment of risks and gaps of knowledge enables precautionary regulation and a prudent approach to 5G*" (Kastenhofer, 2020).

The Health Council of the Netherlands published its opinion on 5G and health in September 2020. A selection of quotes from the report are as follow: *"The rollout of 5G networks has only just begun. Therefore, there are no studies as yet into the health effects of (long-term) exposure to electromagnetic fields with the frequencies that are reserved for 5G"; "According to the committee, it cannot be excluded that the incidence of cancer, reduced male fertility, poor pregnancy outcomes and birth defects could be associated with exposure to RF electromagnetic fields. However, the committee deems the relationship between exposure and these and other diseases or conditions neither proven nor probable"; "There has been almost no research into the effects of exposure to frequencies around 26 GHz" ; "The committee recommends not using the 26 GHz frequency band for 5G for as long as the potential health risks have not been investigated"; "The committee recommends using the latest guidelines from the International Commission on Non-Ionising Radiation Protection (ICNIRP) as the basis for exposure policy in the Netherlands. Because it cannot be excluded that exposure under the latest ICNIRP standards also has the potential to affect health, the committee recommends taking a cautious approach and keeping exposures as low as reasonably achievable".* In this report, common adverse effects from RF exposure are reported, but as a conclusion the committee only recommends taking a cautious approach (Health Council of the Netherlands, 2020).

In Switzerland, the Federal Office for the Environment (FOEN) is the government body responsible for monitoring and assessing research on health effects of NIR from stationary sources in the environment. This includes informing and updating the public about the current state of research, which is the basis for the ambient regulatory limits stated in the Swiss "ordinance relating to protection from non-ionising radiation (NIR)". In the case of reliable new scientific knowledge and experiences, the FOEN would advise the Federal Council of Switzerland to adapt these ambient regulatory limits. The FOEN has therefore nominated a consultative group of Swiss experts from various disciplines with scientific competence regarding EMF and NIR, which commenced its work in July 2014. The group is called BERENIS, based on an acronym of the respective German term. The BERENIS experts regularly screen the scientific literature, and assess the publications which they consider relevant for the protection of humans from potentially adverse effects. As part of the work of BERENIS, non-ionising radiation (NIR) at frequencies below 10 GHz is addressed.

In the special issue of the BERENIS newsletter (BERENIS, 2021), an up-to-date assessment of a possible correlation between oxidative stress and exposure to EMF and their putative effects on health are presented. For this purpose, relevant animal and cell studies published between 2010 and 2020 were identified and summarised. An extended report presenting these recent studies in more detail will be published soon by FOEN 1 (not yet available at the time of this report). The newsletter contains a short version of the report, writing that: "*The majority of the animal and more than half of the cell studies provided evidence of increased oxidative stress caused by RF-EMF (...). This notion is based on observations in a large number of cell types, applying different exposure times and dosages (SAR [Specific Absorption Rate] or field strengths), also in the range of the regulatory limits.*". This review of the literature evidences that one of the mechanisms underlying adverse effects from RF-EMF is oxidative stress, forming free radicals that impair a number of different functions (Yakymenko, 2016).

1.4 Biologically effects other than the ones analysed in this review (both FR1 and FR2)

The present review examines only carcinogenicity and reproductive/developmental adverse effects related to RF exposure observed in epidemiological and laboratory animal studies, published since 1945. However, in order to better understand the impact of RF on human health, we cannot ignore the fact that other biological non thermal effects have been reported. For instance, we need only cite the preponderance of research published from 1990 through 2020, which has found various significant effects from exposure to radio frequency radiation. Overall, 75% (n=711) of 944 analysed radio frequency radiation studies have reported biological effects (Moskowitz, 2018).

The National Toxicology Program (NTP) found that RF-EMF exposure was associated with an increase in DNA damage. Specifically, they found RF-EMF exposure was linked with significant increases in DNA damage in the frontal cortex of the brain in male mice; the blood cells of female mice, and the hippocampus of male rats. There are many factors that influence whether damaged DNA will lead to tumours. NTP plans to conduct additional studies to learn more about how RF-EMF might cause DNA damage (Smith-Roe et al., 2019). Other adverse effects were observed in the NTP studies, including reduced birth weights, DNA strand breaks in brain cells, which is supportive of the cancer findings (Yakymenko, 2015), increased incidences of proliferative lesions (hyperplasia), and exposure-related increases in the incidence of cardiomyopathy of the right ventricle in male and female rats (NTP, 2018).

MMWs rarely included in the above mentioned studies have specific characteristics. MMWs are mostly absorbed within 1 to 2 millimetres of human skin and in the surface layers of the cornea. Thus, the skin or near-surface zones of tissues are the primary targets of such radiation. Since the skin contains capillaries and nerve endings, MMW bio-effects may be transmitted through molecular mechanisms by the skin or through the nervous system. Thermal (or heating) effects occur when the power density of the waves is above 5–10 mW/cm2 (Foster, 1998).

Such high-intensity MMWs act on human skin and the cornea in a dose-dependent manner—beginning with heat sensation followed by pain and physical damage at higher exposures. Temperature elevation affects the growth, morphology and metabolism of cells, induces production of free radicals, and damages DNA. Few studies have examined prolonged exposure to low-intensity MMWs, and no research has focused on exposure to MMWs combined with other RF radiation. Some studies reported that the radiation inhibits cell cycle progression, and some studies reported no biological effects (Le Drean et al., 2013).

(Ramundo-Orlando, 2010) noted that: "*A large number of cellular studies have indicated that MMW may alter structural and functional properties of membranes*". Exposure to MMWs may affect the plasma membrane either by modifying ion channel activity or by modifying the phospholipid bilayer. Water molecules also seem to play a role in these effects. Skin nerve endings are a likely target of MMWs and the possible starting point of numerous biological effects. MMWs may activate the immune system through stimulation of the peripheral neural system (Ramundo-Orlando, 2010).

In 1998, scientists employed by U.S. Army research institutes published a seminal review of the research on MMWs. They reported: "*Increased sensitivity and even hypersensitivity of individual specimens to MMW may be real. Depending on the exposure characteristics, especially wavelength, a low-intensity MMW radiation was perceived by 8 to 30% of healthy examinees (Lebedeva, 1993, 1995). Some clinical studies reported MMW hypersensitivity, which was or was not limited to a certain wavelength (Golovacheva, 1995). It should also be realized that biological effects of a prolonged or chronic MMW exposure of the whole body or a large body area have never been investigated. Safety limits for these types of exposures are based solely on predictions of energy deposition and MMW heating, but in view of recent studies this approach is not necessarily adequate*" (Pakhomov et al., 1998).

In 1977, Zalyubovskaya published a study which examined the effects of exposing mice to millimetre radiation (37-60 GHz; 1 milliwatt per square centimetre) for 15 minutes daily for 60 days. The animal results were compared to a sample of people working with millimetre generators. The summary of the paper reports: "*Morphological, functional, and biochemical studies conducted in humans and animals revealed that millimeter waves caused changes in body manifested in structural alteration in the skin and internal organs, qualitative and quantitative changes in the blood and bone marrow composition and changes of the conditioned reflex activitiy, tissue respiration, activity of enzymes participating in the processes of tissue respiration and nucleic metabolism. The degree of unfavorable effect of millimeter waves depends on the duration of the radiation and individual characteristics of the organism*" (Zalyubovskaya, 1977).

Microbes are also affected by MMW radiations. In 2014 a review on the effects of MMWs on bacteria was published. The authors summarised their findings as follows: "(…) *bacteria and other cells might communicate with each other by electromagnetic field of sub-extremely high frequency range. These MMW affected Escherichia coli and many other bacteria, mainly depressing their growth and changing properties and activity. These effects were non-thermal and depended on different factors. The consequences of MMW interaction with bacteria are the changes in their sensitivity to different biologically active chemicals, including antibiotics. These effects are of significance for understanding changed metabolic pathways and distinguish the role of bacteria in the environment; they might be leading to antibiotic resistance in bacteria.These effects are of significance for understanding changed metabolic pathways and distinguish the role of bacteria in the environment; they might be leading to antibiotic resistance in bacteria"* (Adebayo et al., 2014).

"Changing the sensitivity of bacteria to antibiotics by MMW irradiation can be important for the understanding of antibiotic resistance in the environment. In this respect, it is interesting that bacteria [that] survived near telecommunication-based stations like Bacillus and Clostridium spp. have been found to be multidrug resistant" (Soghomonyan et al., 2016).

In a recently published paper,it was) found that: "*Taken together, MW-irradiated water [pulsed 3.5GHz high power] microwaves irradiation can alter cellular physiology noticeably, whereas irradiated media and buffered saline solutions induce negligible or irrelevant changes that do not affect cellular health"* (Bhartiya et al., 2021).

Yet we know that athermal bio-responses exist. Indeed, some frequencies are already being used for therapeutic purposes in a number of branches of medicine. These include nerve regeneration, wound healing, graft behaviour, diabetes, and myocardial and cerebral ischaemia (heart attack and stroke), among other conditions. Some studies even suggest possible benefits in controlling malignancy. Low-intensity, intermediate-frequency, alternating electric fields (tumour-treating fields) that target dividing cells in glioblastoma multiforme (brain malignant tumour) while generally not harming normal cells, are used for therapy purposes (Guo et al., 2011; Zimmerman et al., 2013; Alphandéry, 2018).

Since any drug, may also entail some adverse effects, non-thermal adverse effects of RF-EMF should also be considered for risk assessment. In sum, the peer-reviewed research shows that short-term exposure MMW radiation not only affects human cells, it may also result in changes in sensitivity of bacteria harmful to humans, and to various biologically active chemicals, including antibiotics.

Since little research has been conducted on the health consequences from long-term exposure to MMWs, widespread deployment of 5G infrastructure constitutes a massive experiment that may have adverse impacts on public health. Unfortunately, few studies have examined prolonged (long-term) exposure to low-intensity MMWs, and no research that we are aware of has focused on exposure to MMWs combined with other RF radiation.

1.5 Social conflict related to 5G

Another aspect of the 5G discussion is social polarisation. Currently, both activists for the 'Stop 5G' movements and 5G promoters claim there are thousands of studies on the health effects of RF used in wireless communication and their related EMF. Activists claim that studies show a lot of different harmful health effects, 5G promoters claim that studies do not show any adverse health effects. Both sides refer to the EMF Portal, a specialized database in Germany: "*The internet information platform EMF-Portal of the RWTH Aachen University summarizes systematically scientific research data on the effects of electromagnetic fields (EMF). All information is made available in both English and German. The core of the EMF-Portal is an extensive scoping database with an inventory of 32,119 publications and 6,805 summaries of individual scientific studies on the effects of EMF*" (EMF Portal homepage). The number of 32.119 publications (October 20, 2020) includes the studies of all types of biological and technical end points on all EMF originating from RF. However, the collection of 5G MMW frequencies-related studies is scanty (around 100) and, for the most part, regards technical/dosimetric studies. As a consequence, both claims, presence or lack of harms, about 5G MMW safety are based on assumption, not on scientific evidence.

The issue of social conflict is well developed by Leszczynski (2020). It is evident that the scenario in which 5G should be exploited is full of uncertainty on one side, denial on the other, and exaggerated alarmism in yet another.

2. Aims of the study and methodology

This review aims to evaluate the current state of knowledge on non-thermal effects regarding both the carcinogenic and the reproductive/developmental hazards of RF-EMF exploited by 5G as they emerge from in vivo experimental studies and epidemiological studies, considering separately the frequencies 700-3600 MHz and 26,000 MHz.

2.1 Rationale

This review of the currently available scientific evidence focuses on both the carcinogenic and the reproductive/developmental effects of RF from mobile phone telecommunications systems using 2-5G networks, based on both in vivo animal studies and human epidemiological studies.

The studies evaluated have been divided into 2 groups:

1) Studies evaluating health effects due to RF at the lower frequency range (FR) (FR1: 450 to 6000 MHz), which also includes the frequencies used in existing 2-4 generations of the broadband cellular network. The current evidence from 1G-4G studies is the best evidence currently available. The studies were evaluated using narrative methods.

2) Studies evaluating health effects due to RF at the higher frequency range (FR2: 24 to 100 GHz - MMW). The higher frequencies are new, previously not used for mobile communication and specific for the new 5G technology, which have particular physical characteristics and interactions with biological matter (lower penetration, higher energy, etc.): they were considered separately with a scoping review method.

Scoping reviews have great utility for evaluating research evidence and are often used to categorize or group existing scientific evidence in a given field in terms of its nature, quality, other features, and volume. This scoping review was performed assuming the principles of transparency, reproducibility and rigour. This was achieved by adopting the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) as the methodological framework of this work. At least two reviewers worked independently on every stage of this review: uniformity and standardisation in decision making was obtained through discussion and consensus-reaching among the reviewers. A distinction is made between the narrative review (FR1) and the scoping review (FR2), but the selection and assessment criteria indicated for scoping reviews were adopted for both searches and for including/excluding studies on the cancer and reproductive/developmental biological end-points.

2.1.1 Cancer

Epidemiological studies are potentially susceptible to several different sources of error. Study quality was assessed as part of the review process and all informative studies were considered. The informativeness of a study is its ability to show a true association, if there is one, between the agent and cancer, and the lack of an association, if no association exists. Key determinants of informativeness include: having a study population of sufficient size to obtain precise estimates of effect; sufficient time elapsing from exposure to measurement of outcome for the effect, if present, to be observable; presence of an adequate exposure contrast (intensity, frequency, and/or duration); biologically relevant definitions of exposure; and relevant and well-defined time windows for exposure and outcome (IARC Preamble, 2019).

As explained in the IARC Preamble, most human carcinogens that have been studied adequately for carcinogenicity in experimental animals have produced positive results in one or more animal species. For some agents, carcinogenicity in experimental animals was demonstrated before epidemiological studies identified their carcinogenicity in humans. Although such observation cannot establish that all agents that cause cancer in experimental animals also cause cancer in humans, it is biologically plausible that agents for which there is sufficient evidence of carcinogenicity in experimental animals should present a carcinogenic hazard to humans (IARC Preamble, 2019).

All available long-term studies of cancer in experimental animals on RF-EMF were considered in the review, after a thorough evaluation of the study features. Those studies that we judged to be irrelevant to the evaluation or judged to be inadequate (e.g. too short a duration, too few animals, poor survival; exposure assessment, etc) were omitted. Guidelines for conducting long-term carcinogenicity experiments have been published (e.g. OECD, 2018a) and their criteria were considered as a reference for assessing the adequacy of studies.

As concerns cancer-related studies on RF, both epidemiological and experimental, comprehensive reviews of the literature had already been performed in the last decades; in particular, we refer to the IARC Monograph 102, which dealt with the RF range 30 kHz-300 Ghz. In May 2011, 30 scientists from 14 countries met at IARC in Lyon, France, to assess the carcinogenicity of RF-EMF. These assessments were published as Volume 102 of the IARC Monographs. A summary of the conclusions of the Working Group and the rationale for the evaluation together with the studies supporting the conclusions was published in May 2011 (Baan et al., 2011), the full Monograph was published in April 2013 (IARC, 2013).

Preparation of the IARC Monograph on RF was scheduled so as to include the results of the large international case-control study INTERPHONE on mobile phone use (performed in 2003-2004; published in 2010). We thus decided to adopt the IARC publication Monograph 102 (IARC, 2013) as a 'key reference' upon which to update the 2011 data to the year 2020 and hence produce the present report. After collecting and examining the original works related to the IARC 2011 analyis, published in 2013, and cited throughout as (IARC, 2013) considering their assessment criteria so as to conform to them in later assessments, we collected all relevant works dating from 2011 on, following the same criteria.

Once we had selected and examined the literature available according to the criteria described below, consistent with a scoping review, we updated the IARC (2013) tables to 2020. The studies selected, in abstract form, are included in the text, and tables in the "Assessment of individual studies" chapter, divided by end-point studied and by study characteristics. Each study is numbered in the same sequence in both abstract and corresponding table. In the summary tables, the studies are classified without specific comments, but only as adequate/inadequate for sample size, study design, exposure assessment and, when adequate, positive/negative/equivocal results:

- *Adequate*: no major qualitative or quantitative limitations.
- *Inadequate*: major qualitative or quantitative limitations affect the study, not valid for showing either the presence or absence of specific adverse effects.

When adequate:

- *Positive*: statistically significant increase of the specific pathology in association with RF-EMF exposure.
- *Equivocal:* adverse effect is demostrated showing a marginal increase (not statistically significant increase) of the specific pathology that may be associated with RF-EMF.
- *Negative*: no RF-EMF-related increases in specific pathologies.

2.1.2 Reproduction/development

Since no adequate, major review of studies on the reproduction/development effects exists to this date, such a review of all studies published between 1945 and 2020 was performed. Once we had selected and examined the literature according to the criteria described below, we summarized data up to 2020 in specific tables.

Regarding animal studies, in order to select informative studies only, another selection of studies was based on the guidelines NTP Modified One Generation Study and OECD 443, assessed in 2014 (Foster et al., 2014), planned in order to study experimental animals (rodents) for evidence of developmental pathology, endocrine disrupters, female reproduction, male reproduction, the reproductive system. The guideline study design envisages at least 10 animals/sex/group in order to produce statistically robust results.

The abstracts of the selected studies are included in the text and tables in the 'Assessment of individual studies' chapter, divided according to end-point studied and the study characteristics. Each study is numbered and presented in the same sequence of the corresponding table. In the summarising tables, the studies are classified without specific comments, but only as adequate/ inadequate for sample size, study design, exposure assessment and, when adequate, positive/negative/equivocal results:

- *Adequate*: no major qualitative or quantitative limitations.
- *Inadequate*: major qualitative or quantitative limitations affect the study, not valid for showing either the presence or absence of specific adverse effects.

When adequate:

- *Positive*: statistically significant increase of the specific pathology in association with RF-EMF exposure.
- *Equivocal:* adverse effect is demostrated showing a marginal increase (not statistically significant increase) of the specific pathology that may be associated with RF-EMF.
- *Negative*: no RF-EMF-related increases in specific pathologies.

2.2 Search strategy

First a selection of the most appropriate keywords was performed:

Exposure: EMF; RF; 5G; radiofrequency radiation; radiofrequency; electromagnetic field; electromagnetic radiation.

Population (animal): in vivo; experimental; animal; rodent(s); rat(s); mouse; mice.

Population (human): epidemiological; observational; cross-sectional; case-control; worker(s); military; population.

Outcome (carcinogenic effects): cancer; tumour.

Outcome (reproductive effects): reproductive; development; fertility; sperm; ovary; pregnancy; ano-genital; estrus.

Based on the keywords, the following search strings were prepared to collect any studies of interest from PubMed, a major database that comprises more than 30 million citations for biomedical literature from MEDLINE, life science journals, and online books. Citations may include links to full-text content from PubMed Central and publisher web sites.

Studies on Humans, Carcinogenic effects

((epidemiologic* OR observation* OR "cross sectional" OR "case control" OR worker OR military OR population OR child OR employ*) AND (EMF OR RF OR 5G OR "radiofrequency radiation" OR radiofrequency OR "electromagnetic field" OR "electromagnetic radiation") AND (cancer OR tumour)) NOT (therapy OR ablation).

In vivo studies (rodents), Carcinogenic effects

(("in vivo" OR experimental OR animal OR rodent* OR rat OR mouse OR mice OR hamster* OR rabbit*) AND (EMF OR RF OR 5G OR "radiofrequency radiation" OR radiofrequency OR "electromagnetic field" OR "electromagnetic radiation") AND (cancer OR tumour)) NOT (therapy OR ablation)

Studies on Humans, Reproductive- developmental effects

((epidemiologic* OR observation* OR “cross sectional” OR “case control” OR worker OR military OR population OR child OR employ*) AND (EMF OR RF OR 5G OR “radiofrequency radiation” OR radiofrequency OR “electromagnetic field” OR “electromagnetic radiation”) AND (reproductive OR development OR fertility OR sperm OR ovary OR pregnancy OR “ano genital” OR estrus)) NOT (therapy OR ablation)

In vivo (rodents) and Reproductive- developmental effects

((“in vivo” OR experimental OR animal OR rodent* OR rat OR mouse OR mice OR hamster* OR rabbit*) AND (EMF OR RF OR 5G OR “radiofrequency radiation” OR radiofrequency OR “electromagnetic field” OR “electromagnetic radiation”) AND (reproductive OR development OR fertility OR sperm OR ovary OR pregnancy OR “ano genital” OR estrus)) NOT (therapy OR ablation).

We systematically searched the electronic academic database PubMed and the EMF Portal for potentially eligible records. The PubMed search occurred on 24 February 2020 for epidemiological and experimental carcinogenicity studies, and on the 20 July 2020 for epidemiological and experimental studies on reproductive outcomes - all searches being updated on the EMF Portal in January 2021. The first 100 results obtained from Google and Google Scholar were evaluated to check for any relevant, non-duplicate results. We also checked the bibliographies of the studies selected for the same purpose. Finally, we asked experts in the field to revise our lists and suggest any additional relevant studies.

2.3 Selection of the relevant literature

The “Population, Exposure, Comparator and Outcome” criteria (PECO Statement, Morgan et al. 2018) was adopted to clearly define the scope of this work and consequently the criteria for the selection of literature according to:

Population: RF-exposed population from in vivo studies, in particular experimental bioassays on rodents, as they represent the most predictive models for human health, and workers and the general population included in epidemiological studies;

Exposure: exposure to RF used in 5G networks, in particular the frequencies that were established as standard for use by the European Union: 450 MHz to6 GHz, and 24 to 100 GHz.

Comparator: untreated population (controls) from experimental bioassays on rodents, and, where this was available, groups of healthy or not exposed controls from epidemiological studies;

Type of outcome: health effects of particular concern that have been associated with the exposure to RF, namely reproductive effects, and carcinogenicity effects (Vornoli et al., 2019).

We considered all types of study design for the review; non-original studies, letters, and comments were not considered. Peer-reviewed articles in English, published from 1945 to January 2021 were considered. English is the most widely used language for scientific publications, and papers in other languages usually have an abstract available in English.

2.4 Screening process

The screening process was performed using the online systematic review app Rayyan QCRI. Selection of the literature was performed by two reviewers independently examining all references in two steps: in the first, the decision on exclusion/inclusion was based on title and abstract; in the second, the full texts of the potentially relevant articles were examined thoroughly to verify conformity with the aforementioned PECO criteria. At the second stage of selection, all inclusion/exclusion decisions and all doubts were discussed, solved and agreed upon by the two reviewers. Results of the selection process are illustrated in the following sections using PRISMA flow diagrams (Moher et al., 2009).

2.5 Extraction of information from the relevant literature

It was decided to use two different data-charting forms to extract information from the selected literature, since epidemiological and experimental studies have very different characteristics and peculiarities that need to be accounted for. The tools were chosen to achieve a complete and standardized collection of all information relevant to evaluating the conduct of the study, the exposure assessment and the health effects. The data chart for epidemiological studies was based on the one used for the series of reviews performed to elaborate, perfect and test the *WHO/ILO joint methodology for estimating the work-related burden of disease and injury* (Mandrioli et al, 2018; Sgargi et al., 2020). The data chart for experimental studies was based on the format used in IARC Monographs to evaluate carcinogenicity.

Both forms are validated tools, proven providers of exhaustive data on relevant literature. Calibration and uniformity was obtained through several rounds of independent blind trial extraction, discussion, and reaching of consensus among reviewers.

For epidemiological studies, a wide set of information was extracted, namely:
Ref ID; Type of study; Mode of data collection; Country; Year; N; Sex; Age; Occupation; Source of exposure; Duration of exposure; Frequency of exposure; Intensity of exposure; Any other co-exposure/adjustments; Method for exposure assessment; Observed health effects; Measure of observed health effects; Results; Conclusions; Authors; Affiliations; Conflict of interest; Funding.

For experimental studies, the extracted items from the literature were the following:
Reference ID; Type of study; Strain, Species (Sex); Exposure duration; Frequency; Intensity; Any other co-exposure; Exposure time - No of animals; Increased tumour incidence

The information was extracted by reviewers independently, and then double-checked by all reviewers and a senior expert.

2.6 Evidence synthesis

In finally assessing the results of the review for both epidemiological and experimental study, and for cancer and reproductive/developmental outcomes, we took into account the parameters indicated in (IARC Preamble, 2019), tailored to the needs of the present report, and valid for both end points (i.e. cancer and reproductive/developmental effects):

Sufficient evidence: A causal association between exposure to RF-EMF and the specific adverse effect has been established. That is, a positive association has been observed in the body of evidence on exposure to the agent and the specific adverse effect in studies in which chance, bias, and confounding factors were ruled out with reasonable confidence.

Limited evidence: A causal interpretation of the positive association observed in the body of evidence on exposure to RF-EMF and the specific adverse effect is credible, but chance, bias, or confounding factors cannot be ruled out with reasonable confidence.

No evidence: There are no data available or evidence suggesting lack of adverse effects (to be specified).

2.7 Overall evaluation of the present review

The results of the review for both cancer and reproductive/developmental outcomes, were finally assessed according to the criteria indicated in (IARC Preamble, 2019), tailored to the needs of the present report. Figure 8 presents the streams of evidence used for reaching the overall classification by IARC. The reasoning that the IARC used to reach its evaluation is summarised, so the basis for the evaluation offered is transparent. The IARC Monograph Preamble integrates the major findings from studies of cancer in humans, cancer in experimental animals, and mechanistic evidence (IARC Preamble, 2019).

The IARC criteria regard cancer, but equally apply to assessment of effects on reproductive /developmental parameters. Mechanistic evidence was not considered in the present review, so we integrated the results for cancer and reproductive/developmental effects in humans solely with the results for cancer and reproductive/developmental effects in experimental animals, using the criteria indicated in Figure 9.

Figure 7 – IARC criteria for overall classifications (the evidence in bold italic represents the basis of the overall evaluation) (Source: IARC Preamble, 2019)

Stream of evidence			Classification based on strength of evidence
Evidence of cancer in humans[a]	Evidence of cancer in experimental animals	Mechanistic evidence	
Sufficient	Not necessary	Not necessary	Carcinogenic to humans (Group 1)
Limited or Inadequate	Sufficient	Strong (b) (1) (exposed humans)	
Limited	Sufficient	Strong (b) (2-3), Limited or Inadequate	Probably carcinogenic to humans (Group 2A)
Inadequate	Sufficient	Strong (b) (2) (human cells or tissues)	
Limited	Less than Sufficient	Strong (b) (1-3)	
Limited or Inadequate	Not necessary	Strong (a) (mechanistic class)	
Limited	Less than Sufficient	Limited or Inadequate	Possibly carcinogenic to humans (Group 2B)
Inadequate	Sufficient	Strong (b) (3), Limited or Inadequate	
Inadequate	Less than Sufficient	Strong (b) (1-3)	
Limited	Sufficient	Strong (c) (does not operate in humans)[b]	
Inadequate	Sufficient	Strong (c) (does not operate in humans)[b]	Not classifiable as to its carcinogenicity to humans (Group 3)
All other situations not listed above			

[a] Human cancer(s) with highest evaluation.
[b] The *strong evidence that the mechanism of carcinogenicity in experimental animals does not operate in humans* must specifically be for the tumour sites supporting the classification of *sufficient evidence in experimental animals*.

Figure 8 – Criteria for overall evaluation in the present review (FR1 and FR2)

Evidence in humans	Evidence in experimentalanimals	Evaluation based on strengh of evidence
Sufficient	Not necessary	Clear association between exposure and the adverse effect
Limited	Sufficient	Probable association between exposure and the adverse effect
Limited	Less than sufficient	Possible association between exposure and the adverse effect
Inadequate	Inadequate or limited	Not classificable

3. Limitations of the present review

3.1 Assessment of individual studies

Experimental studies adopt a standardised methodology, following specific guidelines, making it much easier to assess the individual outcomes and evaluate the quality of the study and of the results. Blinded assessment of outcomes, adequacy of the sample size, and appropriateness of statistical analysis were also evaluated and reported for each study, when available. We selected and analysed animal studies considering their compliance with the pertinent guidelines.

As regards epidemiological studies, errors of recall are a systematic danger with epidemiology affecting retrospective studies when participants are interviewed or compile questionnaires about exposure that occurred in the past. Usually the problem is that people's memories may be inaccurate or incomplete; this becomes a serious problem in case-control studies, where cases, whose health was affected, are likely to be more conscious and clear about past exposure, whereas controls are often less aware and remember less precisely. This may increase or diminish the cause-effect relation observed.

3.2 Exposure assessment

Exposure assessment is a critical issue in epidemiological studies of RF from mobile communication, as it can be very demanding and, when not up to the highest standards, can render the findings uninformative. We excluded studies which do not contribute any useful information due to shortcomings in their conduct and analysis.

Recall bias, as mentioned in the previous section, may be a major issue in all case-control studies with self-reported exposures. Furthermore, substantial misclassification is often a concern in studies where exposure assessment is based on job titles alone or mobile phone subscriptions alone; in such cases, this was merely an estimate of the exposure. For a meaningful interpretation, we tried to evaluate all original reports objectively, comprehensively and consistently, following a standardised method, but without presuming that our review could compete with any systematic review by a specific working group.

For experimental studies, the comparability of the procedures for dealing with the exposed and control groups, including sham exposure, quality of the exposure system and dosimetry, possibility of thermal effects due to tissue heating, were considered for achieving a correct analysis.

As described in the report, the frequencies are (amongst other things) related to depth of penetration into tissues, but other dimensions of exposure may also affect health outcomes. Given certain new features of 5G (MIMO, beamforming) and the related and acknowledged uncertainties regarding exposure and exposure assessment, it is questionable wether the studies on 1G-4G can be directly generalized to 5G (even when using the same frequencies, here FR1). These uncertainties in exposure characterisation will impact on exposure assessment for new studies (particularly for epidemiological studies on 5G, here FR2), and, in terms of risk assessment, some metrics of exposure to RF-EMF and associated adverse health outcomes (suggested or established) could be different. These considerations should not detract from the fact that the current evidence from 1G-4G studies is the best evidence available.

Experimental investigations also include studies that used a mobile phone in GSM mode with an active call at small distances from the animal's body. Active call mode is usually maintained throughout the experiment; the control group (sham exposed group) is treated with the mobile phone switched off. The exposure depends on the quality of the connection with the base station and exposure is measured throughout the study; we considered this kind of study adequate in terms of exposure assessment as they simulate the human counterpart situation.

3.3 Limits for a systematic review on 5G frequencies

STOA asked the author to collect the information available on the impact of 5G frequencies on health. The original aim was to follow the criteria of a systematic review, but we soon realized there are no adequate studies on millimetric waves for the relevant end points. We thus agreed to perform a narrative review of the lowest frequencies (FR1) already assessed by authoritative working groups at least for carcinogenic effects down to 2011, and a scoping review on millimetric waves (FR2) which, as expected, produced no adequate results. However, the review methodology (the scoping review) was kept same for both FR1 and FR2 outcomes.

3.4 Overall evaluation

A scoping review (SR) requires strong subject matter expertise in several disciplines. The assessment of individual studies represented a great challenge for the scientists involved in the review. A systematic assessment would require a full and in-depth review of the underlying studies. This is beyond the scope of this document, which is prepared for, and addressed to, the Members and staff of the European Parliament as background material to assist them in their parliamentary work.

The evaluation criteria adopted by the IARC as described in its Preamble (IARC Preamble, 2019) were tailored to and used for both cancer and reproductive /developmental effects. We used these consolidated criteria in order to work in complete transparency and allow reviewers to check our work.

This report was written by Dr Fiorella Belpoggi, an expert on RF-EMF, experimental carcinogenesis and experimental studies on reproductive and developmental health outcomes. The author was supported by experts with expertise in systematic/scoping review methodology (DM), biostatistics (DS), cancer research (AV), exposure assessment (FaB) and human reproduction and development (CF, AG). Together, the team fields strong expertise in most domains required for this review, perhaps with some room for improvement in cancer epidemiology.

4. Assessment of individual studies

4.1 Carcinogenicity by frequency range

4.1.1 Cancer in epidemiological studies: Studies evaluating health effects due to RF at a lower frequency range (FR1: 450 to 6000 MHz), which also includes the frequencies used in previous generations' broadband cellular networks (1G-4G)

The articles identified through database searching and other sources were 950. After removal of duplicates (20) and excluding non-pertinent articles (685) based on title and abstracts, 245 articles remained. Based on full-text screening, 90 papers were further excluded, so that the articles with appropriate frequencies to be included in this qualitative synthesis were 155.

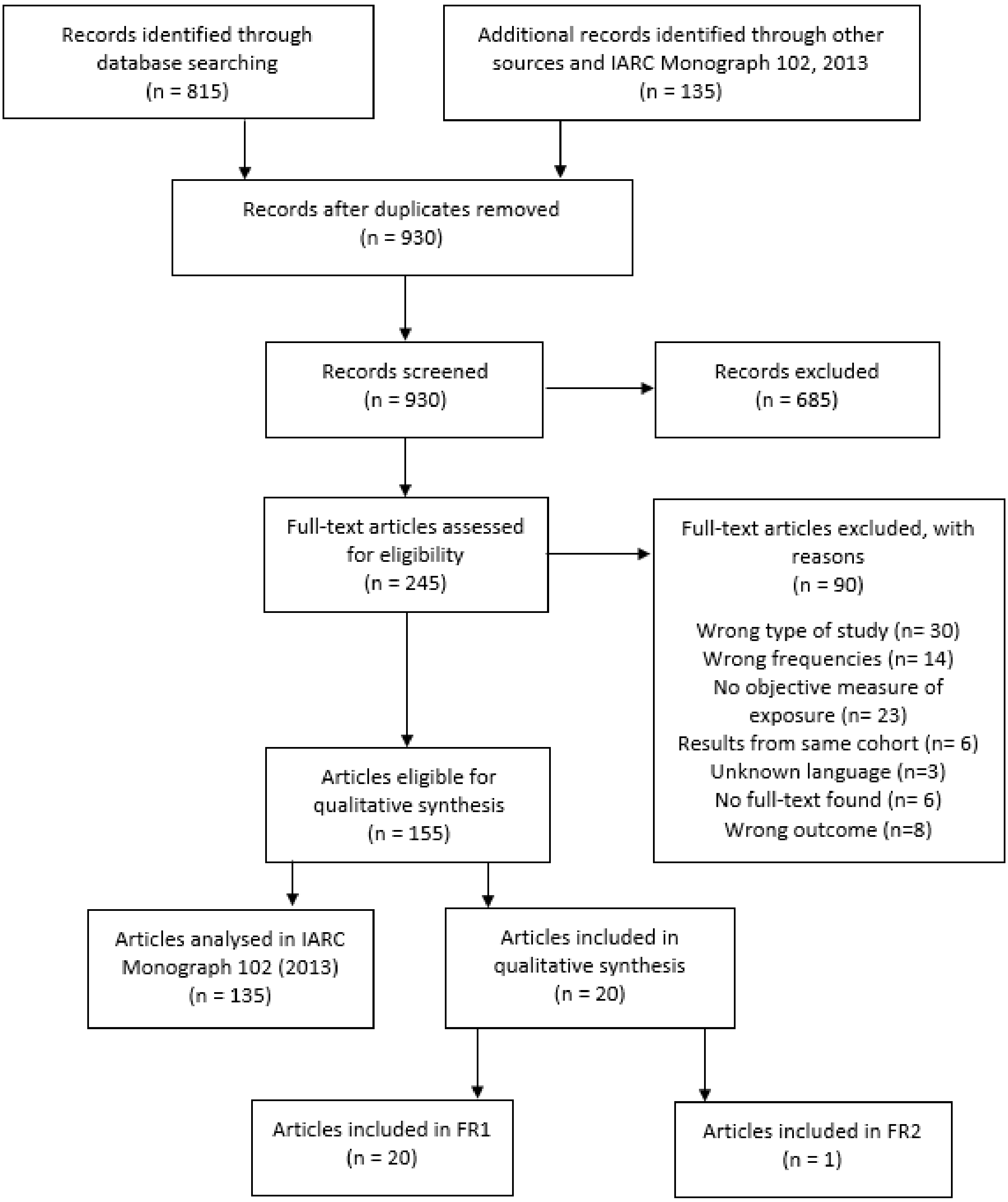
As further explained in the methodology section, we considered IARC (2013) as our key reference for all studies published until 2011: all original papers (135) that were included in the IARC monograph were analysed and referenced in this report as well; of course, for this report we considered only the final IARC classification. The remaining 20 articles published after 2011 were included in this scoping review.

At this stage, a separation based on frequency range was also performed: of the 20 papers included, all 20 reported exposures belonging to the band considered in FR1, and one also reported exposures regarding FR2, in particular MMW from occupational exposure to radar.

For each article, the abstract is presented, together with a table summarising the most important information; furthermore, a senior expert evaluated their adequacy for assessing carcinogenic effects (adequate/inadequate), and expressed an overall synthesis of the results (positive/negative/equivocal) following criteria described in the Methodology section.

The flow chart regarding the selection of papers on cancer epidemiological studies for FR1 is presented in Fig. 9.

Figure 9 – Flow diagram. Epidemiological studies on cancer (FR1)



KEY REFERENCE: IARC 2013

The IARC Monograph 102 (IARC, 2013) is the key reference for the present evaluation. In May 2011, after 1 year of preparing and reviewing drafts, 30 scientists from 14 countries met at the International Agency for Research on Cancer (IARC) in Lyon, France, to assess the carcinogenicity of radiofrequency electromagnetic fields (RF-EMF). This assessment was published as Volume 102 of the IARC Monographs (IARC, 2013). Epidemiological evidence for an association between RF-EMF and cancer comes from cohort, case-control, and time-trend studies. The populations in these studies were exposed to RF-EMF in occupational settings, from sources in the general environment, and from use of wireless (mobile and cordless) telephones, which is the most extensively studied exposure source.

One cohort study (Schüz et al., 2006) and five case-control studies (Muscat et al., 2000; Inskip et al., 2001; Auvinen et al., 2002; INTERPHONE Study Group, 2010; Hardell et al., 2011) were judged by the Working Group to offer potentially useful information regarding associations between use of wireless phones and glioma.

Although both the INTERPHONE study and the Swedish pooled analysis are susceptible to bias—due to recall error and selection for participation— the Working Group concluded that the findings could not be dismissed as reflecting bias alone, and that a causal interpretation between mobile phone RF-EMF exposure and glioma is possible. A similar conclusion was drawn for acoustic neuroma, although the case numbers were substantially smaller than for glioma. Additionally, a study from Japan (Sato et al., 2011) found some evidence of an increased risk of acoustic neuroma associated with ipsilateral mobile phone use.

For meningioma, parotid-gland tumours, leukaemia, lymphoma, and other tumour types, the Working Group found the available evidence insufficient to reach a conclusion on the potential association with mobile phone use. Epidemiological studies of individuals with potential occupational exposure to RF-EMF have investigated brain tumours, leukaemia, lymphoma, and other types of malignancy including uveal melanoma, and cancers of the testis, breast, lung, and skin. The Working Group noted that the studies had methodological limitations and the results were inconsistent. In reviewing studies that addressed the possible association between environmental exposure to RF-EMF and cancer, the Working Group found the available evidence insufficient for any conclusion.The Working Group concluded that there is "*limited evidence in humans*" for the carcinogenicity of RFEMF, based on positive associations between glioma and acoustic neuroma and exposure to RF-EMF from wireless phones.

At that time, a few members of the Working Group considered the current evidence in humans "inadequate". In their opinion there was inconsistency between the two case-control studies and a lack of an exposure-response relationship in the INTERPHONE study results; no increase in rates of glioma or acoustic neuroma was seen in the Danish cohort study (Shuz et al., 2006) and up to that time, reported time trends in incidence rates of glioma had not shown a parallel with time trends in mobile phone use (Baan et al., 2011).

REVIEW OF EPIDEMIOLOGICAL STUDIES 2011-2020

Starting from 2011, the present review evaluates by type of study and by year of publication (2011-2020) the epidemiological studies also summarized in Tables 1-4. The author adds to short abstracts her own brief comments on the results of the different studies.

CASE-CONTROL STUDIES (Tables 1, a-m)

1. Aydin et al., 2011.

Denmark, Sweden, Norway, and Switzerland. 2004-2008.CEFALO multicenter case-control study.

Mobile phone use association with brain tumour risk among children and adolescents is studied. CEFALO is a multicenter case-control study conducted in Denmark, Sweden, Norway, and Switzerland that includes all children and adolescents aged 7-19 years who were diagnosed with a brain tumour between 2004 and 2008. Interviews, in person, with 352 case patients (participation rate: 83%) and 646 control subjects (participation rate: 71%) and their parents. Control subjects were randomly selected from population registries and matched by age, sex, and geographical region. We asked about mobile phone use and included mobile phone operator records when available. Odds ratios (ORs) for brain tumour risk and 95% confidence intervals (CIs) were calculated using conditional logistic regression models. Regular users of mobile phones were not statistically significantly more likely to have been diagnosed with brain tumours compared with nonusers (OR = 1.36; 95% CI = 0.92 to 2.02). Children who started to use mobile phones at least 5 years ago were not at increased risk compared with those who had never regularly used mobile phones (OR = 1.26, 95% CI = 0.70 to 2.28). In a subset of study participants for whom operator recorded data were available, brain tumour risk was related to the time elapsed since the mobile phone subscription was started but not to amount of use. No increased risk of brain tumours was observed for brain areas receiving the highest amount of exposure. The absence of an exposure-response relationship either in terms of the amount of mobile phone use or by localisation of the brain tumour argues against a causal association.

Comment*: *Extent of exposure not assessed. The study was not statistically powered to detect small risk increases. Several RR increased in highest exposure category, albeit not statistically significant.

2. Atzmon et al., 2012.

Israel, diagnosis between 1989 and 2007. Population-based case control study.

The study was initiated to examine the claims of the residents of the Druze Isifya Village in Northern Israel that their high cancer rates were associated with past exposures to radiation from radio and cellular transmitters.To investigate the association between past exposure to RF/MW transmitters and cancer risks, familial cancer history and occupational exposures and indicators of life-style were taken into account; a population-based case-control study involved 307 residents, of whom 47 were diagnosed between 1989 and 2007 with different types of cancer and 260 controls. Cancer diagnoses were obtained from medical records. Exposure status of individual houses was determined from a map, based on the distances between each house and RF/MW antennas, and calculated using geographic information systems (GIS). Data on additional risk factors for cancer, like smoking and occupation, were obtained from individual questionnaires. The analysis was adjusted for measures of life style and occupational exposure, and Binary multiple logistic regressions was used, for all cancer sites and for individual cancer types for those cancers with at least 5 documented cases. Past occupational exposures to chemicals (e.g., pesticides) and electronics, were found to be strongly associated with increased cancer risks (all sites: OR=2.79; CI=1.14-6.82; P<0.05), but no discernible trend in overall cancer risk was associated with proximity to sources of past RF/MW radiation exposure (n=47 OR=1.00; CI=0.99-1.02; P>0.4). Colorectal cancer showed a negligible elevated adjusted risk associated with radiation intensity (n=11 OR=1.03; CI=1.01-1.05; P<0.01). There was evidence for an increased risk of cancers which were associated with chemicals in manufacturing and agriculture and electronics, where there may have been exposure to EMF, but the study did not confirm the suspicion of increased cancer risks associated with radiation for most cancer types in this village. Misclassification of past exposures could explain the negative finding.

Comment*: *No appropriate measurement of RF radiation was provided. Results inconclusive.

3. Li et al., 2012.

Taiwan, 1998-2007. Population-based case–control study (childhood neoplasms).

This population-based case-control study in Taiwan considered incident cases aged 15 years or less and admitted from 2003 to 2007 for all neoplasms (ICD-9-CM: 140-239) (n=2606), including 939 leukemia and 394 brain neoplasm cases. Controls were randomly selected, with a case/control ratio of 1:30 and matched by year of birth, from all non-neoplasm children insured in the same year when the index case was admitted. Annual summarized power (ASP, watt-year) was calculated for each of the 71,185 mobile phone base stations (MPBS) in service between 1998 and 2007. Then, the annual power density (APD, watt-year/km(2)) of each township (n=367) was computed as a ratio of the total ASP of all MPBS in a township to the area of that particular township. Exposure of each study subject to radio frequency (RF) was indicated by the averaged APD within 5 years prior to the neoplasm diagnosis (cases) or July 1st of the year when the index case was admitted (controls) in the township where the subject lived. An unconditional logistic regression model with a generalized estimation equation was employed to calculate the covariate-adjusted odds ratio [AOR] of childhood neoplasm in relation to RF exposure. A higher than median averaged APD (approximately 168 WYs/km(2)) was significantly associated with an increased AOR for all neoplasms (1.13; 1.01 to 1.28), but not for leukaemia (1.23; 0.99 to 1.52) or brain neoplasm (1.14, 0.83 to 1.55). This study noted a significantly increased risk of all neoplasms in children with higher-than-median RF exposure to MPBS. The slightly elevated risk was seen for leukaemia and brain neoplasm, but was not statistically significant. These results may occur due to several methodological limitations.

Comment: The authors admit several methodological limitation. Inconclusive study.

4. Soderqvist et al., 2012.

Sweden, 2000-2003. Case–control study.

The objective of this case-control study was to assess whether the use of wireless phones is associated with an increased risk of tumour at this site. Sixty-nine patients with salivary gland tumours (63 with a parotid gland tumour) and 262 randomly recruited controls were included. Unconditional logistic regression - adjusted for age at diagnosis, sex, year of diagnosis and socioeconomic index - was used to produce odds ratios and 95% confidence intervals. The use of wireless phones was not associated with an overall increased risk of salivary gland tumours, odds ratio 0.8, 95% confidence interval 0.4-1.5. Neither was there an increased risk for the different phone types when calculated separately nor was there an increased risk for different latencies or when cumulative use was divided into three groups (1-1000, 1001-2000 and >2000 h). The overall results were similar for the risk of parotid gland tumours. In conclusion, our data add to the evidence against there being an increased risk for parotid gland tumours associated with light-to-moderate use of wireless phones and for less than 10 years of use but offers little information on risk related to more prolonged and/or heavy use.

Comment: Self-reported exposure from postal questionnaire. Any association for parotid gland tumours and light-to-moderate use of mobile phone.

5. Carlberg et al., 2013.

Sweden, 2007-2009. Case-control study.

The association between use of wireless phones and meningioma is studied. A case–control study on brain tumour cases of both genders aged 18–75 years and diagnosed during 2007–2009 is performed. One population-based control matched on gender and age was used to each case. Here we report on meningioma cases including all available controls. Exposures were assessed by a questionnaire. Unconditional logistic regression analysis was performed. In total 709 meningioma cases and 1,368 control subjects answered the questionnaire. Mobile phone use in total produced odds ratio (OR) = 1.0, 95% confidence interval (CI) = 0.7-1.4 and cordless phone use gave OR = 1.1, 95% CI = 0.8-1.5. The risk increased statistically significant per 100 h of cumulative use and highest OR was found in the fourth quartile (>2,376 hours) of cumulative use for all studied phone types. There was no statistically significant increased risk for ipsilateral mobile or cordless phone use, for meningioma in the temporal lobe or per year of latency. Tumour volume was not related to latency or cumulative use in hours of wireless phones. No conclusive evidence of an association between use of mobile and cordless phones and meningioma was found. An indication of increased risk was seen in the group with highest cumulative use but was not supported by statistically significant increasing risk with latency. Results for even longer latency periods of wireless phone use than in this study are desirable.

Comment*: *Self-reported exposure. No conclusive association for meningioma and use of mobile phone was found.

6. Hardell et al., 2013a.

Sweden, 2007-2009. Case-control study.

Previous studies have shown a consistent association between long-term use of mobile and cordless phones and glioma and acoustic neuroma, but not for meningioma. The aim of this study was to further explore the relationship between especially long-term (>10 years) use of wireless phones and the development of malignant brain tumours. A new case-control study of brain tumour cases of both genders aged 18-75 years and diagnosed during 2007-2009 was conducted. One population-based control matched on gender and age (within 5 years) was used in each case. Malignant cases including all available controls are reported. Exposures on e.g. use of mobile phones and cordless phones were assessed by a self-administered questionnaire. An unconditional logistic regression analysis was performed, adjusting for age, gender, year of diagnosis and socio-economic index using the whole control sample. Of the cases with a malignant brain tumour, 87% (n=593) participated, and 85% (n=1,368) of controls in the whole study answered the questionnaire. The odds ratio (OR) for mobile phone use of the analogue type was 1.8, 95% confidence interval (CI)=1.04-3.3, increasing with >25 years of latency (time since first exposure) to an OR=3.3, 95% CI=1.6-6.9. Digital 2G mobile phone use rendered an OR=1.6, 95% CI=0.996-2.7, increasing with latency >15-20 years to an OR=2.1, 95% CI=1.2-3.6. The results for cordless phone use were OR=1.7, 95% CI=1.1-2.9, and, for latency of 15-20 years, the OR=2.1, 95% CI=1.2-3.8. Few participants had used a cordless phone for >20-25 years. Digital type of wireless phones (2G and 3G mobile phones, cordless phones) gave increased risk with latency >1-5 years, then a lower risk in the following latency groups, but again increasing risk with latency >15-20 years. Ipsilateral use resulted in a higher risk than contralateral mobile and cordless phone use. Higher ORs were calculated for tumours in the temporal and overlapping lobes. Using the meningioma cases in the same study as the reference entity gave somewhat higher ORs indicating that the results were unlikely to be explained by recall or observational bias. These findings provide support for the hypothesis that RF-EMFs play a role in both the initiation and promotion stages of carcinogenesis.

Comment*: *Self-reported exposure. This study confirms previous results of an association between heavy mobile and cordless phone use and malignant brain tumours.

7. Hardell et al., 2013b, Hardell and Carlberg, 2015.

Sweden, 1997-2003 and 2007-2009. Case-control study.

A case-control study of acoustic neuroma was previously conducted by the authors. Subjects of both genders aged 20-80 years, diagnosed during 1997-2003 in parts of Sweden, were included, and the results were published. A further study for the time period 2007-2009 including both men and women aged 18-75 years selected from throughout the country was performed. Similar methods were used for both study periods. In each, one population-based control, matched on gender and age (within five years), was identified from the Swedish Population Registry. Exposures were assessed by a self-administered questionnaire supplemented by a phone interview. Since the number of acoustic neuroma cases in the new study was low, pooled results from both study periods based on 316 participating cases and 3,530 controls were presented. An unconditional logistic regression analysis was performed, adjusting for age, gender, year of diagnosis and socio-economic index (SEI). Use of mobile phones of the analogue type gave odds ratio (OR) = 2.9, 95% confidence interval (CI) = 2.0-4.3, increasing with >20 years latency (time since first exposure) to OR = 7.7, 95% CI = 2.8-21. Digital 2G mobile phone use gave OR = 1.5, 95% CI = 1.1-2.1, increasing with latency >15 years to an OR = 1.8, 95% CI = 0.8-4.2. The results for cordless phone use were OR = 1.5, 95% CI = 1.1-2.1, and, for latency of >20 years, OR = 6.5, 95% CI = 1.7-26. Digital type wireless phones (2G and 3G mobile phones and cordless phones) gave OR = 1.5, 95% CI = 1.1-2.0 increasing to OR = 8.1, 95% CI = 2.0-32 with latency >20 years. For total wireless phone use, the highest risk was calculated for the longest latency time >20 years: OR = 4.4, 95% CI = 2.2-9.0. Several of the calculations in the long latency category were based on low numbers of exposed cases. Ipsilateral use resulted in a higher risk than contralateral for both mobile and cordless phones. OR increased per 100 h cumulative use and per year of latency for mobile phones and cordless phones, though the increase was not statistically significant for cordless phones. The percentage tumour volume increased per year of latency and per 100 h of cumulative use, statistically significant for analogue phones. This study confirmed previous results demonstrating an association between mobile and cordless phone use and acoustic neuroma.

A pooled analysis was performed of two case-control studies on malignant brain tumours with patients diagnosed during 1997–2003 and2007–2009. They were aged 20–80 years and 18–75 years, respectively, at the time of diagnosis. Only cases with histopathological verificationof the tumour were included. Population-based controls, matched on age and gender, were used. Exposures were assessed by questionnaire.The whole reference group was used in the unconditional regression analysis adjusted for gender, age, year of diagnosis, and socio-economicindex. In total, 1498 (89%) cases and 3530 (87%) controls participated. Mobile phone use increased the risk of glioma, OR = 1.3, 95%CI = 1.1–1.6 overall, increasing to OR = 3.0, 95% CI = 1.7–5.2 in the >25 year latency group. Use of cordless phones increased the risk toOR = 1.4, 95% CI = 1.1–1.7, with highest risk in the >15–20 years latency group yielding OR = 1.7, 95% CI = 1.1–2.5. The OR increasedstatistically significant both per 100 h of cumulative use, and per year of latency for mobile and cordless phone use. Highest ORs overall werefound for ipsilateral mobile or cordless phone use, OR = 1.8, 95% CI = 1.4–2.2 and OR = 1.7, 95% CI = 1.3–2.1, respectively. The highest riskwas found for glioma in the temporal lobe. First use of mobile or cordless phone before the age of 20 gave higher OR for glioma than in laterage groups.

***Comment*: Self-reported exposure.These studies confirm previous results demonstrating an association between heavy mobile and cordless phone use, with acoustic neuroma and glioma.**

8. Coureau et al., 2014.

France. 2004-2006. CERENAT. Case-control study.

The objective was to analyse the association between mobile phone exposure and primary central nervous system tumours (gliomas and meningiomas) in adults. CERENAT is a multicenter case-control study carried out in four areas in France in 2004-2006. Data about mobile phone use were collected through a detailed questionnaire delivered in a face-to-face manner. Conditional logistic regression for matched sets was used to estimate adjusted ORs and 95% CIs. A total of 253 gliomas, 194 meningiomas and 892 matched controls selected from the local electoral rolls were analysed. No association with brain tumours was observed when comparing regular mobile phone users with non-users (OR=1.24; 95% CI 0.86 to 1.77 for gliomas, OR=0.90; 95% CI 0.61 to 1.34 for meningiomas). However, the positive association was statistically significant in the heaviest users when considering life-long cumulative duration (≥896 h, OR=2.89; 95% CI 1.41 to 5.93 for gliomas; OR=2.57; 95% CI 1.02 to 6.44 for meningiomas) and number of calls for gliomas (≥18,360 calls, OR=2.10, 95% CI 1.03 to 4.31). Risks were higher for gliomas, temporal tumours, occupational and urban mobile phone use. These additional data support previous findings concerning a possible association between heavy mobile phone use and brain tumours.

***Comment*: Self reported exposure with face to face interview by trained personel.This study confirms previous results of a possible association between heavy mobile phone use and malignant brain tumours.**

9. Pettersson et al., 2014.

Sweden, 2002-2007. Population-based case-control study.

A population-based, nation-wide, case-control study of acoustic neuroma in Sweden was conducted. Eligible cases were persons aged 20 to 69 years, who were diagnosed between 2002 and 2007. Controls were randomly selected from the population registry, matched on age, sex, and residential area. Postal questionnaires were completed by 451 cases (83%) and 710 controls (65%). Ever having used mobile phones regularly (defined as weekly use for at least 6 months) was associated with an odds ratio (OR) of

1.18 (95% confidence interval = 0.88 to 1.59). The association was weaker for the longest induction time (≥10 years) (1.11 [0.76 to 1.61]) and for regular use on the tumour side (0.98 [0.68 to 1.43]). The OR for the highest quartile of cumulative calling time (≥680 hours) was 1.46 (0.98 to 2.17). Restricting analyses to histologically confirmed cases reduced all ORs; the OR for ≥680 hours was 1.14 (0.63 to 2.07). A similar pattern was seen for cordless land-line phones, although with slightly higher ORs. Analyses of the complete history of laterality of mobile phone revealed considerable bias in laterality analyses. The findings do not support the hypothesis that long-term mobile phone use increases the risk of acoustic neuroma. The study suggests that phone use might increase the likelihood that an acoustic neuroma case is detected and that there could be bias in the laterality analyses performed in previous studies

Comment: Self-reported exposure. Weak evidence of association between heavy mobile phone use and acoustic neuroma.

10. Yoon et al., 2015.

Korea; 2002- 2007; case- control study.

Study methods were based on the International Interphone study that aimed to evaluate possible adverse effects of mobile phone use. This study included 285 histologically-confirmed Korean patients 15 to 69 years of age, with gliomas diagnosed between 2002 and 2007 in 9 hospitals. The 285 individually matched controls were healthy individuals that had their medical check-up in the same hospitals. Unconditional logistic regression was used to calculate the adjusted odds ratios (aORs) and 95% confidence intervals (CIs) for use of mobile phones. For the entire group, no significant relationship was investigated between gliomas and regular use of mobile phones, types of mobile phones, lifetime years of use, monthly service fee, and the other exposure indices. Analyses restricted to self-respondents showed similar results. For ipsilateral users, whose body side for usual mobile phone use matched the location of glioma, the aORs (95% CIs) for lifetime years of use and cumulative hours of use were 1.25 (0.55 to 2.88) and 1.77 (0.32 to 1.84), respectively. However, contralateral users showed a slightly lower risk than ipsilateral users. Results do not support the hypothesis that the use of mobile phones increases the risk of glioma; however, we found a non-significant increase in risk among ipsilateral users. These findings suggest further evaluation for glioma risk among long-term mobile phone users.

Comment: Self reported exposure. Weak evidence of association between mobile phone use and brain tumour is found among ipsilateral users.

11. Al-Qahtani, 2016.

Saudi Arabia; 1996-2013; Retrospective case-control study.

A total of 26 patients diagnosed with parotid gland tumours and 61 healthy controls were enrolled through a hospital-based retrospective case-control study. The patients were referred and admitted to a tertiary hospital from January 1996 to March 2013. The Odds of exposure were 3.47 times higher among patients compared to their controls. 95% CI suggested that the true Odds Ratio (OR) at the population level could be somewhere between 1.3 and 9.23 and so the observed OR was statistically significant at 5% level of significance. Overall, an association between the exposure of cellular phone use for more than 1 hour daily and parotid tumour was observed. This association should be interpreted with caution because of the relatively small sample size.

Comment: Small sample size; poor methodology. Inconclusive study.

12. Satta et al., 2018.

Italy; 1998–2004; Population-based case-control study as part of the European multicenter study EPILYMPH.

A case-control study comprised of 322 patients and 444 individuals serving as controls in Sardinia, Italy in 1998-2004. Questionnaire information included the self-reported distance of the three longest held residential addresses from fixed radio-television transmitters and mobile phone base stations. For each address within a 500-meter radius from a mobile phone base station, RF-EMF intensity using predictions from spatial models was estimated, and RF-EMF measurements performed at the door in the subset of the longest held addresses within a 250-meter radius. Risk of lymphoma and its major subtypes associated with the RF-EMF exposure metrics with unconditional logistic regression, adjusting by age, gender and years of education. Risk associated with residence in proximity (within 50 meters) to fixed radio-television transmitters was likewise elevated for lymphoma overall [odds ratio = 2.7, 95% confidence interval = 1.5-4.6], and for the major lymphoma subtypes. With reference to mobile phone base stations, the authors did not observe an association with either the self-reported, or the geocoded distance from mobile phone base stations. RF-EMF measurements did not vary by case-control status. By comparing the self-reports to the geocoded data, cases tended to underestimate the distance from mobile phone base stations differentially from the controls (P = 0.073). The interpretation of findings is compromised by the limited study size, particularly in the analysis of the individual lymphoma subtypes, and the unavailability of the spatial coordinates of radio-television transmitters. Nonetheless, our results do not support the hypothesis of a link between environmental exposure to RF-EMF from mobile phone base stations and risk of lymphoma subtypes.

***Comment*: Limited study size, exposure assessment unclear (far field, radiobase-stations). The study does not support the hypothesis of a link between environmental exposure to RF-EMF from mobile phone base stations and risk of lymphoma subtypes.**

13. Balekouzou et al., 2017.

Central Africa. Case- control study.

Breast cancer is recognized as a major public health problem in developing countries; however, there is very little evidence of behavioral factors associated with breast cancer risk. This study was conducted to identify lifestyles as risk factors for breast cancer among Central African women. A case-control study was conducted with 174 cases confirmed histologically by the pathology unit of the National Laboratory and 348 age-matched controls. Data collection tools included a questionnaire with interviews and medical records of patients. Data were analyzed using SPSS software version 20. Odd ratio (OR) and 95% confidence intervals (95% CI) were obtained by unconditional logistic regression. In total, 522 women were studied with a mean age of 45.8 (SD = 13.4) years. By unconditional logistic regression model, women with breast cancer were more likely to have attained illiterate and elementary education level [11.23 (95% CI, 4.65±27.14) and 2.40 (95% CI, 1.15±4.99)], married [2.09 (95% CI, 1.18±3.71)], positive family history [2.31 (95% CI, 1.36±3.91)], radiation exposure [8.21 (95% CI, 5.04±13.38)], consumption charcuterie [10.82 (95% CI, 2.39±48.90)], fresh fish consumption [4.26 (95% CI, 1.56±11.65)], groundnut consumption [6.46 (95% CI, 2.57± 16.27)], soybean consumption [16.74 (95% CI, 8.03±39.84)], alcohol [2.53 (95% CI, 1.39± 4.60)], habit of keeping money in bras[3.57 (95% CI, 2.24±5.69)], overweight [5.36 (95% CI, 4.46±24.57)] and obesity [3.11(95% CI, 2.39±20.42)]. However, decreased risk of breast cancer was associated with being employed [0.32 (95% CI, 0.19±0.56)], urban residence [0.16 (95% CI, 0.07±0.37)], groundnut oil consumption [0.05 (95% CI, 0.02±0.14)], wine consumption [0.16 (95% CI, 0.09±0.26)], non habit of keeping cell phone in bras [0.56 (95% CI, 0.35±0.89)] and physical activity [0.71(95% CI, 0.14±0.84)]. The study showed that little or no education, marriage, positive family history of cancer, radiation exposure, charcuterie, fresh fish, groundnut, soybean, alcohol, habit of keeping money in bras, overweight and obesity were associated with breast cancer risk among Central African women living in Bangui. Women living in Bangui should be more cautious on the behavioral risk associated with breast cancer.

***Comment*: Limitations in self reporting of data. Many confounders. Any conclusive finding for an association beetween keeping cell phone in bras and mammary cancer.**

14. Vila et al., 2018.

Australia, Canada, France, Germany, Israel, New Zealand and the United Kingdom; 2000-2004; INTEROCC study: international case-control study on mobilephone use and brain cancer risk in seven countries.

This study examines the relation between occupational RF and intermediate frequency (IF) EMF exposure and brain tumour (glioma and meningioma) risk in the INTEROCC multinational population-based case-control study (with nearly 4000 cases and over 5000 controls), using a novel exposure assessment approach. Individual indices of cumulative exposure to RF and IF-EMF (overall and in specific exposure time windows) were assigned to study participants using a source-exposure matrix and detailed interview data on work with or nearby EMF sources. Conditional logistic regression was used to investigate associations with glioma and meningioma risk. Overall, around 10% of study participants were exposed to RF while only 1% were exposed to IF-EMF. There was no clear evidence for a positive association between RF or IF-EMF and the brain tumours studied, with most results showing either no association or odds ratios (ORs) below 1.0. The largest adjusted ORs were obtained for cumulative exposure to RF magnetic fields (as A/m-years) in the highest exposed category (≥90th percentile) for the most recent exposure time window (1-4 years before the diagnosis or reference date) for both glioma, OR = 1.62 (95% confidence interval (CI): 0.86, 3.01) and meningioma (OR = 1.52, 95% CI: 0.65, 3.55). Despite the improved exposure assessment approach used in this study, no clear associations were identified. However, the results obtained for recent exposure to RF electric and magnetic fields are suggestive of a potential role in brain tumour promotion/progression and should be further investigated.

Comment: Study suggestive of a potential role in brain tumour promotion/progression.

15. Luo et al., 2019.

USA. 2010-2011. Population-based case-control study.

This study aims to investigate the association between cell phone use and thyroid cancer. A population-based case-control study was conducted in Connecticut between 2010 and 2011 including 462 histologically confirmed thyroid cancer cases and 498 population-based controls. Multivariate unconditional logistic regression was used to estimate odds ratios (OR) and 95% confidence intervals (95% CI) for associations between cell phone use and thyroid cancer. Cell phone use was not associated with thyroid cancer (OR: 1.05, 95% CI: 0.74–1.48). A suggestive increase in risk of thyroid microcarcinoma (tumour size ≤10mm) was observed for long-term and more frequent users. Compared to cell phone non-users, several groups had nonstatistically significantly increased risk of thyroid microcarcinoma: individuals who had used a cell phone >15 years (OR: 1.29, 95% CI: 0.83–2.00), who had used a cell phone >2 hours per day (OR: 1.40, 95% CI: 0.83–2.35), who had the most cumulative use hours (OR: 1.58, 95% CI: 0.98–2.54), and who had the most cumulative calls (OR: 1.20, 95% CI: 0.78–1.84) Cumulative cell phone use was estimated by multiplying cell phone use hours or calls per day with the duration of use. Each variable was categorized into tertiles based on its distribution among controls.. This study found no significant association between cell phone use and thyroid cancer. A suggestive elevated risk of thyroid microcarcinoma associated with long-term and more frequent uses warrants further investigation.

Comment: Self reported exposure. No significant association was found, but a suggestive elevated risk of thyroid microcarcinoma associated with long-term and more frequent users.

ECOLOGICAL STUDIES (Table 2, a)

16. Gonzalez Rubio et al., 2017.

Spain. 2012-2015. Case-control ecological study.

This paper presents the results of a preliminary epidemiological study, combining Epidemiology, Statistics and Geographical Information Systems (GIS), in which the correlation between exposure to RF-EMF in the city of Albacete (166,000 inhabitants, southeast Spain) and the incidence of several cancers with unspecific causes (lymphomas, and brain tumours) are analysed. Statistical tools to analyze the spatial point patterns and aggregate data so as to study the spatial randomness and to determine the zones with the highest incidence from 95 tumours studied (65 lymphomas, 12 gliomas and 18 meningiomas) were used. A correlation (Spearman) study between the personal exposure to RF-EMF in 14 frequency bands, recorded by an EME Spy 140 (Satimo) exposimeter in the city's administrative regions, and the incidence of the tumours registered from January 2012 to May 2015. The cancer cases studied have a random spatial distribution inside the city. On the other hand, and by means of an ecological study, the exposure to RF-EMF registered in the city of Albacete shows little correlation with the incidence of the tumours studied (gliomas (ρ=0.15), meningiomas (ρ=0.19) and lymphomas (ρ=-0.03)). The proposed methodology inaugurates an unexplored analysis path in this field.

***Comment*: *Little correlation between environmental exposure to RF-EMF and glioma, meningioma and lymphomas. Exposure assessment not clear*.**

COHORT STUDIES (Tables 3, a-d)

17. Frei et al., 2011.

Denmark. Subscribers and non-subscribers of mobile phones before 1995.

All Danes aged ≥30 and born in Denmark after 1925, subdivided into subscribers and non-subscribers of mobile phones before 1995. Main outcome measures Risk of tumours of the central nervous system, identified from the complete Danish Cancer Register. Sex specific incidence rate ratios estimated with log linear Poisson regression models adjusted for age, calendar period, education, and disposable income. Results 358,403 subscription holders accrued 3.8 million person years. In the follow-up period 1990-2007, there were 10,729 cases of tumours of the central nervous system. The risk of such tumours was close to unity for both men and women. When restricted to individuals with the longest mobile phone use—that is, ≥13 years of subscription—the incidence rate ratio was 1.03 (95% confidence interval 0.83 to 1.27) in men and 0.91 (0.41 to 2.04) in women. Among those with subscriptions of ≥10 years, ratios were 1.04 (0.85 to 1.26) in men and 1.04 (0.56 to 1.95) in women for glioma and 0.90 (0.57 to 1.42) in men and 0.93 (0.46 to 1.87) in women for meningioma. There was no indication of dose-response relation either by years since first subscription for a mobile phone or by anatomical location of the tumour—that is, in regions of the brain closest to where the handset is usually held to the head. Conclusions In this update of a large nationwide cohort study of mobile phone use, there were no increased risks of tumours of the central nervous system, providing little evidence for a causal association.

Comment*: *Limits in exposure assessment. No increased risks of tumours of the central nervous system.

18. Benson et al., 2013.

UK. Million Women Study. 1999-2005 and 2005-2009. Prospective cohort study.

The relation between mobile phone use and incidence of intracranial central nervous system (CNS) tumours and other cancers was examined in 791,710 middle-aged women in a UK prospective cohort, the Million Women Study. Cox regression models were used to estimate adjusted relative risks (RRs) and 95% confidence intervals (CIs). Women reported mobile phone use in 1999 to 2005 and again in 2009. Results During 7 years' follow-up, 51 680 incident invasive cancers and 1 261 incident intracranial CNS tumours occurred. Risk among ever vs never users of mobile phones was not increased for all intracranial CNS tumours (RR=1.01, 95% CI=0.90–1.14, P=0.82), for specified CNS tumour types nor for cancer at 18 other specified sites. For longterm users compared with never users, there was no appreciable association for glioma (10þ years: RR¼0.78, 95% CI¼0.55–1.10, P¼0.16) or meningioma (10+ years: RR=1.10, 95% CI=0.66–1.84, P=0.71). For acoustic neuroma, there was an increase in risk with long term use vs never use (10+ years: RR=2.46, 95% CI=1.07– 5.64, P=0.03), the risk increasing with duration of use (trend among users, P=0.03). Conclusions In this large prospective study, mobile phone use was not associated with increased incidence of glioma, meningioma or non-CNS cancers.

Comment: Self reported exposure. For acoustic neuroma, there was an increase in risk with long term use vs never use; the risk increasing with duration of use.

19. Poulsen et al., 2013.

Denmark, 1982-1995, follow up until 2007. Cohort study: CANULI study of social inequality and cancer incidence and survival.

In a nationwide cohort study, 355,701 private mobile phone subscribers in Denmark from 1987 to 1995 were followed up through 2007. We calculated incidence rate ratios (IRRs) for melanoma, basal cell carcinoma, and squamous cell carcinoma by using Poisson regression models adjusted for age, calendar period, educational level, and income. Separate IRRs for head/neck tumours and torso/leg tumours were compared (IRR ratios) to further address potential confounders. We observed no overall increased risk for basal cell carcinoma, squamous cell carcinoma, or melanoma of the head and neck. After a follow-up period of at least 13 years, the IRRs for basal cell carcinoma and squamous cell carcinoma remained near unity. Among men, the IRR for melanoma of the head and neck was 1.20 (95% confidence interval: 0.65, 2.22) after a minimum 13-year follow-up, whereas the corresponding IRR for the torso and legs was 1.16 (95% confidence interval: 0.91, 1.47), yielding an IRR ratio of 1.04 (95% confidence interval: 0.54, 2.00). A similar risk pattern was seen among women, though it was based on smaller numbers. In this large, population-based cohort study, little evidence of an increased skin cancer risk was observed among mobile phone users.

Comment: Extent of exposure not assessed. Little evidence of an increased skin cancer risk was observed among mobile phone users.

20. Hauri et al., 2014.

Switzerland. 2000-2008. Census-based cohort study (far field, radiobase stations).

The association between exposure to radio-frequency electromagnetic fields (RF-EMFs) from broadcasting transmitters and childhood cancer was investigated. Time-to-event analysis including children under age 16 years living in Switzerland on December 5, 2000 was performed. Follow-up lasted until December 31, 2008. All children living in Switzerland for some time between 1985 and 2008 were included in an incidence density cohort. RF-EMF exposure from broadcasting transmitters was modeled. Based on 997 cancer cases, adjusted hazard ratios in the time-to-event analysis for the highest exposure category (>0.2 V/m) as compared with the reference category (<0.05 V/m) were 1.03 (95% confidence interval (CI): 0.74, 1.43) for all cancers, 0.55 (95% CI: 0.26, 1.19) for childhood leukemia, and 1.68 (95% CI: 0.98, 2.91) for childhood central nervous system (CNS) tumours. Results of the incidence density analysis, based on 4,246 cancer cases, were similar for all types of cancer and leukemia but did not indicate a CNS tumour risk (incidence rate ratio = 1.03, 95% CI: 0.73, 1.46). This large census-based cohort study did not suggest an association between predicted RF-EMF exposure from broadcasting and childhood leukemia. Results for CNS tumours were less consistent, but the most comprehensive analysis did not suggest an association.

Comment: Limits in the assessment of residential exposure. No association between RF-EMF and cancer in children is suggested.

Table 1 – Cancer in epidemiological case-control studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
1. Aydin et al. 2011. Denmark, Sweden, Norway, and Switzerland; 2004-2008; CEFALO-Multicenter case-control study.	352 cases; 646 population-based matched controls (M and F). Age 7-19 years. Data from reports from pediatric, oncology, and neurosurgery departments and from national population-based registries.	Use of mobile phones, assessed by face-to-face interviews with the subjects and their parents.	Mobile phone use.	Intracranial central nervous system tumours..	**Odds ratio (OR) and 95% confidence intervals (95% CI) from conditional logistic regression. Trend from two-sided Wald testOR (95% CI) for brain tumours**	**p-value for trend**	Education, family history of cancer, past medical radiation exposure to the head, maternal smoking during pregnancy, past head injuries, use of baby monitors near the head, use of cordless phones, contact with animals, location where the child lived before age, having siblings, birth weight, born premature, ever doctor-diagnosed asthma, ever doctor-diagnosed atopic eczema, and ever doctor-diagnosed hay fever.	Adequate/ Equivocal (brain tumour) Children and adolescent
			Regular use (at least once per week, > 6 months)					
			No		1.0 (ref.)			
			Yes		1.36 (0.92 -2.02)			
			Time since first use (years)					
			Never regular user		1.0 (ref.)	0.37		
			≤3.3		1.35 (0.89 to 2.04)			
			3.3–5.0		1.47 (0.87 to 2.49)			
			>5.0		1.26 (0.70 to 2.28)			
			Cumulative duration of calls (hours)					
			Never regular user		1.0 (ref.)	0.42		
			≤35		1.33 (0.89 to 2.01)			
			36-144		1.44 (0.85 to 2.44)			
			>144		1.55 (0.86 to 2.82)			

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjustments	Comments
2. Atzmon et al 2012. Israel, diagnosis between 1989 and 2007. Population-based case-control study/ The present analysis is a retrospective follow up study at diagnosis.	307 subjects, of whom 47 cases (M and F), median age 48. Cases from medical documents with confirmed diagnosis of cancer. Face-to-face interviews in the participant's home.	Exposure to radio and cellular transmitters located in the village prior to 2000. Individual exposure (E) was estimated using the following formula: E=1/D2, where D is distance (in meters) between a house and the closest transmitter.	Individual exposure and years of residence.	Cancer: colorectal (11), breast cancer (10), lymphoma (6), leukemia (3), lungs (2), uterine (2), liver (2), stomach (2), ovarian (2), pancreas (2), prostate (2), cervix (1), brain (1), and bladder (1). Odds ratios and confidence intervals (OR, 95% CI) from binary logistic regression model.	**OR (95% CI), Colorectal**	**OR (95% CI), Lymphoma**	**OR (95% CI), Uterine**	**OR (95% CI), Prostate**	**OR (95% CI), Brain**	Duration of residence in the same house; alcohol consumption; nutritional habits; frequency of physical exercise; use of cellular phones; exposure to wireless equipment in the house; use of oral contraceptives or hormones replacement therapy and income	**Inadequate**
			Radiation intensity		1.03 (1.01-1.05)	0.95 (0.86-1.06)	0.99 (0.91-1.07)	1.67 (0.04-61.04)	12.45 (0.34–453.54)	**No appropriate measurement of RF exposure**	
			Years of exposure to radiation		0.97 (0.877-1.082)	0.95 (0.82-1.11)	1.12 (0.88-1.42)	0.97 (0.86-1.10)	0.96 (0.84–1.11)		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued c)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
3. Li et al. 2012. Taiwan; 2003-2007; Population-based case-control study.	2606 childhood neoplasm cases (M and F), 78180 matched controls (939-28170 for leukemia; 394- 11820 for brain neoplasms). Age < 15 years. Clinical data from the National Health Insurance Research Database (NHIRD).	RF exposure metric was estimated from the averaged Annual Power Density for the five-year period prior to the neoplasm diagnosis in the township where the subject lived at the time of neoplasm diagnosis. Information on MPBS from the Taiwan National Communication Council (NCC).	Exposure to mobile phone base stations (MPBS): 800-900 MHz; 1800-2200 Mhz. Estimate APD	All neoplasms; Leukemia; Brain neoplasms. Odds ratio (OR) and 95% confidence intervals (95% CI) from multiple unconditional logistic regression models	**OR (95% CI) for all neplasms**	**OR (95% CI) for leukemia**	**OR (95% CI) for brain neplasms**	age, gender, calendar year of neoplasm diagnosis, urbanisation level of township, and high-voltage (69/161/345 kV) transmission line (HVTL) density of the township. Limits in exposure assessment	Inadequate
			Level of exposure (compared to median= 167.02 WYs/km2						
			<Median		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			≥Median		1.13 (1.01–1.28)	1.23 (0.99-1.52)	1.14 (0.83-1.55)		
			p-value		0.048	0.052	0.426		
4. Soderqvist et al. 2012. Sweden, 2000-2003. Case–control study.	78 cases; 312 controls (M and F), age 22–80, median 69. Patients were recruited as reported by the Regional Oncology Centre of Uppsala/Orebro and Linkoping, including nine of 21 Swedish counties. Controls were drawn from the population registry at random.	Use of wireless phones, i.e. both mobile and cordless phones. Self-reported exposure from postal questionnaire.	The cumulative number of hours of use was calculated using the number of years and average time used per day. Cumulative hours of use was also divided into three groups, 1–1000, 1001–2000 and more than 2000 h. Use of wireless phones within 1 year before diagnoses were treated as unexposed.	Salivary gland tumour. Odds ratios and 95% confidence intervals from unconditional logistic regression.	**OR (95% CI) for Mobile phones**	**OR (95% CI) for cordless phones**	**OR (95% CI) for wireless phones, total**	No information available Limits in exposure assessment	Inadequate
			Cumulative use (h)						
			Unexposed		1 (Ref.)	1 (Ref.)	1 (Ref.)		
			1–1000		0.9 (0.4–1.7)	0.6 (0.3–1.3)	0.8 (0.5-1.6)		
			1001–2000		0.7 (0.1–3.6)	1.2 (0.2–7.8)	0.7 (0.2–2.7)		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued d)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)				Any Other Co-Exposure/adjustments	Comments
5. Carlberg et al. 2013. Sweden; 2007-2009; Case-control study.	709 cases; 1368 population-based matched controls (M and F). Age 18-75 years. Data from a cancer register.	Use of wireless phones (mobile and cordless phones), assessed by a self-administered structured phone questionnaire.	Mobile phone use (UMTS, 4G); cordless phone use (1900 MHz).	Meningioma. Odds ratio (OR) and 95% confidence intervals (95% CI) from unconditional logistic regression.	**OR (95% CI) for meningioma, Digital (2G)**	**OR (95% CI) for meningioma, Digital (UMTS, 3G)**	**OR (95% CI) for meningioma, Cordless phone**	**OR (95% CI) for meningioma, Digital type**	Gender, age, year of diagnosis, socio-economic index (SEI).	Adequate/ Positive (meningioma)
			Cumulative use of wireless phones (h)							
			<39-405		1.0 (0.7-1.4)	0.7 (0.3-1.3)	1.0 (0.7-1.4)	1.1 (0.8-1.6)		
			406–1091		1.0(0.7-1.5)	0.4 (0.1-1.2)	0.9 (0.6-1.3)	0.9 (0.6-1.3)		
			1092-2376		0.9 (0.6-1.4)	0.6 (0.2-1.8)	1.2 (0.8-1.8)	0.9 (0.6-1.3)		
			>2376		1.5 (0.9-2.3)	7.3 (1.2-46)	1.8 (1.2-2.8)	1.4 (0.96-2.6)		
			P for trend		0.06	0.04	0.0003	0.002		
6. Hardell et al. 2013a. Sweden, 2007-2009. Case-control study.	593 cases, 1368 controls (M and F), age 18-75. Newly diagnosed brain tumour cases from the regional and national Swedish cancer registers. The Swedish Population Registry was used for identification of controls.	Use of wireless phones, i.e. both mobile and cordless phones. Self-reported exposure from self-administered questionnaire supplemented by a phone interview.	Frequency of use; Duration of exposure.	Malignant brain tumours. Odds ratio (OR) and 95% confidence interval (CI) from unconditional logistic regression analysis.	**OR (95% CI) for Mobile phone use (Analogue, 2G, 3G)**	**OR (95% CI) for digital phone use (2G, 3G, cordless)**	**OR (95% CI) for all wireless phones**		Occupational history, exposure to different agents, smoking habits, medical history including hereditary risk factors, and exposure to ionising radiation.	Adequate/ Positive (Malignant brain tumours)
			Frequency of use							
			Non users (<1 years)		1 (Ref.)	1 (Ref.)	1 (Ref.)			
			Users (>1 years)		1.6 (0.99 - 2.7)	1.7 (1.04 - 2.8)	1.7 (1.04 - 2.8)			
			Duration of use (years)							
			1-5		1.8 (1.002 - 3.4)	2.6 (1.4 - 4.9)	2.6 (1.4 - 5.0)			
			5-10		1.7 (0.98 - 2.8)	1.6 (0.9 - 2.7)	1.6 (0.98 - 2.8)			
			10-15		1.3 (0.8 - 2.2)	1.4 (0.8 - 2.3)	1.3 (0.8 - 2.2)			
			15-20		1.5 (0.8 - 2.6)	2.2 (1.3 - 3.6)	1.7 (1.02 - 3.0)			
			20-25		1.9 (1.1 - 3.5)	1.5 (0.5 - 4.6)	1.9 (1.04 - 3.4)			
			>25		2.9 (1.4 - 5.8)	-	3.0 (1.5 - 6.0)			

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued e)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
7. Hardell et al. 2013b and Hardell and Carlberg 2015. Sweden, 1997-2003 and 2007-2009. Pooled case-control study.	316 cases of acoustic neuroma, 3530 controls (M and F), aged 20–80 years (1997–2003) and18–75 years (2007–2009) at the time of diagnosis. Cases reported from cancer registries.	Use of wireless phones, i.e. both mobile and cordless phones. Self-reported exposure from self-administered questionnaire supplemented by a phone interview.		Acoustic neuroma. Odds ratio (OR) and 95% confidence intervals (CI) from unconditional logistic regression analysis.	**OR (95% CI) for Mobile phone use (Analogue, 2G, 3G)**	**OR (95% CI) for digital phone use (2G, 3G, cordless)**	**OR (95% CI) for all wireless phones**	Occupational history, exposure to different agents, smoking habits, medical history including hereditary risk factors, and exposure to ionising radiation.	Adequate/ Positive (acoustic neuroma and glioma)
			Frequency of use						
			Non users (<1 years)		1 (Ref.)	1 (Ref.)	1 (Ref.)		
			Users (>1 years)		1.6 (1.2 - 2.2)	1.5 (1.1 - 2.0)	1.5 (1.1 - 2.0)		
			Duration of use (years)					Positive association in heavy users	
			1-5		1.3 (0.9 - 1.8)	1.4 (1.01 - 1.9)	1.2 (0.8 - 1.6)		
			5-10		2.3 (1.6 - 3.3)	1.6 (1.1 - 2.3)	1.9 (1.3 - 2.7)		
			10-15		2.1 (1.3 - 3.5)	1.6 (0.97 - 2.8)	2.0 (1.3 - 3.2)		
			15-20		2.1 (1.02 - 4.2)	1.1 (0.5 - 2.5)	1.7 (0.9 - 3.3)		
			>20		4.5 (2.1 - 9.5)	8.1 (2.0 - 32)	4.4 (2.2 - 9.0)		
	1380 cases of glioma, 3530 controls (M and F), aged 20–80 years (1997–2003) and18–75 years (2007–2009) at the time of diagnosis. Cases reported from cancer registries.	Use of wireless phones, i.e. both mobile and cordless phones. Self-reported exposure from self-administered mailed questionnaire.		Glioma. Odds ratio (OR) and 95% confidence intervals (CI) from unconditional logistic regression analysis.	**OR (95% CI) for Mobile phone use (Analogue, 2G, 3G)**	**OR (95% CI) for digital phone use (2G, 3G, cordless)**	**OR (95% CI) for all wireless phones**	Occupational history, exposure to different agents, smoking habits, medical history including hereditary risk factors, and exposure to ionising radiation.	)
			Frequency of use						
			Non users (<1 years)		1 (Ref.)	1 (Ref.)	1 (Ref.)		
			Users (>1 years)		1.6 (1.2 - 2.0)	1.3 (1.1- 1.6)	1.3 (1.1- 1.6)		
			Duration of use (years)						
			1-5		1.1 (0.7- 1.7)	1.2 (0.9- 1.4)	1.1 (0.9- 1.4)		
			5-10		1.1 (0.8- 1.6)	1.6 (1.3 - 2.0)	1.5 (1.2- 1.9)		
			10-15		2.2 (1.5 - 3.7)	1.4 (1.1- 1.9)	1.4 (1.1- 1.8)		
			15-20		2.4 (1.5- 3.7)	2.0 (1.5- 2.8)	1.7 (1.2- 2.3)		
			20- 25		3.2 (1.9- 5.5)	1.6 (0.6- 4.4)	1.9 (1.3- 2.9)		
			> 25		4.8 (2.5- 9.1)	-	3.0 (1.7- 5.2)		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued f)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
8. Coureau et al.2014. France. 2004-2006. CERENAT. Case-control study.	596 cases and 1192 controls (M and F) over 16 years of age. Cases identified from populationbased cancer registries. Two controls with no history of CNS tumour were randomly selected from the local electoral rolls matched on age (±2 years), sex and department of residence.	Exposure from mobile phone use. Self-reported exposure from standardised questionnaires delivered as face-to-face non-blinded structured interviews by trained interviewers.	Time since first use (years), Cumulative duration of calls (hours)	Gliomas, meningiomas. Conditional logistic regression for matched sets was used to estimate ORs and 95%Cis	**OR (95% CI) for glioma**	**OR (95% CI) for meningioma**	Level of education, smoking, alcohol consumption. Potential occupational confounders were identified from detailed job calendars, and from specific questions about exposure to pesticides, extremely low-frequency electromagnetic fields (ELF-EMF), RF-EMF, and ionising radiation	Adequate/ Positive (glioma, meningioma)
			Regular mobile phone use					
			Not regular user		1 (Ref.)	1 (Ref.)	Positive association in heavy users	
			Regular user		1.24 (0.86 - 1.77)	0.90 (0.61 - 1.34)		
			Time since first use (years)					
			1-4		0.88 (0.56 - 1.39)	0.79 (0.49 - 1.27)		
			5-10		1.34 (0.87 - 2.06)	0.97 (0.58 - 1.61)		
			>10		1.61 (0.85 - 3.09)	1.57 (0.64 - 3.86)		
			Cumulative duration of calls (hours)					
			<43		0.83 (0.48 - 1.44)	1.12 (0.61 - 2.04)		
			43-112		0.77 (0.42 - 1.41)	0.85 (0.45 - 1.61)		
			113-338		1.07 (0.60 - 1.90)	0.52 (0.25 - 1.07)		
			339-895		1.78 (0.98 - 3.24)	0.52 (0.18 - 1.45)		
			>896		2.89 (1.41 - 5.93)	2.57 (1.02 - 6.44)		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued g)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
9. Pettersson et al. 2014. Sweden, 2002-2007. Population-based case-control study.	422 cases with acoustic neuroma, 643 controls for analyses of mobile phone use. 417 cases with acoustic neuroma, 635 controls for analyses of cordless phone use (M and F), age 20-69 years. Cases identified in clinics, the Swedish Regional Cancer Registers and local acoustic neuroma registries. Two matched controls per case randomly selected from the Swedish population register.	Use of mobile phone and cordless phone . Self-reported exposure from mail questionnaire.	Frequency of use; Duration of exposure; Cumulative hours of use	Acoustic Neuroma. Odds Ratios (OR) with 95% CIs from conditional logistic regression	**OR (95% CI) for Mobile phone users**	**OR (95% CI) for Cordless phone users**	Smoking, education, marital status, and parity; for cordless phone analyses: hands-free use. Limits in exposure assessment. Positive association in heavy users.	Adequate/ Equivocal (Acoustic neuroma)
			Frequency of use					
			Never or rarely		1 (Ref.)	1 (Ref.)		
			Regular use		1.18 (0.88 - 1.59)	1.41 (1.07 - 1.86)		
			Duration of use (years)					
			<5		1.06 (0.73 - 1.54)	1.35 (0.97 - 1.89)		
			5 to 9		1.39 (0.97 - 1.97)	1.74 (1.22 - 2.46)		
			=>10		1.09 (0.75 - 1.59)	1.10 (0.73 - 1.64)		
			Cumulative use (hours)					
			<38		1.09 (0.73 - 1.62)	1.22 (0.82 - 1.82)		
			39-189		1.12 (0.74 - 1.69)	1.27 (0.85 - 1.89)		
			190-679		1.13 (0.75 - 1.70)	1.42 (0.96 - 2.09)		
			=>680		1.46 (0.98 - 2.17)	1.67 (1.13 - 2.49)		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued h)

Study information	Population	Type of Exposure and assessment method		Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)	Any Other Co-Exposure/adjustments	Comments
10 Yoon et al. 2015. Korea; 2002- 2007; case-control study.	285 cases, 285 controls (M and F), mean age 42.3 (±14.1) cases; 42.5 (±14.0) controls. Patients recruited from five areas including Seoul and checked at department of neurosurgery in nine hospitals. The control group persons who received health screenings at the same hospitals.	Exposure from mobile phone use. Self-reported exposure from questionnaires.		Cumulative hours and lifetime years of use; average daily receiving call and the average daily sending call; average call duration time	Glioma; adjusted odds ratios (aORs) and 95% CIs were calculated using logistic regression	**OR (95% CI) for glioma**	adjusted for sex, age, type of respondent, five residential regions, educational achievement, the use of dye, alcohol drinking, the use of computer, and the use of electric blanket	Adequate/ Equivocal (Glioma)
				Use of mobile phone				
				Non users		1 (Ref.)		
				Users		1.17 (0.63 - 2.14)		
				Lifetime years of use (months)				
				< 48		1.28 (0.62 - 2.64)		
				48-84		1.27 (0.63 - 2.56)		
				>48		1.04 (0.52 - 2.09)		
				Cumulative hours of use (h)				
				< 300		1.25 (0.64 - 2.45)		
				300-900		1.59 (0.72 - 3.21)		
				>900		0.64 (0.30 - 1.34)		
				Average duration time (min)				
				<2		1.18 (0.62 - 2.24)		
				3-4		1.31 (0.65 - 2.63)		
				>5		1.00 (0.45 - 2.24)		
11. Al-Qahtani 2016. Saudi Arabia; 1996-2013; Retrospective case-control study.	26 cases, 61 controls (M and F). <30 years: 28; 30-39 years: 23; 40-49 years: 15; >50 years: 21. Hospital records.	Exposure from mobile phone use. Self-reported exposure from telephone and in-person interviews using standardized questionnaire.		Everyday use: <=1 h/day: unexposed; >1 h/day: exposed. Latency: <10 years of use; =>10 years of use	Parotid gland tumour. OR and 95% confidence interval	**OR (95% CI) for parotid gland tumour**	Smoking Other confounding not considered. Small sample.	Inadequate
				Everyday use				
				Non exposed		1 (Ref.)		
				Exposed		3.47 (1.30 - 9.23)		
				Duration of exposure				
				< 10 years		3.6 (0.97 - 13.36)		
				10 years or more		3.46 (0.77 - 15.56)		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued i)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)				Any Other Co-Exposure/adjustments	Comments
12. Satta et al. 2018. Sardinia, Italy; 1998–2004; Population-based case-control study as part of the European multicenter study EPILYMPH.	322 lymphoma cases; 444 matched controls (M and F). Cases aged 25 to 74 years. In person interviews using a standardized questionnaire.	Exposure from radio-television transmitter or mobile phone base station near the three most prolonged residential addresses at any time of the life. Distance used as proxy for intensity of exposure; RF-EMF measurements at the door of the longest residential addresses available for the subset of subjects residing within 250 m of the closest transmitter base station, using a Microrade broadband detector.	Radiofrequency field estimates (V/m):	Lymphoma subtypes: B-cell; T-cell; Hodgkin; not otherwise specified NHL; OR and 95% confidence interval from logistic regression.	**OR for all lymphomas**	**OR for B-cell lymphoma**	**OR for Chronic lymphocytic leukemia**		Age, gender, years of education (categorized as 8 years, 9–13 years, 14 years), level of education and quartiles of vehicular traffic in proximity to the residential addresses of study subjects.	Inadequate
			RF field estimates (V/m):							
			<0.01		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		Uncertain exposure assessment	
			0.01- 1.23		0.7 (0.4 - 1.5)	0.8 (0.4 - 2.0)	1.5 (0.5 - 4.4)			
			1.24- 1.50		0.7 (0.3 - 1.5)	0.9 (0.4 - 2.1)	-			
			1.51- 1.7401		1.0 (0.5 - 2.1)	1.1 (0.5 - 2.7)	0.6 (0.1 - 3.1)			
			>1.7401		1.2 (0.6 - 2.6)	1.4 (0.6 - 3.4)	0.9 (0.2 - 4.6)			
13. Balekouzou et al. 2017. Central African Republic; 2003-2015; Case-control study.	174 cases; 348 age-matched controls (F). Age >15 years. Data from a cancer register.	Use of mobile phones,radiation exposure. Trained interviewers administered a standardized in person interview.	Exposure to radiation; habit to keep mobile phone in the bra.	Breast cancer. Odds ratio (OR) and 95% confidence intervals (95% CI) from unconditional logistic regression.	**OR (95% CI) for Breast cancer, univariate analysis**	**p-value**	**OR (95% CI) for Breast cancer, multivariate analysis**	**p-value**	Age, occupation, economic status, education, residence, ethnic group and marital status, family history, radiation exposure, food consumption, physical activity, alcohol, tobacco, use of bra, habit to keep money or cell phones in bras, height, weight and BMI.	Inadequate
			Daily use (h/day)						Self reported habit to keep mobilphone in the bra	
			No		1.00 (ref.)		1.00 (ref.)			
			Yes		8.02 (5.16-12.47)	0.000	8.21 (5.04 – 13.38)	0.000		
			Habit of keeping cell phone in bras							
			Yes		1.00 (ref.)		1.00 (ref.)			
			No		0.45 (0.31-0.65)	0.000	0.56 (0.35-0.89)	0.01		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued j)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
14. Vila et al. 2018. Australia, Canada, France, Germany, Israel, New Zealand and the United Kingdom; 2000-2004; INTEROCC study: international case-control study on mobilephone use and brain cancer risk in seven countries. "	2054 glioma cases; 1924 meningioma cases; 5601 controls (M and F). Cases aged 30 to 59 years of age; up to 69 years in Germany; 18 years and above in Israel; 18 to 69 years in the United Kingdom. In person computer-assisted personal interview.	Self-reported occupational exposure or proximity to radars, telecommunication antennas, transmitters, equipment for semiconductors manufacturing, medical diagnosis and treatment, industrial heating or food heating. A source-exposure matrix (SEM) was used to assign average exposure levels to each RF and IF source reported. Field intensities for each EMF source were weighted using the frequency-dependent reference levels (RLs) by the International Commission on Non-Ionising Radiation Protection (ICNIRP) for occupational exposure. Frequency of exposure: 10 MHz- 300 GHz.	E-field (V/m, Arithmetic mean exposure levels from the SEM. RF sources organized by E-field exposure level)	Glioma and meningioma risk; adjusted OR and 95% confidence intervals.	**OR (95% CI) for Gliomas**	**OR for Meningiomas**	No information available Study suggestive of a potential role in brain tumour promotion/progression	Adequate/ negative (Glioma and meningioma)
			Duration of exposure: 1-4 years					
			Non exposed		1.00 (ref.)	1.00 (ref.)		
			<0.42		0.69 (0.49 - 0.98)	0.60 (0.38 - 0.96)		
			0.42–4.47		0.85 (0.54 - 1.35)	1.13 (0.60 - 2.14)		
			4.48–18.8		0.77 (0.44 - 1.37)	0.86 (0.35 - 2.13)		
			≥18.9		1.38 (0.75 - 2.54)	1.30 (0.58 - 2.91)		
			Duration of exposure: 5-9 years					
			Non exposed		1.00 (ref.)	1.00 (ref.)		
			<0.42		0.84 (0.61 - 1.17)	0.60 (0.38 - 0.97)		
			0.42–4.47		0.93 (0.60 - 1.44)	1.48 (0.84 - 2.61)		
			4.48–18.8		0.82 (0.46 - 1.47)	1.08 (0.66 - 2.39)		
			≥18.9		0.90 (0.44 - 1.83)	1.03 (0.45 - 2.63)		

Table 1 - Cancer in epidemiological Case-Control studies (450-6000 MHz) (Continued I)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
15. Luo et al. 2019. Connecticut, USA, 2010-2011; population-based case-control study.	462 cases and 498 population-based controls (M and F), 21-84 years of age.	Use of mobile phones,radiation exposure. Trained interviewers administered a standardized and structured questionnaire.	Use of mobile phones; Duration of exposure.	Thyroid cancer (papillary, follicular, medullary, anaplastic). Multivariate unconditional logistic regression to estimate odds ratios (OR) and 95% confidence intervals (95% CI).	**OR (95% CI) for Thyroid cancer, Overall**	**OR (95% CI) for Thyroid cancer, MM**	**OR (95% CI) for Thyroid cancer, FF**	age, sex, education, family history of thyroid cancer, alcohol consumption, body mass index, previous benign thyroid diseases, occupational radiation exposure, and radiation treatment.	Adequate/ Equivocal (Thyroid cancers)
			Use of mobile phone						
			Non users (< 6 months use)		1 (Ref.)	1 (Ref.)	1 (Ref.)		
			Users (< 6 months use)		1.05 (0.74, 1.48)	1.27 (0.62, 2.61)	0.99 (0.66, 1.47)		
			Daily use (h/day)						
			≤1		1.10 (0.72, 1.66)	1.76 (0.72, 4.32)	0.97 (0.60, 1.56)		
			1-2		1.51 (0.90, 2.53)	1.66 (0.57, 4.82)	1.45 (0.79, 2.65)		
			>2		1.40 (0.83, 2.35)	1.05 (0.35, 3.14)	1.52 (0.83, 2.80)		
			Age at first use (years)						
			≤20		1.08 (0.53, 2.20)	1.49 (0.34, 6.01)	0.95 (0.42, 2.18)		
			21-50		1.06 (0.72, 1.55)	1.44 (0.65, 3.17)	0.96 (0.62, 1.49)		
			>50		1.03 (0.62, 1.70)	0.99 (0.36, 2.70)	1.05 (0.58, 1.90)		
			Duration of use (years)						
			≤12		0.99 (0.66, 1.49)	0.99 (0.39, 2.48)	0.97 (0.61, 1.53)		
			12-15		0.94 (0.63, 1.42)	0.82 (0.34, 1.97)	0.97 (0.61, 1.55)		
			>15		1.29 (0.83, 2.00)	2.11 (0.91, 4.89)	1.03 (0.62, 1.73)	Some evidence in long term users	

Table 2 – Cancer in epidemiological ecological case-control studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjust ments	Comments
16. Gonzalez Rubio et al. 2017. Spain. 2012-2015. Case-control ecological study.	95 cases: 65 lymphomas, 12 gliomas, 18 meningiomas (30 brain tumours); 390 anonymous controls (M and F). Resident population data in the 110 administrative districts from the Spain's National Statistics Institute (INE). Addresses for all cancer cases of gliomas, meningiomas and lymphomas from Oncology Service of the University Hospital of Albacete. Representative random sample of 390 anonymous addresses for the control group from the Statistics Service of the Town Council of Albacete.	Residential exposure to any RF. 14 frequency bands (FM, TV3, TETRA, TV4and5, GSMTx, GSM Rx, DCS Tx, DCS Rx, DECT, UMTS Tx, UMTS Rx,WiFi 2G,WiMAX y WiFI 5G), ranging from 88MHz up to 6 GHz. Personal exposure assessed using an EME Spy 140 (Satimo)exposimeter, conveying the exposimeter in a bicycle. 168266 total measurement, 12019 measurements per frequency, 1540 average measurement records per administrative region.	Average total exposure to RF-EMF (V/m) per administrative region: Min 0.07, max 1.03	Gliomas, meningiomas and lymphomas; Spearman correlation test between exposure and incidence of tumours. Effect estimate not appropriate	**ρ of Spearman for Meningioma, (p-value)**	**ρ of Spearman for Glioma, (p-value)**	**ρ of Spearman for all brain, (p-value)**	**ρ of Spearman for Lymphoma, (p-value)**	**ρ of Spearman for all tumours, (p-value)**	Smoking Other counfounders not analysed Design not clear, particularly given that there seems to be personal exposure assessment	inadequate
	Design not clear, particularly given that there seems to be personal exposure assessment	Not clear exposure assessment			0,19 (0,04)	0,15 (0,13)	0,28 (0,003)	-0,03 (0,72)	0,13 (0,19)		

Table 3 – Cancer in epidemiological cohort studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
17. Frei et al. 2011. Denmark; 1990-2007. Nationwide cohort study.	All Danes aged ≥30 and born in Denmark after 1925, subdivided into subscribers and non-subscribers of mobile phones before 1995.	Use of mobile phones as mobile phone subscription; records for 1982-95 were obtained from the Danish network operators.	Mobile phone use, duration of subscription.	Tumours in the central nervous system. Sex-specific incidence rate ratios (IRR) and 95% confidence intervals from log-linear Poisson regression models.	**IRR (95% CI) for Central nervous system tumours, MM**	**IRR (95% CI) for Central nervous system tumours, FF**	**IRR (95% CI) for Central nervous system tumours, MM with >12 years of education**	Age, calendar period, education, and disposable income.	Inadequate
			Use of mobile phones						
			Non-subscribers		1.0 (ref.)	1.0 (ref.)	1.0 (ref.)		
			Subscribers		1.02 (0.94 to 1.10)	1.02 (0.86 to 1.22)	1.00 (0.83 to 1.22)	Exposure assessment only by subscriptions	
			Years of subscription						
			Non-subscribers		1.0 (ref.)	1.0 (ref.)	1.0 (ref.)		
			1-4		1.07 (0.92 to 1.24)	0.97 (0.69 to 1.36)	1.29 (0.92 to 1.79)		
			5-9		0.95 (0.83 to 1.08)	1.05 (0.81 to 1.37)	0.95 (0.70 to 1.29)		
			10-12		1.08 (0.93 to 1.25)	1.05 (0.75 to 1.47)	0.82 (0.55 to 1.24)		
			≥13		1.03 (0.83 to 1.27)	0.91 (0.41 to 2.04)	0.94 (0.55 to 1.60)		

Table 3 – Cancer in epidemiological cohort studies (450-6000 MHz) (Continued b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjustments	Comments
18. Benson et al. 2013. United Kingdom,; prospective Cohort study , the Million Women Study.	1.3 million middle-aged women recruited for Breast Screening Programme	Use of mobile phone. Postal questionnaire; questions on mobile phone use were asked in 1999–2005, and again in 2009	Use of mobile phone.	Intracranial central nervous system tumours. Cox regression models to estimate adjusted relative risks (RRs) and 95% confidence intervals (CIs)	**RR (95% CI) for all intracranial CNS tumours**	**RR (95% CI) for glioma**	**RR (95% CI) for meningioma**	**RR (95% CI) for pituitary**	**RR (95% CI) for acoustic neuroma**	Socioeconomic status, region, age at baseline, height, BMI, smoking, alcohol intake, exercise, use of menopausal hormone therapy.	Adequate/ Positive (acoustic neuroma, pituitary gland)
			Ever used a mobile phone							Overadjusted for several outcomes.	
			No		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			Yes		1.01 (0.90-1.14)	0.91 (0.76-1.08)	1.05 (0.81-1.38)	1.52 (0.99-2.33)	1.44 (0.91-2.28)		
			Frequency of use								
			Never user		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			<Daily use		1.02 (0.90-1.15)	0.92 (0.77-1.10)	1.05 (0.80-1.37)	1.53 (0.99-2.36)	1.45 (0.91-2.31)		
			Daily use		1.00 (0.80-1.26)	0.80 (0.56-1.14)	1.11 (0.67-1.85)	1.45 (0.68-3.10)	1.37 (0.61-3.07)		
			Duration of exposure (years)					*p-value for trend = 0.23*	*p-value for trend = 0.03*		
			Never user		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			<5		1.00 (0.84-1.20)	0.93 (0.71-1.21)	0.88 (0.60-1.31)	2.31 (1.31-4.06)	1.00 (0.54-1.82)		
			5-9		1.02 (0.89-1.17)	0.92 (0.75-1.13)	1.21 (0.89-1.65)	1.08 (0.64-1.82)	1.80 (1.08-3.03)		
			10+		1.02 (0.81-1.27)	0.78 (0.55-1.10)	1.10 (0.66-1.84)	1.61 (0.78-3.35)	2.46 (1.07-5.64)		

Table 3 – Cancer in epidemiological cohort studies (450-6000 MHz) (Continued c)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)				Any Other Co-Exposure/adjustments	Comments
19. Poulsen et al. 2013. Denmark, 1982-1995, follow up until 2007. Cohort study: CANULI study of social inequality and cancer incidence and survival	355701 (M and F), 30 years to date of the first cancer diagnosis, death, emigration.	Use of mobile phones. Mobile phone subscriptions in Denmark during the period from 1982 until the end of 1995. Person-time within the first year of subscription was defined as unexposed.	Use of mobile phones; Duration of exposure.	Basal Cell Carcinoma of the head and neck, Squamous Cell Carcinoma and Melanoma on the head and neck. Incidence rate ratios (IRRs) and 95% confidence intervals from log-linear Poisson regression models.	**IRR (95% CI) for Basal Cell Carcinoma of the head and neck, FF**	**IRR (95% CI) for Basal Cell Carcinoma of the head and neck, MM**	**IRR (95% CI) for Squamous Cell Carcinoma and Melanoma of the head and neck, FF**	**IRR (95% CI) for Squamous Cell Carcinoma and Melanoma of the head and neck, MM**	Age, calendar year, educational level, and income. Exposure assessment by mobile phone subscription only	Inadequate
			Use of mobile phone							
			Non users (< 1 year subscription)		1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)		
			Users (>1 year subscription)		0.93 (0.82 - 1.05)	0.98 (0.93 - 1.03)	1.01 (0.88 - 1.16)	1.05 (0.80 - 1.37)		
			Duration of use (years)							
			1–4		1.02 (0.80 - 1.30)	1.01 (0.91 - 1.13)	0.86 (0.61 - 1.21)	1.16 (0.69 - 1.94)		
			5-9		0.78 (0.64 - 0.95)	0.96 (0.89 - 1.04)	1.01 (0.81 - 1.26)	1.01 (0.65 - 1.57)		
			10-12		1.02 (0.83 - 1.26)	0.96 (0.87 - 1.05)	1.17 (0.93 - 1.48)	0.92 (0.55 - 1.54)		
			>=13		1.20 (0.79 - 1.82)	1.02 (0.90 - 1.15)	0.91 (0.66 - 1.27)	1.20 (0.65 - 2.22)		

Table 3 – Cancer in epidemiological cohort studies (450-6000 MHz) (Continued d)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
20. Hauri et al. 2014. Switzerland. 2000-2008. Census-based cohort study.	997 cancer cases from Swiss National Cohort: 283 leukemia, 258 CNS tumours, 456 other cancers; 117 cases from Swiss Childhood Cancer Registry, not linked with SNC: 27 leukemia, 26 CNS tumours, 64 other cancers (M and F); ≤15 years.	Residential exposure to broadcast transmitters emitting medium-wave (0.5–1.6 MHz), short-wave (6–22 MHz), very high frequency (VHF; 174–230 MHz), and ultra-high frequency (UHF; 470–862 MHz) EMFs. RF-EMF levels from VHF and UHF transmitters ... were modeled by the Federal Office of Communications for an area with a radius of 10 km around each transmitter for the years 1990 and 2000.	A priori chosen cutpoints to differentiate between low, medium, and high exposure. V/m	Leukemia, acute lymphoblastic leukemia, and Central Nervous System tumours, including benign tumours. Hazard Ratio from time-to-event analysis (Cox Regression), 2000–2008. Incidence Rate Ratio from Poisson regression analysis, 1985–2008.	**HR (95% CI), IRR (95% CI), All cancers**	**HR (95% CI), IRR (95% CI), All leukemias**	**HR (95% CI), IRR (95% CI), CNS tumours**	Sex, benzene, natural background ionising γ radiation, distance to the nearest high-voltage power line, and degree of urbanisation.	Adequate/ Negative (Childood cancers)
			Residential exposure						
			Low		1 (Ref.)	1 (Ref.)	1 (Ref.)		
			Medium		1.14 (0.94 - 1.38) 1.09 (1.00 - 1.20)	0.70 (0.46 - 1.07) 0.92 (0.77 - 1.10)	1.35 (0.94 - 1.95) 1.16 (0.95 - 1.42)		
			High		1.03 (0.74 - 1.43) 0.90 (0.76 - 1.06)	0.55 (0.26 - 1.19) 0.76 (0.55 - 1.05)	1.68 (0.98 - 2.91) 1.03 (0.73 - 1.46)		

Table 4 (summary 1-3) – Collected data on cancer in epidemiological studies (450-6000 MHz)

Total studies FR1*	20			
Adequate studies	11			
Observed Tumour	Total adequate studies	Positive results	Equivocal results	Negative results
Glioma	8	3	2	3
Acoustic neuroma	3	2	1	
Meningioma	4	2		2
Lymphoma	1			1
Thyroid gland	1		1	
Pituitary gland	1	1		

*Some of the studies include more than one tumour site.

1. SUMMARY OF THE RESULTS OF EPIDEMIOLOGICAL STUDIES (FR1: 450 to 6000 MHz) (Table 4)

The epidemiological evidence on possible associations of exposure to RF-EMF with cancer comes from studies of diverse design that assessed a range of exposure sources: the populations included people exposed in occupational settings, people exposed through sources in the general environment, e.g. radio-base stations, and people exposed through use of wireless (mobile and cordless) telephones.

In chapter 4 (Limitations) general methodological concerns related to the assessment of individual studies are covered. The total number of epidemiological studies published after the IARC 2011 evaluation (IARC, 2013) and up to 2020, as selected for the present review for FR1, was 20.

After further deep analyses of the 20 original papers, 11 studies proved to be adequate on the basis of exposure assessment, sample size and appropriateness of confounding analyses.

Gliomas, acoustic neuromas, meningiomas, lymphomas, thyroid and pituitary gland tumours were analysed in the 11 adequate studies for a possible association with exposure to RF-EMF, related to the use of mobile phone, or for environmental/occupational exposure to emissions from radiobase stations. The association of the different neoplasias to RF-EMF exposure is reported below. Between brackets numbers assigned to the various studies are reported.

Glioma: out of 7 adequate studies regarding this outcome, 3 showed a positive association with RF-EMF exposure (Ref: 6, 7, 8), 2 were equivocal (1,10) and 3 negative (Ref: 14,18, 20).

Acoustic neuroma: out of 3 adequate studies regarding this outcome, 2 showed a positive association with the RF-EMF exposure (Ref: 7, 18), 1 was equivocal (Ref:9).

Meningioma: out of 4 adequate studies regarding this outcome, 2 showed a positive association with the RF-EMF exposure (Ref: 5,8), and 2 were negative (Ref: 14, 18).

Lymphoma/leukaemia: the only adequate study (childhood) regarding this outcome was negative (Ref: 20).

Thyroid tumour: the only adequate study regarding this outcome showed equivocal results (Ref: 15).

Pituitary gland tumour: the only adequate study regarding this outcome was positive (Ref: 18).

The results of the different studies for the same outcome are mixed (showing conflicting findings) , as summarized in Table 4. The tumours with more robust evidence of association are glioma and acoustic neuroma. The association of glioma and acoustic neuroma is stronger among long-term heavy users of mobile phones, which is also the most extensively investigated exposure source, and in some cases the onset of tumours was related to the side on which the device was handled.

The IARC evaluation of *limited evidence* of cancerogenicity of RF-EMF in epidemiological studies as regards FR1 is confirmed.

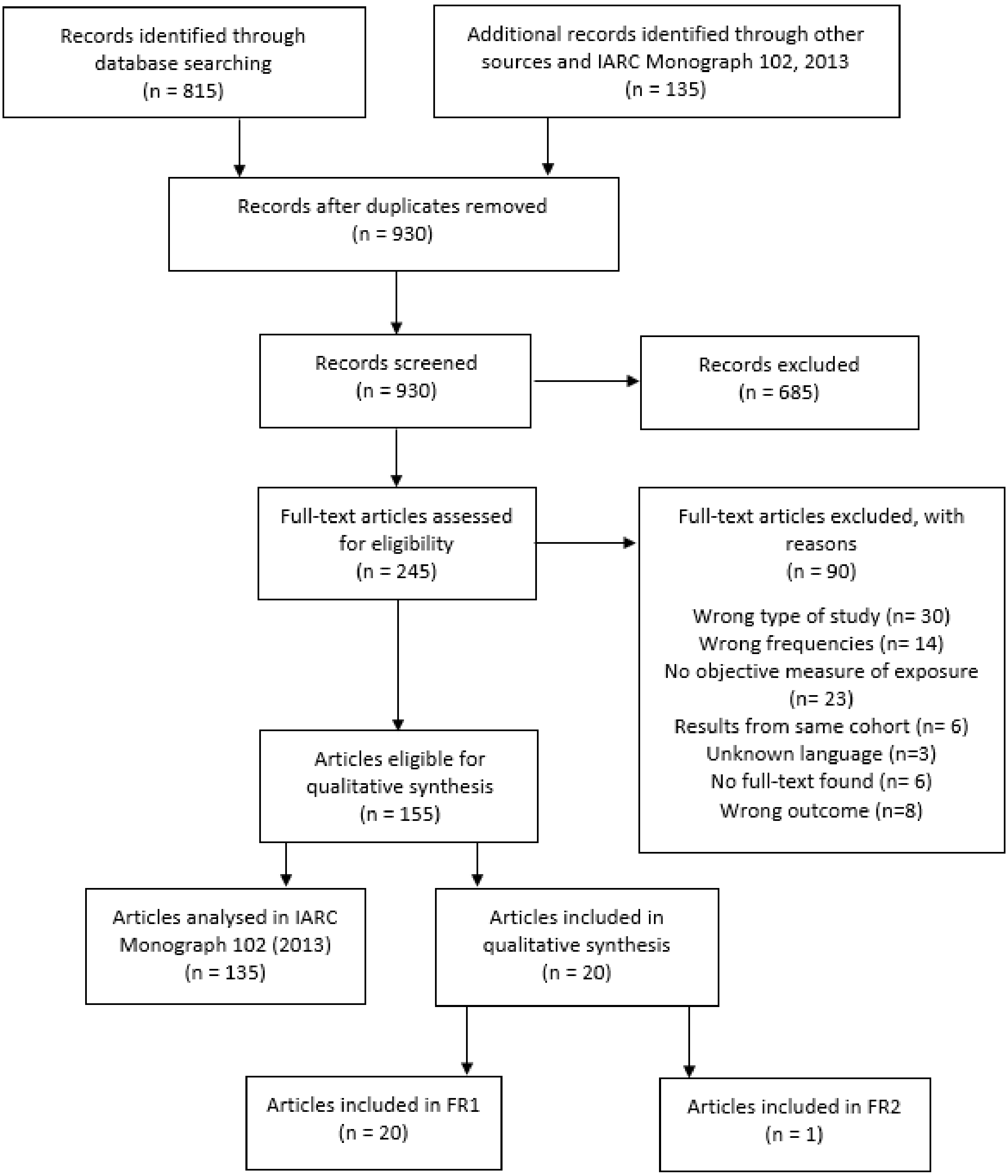
4.1.2 Cancer in epidemiological studies: Studies evaluating health effects due to RF at a higher frequency range (FR2: 24 to 100 GHz, MMW).

The stream of selection of the relevant literature is the same as for FR1, as highlighted in the PRISMA flowchart, 930 articles were screened based on title and abstract and 685 were excluded at this stage; 245 were screened based on full-texts and 90 were excluded at this stage, and after a more thorough assessment, only one published article was eligible for inclusion in the scoping review for the highest range of frequencies (this article reported occupational exposures for both FR1 and FR2, so this doesn't add up to the overall number of included studies) (Fig. 10).

Two articles that were included in IARC Monograph 102 (IARC, 2013) (and are therefore not described here) presented exposures related to FR2 range: it was decided to provide the most important information in the summary tables, since these novel frequencies are the real focal point of this scoping review.

Again, for each article, the abstract is presented, together with a table summarising the most important information; furthermore, a senior expert evaluated their adequacy for assessing carcinogenic effects (adequate/inadequate), and an overall synthesis of the results (positive/negative/equivocal), following the criteria used to assess the adequacy described in the methodology section.

Figure 10 – Flow diagram. Epidemiological studies on cancer for FR2



In conclusion, search on PubMed e EMFPortal databases for epidemiological studies considering exposures from 24GHz to 100 GHz (FR2) included 3 studies. Two were already described in the IARC Monograph 102 (Stang et al., 2001 (1); Baumgardt-Elms et al., 2002 (2)) , one was published after 2011 (Vila et al, 2018 (3)); the latter was also studied in the lower frequencies analysis included in the review.The 3 studies regard occupational exposures of radar operators or workers nearby radar stations. The range of frequencies used by radar telecommunications are represented in Table 5 (IEEE 521-2002). Exposure of workers is not well assessed, as the RF-EMF exposure is self reported, usually quantified by distance from the radar or simply job title:

Table 5 – Range of frequencies used by radar communication.

Range name	Frequency
L	1 - 2 GHz
S	2 – 4 GHz
C	4 – 8 GHz
[3]	8 – 12 GHz
Ku	12 – 18 GHz
K	18 – 27 GHz
Ka	27 – 40 GHz
V	40 – 75 GHz
W	75 – 110 GHz

Summaries of the analysed studies for these frequencies are presented in Tables 6a,b. The epidemiological study not included in the 2011 IARC Working group evaluation is the following:

3. Vila et al., 2018.

Australia, Canada, France, Germany, Israel, New Zealand and the United Kingdom; 2000-2004; INTEROCC study: international case-control study on mobilephone use and brain cancer risk in seven countries.

In 2011, the International Agency for Research on Cancer classified radiofrequency (RF) electromagnetic fields (EMF) as possibly carcinogenic to humans (group 2B), although the epidemiological evidence for the association between occupational exposure to RF-EMF and cancer was judged to be inadequate, due in part to limitations in exposure assessment. This study examines the relation between occupational RF and intermediate frequency (IF) EMF exposure and brain tumour (glioma and meningioma) risk in the INTEROCC multinational population-based case-control study (with nearly 4000 cases and over 5000 controls), using a novel exposure assessment approach. Methods: Individual indices of cumulative exposure to RF and IF-EMF (overall and in specific exposure time windows) were assigned to study participants using a source-exposure matrix and detailed interview data on work with or nearby EMF sources. Conditional logistic regression was used to investigate associations with glioma and meningioma risk. Overall, around 10% of study participants were exposed to RF while only 1% were exposed to IF-EMF. There was no clear evidence for a positive association between RF or IF-EMF and the brain tumours studied, with most results showing either no association or odds ratios (ORs) below 1.0. The largest adjusted ORs were obtained for cumulative exposure to RF magnetic fields (as A/m-years) in the highest exposed category (≥90th percentile) for the most recent exposure time window (1–4 years before the diagnosis or reference date) for both glioma, OR=1.62 (95% confidence interval (CI): 0.86, 3.01) and meningioma (OR=1.52, 95% CI: 0.65, 3.55). Despite the improved exposure assessment approach used in this study, no clear associations were identified. However, the results obtained for recent exposure to RF electric and magnetic fields are suggestive of a potential role in brain tumour promotion/progression and should be further investigated.

Comment*: *Improved exposure assessment. No clear associations were identified for glioma and meningioma, potential role in brain tumour promotion/progression.

Table 6 – Cancer in epidemiological case-control studies (24 to 100 GHz, MMW) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
1.Stang et al. 2001. Germany. 1994-1997. Hospital-based and population-based case-control study.	118 cases, 475 controls (M and F). 35-74 years. Hospital-based case-control study at the Division of Ophthalmology, University of Essen; Controls in the population-based study were selected randomly from mandatory lists of residence.	Occupational sources of electromagnetic radiation. Self-reported exposure from face-to-face interview.	Lifetime exposure: source of exposure, duration, beginning of exposure.	Uveal Melanoma. Odds ratios (ORs) and 95% CI from conditional logistic regression models.	**OR (95% CI), Uveal Melanoma**		Medical history, phenotypic characteristics, life-style factors, Few participants reported exposure to radar	Adequate/negative (Uveal melanoma)
			EMF Source					
			Radar units		0.4 (0.0-2.6)			
2. Baumgardt-Elms et al. 2002. Germany. 1995-1997. Population-based case–control study.	269 cases, 797 controls (M). 15-69 years. Cases were ascertained through an active reporting system of clinical and pathology departments in the study regions. Controls were selected at random from the mandatory registries of residents.	Occupational exposure to EMF. Self-reported exposure from face-to-face interview.	At least 6 months of exposure. Exposures grouped according to the electromagnetic spectrum and assumptions on the strength of the electric and magnetic fields measured in specific workplaces.	Testicular cancer; Odds ratio and 95% confidence intervals (OR, 95% CI) from conditional logistic regression.	**OR (95% CI), testicular cancer**		Matching factors age (ten 5-year age groups since there were no cases in the highest age group) and region of residence (five strata) through stratification; subgroup analysis for blue- and white-collar workers.	Adequate/negative (Tumours of the testis)
			EMF Source					
			Working near radar units		1.0 (0.60-1.75)			

Table 6 – Cancer in epidemiological case control studies (24 to 100 GHz, MMW) (continued b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
3. Vila et al. 2018. Australia, Canada, France, Germany, Israel, New Zealand and the United Kingdom; 2000-2004; INTEROCC study: international case-control study on mobilephone use and brain cancer risk in seven countries.	2054 glioma cases; 1924 meningioma cases; 5601 controls (M and F). Cases aged 30 to 59 years of age; up to 69 years in Germany; 18 years and above in Israel; 18 to 69 years in the United Kingdom. In person computer-assisted personal interview.	Self-reported occupational exposure or proximity to radars, telecommunication antennas, transmitters, equipment for semiconductors manufacturing, medical diagnosis and treatment, industrial heating or food heating. A source-exposure matrix (SEM) was used to assign average exposure levels to each RF and IF source reported. Field intensities for each EMF source were weighted using the frequency-dependent reference levels (RLs) by the International Commission on Non-Ionising Radiation Protection (ICNIRP) for occupational exposure. Frequency of exposure: 10 MHz-300 GHz.	E-field (V/m, Arithmetic mean exposure levels from the SEM. RF sources organized by E-field exposure level)	Glioma and meningioma risk; adjusted OR and 95% confidence intervals.	**OR (95% CI) for Gliomas**	**OR for Meningiomas**	No information available Improved exposure assessment. No clear associations were identified for glioma and meningioma, potential role in brain tumour promotion/progression.	Adequate/negative (glioma and meningioma)
			Duration of exposure: 1-4 years					
			Non exposed		1.00 (ref.)	1.00 (ref.)		
			<0.42		0.69 (0.49-0.98)	0.60 (0.38-0.96)		
			0.42–4.47		0.85 (0.54-1.35)	1.13 (0.60-2.14)		
			4.48–18.8		0.77 (0.44-1.37)	0.86 (0.35-2.13)		
			≥18.9		1.38 (0.75-2.54)	1.30 (0.58-2.91)		
			Duration of exposure: 5-9 years					
			Non exposed		1.00 (ref.)	1.00 (ref.)		
			<0.42		0.84 (0.61-1.17)	0.60 (0.38-0.97)		
			0.42–4.47		0.93 (0.60-1.44)	1.48 (0.84-2.61)		
			4.48–18.8		0.82 (0.46-1.47)	1.08 (0.66-2.39)		
			≥18.9		0.90 (0.44-1.83)	1.03 (0.45-2.63)		

Table 7 (Summary 6 a, b) – Summary table for epidemiological studies on Cancer, FR2: 24-100 GHz

Total studies*	3			
Adequate studies	3			
Observed Tumour	Total adequate studies	Positive results	Equivocal results	Negative results
Glioma	1			1
Meningioma	1			1
Uveal melanoma	1			1
Testicular cancer	1			1

*one of the studies includes more than one tumour site.

- **SUMMARY OF THE RESULTS EPIDEMIOLOGICAL STUDIES ON CANCER (FR2: 24 to 100 GHz, MMW) (Table 6a, b)**

All 3 adequate studies reviewed did not show any clear association between exposure to higher frequencies (FR2) and the selected cancer (table 7).

The IARC Working group in the summary of data reported for occupational exposure regarding also FR2, concluded:

"Tumours of the brain*: "…exposure misclassification and insufficient attention to possible confounding limit the interpretation of findings. Thus, there is no clear indication of an association of occupational exposure to RF radiation with risk of cancer of the brain. "*

"Leukaemia/Lymphoma*: In summary, while there were weak suggestions of a possible increase in risk of leukaemia or lymphoma associated with occupational exposure to RF radiation, the limited exposure assessment and possible confounding make these results difficult to interpret".*

Other kinds of tumour emerged as potentially associated with exposure to high frequencies (uveal melanoma, cancer of the testis, breast, lung, and skin), but many of the studies showed methodological limitations and the results were inconsistent (IARC 2013). Afterwards, any other adequate study was performed regarding the association of these types of tumours with the exposure to RF-EMF (FR2).

The present review bears out these remarks, so we must confirm that, where the highest 5G (FR2) frequency is concerned, the only 3 epidemiological studies examined for FR2 exposure are *not adequate* to assess the impact on health.

4.1.3 Cancer in experimental animals: Studies evaluating health effects due to RF at a lower frequency range (FR1: 450 to 6000 MHZ), which also includes the frequencies used in previous generations' broadband cellular networks (1G, 2G, 3G and 4G).

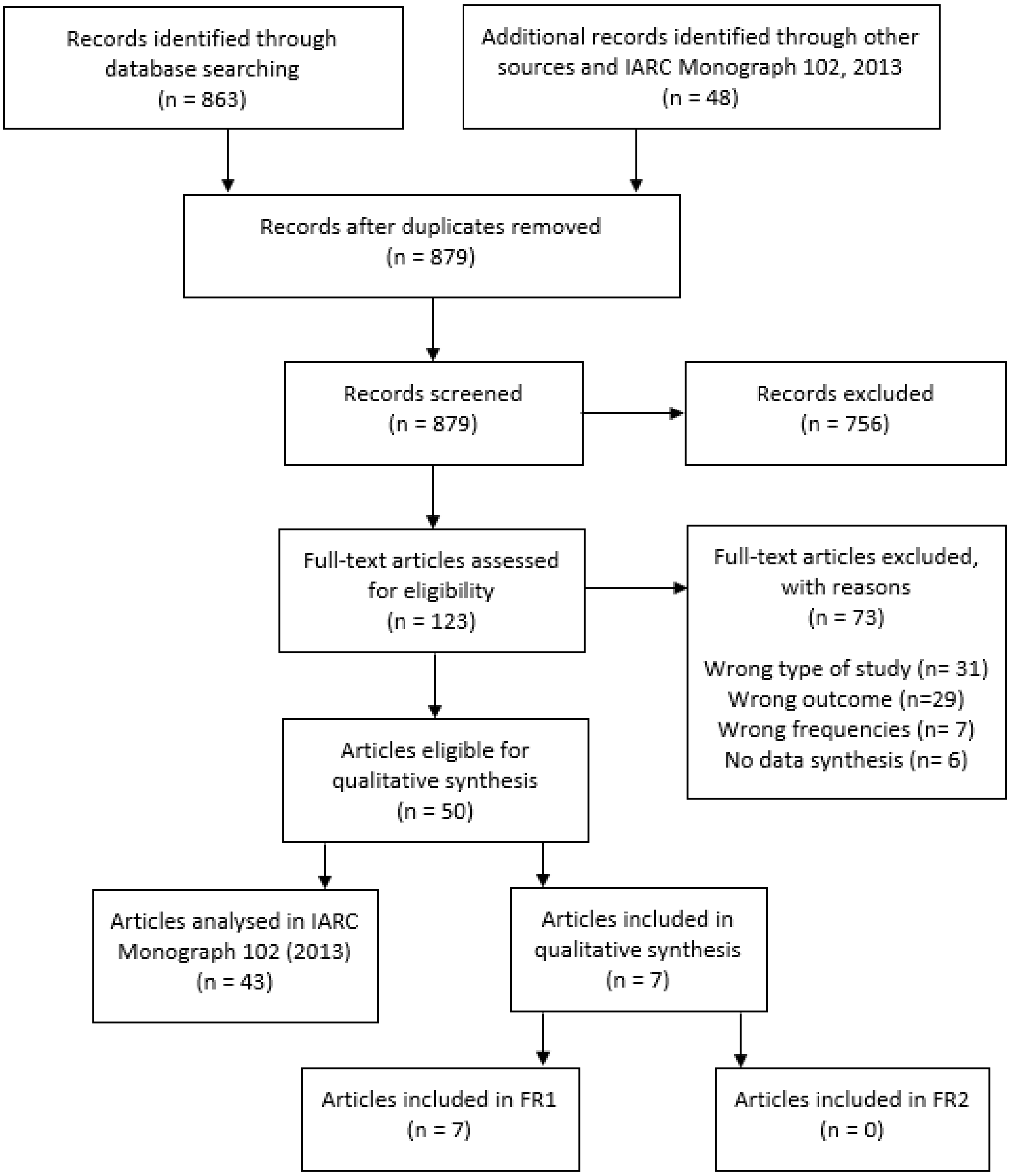
The articles identified through database searching and other sources were 911. After removing duplicates (32) and excluding non-pertinent articles (756) based on title and abstracts, 123 articles remained. Based on full-text screening, 73 papers were further excluded, so that the articles with frequencies appropriate for inclusion in this qualitative synthesis were 50.

As further explained in the methodology section, we considered IARC Monograph 102 (IARC, 2013) as our key reference for all studies on cancer in experimental animals published until 2011: all original papers (43) that were included in the IARC monograph were analysed and referenced in this report as well; of course, we considered for this report only the final IARC classification. Seven adequate studies were published after 2011.

At this stage, a separation based on frequency range was also performed: of the 7 papers included, all reported exposures belonging to the band considered in FR1, and none reported exposures regarding FR2 (Fig. 11).

For each article selected, the abstract is presented, together with the tables summarising the most important information; furthermore, a senior expert evaluated their adequacy for assessing carcinogenic effects adequate/inadequate), and expressed an overall synthesis of the results (positive/negative/equivocal), following the criteria described in the methodology chapter.

Figure 11 – Flow diagram. Cancer in experimental animal studies FR1



KEY REFERENCE: IARC 2013 (43 studies)

The IARC Monograph 102 is the key reference for the present review. The evaluation of the adequate available studies at that time is reported below (IARC, 2013).

In May, 2011, 30 scientists from 14 countries met at the International Agency for Research on Cancer(IARC) in Lyon, France, to assess the carcinogenicity of radiofrequency electromagnetic fields (RF-EMF). These assessments was published as Volume 102 of the IARC Monographs (IARC, 2013).

Four classes of cancer bioassays in animals were reviewed and assessed by the Working Group. These studies involved a variety of animal models, exposure metrics, duration of exposure, and other criteria on which the evaluation of carcinogenicity was based.

The Working Group evaluated:

- 7 two-year cancer bioassays of RF radiation, two in mice and five in rats; six studies were performed to examine the effects of exposure to mobile-phone RF metrics, and one study involved exposure to pulsed RF radiation. When compared with sham controls, no statistically significant increases in the incidence of benign or malignant neoplasms at any organ site were identified in animals exposed to mobilephone RF radiation in any study. In the study with exposure to pulsed RF radiation, an increased incidence of total malignant tumours (all sites combined) was observed in rats; however, the Working Group considered this finding to be of limited biological significance since it resulted from pooling of non-significant changes in tumour incidence at several sites. Exposure to RF radiation did not increase total tumour incidence in any of the other six studies that were evaluated. The Working Group concluded that the results of the 2-year cancer bioassays provided no evidence that long-term exposure to RF radiation increases the incidence of any benign or malignant neoplasm in standard-bred mice or rats.

- 12 studies that used four different tumour-prone animal models; two of these studies demonstrated an increased incidence of tumours in animals exposed to RF radiation. The first study with positive results demonstrated an increased incidence of lymphoma in *Eμ-Piml-transgenic* mice exposed to GSM mobile-phone RF radiation at 900 MHz; however, two subsequent studies by other investigators using the same model system failed to confirm this finding. In the second study with positive results, an increased incidence of tumours of the mammary gland was observed in C3H/HeA mice exposed to RF radiation at 2450 MHz; although two later studies using the same exposure metric did not confirm this finding, these follow-on studies were performed at lower levels of exposure. The Working Group concluded that the results of studies in three tumour-prone animal models (the *Eμ-Piml* mouse model of lymphoma, the *AKR* mouse model of lymphoma, and the *Patchedr -1* mouse model of brain cancer) do not support the hypothesis that the incidence of tumours in the brain or lymphoid tissue would increase as a result of exposure to RF radiation.

- 16 studies of initiation and promotion that were performed with animal models of tumourigenesis in skin, mammary gland, brain, and lymphoid tissue. None of the five studies in models of skin cancer and none of the six studies in models of brain cancer showed an association with exposure to RF radiation. One of four studies with the model of mammary-gland tumour in Sprague-Dawley rats gave positive results; the other three studies - one with a nearly identical protocol - did not show an association, although they used the same experimental model and the same conditions of exposure to RF radiation. Likewise, the study with the model of lymphoma was negative. The Working Group concluded that the evidence from these studies of initiation and promotion failed to demonstrate a consistent pattern of enhancement of carcinogenesis by exposure to RF radiation in any of the tissues studied.

- 6 co-carcinogenesis studies involving five different animal models. Four positive responses were reported. Two studies giving positive results, one in Wistar rats continuously exposed to drinking-water containing MX - a by-product of water disinfection - and another study in pregnant B6C3F1 mice given a single dose of ethyl-nitrosourea, involved exposures to mobile-phone RF radiation at 900 and 1966 MHz, respectively. The other two studies with positive results involved coexposure of BALB/c mice to RF radiation at 2450 MHz and benzo[a]pyrene. Although the value of two of these studies was weakened by their unknown relevance to cancer in humans, the Working Group concluded that they did provide some additional evidence supporting the carcinogenicity of RF radiation in experimental animals.

The conclusion for the animal studies evaluation was: "*There is limited evidence in experimental animals for the carcinogenicity of radiofrequency radiation*" (IARC, 2013).

- REVIEW OF THE ANIMAL STUDIES 2011-2020

Starting from 2011, the present review evaluates by type of study and by year of publication (2011-2020) the animal studies also summarized in Table 3 (a, b, c, d). The author adds to short abstracts her own brief comments on the results of the different studies.

TWO YEAR CANCER BIOASSAY IN MICE (Table 8a)

1. NTP TR 596, 2018.

GSM-modulated RFR, B6C3F1/N mice (M, F), for 24 months, Carcinogenicity study.

Groups of 105 male and 105 female mice were housed in reverberation chambers and received whole-body exposures to GSM-modulated cell phone RFR at power levels of 0 (sham control), 2.5, 5, or 10 W/kg, 9 hours and 10 minutes per day, 7 days per week for 106 (males) or 108 (females) weeks with continuous cycling of 10 minutes on and 10 minutes off during a period of 18 hours and 20 minutes each day. The sham control animals were housed in reverberation chambers identical to those used for the exposed groups, but were not exposed to RFR; shared groups of unexposed mice of each sex served as sham controls for both RFR modulations. Fifteen mice per group were randomly selected from the core group after 10 weeks of study; 10 of those 15 mice per group were used for interim evaluation at 14 weeks, and five mice per group were used for genetic toxicity testing at 14 weeks. The remaining 90 animals per group were exposed up to 2 years. In the 2-year study, percent survival was significantly higher for the 5 W/kg males than the sham control group. Survival of the other exposed groups of males and females was generally similar to that of the sham controls. Mean body weights of exposed groups of males and females were similar to those of the sham controls throughout the study. The combined incidences of fibrosarcoma, sarcoma, or malignant fibrous histiocytoma of the skin were increased in 5 and 10 W/kg males, although not significantly or in a SAR-related manner; however, the incidences exceeded the overall historical control ranges for malignant fibrous histiocytoma. In the lung, there was a significant positive trend in the incidences of alveolar/ bronchiolar adenoma or carcinoma (combined) in males. Compared to the sham controls, all exposed groups of females had increased incidences of malignant lymphoma and the incidences in the 2.5 and 5 W/kg groups were significantly increased. The sham control group had a low incidence of malignant lymphoma compared to the range seen in historical controls. There were no nonneoplastic lesions that were considered related to exposure to GSM-modulated cell phone RFR.

2. NTP TR 596, 2018.

CDMA-modulated RFR, B6C3F1/N mice (M, F), for 24 months, Carcinogenicity study.

Groups of 105 male and 105 female mice were housed in reverberation chambers and received whole-body exposures to CDMA-modulated cell phone RFR at power levels of 0 (sham control), 2.5, 5, or 10 W/kg, 9 hours and 10 minutes per day, 7 days per week for 106 (males) or 108 (females) weeks with continuous cycling of 10 minutes on and 10 minutes off during a period of 18 hours and 20 minutes each day. The sham control animals were housed in reverberation chambers identical to those used for the exposed groups, but were not exposed to RFR; shared groups of unexposed mice of each sex served as sham controls for both RFR modulations. Fifteen mice per group were randomly selected from the core group after 10 weeks of study; 10 of those 15 mice per group were used for interim evaluation at 14 weeks, and five mice per group were used for genetic toxicity testing at 14 weeks. The remaining 90 animals per group were exposed up to 2 years. Percent survival was significantly higher in 2.5 W/kg males compared to that in the sham controls in the 2-year study. Survival of males and females in all other exposed groups was generally similar to that of the sham controls. Mean body weights of exposed groups of males and females were similar to those of the sham controls throughout the study. There was a significantly increased incidence of hepatoblastoma in 5 W/kg males. Compared to the sham controls, the incidences of malignant lymphoma were increased in all exposed groups of females, and the increase was significant in the 2.5 W/kg group. As noted for the GSM study, the shared sham control group had a low incidence of malignant lymphoma compared to the range observed in historical controls.There were no nonneoplastic lesions that were considered related to exposure to CDMA-modulated cell phone RFR.

Comprehensive summary: Under the conditions of these 2-year studies, there was equivocal evidence of carcinogenic activity of GSM-modulated cell phone RFR at 1,900 MHz in male B6C3F1/N mice based on the combined incidences of fibrosarcoma, sarcoma, or malignant fibrous histiocytoma in the skin, and the incidences of alveolar/ bronchiolar adenoma or carcinoma (combined) in the lung. There was equivocal evidence of carcinogenic activity of GSM-modulated cell phone RFR at 1,900 MHz in female B6C3F1/N mice based on the incidences of malignant lymphoma (all organs). There was equivocal evidence of carcinogenic activity of CDMA-modulated cell phone RFR at 1,900 MHz in male B6C3F1/N mice based on the incidences of hepatoblastoma of the liver. There was equivocal evidence of carcinogenic activity of CDMA-modulated cell phone RFR at 1,900 MHz in female B6C3F1/N mice based on the incidences of malignant lymphoma (all organs).

Comprehensive comment*: *Equivocal evidence of carcinogenicity in mice for GSM and CDMA-modulated RFR.

TWO YEAR CANCER BIOASSAY IN RATS (Table 9 a)

3. NTP TR 595, 2018.

GSM-modulated RFR, Harlan SD rats (M, F), prenatal exposure for 24 months, carcinogenicity study.

Beginning on GD 5, groups of 56 time-matched F0 female rats were housed in specially designed reverberation chambers and received whole-body exposures to GSM-modulated cell phone RFR at power levels of 0 (sham control), 1.5, 3, or 6 W/kg for 7 days per week, continuing throughout gestation and lactation. Exposure was up to 18 hours and 20 minutes per day with continuous cycling of 10 minutes on and 10 minutes off during the exposure periods. There were seven exposure groups per sex, including a shared sham control and three exposure groups for each modulation. At weaning, three males and three females per litter from 35 litters were randomly selected per exposure group for continuation. Weaning occurred on the day the last litter reached PND 21, marking the beginning of the 2-year studies. Groups of 105 male and 105 female F1 offspring continued to receive whole-body exposures to GSM-modulated cell phone RFR at the same power levels and under the same exposure paradigm, 7 days per week for up to 104 weeks. After 14 weeks of exposure, 10 rats per group were randomly selected for interim histopathologic evaluation and five were designated for genetic toxicity evaluation. In the heart at the end of the 2-year studies, malignant schwannoma (synonymous neurinoma) was observed in all exposed male groups and the 3 W/kg female group, but none occurred in the sham controls. Endocardial Schwann cell hyperplasia also occurred in a single 1.5 W/kg male and two 6 W/kg males. There were also significantly increased incidences of right ventricle cardiomyopathy in 3 and 6 W/kg males and females. In the brain of males, there were increased incidences of malignant glioma and glial cell hyperplasia in all exposed groups, but none in the sham controls. There was also increased incidences of benign or malignant granular cell tumours in all exposed groups. There were significantly increased incidences of benign pheochromocytoma and benign, malignant, or complex pheochromocytoma (combined) of the adrenal medulla in males exposed to 1.5 or 3 W/kg. In the adrenal medulla of females exposed to 6 W/kg, there were significantly increased incidences of hyperplasia. In the prostate gland of male rats, there were increased incidences of adenoma or adenoma or carcinoma (combined) in 3 W/kg males and epithelium hyperplasia in all exposed male groups. In the pituitary gland (pars distalis), there were increased incidences of adenoma in all exposed male groups. There were also increased incidences of adenoma or carcinoma (combined) of the pancreatic islets in all exposed groups of male rats, but only the incidence in the 1.5 W/kg group was significant. In female rats, there were significantly increased incidences of C-cell hyperplasia of the thyroid gland in all exposed groups, and significantly increased incidences of hyperplasia of the adrenal cortex in the 3 and 6 W/kg groups.

GSM-modulated RFR: Under the conditions of this 2-year whole-body exposure study, there was clear evidence of carcinogenic activity of GSM-modulated cell phone RFR at 900 MHz in male Hsd:Sprague Dawley SD rats based on the incidences of malignant schwannoma of the heart. The incidences of malignant glioma of the brain and benign, malignant, or complex pheochromocytoma (combined) of the adrenal medulla were also related to RFR exposure. The incidences of benign or malignant granular cell tumours of the brain, adenoma or carcinoma (combined) of the prostate gland, adenoma of the pars distalis of the pituitary gland, and pancreatic islet cell adenoma or carcinoma (combined) may have been related to RFR exposure. There was equivocal evidence of carcinogenic activity of GSM-modulated cell phone RFR at 900 MHz in female Hsd:Sprague Dawley SD rats based on the incidences of schwannomas of the heart. Increases in nonneoplastic lesions of the heart, brain, and prostate gland in male rats, and of the heart, thyroid gland, and adrenal gland in female rats occurred with exposures to GSM-modulated RFR at 900 MHz.

Comment*: *Positive evidence of carcinogenicity for malignant Schwannoma (neurinoma) of the heart associated to RF-EMF exposure in the near field (GSM-modulated RFR); the incidences of malignant glioma of the brain and benign, malignant, or complex pheochromocytoma (combined) of the adrenal medulla were also related to RFR exposure. Note: brain tumours and neurinomas are also increased in epidemiological studies.

4. Falcioni et al., 2018.

SD rats (M, F), prenatal exposure until spontaneous death, Carcinogenicity study.

Male and female Sprague-Dawley rats were exposed from prenatal life until natural death to a 1.8 GHz GSM far field of 0, 5, 25, 50 V/m with a whole-body exposure for 19 h/day. A statistically significant increase in the incidence of heart Schwannomas was observed in treated male rats at the highest dose (50 V/m). Furthermore, an increase in the incidence of heart Schwann cells hyperplasia was observed in treated male and female rats at the highest dose (50 V/m), although this was not statistically significant. An increase in the incidence of malignant glial tumours was observed in treated female rats at the highest dose (50 V/m), although not statistically significant. The RI findings on far field exposure to RFR are consistent with and reinforce the results of the NTP study on near field exposure, as both reported an increase in the incidence of tumours of the brain and heart in RFR-exposed Sprague-Dawley rats. These tumours are of the same histotype as those observed in some epidemiological studies on cell phone users. These experimental studies provide sufficient evidence to call for re-evaluation of the IARC conclusions regarding the carcinogenic potential of RFR in humans.

Comment* : *Positive evidence for an association of RF-EMF in the far field (environmental) exposure with an increase in heart Schwannoma (neurinoma is a synonymous) [pubblication of the whole study is ongoing]. Note: brain tumours and neurinomas are also increased in epidemiological studies.

TUMOUR-PRONE MICE (Table 10 a)

5. Lee et al., 2011

AKR/J mice (M, F), 42 weeks (~10 months), Lymphoma-prone.

Carcinogenic effects of combined signal RF-EMFs on AKR/J mice, which were used for the lymphoma animal model, were investigated. Six-week-old AKR/J mice were simultaneously exposed to two types of RF signals: single code division multiple access (CDMA) and wideband code division multiple access (WCDMA). AKR/J mice were exposed to combined RF-EMFs for 45 min/day, 5 days/week, for a total of 42 weeks. The whole-body average specific absorption rate (SAR) of CDMA and WCDMA fields was 2.0 W/kg each, 4.0 W/kg in total. When we examined final survival, lymphoma incidence, and splenomegaly incidence, no differences were found between sham- and RF-exposed mice. However, occurrence of metastasis infiltration to the brain in lymphoma-bearing mice was significantly different in RF-exposed mice when compared to sham-exposed mice, even though no consistent correlation (increase or decrease) was observed between male and female mice. However, infiltration occurrence to liver, lung, and spleen was not different between the groups. From the results, we suggested that simultaneous exposure to CDMA and WCDMA RF-EMFs did not affect lymphoma development in AKR/J mice.

Comment: Short period of exposure. Exposure did not affect lymphoma development in AKR/J mice.

PROMOTION STUDIES IN MICE (Table 11a)

6. Lerchl et al., 2015, B6C3F1 mice (F), 24 months, Promotion study.

(Tillmann et al., 2010) suggested tumour-promoting effects of RF-EMF. A replication study using higher numbers of animals per group and including two additional exposure levels (0 (sham), 0.04, 0.4 and 2 W/kg SAR) was performed. Numbers of tumours of the lungs and livers in exposed animals were significantly higher than in sham-exposed controls. In addition, lymphomas were also found to be significantly elevated by exposure. A clear dose-response effect was absent. We hypothesize that these tumour-promoting effects may be caused by metabolic changes due to exposure. Since many of the tumour-promoting effects in our study were seen at low to moderate exposure levels (0.04 and 0.4 W/kg SAR), thus well below exposure limits for the users of mobile phones, further studies are warranted to investigate the underlying mechanisms. Our findings may help to understand the repeatedly reported increased incidences of brain tumours in heavy users of mobile phones.

Comment: The study does not exactly replicate the Tillmann et al., (2010) study. It shows positive evidence of association between lung, liver tumours, and lymphomas with exposure to RF-EMF.

Table 8 – Cancer in experimental animals: two years cancer bioassays in mice (450-6000 MHz) (a)

Reference, Strain, Species (sex), Duration, Type of study	RF Exposure Level Frequencies, Intensities; Any Other Co-Exposure	Exposure time, No. of Animals	Increased Tumour Incidence (Significance)	Comments
1. NTP TR 596, B6C3F1/N mice (M, F), prenatal exposure for 24 months, carcinogenicity study, 2018	GSM, (1900 MHz), 2.5, 5, and 10 W/Kg	9 h/day, 7 days/week, 105/sex/group	Combined incidences of fibrosarcoma, sarcoma, or malignant fibrous histiocytoma in the skin and the incidences of alveolar/ bronchiolar adenoma or carcinoma (combined) in the lung. In females increased incidences of malignant lymphoma (all organs).	Adequate, equivocal
2. NTP TR 596, B6C3F1/N mice (M, F), prenatal exposure for 24 months, carcinogenicity study, 2018	CDMA (1900 MHz), 2.5, 5, and 10 W/Kg	9 h/day, 7 days/week, 105/sex/group	Hepatoblastoma of the liver. in female increased incidences of malignant lymphoma (all organs).	Adequate, equivocal

Table 9 – Cancer in experimental animals: two years cancer bioassays in rats (450-6000 MHz) (a)

Reference, Strain, Species (sex), Duration, Type of study	RF Exposure Level Frequencies, Intensities; Any Other Co-Exposure	Exposure time, No. of Animals	Increased Tumour Incidence (Significance)	Comments
3. NTP TR 595, SD rats (M, F), prenatal exposure for 24 months, carcinogenicity study, 2018	GSM, CDMA (900 MHz), 1.5, 3, 5 W/kg	9 h/day, 7 days/week, 105/sex/group	Male brain glioma, heart Schwannoma, and combined adrenal pheochromocytoma ($p < 0.05$)	Adequate, positive for heart Schwannomas and brain tumours; positive for adrenal tumours
4. NTP TR 595, SD rats (M, F),), prenatal exposure for 24 months, carcinogenicity study, 2018	GSM, CDMA (900 MHz), 1.5, 3, 5 W/kg	9 h/day, 7 days/week, 105/sex/group	Male brain glioma, heart Schwannoma, and combined adrenal pheochromocytoma ($p < 0.05$)	Adequate, positive for heart Schwannomas and brain tumours; positive for adrenal tumours
5. Falcioni et al., 2018, SD rats (M, F), prenatal exposure until spontaneous death, carcinogenicity study	GSM (1800 MHz), 0.1, 0.03, 0.001 W/Kg	19 h/day, 7 days/week, 200,400 /sex/group	Male heart Schwannoma ($p < 0.05$) and female brain glioma	Adequate, positive for heart Schwannomas; borderline for brain tumours

Table 10a - Cancer in experimental animals: tumour-prone mice (450-6000 MHz) (a)

Reference, Strain, Species (sex), Duration, Type of study	RF Exposure Level Frequencies, Intensities; Any Other Co-Exposure	Exposure time, No. of Animals	Increased Tumour Incidence (Significance)	Comments
6. Lee et al., 2011, AKR/J mice (M, F), 42 weeks (~10 months), Lymphoma-prone	CDMA (849 MHz) and WCDMA (1950 MHz), 4 W/kg (combined)	45 min/day, 5 days/week, 40/sex/group	No statistically significant increase in tumour incidence	Inadequate (Short daily exposure)

Table 10b - Cancer in experimental animals: promotion studies in mice (450-6000 MHz) (a)

Reference, Strain, Species (sex), Duration, Type of study	RF Exposure Level Frequencies, Intensities; Any Other Co-Exposure	Exposure time, No. of Animals	Increased Tumour Incidence (Significance)	Comments
7. Lerchl et al., 2015, B6C3F1 mice (F), 24 months, Promotion study	UMTS fields, 0.04, 0.4 and 2.0 W/kg; prenatal ENU 40mg/kg b.w.	23.5 h/day, 7 days/week, 96/group	Female lymphoma, lung adenoma and carcinoma, liver carcinoma (tumour promotion) ($p < 0.05$)	Adequate, positive

Table 11 (summary tables 8-10) - Collected data for experimental studies on Cancer (FR1: 450-6000 MHz)

Total studies FR1*	7							
Adequate studies	7							
	Rat				Mouse			
Observed Tumour	**Total adequate studies[a]**	**Positive results**	**Equivocal results**	**Negative results**	**Total adequate studies[b]**	**Positive results**	**Equivocal results**	**Negative results**
Glioma	3	2	1					
Heart Schwannoma	3	3						
Alveolar-bronchiolar adenoma, carcinoma					3	1	2	
Liver tumours	2		1		3	1	2	
Adrenal pheochromocytoma	2	2						
Pancreatic islet adenoma+carcinoma	2		2					
Prostate adenoma+carcinoma	2		2					
Pituitary gland adenoma	2		2					
Lymphoma					4	1	2	1
Fibrosarcoma, fibro-histiocitic sarcoma of the skin					3		2	

*Some of the studies include more than one tumour site. [a] 1 study published only partial results on brain and heart.[b]1 study on lymphoma prone mice

SUMMARY OF THE RESULTS OF CANCER IN EXPERIMENTAL ANIMALS STUDIES (FR1: 450 to 6000 MHZ)(Table 11)

Based on full-text screening, the articles with frequencies appropriate for inclusion in this qualitative synthesis were 50. As further explained in the methodology section, we considered IARC Monograph 102 (IARC, 2013) as our key reference for all studies on cancer in experimental animals published until 2011: all original papers (43) that were included in the IARC monograph were analysed and referenced in this report as well; of course, we considered for this report only the final IARC classification. Seven adequate studies were published after 2011. From the present review, 7 studies on carcinogenicity in experimental animals were selected. 4 studies were performed on mice, 3 were performed on rats. Summaries of the results are presented in Table 27.

Out of the 7 adequate studies, the results were:

- Carcinogenicity in mice:

Two adequate carcinogenicity studies were performed to investigate possible non-thermal adverse effects on carcinogenicity related to RF-EMF exposure in mice. The studies were performed by the NTP laboratory in the USA .

Ref: 1: GSM-modulated cell phone RFR at 1,900 MHz in male B6C3F1/N mice showed: *positive* association of RF-EMF exposure with combined incidences of fibrosarcoma, sarcoma, or malignant fibrous histiocytoma in the skin, and the incidences of alveolar/ bronchiolar adenoma or carcinoma (combined) in the lung. There was *equivocal* evidence of carcinogenic activity in female B6C3F1/N mice based on the incidences of malignant lymphoma (all organs).

Ref: 2: There was *equivocal* evidence of carcinogenic activity of CDMA-modulated cell phone RFR at 1,900 MHz in male B6C3F1/N mice based on the incidences of hepatoblastoma of the liver. There was equivocal evidence of carcinogenic activity of CDMA-modulated cell phone RFR at 1,900 MHz in female B6C3F1/N mice based on the incidences of malignant lymphoma (all organs).

Two studies with different animal model and design were also performed on mice:

Ref: 6: one study on lymphoma-prone mice did not show any increase in lymphoma (*no* evidence).

Ref: 7: one two-years promotion study showed a statistically significant increase of tumours of the lung and liver in exposed animals. In addition, lymphomas were also found to be significantly increased (*positive* ass0ciation)

- Carcinogenicity in rats

Three adequate carcinogenicity studies were performed to investigate possible non-thermal adverse effects on carcinogenicity related to RF-EMF exposure in rats. Two studies were performed by the NTP laboratory in the USA (Ref:3,4) , one study (partially published) by the Ramazzini Institute in Italy (Ref: 5).

The most convincing evidence for the 3 studies regards the statistically significant increase (positive association) of brain tumours (Ref: 3, 4) supported by the *equivocal* association of the same tumour in the third study (Ref: 5) and the statistically significant increase of a very rare tumour of the heart, malignant Schwannoma, in all 3 studies (*positive* association). The increase of adrenal pheochromocytoma was statistically significant (positive association), and pancreatic islet adenoma+carcinoma, prostate adenoma+carcinoma, pituitary gland adenoma were also increased in treated groups (Ref: 3, 4) (*equivocal* association).

FR1: Our review on experimental studies on rats and mice shows a sufficient evidence of carcinogenicity of RF-EMF at lower frequencies (FR1). The observation of tumours of the nervous system (central and peripheral) in male rats is of particular significance, because supporting findings of epidemiological studies.

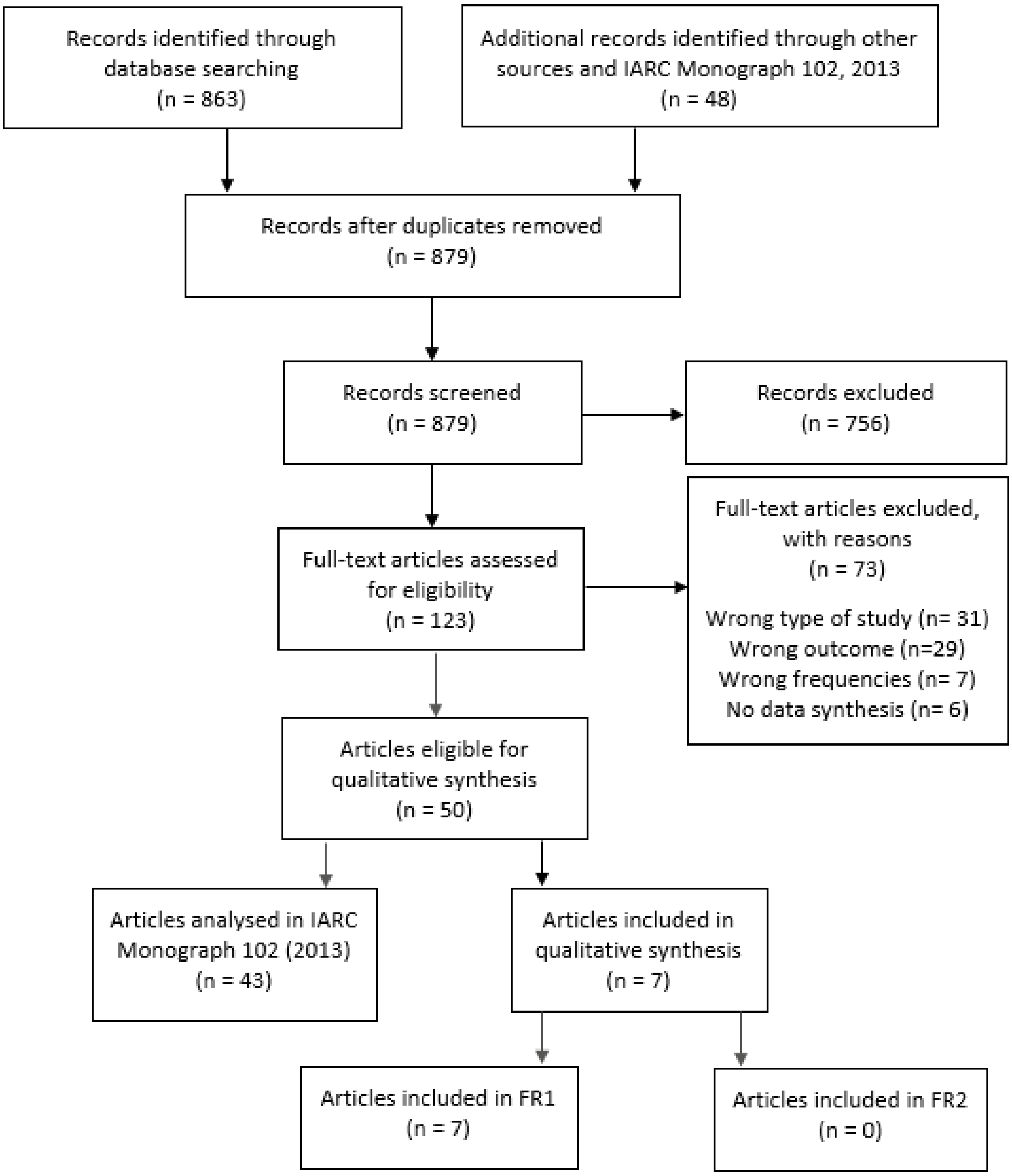
4.1.4 Cancer in experimental animals: Studies evaluating health effects due to RF at a higher frequency range (FR2: 24 to 100 GHz, MMW).

The articles identified through database searching and other sources were 911. After removing duplicates (32) and excluding non-pertinent articles (756) based on title and abstracts, 123 articles remained. Based on full-text screening, 73 papers were further excluded, so that the articles with frequencies appropriate for inclusion in this qualitative synthesis were 50 (Fig. 12).

As further explained in the methodology section, we considered IARC Monograph 102 (IARC, 2013) as our key reference for all studies on cancer in experimental animals published until 2011: all original papers (43) that were included in the IARC monograph were analysed and referenced in this report as well; of course, we considered for this report only the final IARC classification. Seven adequate studies were published after 2011.

At this stage, a separation based on frequency range was also performed: of the 7 papers included, all reported exposures belonging to the band considered in FR1, and none reported exposures regarding FR2. In conclusion, there is no available literature regarding the association between RF radiation at the range 24 to 100 GHz (MMW) in experimental carcinogenicity studies.

Figure 12 – Flow diagram. Cancer in experimental animal studies FR2



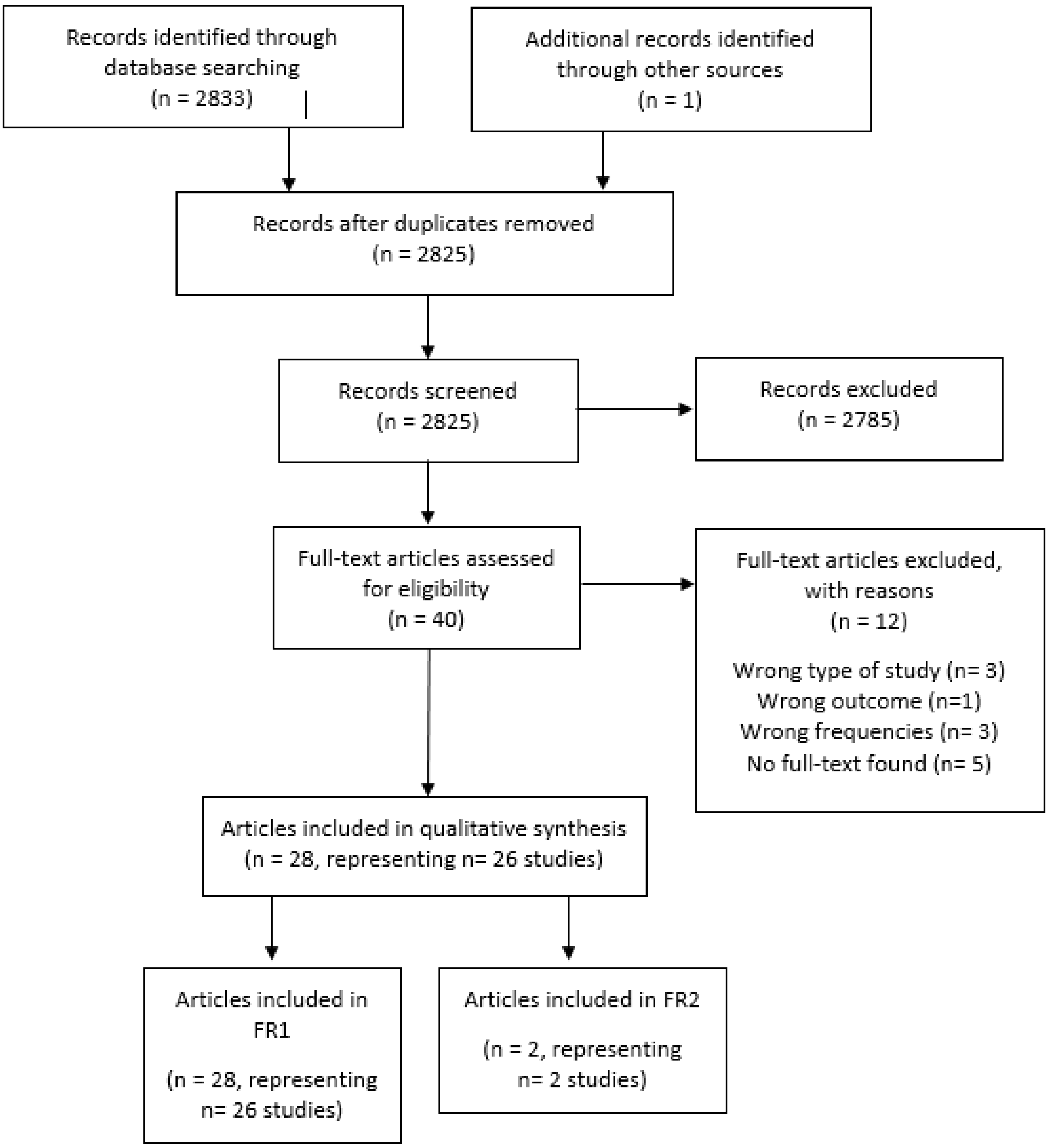
4.2 Reproductive/developmental adverse effects by frequency range

4.2.1 Reproductive/developmental effects in epidemiological studies: Studies evaluating health effects due to RF at a lower frequency range (FR1: 450 to 6000 MHZ), which also includes the frequencies used in previous generations' broadband cellular networks (1G, 2G, 3G and 4G).

The articles identified through database searching and other sources were 2834. After removing duplicates (9) and excluding non-pertinent articles (2785) based on title and abstracts, 40 articles remained. Based on full-text screening, 12 papers were further excluded, so that the published articles with appropriate frequencies to be included in this qualitative synthesis were 28, corresponding to 26 studies (in two cases, two papers were published reporting information on the same study) (Fig. 13).

At this stage, selection based on frequency range was also performed: 28 papers/26 studies referred to exposures belonging to the FR1 range, and 2 referred to FR2 as well. These 2 papers report exposures suitable for both FR1 and FR2, so they don't add up to the overall number of included studies; the same study is analysed therefore twice, once in every frequency range.

Figure 13 – Flow diagram. Epidemiological studies on reproductive/developmental effects FR1



MALE FERTILITY

Case-control studies (Tables 12a)

1. Al-Quzwini et al., 2016.

Iraq. Case-control study.

A seminal fluid analysis is clinical marker of male reproductive potential. To find out whether environmental hazard such as mobile phone tower has an effect on male reproductive ability. Two hundred couples were enrolled, one hundred subfertile couples as a study group (n=100), and one hundred fertile couples as a control group (n= 100). Environmental exposure to electromagnetic radiation from mobile phone towers and occupational state was assessed by standard questionnaire. Semen analysis was done for the subfertile males, because the fertile males (control group) refused to give semen samples. The occupational hazard expressed significant difference between the subfertile and the control groups (38% versus 12%) (p< 0.05), with odds ratio (OR) =4.5 and 95% Confidence Interval (CI): 2.175–9.288, and also the environmental factor (mobile tower within fifty meters from their house) showed significant difference (29% versus 12%) (p< 0.05), with OR= 3; 95% CI: 1.426–6.290. SFA of the subfertile males was 40% abnormal versus 60% normal semen analysis. These abnormalities were classified into 35% oligozoospermia, 55% asthenospermia, and 10% teratozoospermia. Oligozoospermia was associated with more occupational hazard (OR= 1.8, 95% CI: 0.569–5.527). Teratozoospermia was associated with more occupational hazard (OR= 5.23, 95% CI: 0.524–52.204), and with exposure to environmental hazard (OR = 2.6, 95% CI: 0.342– 19.070), and associated with smoking hazard (OR =1.7, 95% CI: 0.225–12.353). Male fertility represented by quality of semen might be affected by occupational and environmental exposures, so it seems that prevention of occupational and environmental risk factors, may lead to improvement of semen quality in subfertile men.

Comment*: *Inadequate/Inconclusive.

Cross-sectional studies (Tables 13, a-d)

2. Baste et al., 2008.

Norway. 2002-2004. Cross-sectional study, occupational exposure.

The authors performed a cross-sectional study among military men employed in the Royal Norwegian Navy, including information about work close to equipment emitting radiofrequency electromagnetic fields, one-year infertility, children and sex of the offspring. Among 10,497 respondents, 22% had worked close to high-frequency aerials to a "high" or "very high" degree. Infertility increased significantly along with increasing self-reported exposure to radiofrequency electromagnetic fields. In a logistic regression, the odds ratio (OR) for infertility among those who had worked closer than 10 m from high-frequency aerials to a "very high" degree relative to those who reported no work near high-frequency aerials was 1.86 (95% confidenceinterval (CI): 1.46–2.37), adjusted for age, smoking habits, alcohol consumption and exposure to organic solvents, welding and lead. Similar adjusted OR for those exposed to a "high", "some" and "low" degree were 1.93 (95% CI: 1.55–2.40), 1.52 (95% CI: 1.25–1.84), and 1.39 (95% CI: 1.15–1.68), respectively. In all age groups there were significant linear trends with higher prevalence of involuntary childlessness with higher self-reported exposure to radiofrequency fields. However, the degree of exposure to radiofrequency radiation and the number of children were not associated. For self-reported exposure both to high-frequency aerials and communication equipment there were significant linear trends with a lower ratio of boys to girls at birth when the father reported a higher degree of radiofrequency electromagnetic exposure.

Comment*: *Self-reported level of exposure. Higher degree of RF-EMF exposure associated to infertility and a lower ratio of boys to girls at birth.

3. Mollerlekken and Moen, 2008.

Norway. 2002. Cross-sectional, occupational exposure.

The aim of this study was to examine the relationship between workers exposed to electromagnetic fields and their reproductive health. We obtained data using a questionnaire in a cross-sectional study of naval military men, response rate 63% (n¼1487). The respondents were asked about exposure, lifestyle, reproductive health, previous diseases, work and education. An expert group categorized the work categories related to electromagnetic field exposure. We categorized the work categories "tele/communication," "electronics" and "radar/sonar" as being exposed to electromagnetic fields. Logistic regression adjusted for age, ever smoked, military education, and physical exercise at work showed increased risk of infertility among tele/ communication odds ratio (OR≤1.72, 95% confidence interval 1.04–2.85), and radar/sonar odds ratio (OR≤2.28, 95% confidence interval 1.27–4.09). The electronics group had no increased risk. This study shows a possible relationship between exposure to radiofrequency fields during work with radiofrequency equipment and radar and reduced fertility. However, the results must be interpreted with caution.

Comment*: *Self-reported exposure. Possible increased risk of infertility among telecommunication and radar/sonar operators.

4. Fejez et al., 2005.

Hungary. Cross-sectional study.

The history-taking of men in our university clinic was supplemented with questions concerning cell phone use habits, including possession, daily standby position and daily transmission times. Semen analyses were performed by conventional methods. Statistics were calculated with SPSS statistical software. A total of 371 were included in the study. The duration of possession and the daily transmission time correlated negatively with the proportion of rapid progressive motile sperm (r = 0.12 and r = 0.19, respectively), and positively with the proportion of slow progressive motile sperm (r =0.12 and r = 0.28, respectively). The low and high transmitter groups also differed in the proportion of rapid progressive motile sperm (48.7% vs. 40.6%). The prolonged use of cell phones may have negative effects on the sperm motility characteristics.

Comment*: *Exposure self-reported. Confounding factors not analysed.

5. Jurewicz et al., 2014, Radwan et al., 2016 (they published the same study).

Poland. Cross-sectional study.

The aim of the study was to examine the association between modifiable lifestyle factors and main semen parameters, sperm morphology, and sperm chromatin structure. The study population consisted of 344 men who were attending an infertility clinic for diagnostic purposes with normal semen concentration of 20–300 M/ml or with slight oligozoospermia (semen total concentration of 15–20 M/ml) [WHO 1999]. Participants were interviewed and provided semen samples. The interview included questions about demographics, socio-economic status, medical history, lifestyle factors (consumption of alcohol, tobacco, coffee intake, cell phone and sauna usage), and physical activity. The results of the study suggest that lifestyle factors may affect semen quality. A negative association was found between increased body mass index (BMI) and semen volume (p≤0.03). Leisure time activity was positively associated with sperm concentration (p≤0.04) and coffee drinking with the percentage of motile sperm cells, and the percentage of sperm head and neck abnormalities (p≤0.01, p≤0.05, and p≤0.03, respectively). Drinking red wine 1–3 times per week was negatively related to sperm neck abnormalities (p≤0.01). Additionally, using a cell phone more than 10 years decreased the percentage of motile sperm cells (p≤0.02). Men who wore boxer shorts had a lower percentage of sperm neck abnormalities (p≤0.002) and percentage of sperm with DNA damage (p≤0.02). These findings may have important implications for semen quality and lifestyle.

Comment*: *Self-reported exposure. Different confounders could affect results.

6. Yildirim et al., 2015.

   Turkey. Cross-sectional study.

Semen for analyses from the male patients coming to our infertility division and also asked them to fill out an anonymous questionnaire. We queried their mobile phone and wireless internet usage frequencies in order to determine their radiofrequency-electromagnetic radiation exposure. A total of 1082 patients filled the questionnaire but 51 of them were excluded from the study because of azoospermia. There was no significant difference between sperm counts and sperm morphology excluding sperm motility, due to mobile phone usage period, ($p = 0.074$, $p = 0.909$, and $p = 0.05$, respectively). The total motile sperm count and the progressive motile sperm count decreased due to the increase of internet usage ($p = 0.032$ and $p = 0.033$, respectively). In line with the total motile sperm count, progressive motile sperm count also decreased with wireless internet usage compared with the wired internet connection usage ($p = 0.009$ and $p = 0.018$, respectively). There was a negative correlation between wireless internet usage duration and the total sperm count ($r = -0.089$, $p = 0.039$). We have also explored the negative effect of wireless internet use on sperm motility according to our preliminary results.

Comment*: *Exposure self-reported. Confounding factors were not analysed. Any difference between sperm parameters and cell phone and wireless internet usage is the authors conclusions.

7. Zilberlicht et al., 2015.

   Israel. Cross-sectional.

Male infertility constitutes 30–40% of all infertility cases. Some studies have shown a continuous decline in semen quality since the beginning of the 20th century. One postulated contributing factor is radio frequency electromagnetic radiation emitted from cell phones. This study investigates an association between characteristics of cell phone usage and semen quality. Questionnaires accessing demographic data and characteristics of cell phone usage were completed by 106 men referred for semen analysis. Results were analysed according to WHO 2010 criteria. Talking for ≥1 h/day and during device charging were associated with higher rates of abnormal semen concentration (60.9% versus 35.7%, $P < 0.04$ and 66.7% versus 35.6%, $P < 0.02$, respectively). Among men who reported holding their phones ≤50 cm from the groin, a non-significantly higher rate of abnormal sperm concentration was found (47.1% versus 11.1%). Multivariate analysis revealed that talking while charging the device and smoking were risk factors for abnormal sperm concentration (OR = 4.13 [95% CI 1.28–13.3], $P < 0.018$ and OR = 3.04 [95% CI 1.14–8.13], $P < 0.027$, respectively). Our findings suggest that certain aspects of cell phone usage may bear adverse effects on sperm concentration. Investigation using largescale studies is thus needed.

Comment*: *Self-reported exposure. Some association was found.

8. Al-Bayyari, 2017.

   Jordan. Cross-sectional observational study.

The objective was to study the effect of cell phone usage on semen quality and men's fertility. A cross-sectional observational study conducted on 159 men attending infertility clinics at North, Middle and South Governorates in Jordan and undergoing infertility evaluation were divided into two groups according to their active cell phone use: group A: ≤1 h/day and group B: >1 h/day. No interventions were given to patients and semen samples were collected by masturbation in a sterile container after an abstinence period of 5 days. The main outcome measures were sperm volume, liquefaction time, pH, viscosity, count, motility and morphology.

Time of talking by cell phone was recorded and the subjects were divided into 2 groups; group A ≤ 1 h/day (n = 104); group B > 1 h/day (n = 52) and participants who did not use cell phone (n = 3) were excluded from the statistical analysis regarding studying the effect of time spent in calling or receiving calls.There were no statistical significance differences ($p > 0.05$) between both groups regarding sperm quality parameters according to cell phone use, but there were statistical differences in the frequencies of sperm concentration, volume, viscosity, liquefaction time and means of immotile sperms and abnormal morphology. In addition, time spend on watching television and using wireless phones were significantly ($p \leq 0.05$) associated with decreasing mean percentages of normal morphology. The distance from telecommunication tower was significantly ($p \leq 0.05$) associated with decreasing sperms volume. Meanwhile, the time spent on sending or receiving messages was significantly ($p \leq 0.05$) associated with decreasing sperms count and carrying mobile phone in trouser pocket was significantly associated with increasing means of immotile sperms. Cell phone use might have a negative effect on semen quality parameters and further research is needed.

Comment*: *Self-reported exposure. Cell phone use might have a negative effect on semen quality parameters.

9. Shi et al., 2018.

Cross-sectional study.

Three hundred and twenty-eight subjects who underwent semen analysis were recruited. Routine SA, sperm vitality, acrosome reaction (AR) assay and sperm DNA fragmentation index (DFI) were analyzed. Demographic and lifestyle information, including (1) BMI, (2) current smoking and alcohol drinking frequency, (3) sleep habits, (4) daily fluid intake, (5) weekly meat intake, (6) sports frequency, (7) trouser cell phone use, (8) age, and (9) abstinence time, were collected. Generalized additive models were used to analyze the possible non-linear association. The results showed that total sperm count (TSC) was significantly associated with age ($P = 0.001$), abstinence time ($P = 0.001$) and daily coffee intake ($P = 0.044$). Semen volume was significantly associated with age ($P < 0.001$) and daily coffee intake ($P < 0.001$). Sperm concentration was significantly associated with abstinence time ($P = 0.011$) and average sleep duration ($P = 0.010$). Sperm motility was significantly associated with age ($P = 0.002$) and daily juice intake ($P = 0.001$). Total motile sperm count was significantly associated with age ($P = 0.003$) and abstinence time ($P = 0.009$). DFI was significantly associated with age ($P = 0.002$), irregular sleeping habit ($P = 0.008$) and abstinence time ($P = 0.032$). The percentage of AR sperm was significantly associated with daily juice intake ($P = 0.013$). In conclusion, DFI and TSC were the most sensitive semen parameters for demographic and lifestyle features, whereas age had more influence on semen parameters than other demographic and lifestyle features. Trouser cell phone use was not significantly associated with any alteration of the sperm parameters examined.

Comment*: *Self-reported exposure. Many confounders in age and lifestyle. Any association with sperm alteration.

10. Blay et al., 2020.

Ghana. Cross-sectional study.

Male infertility is known to contribute about half of all infertility cases. In Ghana, the prevalence of male infertility is higher (15.8%) than in females (11.8%). Sperm quality is associated with the likelihood of pregnancy and known to be the cause of male fertility problems 90% of the time. Exposure to certain environmental factors reduces semen quality in men. The study examined the effects of environmental and lifestyle factors on semen quality in Ghanaian men. Materials and Methods. This was a cross-sectional study involving 80 apparent healthy adult males in their reproductive age. Participants were males referred to the laboratory (Immunology Unit of the Korle-Bu Teaching Hospital) for semen analysis test and/or culture and sensitivity. Participants were made to fill out a questionnaire which entailed selected environmental factors (accidents or trauma, exposure to chemicals, radiation, and heat) and lifestyle habits (including alcohol consumption, smoking, and whether participants sat more or less than 4 hours per day).

Semen samples were then collected by masturbation into sterile containers and analysed in accordance with WHO guidance for semen analysis within 60 minutes after ejaculation and collection. Results. About 69% of participants had semen pH within the normal range compared to 15% whose pH were lower than 7.2. There was a significantly high number of immotile sperm cells (p value = 0.017) in participants who sat for more than 4 hours as compared to those that sat for less than 4 hours in a day. Active sperm motility and viability showed significant increase (p value = 0.002 and 0.009, respectively) in participants who kept their cell phones in their side pockets. Smoking produced a twofold decrease in sperm count as smokers had a significantly lower sperm count (12:28 ± 10:95 × 106/ml) compared to the smoke-free (23:85 ± 22:14 × 106/ml). For exposure to STDs, no significant differences were recorded among study groups concerning semen quality. Conclusion. Sperm quality in Ghanaian men is associated with lifestyle habits. Smoking and sitting for long hours influenced sperm motility and count, respectively. Knowledge of the factors that influence sperm quality in this geographical region can contribute to informed decisions on effective management of infertility in Ghanaian men.

Comment: Self-reported exposure, uncertain. Increased activity and viability associated to cell phone in their side pockets. Many confounders.

Cohort studies (Tables 14, a-c)

11. Zhang, 2016.

China. 2013-2015. Cohort study.

Recruiting participants from infertility clinic not from general population may raise the possibility of a selection bias. To investigate effects of cell phone use on semen parameters in a general population. We screened and documented the cell phone use information of 794 young men from the Male Reproductive Health in Chongqing College students (MARHCS) cohort study in 2013, followed by 666 and 568 in 2014 and 2015, respectively. In the univariate regression analyses, we found that the daily duration of talking on the cell phone was significantly associated with decreased semen parameters, including sperm concentration [β coefficient = −6.32% per unit daily duration of talking on the cell phone (h); 95% confidence interval (CI), −11.94, −0.34] and total sperm count (−8.23; 95% CI, −14.38, −1.63) in 2013; semen volume (−8.37; 95% CI, −15.93, −0.13) and total sperm count (−16.59; 95% CI, −29.91, −0.73) in 2015]. Internet use via cellular networks was also associatedwith decreased sperm concentration and total sperm counts in 2013 and decreased semen volume in 2015. Multivariate analyseswere used to adjust for the effects of potential confounders, and significant negative associations between internet use and semen parameters remained. Consistent but nonsignificant negative associations between talking on the cell phone and semen parameters persisted throughout the three study years, and the negative association was statistically significant in a mixed model that considered all three years of data on talking on the cell phone and semen quality. Our results showed that certain aspects of cell phone use may negatively affect sperm quality inmen by decreasing the semen volume, sperm concentration, or sperm count, thus impairing male fertility.

Comment: Self-reported exposure. Confounding not analysed. Association with impairment of male fertility.

12. Lewis et al., 2017.

USA. 2004-2015. Longitudinal cohort study, part of the EARTH Study.

This is a longitudinal cohort study that recruited couples seeking infertility treatment from the Massachusetts General Hospital (MGH) Fertility Center; difficulty conceiving may be related to a male factor, a female factor, or a combination of both male and female factors. The relationship between mobile phone use patterns and markers of semen quality was explored in a longitudinal cohort study of 153 men that attended an academic fertility clinic in Boston, Massachusetts. Men between the ages of 18–56 years were eligible to participate. Information on mobile phone use duration (no use, <2 h/day,2–4 h/day, >4 h/day), headset or earpiece use (never, occasionally, some of the time, most of the time, all of the time), and location in which the mobile phone was carried (pants pocket, belt, bag, other) was ascertained via nurse-administered questionnaire. Semen samples (n = 350) were collected and analysed onsite. To account for multiple semen samples per man, linear mixed models with random intercepts were used to investigate the association between mobile phone use and semen parameters. Overall, there was no evidence for a relationship between mobile phone use and semen quality.

Comment*: *Self-reported exposure. No evidence for a relationship between mobile phone use and semen quality.

DEVELOPMENTAL STUDIES

Case-control studies (Tables 15 a-f)

13. Tan et al., 2014.

Singapore. Case-control study.

Threatened miscarriage occurs in 20% of pregnancies. We conducted a case-control study to assess the association between maternal lifestyle factors and risk of threatened miscarriage. Cases were 154 women presenting with threatened miscarriage in the 5th to 10th weeks of gestation; controls were 264 women without threatened miscarriage seen in antenatal clinic in the 5th to 10th week of pregnancy. Lifestyle variables were: current and past cigarette smoking, current second-hand cigarette smoke exposure, computer and mobile-phone use, perceived stress, past contraceptive use, past menstrual regularity and consumption of fish oils, caffeine and alcohol. Logistic regression was performed. In multivariate analysis, we found a positive association of threatened miscarriage with second-hand smoke exposure (OR 2.93, 95% CI 1.32–6.48), computer usage (>4 hours/day) (OR 6.03, 95% CI 2.82–12.88), mobile-phone usage (>1 hour/day) (OR 2.94 95% CI 1.32–6.53) and caffeine consumption (OR 2.95 95% CI 1.57– 5.57). Any fish oil consumption was associated with reduced risk of threatened miscarriage (OR 0.20, 95% CI 0.09–0.42). Prolonged mobile phone and computer use and fish oil supplementation are potential novel correlates of threatened miscarriage that deserve further study.

Comment*: *Self-reported exposure. Stress as a confounding variable not considered. Correlation between mobile phone and computer use and threatened miscarriage observed.

14. Mahmoudabadi et al., 2015.

Iran. Case-control study.

Exposure to electromagnetic fields of cell phones increasingly occurs, but the potential influence on spontaneous abortion has not been thoroughly investigated. Methods: In a case–control study, 292 women who had an unexplained spontaneous abortion at < 14 weeks gestation and 308 pregnant women > 14 weeks gestation were enrolled. Two data collection forms were completed; one was used to collect data about socioeconomic and obstetric characteristics, medical and reproductive history, and lifestyles. Another was used to collect data about the use of cell phones during pregnancy. For the consideration of cell phone effects, we measured the average calling time per day, the location of the cell phones when not in use, use of hands-free equipment, use of phones for other applications, the specific absorption rate (SAR) reported by the manufacturer and the average of the effective SAR (average duration of calling time per day × SAR). Analyses were carried out with statistical package state software (SPSS)v.16. The association between use of cell phones and the risk of spontaneous abortions against potential confounders was supported by evidence that despite adjustments for many known or suspected risk factors in logistic regression analyses, the estimation was not significantly altered. All the data pertaining to mobile phones were different between the two groups except the use of hands-free devices ($p < 0.001$). Our result suggests that use of mobile phones can be related to the early spontaneous abortions.

Comment*: *Self-reported exposure. Use of mobile phones may be related to the early spontaneous abortions.

Cross-sectional studies (Tables 16, a,b)

15. Col-Araz, 2013.

Turkey. 2009. Cross-sectional study.

The study was conducted in Turkey at Gazintep University, Faculty of Medicine's Outpatient Clinic at the Paediatric Ward. It comprised 500 patients who presented at the clinic from May to December 2009. All participants were administered a questionnaire regarding their pregnancy history. SPSS 13 was used for statistical analysis. In the study, 90 (19%) patients had pre-term birth , and 64 (12.9%) had low birth weight rate Birth weight was positively correlated with maternal age and baseline maternal weight (r= 0.115, p= 0.010; r= 0.168, p= 0.000, respectively). Pre-term birth and birth weight less than 2500g were more common in mothers with a history of disease during pregnancy (p=0.046 and p=0.008, respectively). The habit of watching television and using mobile phones and computer by mothers did not demonstrate any relationship with birth weight. Mothers who used mobile phones or computers during pregnancy had more deliveries before 37 weeks (p=0.018, p=0.034; respectively). Similarly, pregnancy duration was shorter in mothers who used either mobile phone or computers during pregnancy (p=0.005, p=0.048, respectively). Mobile phones and computers may have an effect on pre-term birth.

Comment*: *Self-reported exposure. Mobile phones and computers may have an effect on pre-term birth.

16. Zarei S. et al., 2015.

Iran. 2014. Cross-sectional study.

The purpose of this study was to investigate whether the maternal exposure to different sources of electromagnetic fields affects the rate and severity of speech problems in their offspring. In this study, mothers of 35 healthy 3-5 years old children (control group) and 77 children diagnosed with speech problems who had been referred to a speech treatment centre in Shiraz, Iran were interviewed. These mothers were asked whether they had exposure to different sources of electromagnetic fields such as mobile phones, mobile base stations, Wi-Fi, cordless phones, laptops and power lines. A significant association between either the call time (P=0.002) or history of mobile phone use (months used) and speech problems in the offspring (P=0.003) was found. However, other exposures had no effect on the occurrence of speech problems. To the best of our knowledge, this is the first study to investigate a possible association between maternal exposure to electromagnetic fields and speech problems in the offspring. Although a major limitation in our study is the relatively small sample size, this study indicates that the maternal exposure to common sources of electromagnetic fields such as mobile phones can affect the occurrence of speech problems in the offspring.

Comment*: *Small sample size, limit in exposure assessment. Association between maternal use of mobile phone and speech problems in the offspring.

17. Abad et al., 2016.

Iran. Cross-sectional study.

Investigation of the associations between electromagnetic field exposure and miscarriage among women of Tehran. In this longitudinal study, 462 pregnant women with gestational age <12 wks from seven main regions of Teheran city in Iran with similar social and cultural status were participated. The mean age of women was 28.22±4.53 years old. The frequency of spontaneous miscarriage was 56 cases. The incidence of abortion was 12.3%. Women were interviewed face-to face to collect data. Reproductive information was collected using medical file recorded in those hospitals the subjects had delivery. The measuring device measured electromagnetic waves, Narda safety test solutions with valid calibration date at the entrance door of their houses. A significant likelihood of miscarriage in women who exposed to significant level of electromagnetic wave. However, this association was not confirmed by Wald test. This study may not provide strong or consistent evidence that electromagnetic field exposure is associated or cause miscarriage. This issue may be due to small sample size in this study.

Comment : Self-reported exposure. Small sample. Uncertain association between miscarriage and use of mobile phone.

18. Lu et al., 2017.

Japan. 2012-2014. Cross sectional study from cohort data.

The aim of the study was to determine the associations of excessive mobile phone use with neonatal birth weight and infant health status. A sample of 461 mother and child pairs participated in a survey on maternal characteristics, infant characteristics, and information about maternal mobile phone usage during pregnancy. Results showed that pregnant women tend to use mobile phones excessively in Japan. The mean infant birth weight was lower in the excessive use group than in the ordinary use group, and the frequency of infant emergency transport was significantly higher in the excessive use group than in the ordinary use group. Excessive mobile phone use during pregnancy may be a risk factor for lower birth weight and a high rate of infant emergency transport.

Comment: Self-reported exposure. Limited sample size. Limited assessment of mothers' exposure. Inconclusive.

Cohort studies (Tables 17, a-f)

19. Mjøen et al., 2006.

Norway. 1976-1995. Cohort study on adverse pregnancy outcome, occupational exposure.

The objective was to assess associations between paternal occupational exposure to RF-EMF and adverse pregnancy outcomes including birth defects using population-based data from Norway. Data on reproductive outcomes derived from the Medical Birth Registry of Norway were linked with data on paternal occupation derived from the general population censuses. Maritime occupations, telephone repair and installation workers and welders were chosen as three separate groups. An expert panel categorized occupations according to exposure. Three occupational exposure levels were assessed, reflecting probability of exposure to RFR; one group was "probably not exposed" (376,837 births), one group of "possibly exposed" (139,871 births), and one group of "probably exposed" (24,885 births). Using logistic regression 24 categories of birth defects as well as other adverse outcomes were analysed. In the offspring of fathers most likely to have been exposed, increased risk was observed for preterm birth (OR: 1.08, 95% confidence interval (CI): 1.03, 1.15). In this group we also observed a decreased risk of cleft lip (OR: 0.63, 95% CI: 0.41, 0.97). In the medium exposed group, we observed increased risk for a category of "other defects" (OR: 2.40, 95% CI:1.22, 4.70), and a decreased risk for a category of "other syndromes" (OR: 0.75, 95% CI: 0.56, 0.99) and upper gastrointestinal defects (OR: 0.61, 95% CI: 0.40, 0.93). The study is partly reassuring for occupationally exposed fathers.

Comment: Level of exposure uncertain. No evidence for a relationship between occupational exposure to RF-EMF and adverse pregnancy outcome.

20. Divan at al., 2008; Divan et al., 2011.

Denmark. Children born between 1997 and 1999, then updated to 2002. Cohort study.

The association between prenatal and postnatal exposure to cell phones and behavioral problems in young children was examined. Mothers were recruited to the Danish National Birth Cohort early in pregnancy. When the children of those pregnancies reached 7 years of age in 2005 and 2006, mothers were asked to complete a questionnaire regarding the current health and behavioral status of children, as well as past exposure to cell phone use. Mothers evaluated the child's behavior problems using the Strength and Difficulties Questionnaire. Mothers of 13,159 children completed the follow-up questionnaire reporting their use of cell phones during pregnancy as well as current cell phone use by the child. Greater odds ratios for behavioral problems were observed for children who had possible prenatal or postnatal exposure to cell phone use. After adjustment for potential confounders, the odds ratio for a higher overall behavioral problems score was 1.80 (95% confidence interval 1.45–2.23) in children with both prenatal and postnatal exposure to cell phones. Exposure to cell phones prenatally—and, to a lesser degree, postnatally—was associated with behavioral difficulties such as emotional and hyperactivity problems around the age of school entry.

Comment*: *Self-reported exposure and other possible confounders. Exposure to cell phone prenatally—and, to a lesser degree, postnatally—was associated with behavioral difficulties such as emotional and hyperactivity problems around the age of school entry.

Denmark. Children born between 1996 and 2002. Cohort study.

The aim of the second study was to examine if prenatal use of cell phones by pregnant mothers is associated with developmental milestones delays among offspring up to 18 months of age.
Methods Our work is based upon the Danish National Birth Cohort (DNBC), which recruited pregnant mothers from 1996–2002, and was initiated to collect a variety of detailed information regarding in utero exposures and various health outcomes. At the end of 2008, over 41 000 singleton, live births had been followed with the Age-7 questionnaire, which collected cell-phone-use exposure for mothers during pregnancy. Outcomes for developmental milestones were obtained from telephone interviews completed by mothers at age 6- and 18-months postpartum. Results A logistic regression model estimated the odds ratios (OR) for developmental milestone delays, adjusted for potential confounders. Less than 5% of children at age 6 and 18 months had cognitive/language or motor developmental delays. At 6 months, the adjusted OR was 0.8 [95% confidence interval (95% CI) 0.7–1.0] for cognitive/ language delay and 0.9 (95% CI 0.8–1.1) for motor development delay. At 18 months, the adjusted OR were 1.1 (95% CI 0.9–1.3) and 0.9 (95% CI 0.8–1.0) for cognitive/language and motor development delay, respectively. Conclusions No evidence of an association between prenatal cell phone use and motor or cognitive/language developmental delays among infants at 6 and 18 months of age was observed. Even when considering dose–response associations for cell phone use, associations were null.

***Comment*: *Self-reported exposure. No evidence of an association between prenatal cell phone use and motor or cognitive/language developmental delays*.**

21. Guxens et al., 2013.

The Netherlands. 2003-2004 enrolment; 2008-2009 assessment of behavioural problems; 2010-2011 retrospective exposure assessment.

The study was embedded in a population-based prospective birth cohort study. Together with cell phones, cordless phones represent the main exposure source of radiofrequency-electromagnetic fields to the head. Therefore, we assessed the association between maternal cell phone and cordless phone use during pregnancy and teacher-reported and maternal-reported child behaviour problems at age 5. The study was embedded in the Amsterdam Born Children and their Development study, a population-based birth cohort study in Amsterdam, the Netherlands (2003–2004). Teachers and mothers reported child behaviour problems using the Strength and Difficulties Questionnaire at age 5. Maternal cell phone and cordless phone use during pregnancy was asked about when children were 7 years old. A total of 2618 children were included. As compared to non-users, those exposed to prenatal cell phone use showed an increased but non-significant association of having teacher-reported overall behaviour problems, although without dose-response relationship. with the number of calls (OR=2.12 (95% CI 0.95 to 4.74) for <1 call/day, OR=1.58 (95% CI 0.69 to 3.60) for 1–4 calls/day and OR=2.04 (95% CI 0.86 to 4.80) for ≥5 calls/day). ORs for having teacher-reported overall behaviour problems across categories of cordless phone use were below 1 or close to unity. Associations of maternal cell phone and cordless phone use with maternal-reported overall behaviour problems remained non-significant. Non-significant associations were found for the specific behaviour problem subscales. Our results do not suggest that maternal cell phone or cordless phone use during pregnancy increases the odds of behaviour problems in their children.

Comment*: *Self-reported exposure and other possible confounders. Use of mobile phone during pregnancy increases specific behaviour problems, non significant.

22. Choi et al., 2017.

South Korea. 2006-2016. Multi-centre prospective cohort study (the Mothers and Children's Environmental Health (MOCEH) study).

Studies examining prenatal exposure to mobile phone use and its effect on child neurodevelopment show different results, according to the child's developmental stages. To examine neurodevelopment in children up to 36 months of age, following prenatal mobile phone use and radiofrequency radiation (RF-EMF) exposure, in relation to prenatal lead exposure, we analyzed 1198 mother-child pairs from a prospective cohort study (the Mothers and Children's Environmental Health Study). Questionnaires were provided to pregnant women at ≤20 weeks of gestation to assess mobile phone call frequency and duration. A personal exposure meter (PEM) was used to measure RF-EMF exposure for 24 h in 210 pregnant women. Maternal blood lead level (BLL) was measured during pregnancy. Child neurodevelopment was assessed using the Korean version of the Bayley Scales of Infant Development- Revised at 6, 12, 24, and 36 months of age. Logistic regression analysis applied to groups classified by trajectory analysis showing neurodevelopmental patterns over time. The psychomotor development index (PDI) and the mental development index (MDI) at 6, 12, 24, and 36 months of age were not significantly associated with maternal mobile phone use during pregnancy. However, among children exposed to high maternal BLL in utero, there was a significantly increased risk of having a low PDI up to 36 months of age, in relation to an increasing average calling time (p-trend=0.008). There was also a risk of having decreasing MDI up to 36 months of age, in relation to an increasing average calling time or frequency during pregnancy (p-trend=0.05 and 0.007 for time and frequency, respectively). There was no significant association between child neurodevelopment and prenatal RF-EMF exposure measured by PEM in all subjects or in groups stratified by maternal BLL during pregnancy. No association between prenatal exposure to RF-EMF and child neurodevelopment during the first three years of life was found; however, a potential combined effect of prenatal exposure to lead and mobile phone use was suggested.

Comment*: *Maternal blood lead level as main confounding factor. A potential combined effect is suggested.

23. Papadopoulou et al., 2017.

Norway. 1999-2008. Prospective population-based pregnancy cohort study MoBa, Norwegian Institute of Public Health.

The association between maternal cell phone use in pregnancy and child's language, communication and motor skills at 3 and 5 years was studied. This prospective study includes 45,389 mother-child pairs, participants of the MoBa, recruited at mid-pregnancy from 1999 to 2008. Maternal frequency of cell phone use in early pregnancy and child language, communication and motor skills at 3 and 5 years, were assessed by questionnaires. Logistic regression was used to estimate the associations. Results: No cell phone use in early pregnancy was reported by 9.8% of women, while 39%, 46.9% and 4.3% of the women were categorized as low, medium and high cell phone users. Children of cell phone user mothers had 17% (OR = 0.83, 95% CI: 0.77, 0.89) lower adjusted risk of having low sentence complexity at

3 years, compared to children of non-users. The risk was 13%, 22% and 29% lower by low, medium and high maternal cell phone use. Additionally, children of cell phone users had lower risk of low motor skills score at 3 years, compared to children of non-users, but this association was not found at 5 years. We found no association between maternal cell phone use and low communication skills. We reported a decreased risk of low language and motor skills at three years in relation to prenatal cell phone use, which might be explained by enhanced maternal-child interaction among cell phone users. No evidence of adverse neurodevelopmental effects of prenatal cell phone use was reported.

Comment: Self-reported exposure. No evidence of adverse neurodevelopmental effects of prenatal cell phone use was reported.

24. Sudan et al., 2018.

Denmark DNBC, Spain INMA, and Korea MOCEH.

The relationship between maternal cell phone use during pregnancy and cognitive performance in 5-years old children is studied. This study included data from 3 birth cohorts: the Danish National Birth Cohort (DNBC) (n=1209), Spanish Environment and Childhood Project (INMA) (n=1383), and Korean Mothers and Children's Environment Health Study (MOCEH) (n=497). All cohorts collected information about maternal cell phone use during pregnancy and cognitive performance in children at age 5. Linear regression to compute mean differences (MD) and 95% confidence intervals (CI) in children's general, verbal, and non-verbal cognition scores comparing frequency of maternal prenatal cell phone use with adjustments for numerous potential confounding factors were performed. Models were computed separately for each cohort and using pooled data in meta-analysis. No associations were detected between frequency of prenatal cell phone use and children's cognition scores. Scores tended to be lower in the highest frequency of use category; MD (95% CI) in general cognition scores were 0.78 (−0.76, 2.33) for none, 0.11 (−0.81, 1.03) for medium, and −0.41 (−1.54, 0.73) for high compared to low frequency of use. This pattern was seen across all cognitive dimensions, but the results were imprecise overall. Patterns of lower mean cognition scores among children in relation to high frequency maternal prenatal cell phone use were observed. The causal nature and mechanism of this relationship remain unknown.

Comment: Self-reported exposure. Patterns of lower mean cognition scores among children in relation to high frequency maternal prenatal cell phone use were observed.

25. Tsarna et al., 2019.

Denmark, Netherlands, Spain, South Korea. 1996-2011. Four population-based birth cohort studies participating in the GERoNiMO Project—namely, the Danish National Birth Cohort (DNBC), the Amsterdam Born Children and Their Development Study (ABCD), the Spanish Environment and Childhood Project (INMA), and the Korean Mothers and Children's Environment Health Study (MOCEH).

Results from studies evaluating potential effects of prenatal exposure to radio-frequency electromagnetic fields from cell phones on birth outcomes have been inconsistent. Using data on 55,507 pregnant women and their children from Denmark (1996–2002), the Netherlands (2003–2004), Spain (2003–2008), and South Korea (2006–2011), we explored whether maternal cell-phone use was associated with pregnancy duration and fetal growth. On the basis of self-reported number of cell-phone calls per day, exposure was grouped as none, low (referent), intermediate, or high. Pregnancy duration (gestational age at birth, preterm/post-term birth), fetal growth (birth weight ratio, small/large size for gestational age), and birth weight variables (birth weight, low/ high birth weight) and meta-analysed cohort-specific estimates were examined. The intermediate exposure group had a higher risk of giving birth at a lower gestational age (hazard ratio = 1.04, 95% confidence interval: 1.01, 1.07), and exposure response relationships were found for shorter pregnancy duration ($P < 0.001$) and preterm birth ($P = 0.003$). We observed no association with fetal growth or birth weight. Maternal cell-phone use during pregnancy may be associated with shorter pregnancy duration and increased risk of preterm birth, but these results should be interpreted with caution, since they may reflect stress during pregnancy or other residual confounding rather than a direct effect of cell-phone exposure.

Comment: Stress as a confounding factor. Uncertain association.

26. Boileau et al, 2020.

France. 2014-2017.Prospective, longitudinal, multicenter observational cohort study

The aim of this study was to evaluate the association between mobile phone use by pregnant women and fetal development during pregnancy in the general population.Data came from the NéHaVi cohort ("prospective follow-up, from intrauterine development to the age of 18 years, for children born in Haute-Vienne"), a prospective, longitudinal, multicenter (three maternity units in Haute-Vienne) observational cohort focusing on children born between April 2014 and April 2017. Main objective was to investigate the association of mobile phone use on fetal growth. Univariate and multivariate models were generated adjusted for the socioprofessional category variables of the mother, and other variables likely to influence fetal growth. For the analysis 1378 medical charts were considered from which 1368 mothers (99.3 %) used their mobile phones during pregnancy. Mean phone time was 29.8 min (range: 0.0–240.0 min) per day. After adjustment, newborns whose mothers used their mobile phones for more than 30 min/day were significantly more likely to have an AUDIPOG score ≤10th percentile than those whose mothers used their mobile phones for less than 5 min/day during pregnancy (aOR = 1.54 [1.03; 2.31], p = 0.0374). For women using their cell phones 5–15 min and 15–30 min, there wasn't a significant association with an AUDIPOG score ≤ 10th, respectively aOR = 0.98 [0.58; 1.65] and aOR = 1.68 [0.99; 2.82]. Using a mobile phone for calls for more than 30 min per day during pregnancy may have a negative impact on fetal growth. A prospective study should be performed to further evaluate this potential link.

Comment: Fetal growth restriction observed when mother were using mobile phone more than 30'/day.

Table 12 - Reproductive/developmental effects in humans: man fertility, epidemiologic case-control studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjust ments	Comments
1. Al-Quzwini et al., 2016. Iraq, 2014-2015. Case-control study.	100 randomly selected subfertile couples that attended the infertility clinic of Babylon Teaching Hospital for Maternity and Pediatric in Al-Hilla city in Iraq; 100 volounteers fertile couples fro staff or relatives from same hospital as control group.	Environmental exposure to electromagnetic radiation from mobile phone towers and occupational state was assessed by standard questionnaire.	Living near to mobile phone base station (<50m) and with power intensity of 71.226 mW/m2, duration of exposure to the electromagnetic radiation. Occupational exposure to work hazard (ex. "driver" sitting for long period, "worker" painters and construction workers and "militaries")	Seminal fluid analysis of the subfertile males. Odds ratios and 95% CI, and Chi-square test for differences.	**Oligozoospermia among subfertile males, OR (95% CI)**	**Asthenospermia among subfertile males, OR (95% CI)**	**Teratozoospermia among subfertile males, OR (95% CI)**			Smoking	Inadequate Semen analysis was done for the subfertile males, because the fertile males (control group) refused to give semen samples.
			Type of hazard								
			Occupational		**1.8 (0.57-5.53)**	1.07 (0.87-1.32)	**5.23 (0.52-52.20)**				
			Environmental		1.03 (0.841.19)	1.19 (0.43-3.31)	**2.6 (0.34-19.07)**				

Table 13 - Reproductive/developmental effects in humans: man fertility, epidemiologic cross sectional -studies (450-6000 MHz) (occupational) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)						Any Other Co-Exposure/adjust ments	Comments
2. Baste et al., 2008. Norway. 2002-2004. Cross-sectional study	9925 current and former male military employees in the Royal Norwegian Navy, defined by the military employment list (M); mean age 49.	High-frequency aerials, communication equipment, radar. Self-assessed occupational exposure and age categories assessed by mail questionnaire.	Exposure to radiofrequency electromagnetic fields: work closer than 10 m from high-frequency aerials, work closer than 3 m from communication equipment and work closer than 5 m from radar.	Infertility. Odds ratios and 95% CI from adjusted logistic regression models; Mantel–Haenszel test for linear trend.	**Total Infertility - <10 m from high-frequency aerials, OR (95% CI)**	**Test for linear trend (Mantel–Haenszel chi-square)**	**Total Infertility - <3 m from communication equipment, OR (95% CI)**	**Test for linear trend (Mantel–Haenszel chi-square)**	**Total Infertility - <5 m from radar, OR (95% CI)**	**Test for linear trend (Mantel–Haenszel chi-square)**	Infertility. Odds ratios and 95% CI from adjusted logistic regression models; Mantel–Haenszel test for linear trend.	**Adequate/ Positive**
			Age <29									
			Not exposed									
			Low		1.00 (ref.)	0.013	1.00 (ref.)	0.077	1.00 (ref.)	0.001	Self-reported level of exposure.	
			Some		1.10 (0.30–4.07)		1.86 (0.54–6.40)		0.87 (0.25–2.99)			
			High		0.71 (0.15–3.34)		3.56 (1.05–12.08)		2.13 (0.64–7.06)			
			Very high		3.84 (1.09–13.52)		3.50 (0.83–14.78)		1.11 (0.20–6.00)			
			Age 30-39		2.70 (0.76–9.53)		2.49 (0.60–10.42)		5.09 (1.59–16.30)			
			Not exposed									
			Low		1.00 (ref.)	0.011	1.00 (ref.)	0.007	1.00 (ref.)	0.005		
			Some		1.24 (0.83–1.87)		1.53 (1.04–2.26)		1.46 (0.99–2.15)			
			High		1.36 (0.90–2.04)		1.88 (1.25–2.82)		1.32 (0.87–2.02)			
			Very high		1.51 (0.97–2.37)		1.76 (1.11–2.80)		1.79 (1.14–2.82)			
			Age 40-49		1.72 (1.08–2.74)		1.80 (1.10–2.96)		1.91 (1.19–3.07)			
			Not exposed									
			Low		1.00 (ref.)	<0.001	1.00 (ref.)	<0.001	1.00 (ref.)	0.002		
			Some		1.46 (1.03–2.07)		1.04 (0.75–1.45)		1.22 (0.87–1.71)			
			High		1.43 (0.99–2.07)		1.28 (0.91–1.81)		1.24 (0.87–1.79)			
			Very high		1.82 (1.21–2.75)		1.37 (0.91–2.08)		1.59 (1.05–2.41)			
			Age >50		1.90 (1.20–3.01)		1.86 (1.18–2.94)		1.50 (0.95–2.35)			
			Not exposed									
			Low		1.00 (ref.)	<0.001	1.00 (ref.)	<0.001	1.00 (ref.)	0.001		
			Some		1.28 (0.96–1.69)		1.02 (0.78–1.34)		1.11 (0.84–1.46)			
			High		1.59 (1.20–2.11)		1.31 (0.99–1.73)		1.58 (1.20–2.09)			
			Very high		2.02 (1.45–2.81)		1.71 (1.23–2.37)		1.39 (0.98–1.97)			

Table 13 - Reproductive/developmental effects in humans: man fertility, epidemiologic cross- sectional studies (450-6000 MHz) (occupational) (continue b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjust ments	Comments
3. Møllerløkken et al., 2008. Norway. 2002. Cross-sectional study.	2265 (M) employees who were currently serving in the Navy, both military and civilians. Mean age of 36 years of age, range 20–62.	Occupational exposure from military communication equipment. Information on occupational history from mail questionnaire. An expert group determined work categories related to electromagnetic field exposure.	Workers in the radar/sonar-, the tele/communication, electronics, other jobs (unexposed).	Infertility, Biological Children, Anomalies, Chromosomal Errors, Preterm and Stillbirths or Infant Deaths. Incidence of outcome by exposure group (%); Chi2 or Fisher Exact Tests to assess significance of differences among groups.	**Infertility - % (p-value from Chi2 tests)**	**Having biological children - % (p-value from Chi2 tests)**	**Children with anomalies or chromosomal errors - % (p-value from Chi2 or Fisher's Exact tests)**	**Children with preterm births - % (p-value from Chi2 or Fisher's Exact tests)**	**Stillbirths and infant deaths within 1 year - % (p-value from Fisher's Exact tests)**	Age, ever smoked, military education, and physical exercise at work.	Adequate /positive
			Other jobs (unexposed group)		8.6	62.0	3.5	7.9	2.3		
			Tele/communication workers (communication equipment, radio)		**14.8 (0.01)**	63.5 (0.70)	6.0 (0.18)	10.8 (0.18)	3.6 (0.22)		
			Electronics (electronics for weapons and communication systems)		12.1 (0.15)	58.6 (0.40)	1.8 (0.19)	9.5 (0.44)	1.8 (0.47)		
			Radar/sonar workers (radar)		**17.5 (<0.01)**	70.4 (0.10)	7.1 (0.11)	9.1 (0.37)	2.0 (0.61)		

Table 13 - Reproductive/developmental effects in humans: man fertility, epidemiologic cross-sectional studies (450-6000 MHz) (continued c)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjustments	Comments
4. Fejez et al. 2005. Hungary. Cross-sectional study.	611 consecutive Caucasian men of reproductive age from clinic for infertility problems.	Self reported	Duration of possession (in months), duration of standby position closer than 50 cm to the patient (in hours) and duration of daily transmission (in minutes).	Quality of semen. Parametric t-test and the Pearson correlation tests were applied.	**Volume (ml), correlation, p-value**	**Sperm concentration (mln/ml)**	**Total motility (%)**	**Total sperm count (mln/ ejaculate)**	**Total motile sperm count (mln/ ejaculate)**	Occupational exposure to some chemical pesticides, petroleum, solvents, lead and nitrosamines, tobacco consumption.	Inadequate
			Duration of possession (months)		-0.02, 0.64	-0.01, 0.91	-0.08, 0.14	-0.01, 0.81	-0.03, 0.53	Many confounders not analysed	
			Duration of daily standby (h)		0.05, 0.42	-0.01, 0.39	-0.03, 0.64	-0.05, 0.41	-0.07, 0.22		
			Duration of daily transmission (min)		-0.01, 0.84	0.04, 0.84	-0.07, 0.16	0.03, 0.58	0.00, 0.54		
5. Jurewicz et al. 2014, and Radwan et al. 2016. Poland. Cross-sectional study.	344 men, age <45 years, attending infertility clinics in Lodz, Poland in 2008-2011 for diagnostic purposes.	Modifiable lifestyle factors, among which use of cell phone, assessed using self-administered questionnaire.	Duration of exposure from use of cell phones, assessed in years.	Semen quality (WHO 1999 reference values) and DNA fragmentation. Multiple linear regressions were used to assess association.	**Coeff for cell phone use, 0-5 years (p-value)**	**Coeff for cell phone use, 6-10 years (p-value)**	**Coeff for cell phone use, 11-25 years (p-value)**			Using cell phone more than 10 years decreased the percentage of motile sperm cells	Adequate/ positive
				Volume	1.16 (ref.)	-0.06 (0.32)	-0.01 (0.84)				
				Concentration	3.03 (ref.)	0.29 (0.22)	0.42 (0.13)				
				Motility	60.77 (ref.)	-4.13 (0.30)	**-11.27 (0.01)**				
				Atypical	45.73 (ref.)	4.44 (0.42)	**19.00 (0.01)**				
				Sperm head abnormalities	32.42 (ref.)	2.28 (0.69)	**17.58 (0.01)**				
				Sperm neck abnormalities	12.04 (ref.)	-0.25 (0.86)	0.12 (0.94)				
				Sperm tail abnormalities	2.02 (ref.)	-0.01 (0.96)	-0.02 (0.93)				
				DNA fragmentation index	2.52 (ref.)	0.01 (0.97)	0.20 (0.22)				

Table 13 - Reproductive/developmental effects in humans: man fertility, epidemiologic cross-sectional studies (450-6000 MHz) (continued d)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate					Any Other Co-Exposure/adjustments	Comments
6. Yildirim et al., 2015. Turkey, 2013-2014. Cross-sectional study.	1031 healthy men from the Andrology subdivision of the Urology Dept (Turgut Ozal University)	Use of mobile cell (850-1800 MHz) and wireless internet (2400 MHz), assessed using an anonymous questionnaire.	Daily the cell phone usage duration, habits of carrying mobile phone, wireless internet usage duration, and type of internet use.	Sperm parameters. Pearson correlation Coefficients, Student t test (2-tailed) and one way analysis of variance (ANOVA).	**Volume**	**Total sperm count (mln)**	**Total motile sperm count (mln)**	**Progressive motile sperm count (mln)**	**Morphology**	-	Inadequate
		Self-reported	*Duration of cell phone use (h)*	One way analysis of variance, p-value	0.194	0.074	**0.05**	0.083	0.909	Confounding factors not analysed	
			< 0.5		2.9 ± 1.41	42.3 ± 16.3	61.1 ± 60.6	47.5 ± 50.8	2.8 ± 1.9		
			0.5-2		2.9 ± 1.19	39.2 ± 16.3	54.6 ± 50.6	42.5 ± 42.1	2.57 ± 1.76		
			>2		3.01 ± 1.45	37.8 ± 16.1	53.8 ± 59	41.6 ± 51.2	2.74 ± 1.72		
			Mobile phone carrying habits	One way analysis of variance, p-value	0.973	0.256	0.168	0.538	**0.034**		
			Trouser pocket		2.9 ± 1.37	39.1 ± 31.1	56.5 ± 60.1	43.8 ± 51	2.72 ± 1.81		
			Handbag		3.08 ± 1.4	45 ± 31.6	63 ± 48.6	49.6 ± 41.4	3.18 ± 2.47		
			Jacket pocket		3.02 ± 1.38	40.3 ± 27	53.6 ± 49.1	41.9 ± 41.1	2.43 ± 1.38		
			Duration of wireless internet use (h)	One way analysis of variance, p-value	0.43	0.093	**0.032**	**0.033**	0.305		
			< 0.5		2.99 ± 1.4	43 ± 33	61.7 ± 60.2	48.2 ± 53.7	2.73 ± 1.84		
			0.5-2		2.81 ± 1.32	41.8 ± 28.2	56.2 ± 57.5	43 ± 42.1	2.65 ± 1.75		
			>2		2.99 ± 1.36	37.4 ± 29.4	53.8 ± 57.5	41.8 ± 49.6	2.73 ± 1.85		
			Internet usage	Student t test, p-value	0.064	0.054	**0.009**	**0.018**	0.182		
			Cable		2.92 ± 1.25	42 ± 32.3	62.7 ± 61.3	48.9 ± 50.3	2.82 ± 1.72		
			Wireless		2.98 ± 1.43	38.8 ± 29.6	53.6 ± 55.2	41.1 ± 47.7	2.67 ± 1.88		
7. Zilberlicht et al, 2015. Israel, 2011–2012. Cross-sectional study.	80 male patients at infertility workup in the Fertility and IVF division of Carmel Medical Centre.	Daily habits of cell phone use assessed from self-administered questionnaire.	Daily habits of cell phone usage.	Semen quality was assessed using four parameters: volume, concentration, motility and morphology. Variables that were statistically significant in univariate analysis were included in a multivariate logistic regression analysis. OR were calculated with 95% confidence interval (CI).	**P-value of association of Sperm concentration, abnormal vs normal**	**OR (95% CI) for abnormal sperm concentration**	**p-value**			Smoking, age, residential area, occupation, n of children, years of education.	Adequate / positive
			Total daily talking time (≤1h / >1h)		0.040	Not reported	n.s.				
			Talk while charging the device (Yes/no)		0.020	4.13 (1.28-13.3)	0.018				

Table 13 - Reproductive/developmental effects in humans: man fertility, epidemiologic cross-sectional studies (450-6000 MHz) (continued e)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate	Any Other Co-Exposure/adjustments	Comments
8. Al-Bayyari, 2017. Jordan, 2015–2016. cross-sectional observational study.	159 men attending infertility clinics at North, Middle and South Governorates in Jordan.	Daily habits of cell phone use assessed from interviews using a structured questionnaire.	Time of talking by cell phone.	Semen quality. The Pearson's Chi-square (v2) and Fisher's exact tests were applied to assess the association.	**Total daily talking time (≤1 h/day vs >1h/day), p-value**	-	Inadequate
				Sperm concentration (cut-off 20 mln/ml)	0.494	All from an Infertility clinic	
				Volume (ctu-off 3 ml)	0.457		
				Viscosity (Normal vs abnormal)	0.556		
				Liquefaction time (cut-off 20 min)	0.534		
				Sperm motility (%)	n.s.		
				Sperm morphology (%)	n.s.		
9. Shi et al., 2018. China, 2015–2016. Cross-sectional study.	328 men <65 years, attending clinics for sperm analysis.	Use of cell phone assessed using self-report questionnaire.	Habit to carry phone in trousers.	SA, sperm vitality, acrosome reaction (AR) assay and sperm DNA fragmentation index (DFI). Generalized additive models were used to analyze the possible non-linear association.	**Duration of trousers pocket cell phone use (hours/day)**	BMI, smoking and alcohol drinking, sleep, daily fluid intake, weekly meat intake, sports frequency, trouser cell phone use, age, abstinence time.	Inadequate
				Volume	n.s.		
				Concentration	n.s.	All from an Infertility clinic	
				TSC	n.s.		
				Motility	n.s.		
				TMC	n.s.		
				Vitality	n.s.		
				DFI	n.s.		
				AR	n.s.		
10. Blay et al., 2020. Ghana. 2004-2015. Cross-sectional study.	80 men, 21-62 years, recruited from a fertility clinic in Accra, Ghana.	Lifestyle habits assessed using a structured questionnaire.	Mobile phones use and site of common storage on the body.	Parameters of semen quality. Independent Student t-test and Pearson's chi squared test were used to test the association between variables.	**Site of mobile phone storage (side pocket vs other place), p-value**	General characteristics, medical history, particularly disorders of the immune system, smoking habits.	Inadequate
				Volume	0.884	Increased activity and viability associated to cell phone in their side pocket	
				pH	0.741		
				Active motility (%)	**0.002**		
				Sluggish motility (%)	0.269		

				Sluggish motility (%)	0.486	All from an Infertility clinic	
				Viability (%)	**0.009**		
				Count (×106/ml)	0.109		

Table 14 - Reproductive/developmental effects in humans: man fertility epidemiologic cohort studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)				Any Other Co-Exposure/adjustments	Comments
11. Zhang et al., 2016. China, 2013-2015. MARHCS cohort study	794 (2013), 666 (2014) and and 568 (2015) young men, age < 18 years, college students, enrolled in the Male Reproductive Health in Chongqing College Students (MARHCS) study.	Use of mobile cell phones, assessed using a questionnaire.	Number of cell phones owned, presence of 3G function, duration of cell phone use, position in which they carry the cell phone, daily duration that the cell phone is turned on (within 50 cm near the body), daily internet time or monthly data traffic via cellular networks, and daily time spent talking on the cell phone in the last three months.	Sperm parameters. Mixed-effects linear regression model was used to globally assess all three years of data on cell phone use and semen parameters	**Volume (ml), Coeff from mixed effects model (95% CI), p-value**	**Sperm concentration (mln/ml), Coeff from mixed effects model (95% CI), p-value**	**Total sperm count (mln), Coeff from mixed effects model (95% CI), p-value**	**Progressive motile sperm (mln), Coeff from mixed effects model (95% CI), p-value**	Age, duration of abstinence, body mass index (BMI), smoking and drinking status, and the consumption of cola, coffee, and fried food	Adequate/ positive
			Duration of cell phone use (h)		-2.19 (-4.39, 0.06), 0.056	-2.90 (-6.91, 1.27), 0.170	**-4.87 (-9.27, -0.27), 0.038**	-0.77 (-2.71, 1.22), 0.445		
			Internet use via cellular network (h, 2013)		0.42 (-0.71, 1.56), 0.472	**-2.74 (-4.53, -0.91), 0.004**	**-2.75 (-4.76, -0.69), 0.009**	0.51 (-0.29, 1.32), 0.213		
			Monthly data traffic (GB, 2014-2015)		**-1.47 (-2.74, -0.19), 0.025**	-1.65 (-4.04, 0.80), 0.185	**-3.22 (-5.85, -0.52), 0.020**	0.19 (-1.08, 1.48), 0.770		

Table 14 - Reproductive/developmental effects in humans: man fertility epidemiologic cohort studies (450-6000 MHz) (continued b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)						Any Other Co-Exposure/adjustments	Comments
12. Lewis et al., 2017. USA. 2004-2015. Longitudinal cohort study.	384 (M); 18-56 years; Men recruited from a fertility clinic in Boston, Massachusetts, enrolled in the Environment and Reproductive Health (EARTH) Study.	Mobile phones radiofrequencies; Self - reported exposure from mobile phone.	Use, duration (no use, <2 h/day, 2–4 h/day, >4 h/day), headset or earpiece use (H/E, N H/E), and location in which the mobile phone was carried (pants pocket, belt, bag, other).	Sperm motility, total sperm count, total motile sperm count, sperm morphology. Strict Kruger scoring criteria was used to classify men as having normal or below normal morphology by blinded semen analysts. Linear mixed-effects models with random subject effects.	**Absolute differences [ß (95% CI)], Semen volume**	**Absolute differences [ß (95% CI)], Total motility**	**Relative differences [exp(ß) (95% CI)], Total sperm count**	**Relative differences [exp(ß) (95% CI)], Sperm concentration**	**Relative differences [exp(ß) (95% CI)], Total motile sperm count**	**Relative differences [exp(ß) (95% CI)], Normal sperm morphology**	General characteristics, medical history, particularly disorders of the immune system, smoking habits. All from an Infertility clinic	Adequate/ positive
			Category of use (h/day) and headset or earpiece use.									
			No Use		0 (ref.)	0 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			<2 h/day, H/E		0.74 (0.08-1.41)	13.05 (1.57-24.53)	1.60 (1.04-2.46)	1.24 (0.81-1.89)	2.43 (1.17-5.07)	0.94 (0.68-1.31)		
			<2 h/day, N H/E		0.40 (-0.06-0.86)	4.47 (-3.53-12.46)	1.09 (0.80-1.47)	0.99 (0.74-1.33)	1.39 (0.83-2.31)	0.97 (0.77-1.22)		
			>2 h/day, H/E		0.29 (-0.43-1.01)	3.06 (-9.39-15.50)	1.14 (0.71-1.82)	1.03 (0.65-1.63)	1.44 (0.65-3.20)	0.84 (0.59-1.20)		
			>2 h/day, N H/E		-0.12 (-0.93-0.68)	4.10 (-9.72-17.93)	1.47 (0.87-2.47)	1.52 (0.91-2.53)	1.89 (0.78-4.58)	0.83 (0.56-1.23)		

Table 15 - Reproductive/developmental effects in humans: developmental effects, epidemiologic case-control studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
13. Tan et al., 2014. Singapore. November 2010 and February 2011. Case-control study	Women with threatened miscarriage during the 5th to 10th weeks of gestation seen at emergency clinic KK Womens and Childrens Hospital (KKH) in Singapore. (F). Mean age of cases and controls were 30.2 and 30.7, respectively.	Potentially modifiable lifestyle factors were assessed by face to-face interview with cases and controls, conducted at the time of recruitment. Mobile phone and computer usage were quantified as self-reported number of hours of use per day based on the most recent one week.	Exposure to radiofrequency electromagnetic fields of cell phone and television. Greater duration of mobile phone use or computer use was associated with higher risk of threatened miscarriage, with dose-response relationship	Association between potential lifestyle risk factors (cell phone and TV usage) and threatened miscarriage: results of adjusted logistic regression analysis. Multivariate analysis adjusting for all confounders and for gestational age.	**Adjusted odds ratio (95% Confidence Interval):**		Maternal age, paternal age, gestational age, ethnicity, height, weight, regularity of menstrual cycle, housing type, educational level, past medical/ pregnancy/ gynaecological/ psychiatric history, urrent and past cigarette smoking, exposure to second-hand cigarette smoke at home, current and past alcohol consumption, current and past caffeine Consumption, perceived stress levels, DHA consumption, and most recent contraceptive use	**Adequate/ positive**
			Handphone use					
			0 to <1 hour		1		Stress not considered as confounder	
			≥ 1 to <2 hours		2.94 (1.32–6.53)			
			≥ 2hours		6.32 (2.71–14.75)			
			Computer use					
			0 to <1 hour		1			
			≥1 to <4 hours		2.66 (1.16–6.09)			
			≥ 4 hours		6.03 (2.82–12.88)			
14. Mahmoudabadi et al., 2015. Iran. Before 2015. Case-control study	292 women who had an unexplained spontaneous abortion at < 14 weeks gestation and 308 matching pregnant women > 14 weeks gestation were enrolled. The subjects were recruited from 10 hospitals in Tehran.	Data collection form was completed to collect data about the use of cell phones during pregnancy.	Average calling time per day, the location of the cell phones when not in use, use of hands-free equipment, use of phones for other applications, the specific absorption rate (SAR) reported by the manufacturer and the average of the effective SAR (average duration of calling time per day × SAR).	Spontaneous abortions. Logistic regression model was used to calculate OR and 95% CI; *T student test, ** Chi square test or Fisher's exact test were used to assess association.	**OR (95% CI)**	**P(2-tailed)**	Effective SAR, maternal age, paternal age, history of abortion and family relationship Life style confounders not analysed	**Adequate /positive**
			Association of spontaneous abortions with the effective SAR (Specific Absorption Rate)		**1.11 (1.07-1.16)**			
			Calling time per day* (minutes) Mean ± SD			**<0.001**		
			Use of hands free** n (%)			0.09		
			location of phones when not in use** n (%)			**<0.001**		
			use of phone for other applications **n (%)			**<0.001**		
			Effective SAR* Mean ± SD			**<0.001**		

Table 16 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cross-sectional studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
15. Col Araz et al., 2013. Turkey, 2009. Cross-sectional study.	500 mothers from the Outpatient Clinic, Dept of Paediatrics, Gaziantep University.	Use of television, computer and mobile phones during pregnancy assessed using a self-administered questionnaire	Cell phone use, computer use (user vs non-user).	Birth weight and preterm birth. The Chi-square test, independent samples t-test, and OR and 95% CI from logistic regression analysis were used.	**Delivery before 37 weeks, χ^2 (p-value)**	**Delivery week, mean ±SD**	**Delivery week, p-value**	Socio-demographic information, mothers weight, height, weight gained, consumption of tobacco and alcohol during pregnancy, disease history, observance of religious fasting during pregnancy, consumption of tea, milk and yoghurt, birth week and birth weight of the other children, if any.	Adequate /positive
			Cell phone use		**5.584 (<0.018)**		**<0.005**		
			User			38.7±1.9			
			Non user			39.2±1.6			
			Duration of cell phone use				**<0.001**		
			≤1h/day			37.6±2.2			
			>1h/day			38.8±1.8			
			Computer use		**4.510 (<0.034)**		**<0.048**		
			User			38.5±1.8			
			Non user			38.9±1.8			
			Duration of cell phone use				n.s.		
			≤1h/day			Not reported			
			>1h/day			Not reported			
16. Zarei S. et al., 2015. Iran. 2014. Cross-sectional study.	Mothers of 35 healthy children (control group) and 77 children aged 3-5 year and diagnosed with speech problems (F).	Different sources of electromagnetic fields (both RF-EMF and ELF) such as mobile phones, mobile base stations, Wi-Fi, cordless phones, laptops and power lines. Self-assessed exposure to different sources of electromagnetic fields.	The mean daily (mobile phone) call time was about 20 min. Call time, history of mobile phone use (months used), average duration of daily call time, cordless phone use and CRT use during pregnancy.	Speech problems in offspring. A P-value of less than 0.05 was considered as significant.	**Speech problems, P-value of association measure**			Age, proportion of consanguineous marriage, smoking, dental radiography history, mean number of pregnancies	Inadequate
			call time		0.002				
			history of mobile phone use		0.003				
			average duration of daily call time during pregnancy		N.S.				
			cordless phone use		0.528				
			CRT use		0.990				

Table 16 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cross-sectional studies (450-6000 MHz) (continued b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
17. Abad et al., 2016. Iran, 2009. Cross-sectional study.	413 pregnant women (18-35 years of age) from the Tehran region. Reproductive information was collected using medical file recorded in those hospitals the subjects had delivery.	Environmental exposure to EMF (range 27 MHz-3 GHz) assessed using NARDA at the entrance door of their houses three times during the pregnancy (semesters 1, 2, 3). Other information assessed using a face-to face interview.	Environmental exposure to EMF.	Miscarriage (spontaneous abortion, LBW, preterm delivery, and Intra Uterine Fetal Death). Independent samples t-test.	**Miscarriage, p-value from t-test**				Inadequate
			Digital radio and television broadcast services in central frequency 650 MHz		0.85				
			Mobile communications services 1.5 GHz		0.67				
			Wi-Fi access and MISC in central frequency 2.45 GHz		0.42				
18 Lu et al. 2017. Japan. 2012-2014. Cross sectional study from cohort data.	461 mother and child pairs (M and F). Data from the Japan Environment and Children's Study (JECS) and JECS Adjunct Study in Kumamoto.	Mobile phones radiofrequencies; Self-assessed exposure from self-administered questionnaires on maternal mobile phone usage information during pregnancy. A short version of the Self-Perception of Text-Message Dependency Scale (STDS) was used in this study for assessing text message dependency.	Daily mobile phone use times, location of the phone during the day and at night, and power state (on/off) of the mobile phone during sleep). A cut-off of 15 points for the excessive use score in the STDS was used to determine excessive mobile phone use.	Birth weight and infant health status (birth height, birth head circumference, birth chest circumference, mode of delivery, weeks of pregnancy, placental weight, low birth weight), infant emergency transport, and premature birth; linear regression analysis was used.	**ß (95%CI) for Birth weight**	**Adjusted OR (95%CI), Infant emergency transport**	**Adjusted OR (95%CI), Premature birth**	Maternal age, birth height, maternal BMI before pregnancy, maternal age, birth head circumference, primiparity, maternal smoking.	Inadequate
			Daily mobile phone use						
			Normal users		0 (ref.)	1.00 (ref.)	1.00 (ref.)		
			Mobile excessive users		-66.46 (-114.46- -18.46)	7.93 (1.40-44.85)	0.67 (0.09-4.97)		

Table 17 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cohort studies (450-6000 MHz) (a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)						Any Other Co-Exposure/adjustments	Comments
19. Mjøen et al., 2006. Norway. 1976-1995. Cohort study.	541593 births (M and F). Data on all births registered between 1976 and 1995 in Norway from the Medical Birth Registry of Norway; The Norwegian general population censuses contain data on occupations coded according to the Nordic Classification of Occupations.	Paternal occupation categorized as "probably not exposed", "possibly exposed" and "probably exposed", reflecting probability of exposure to RFR. An expert panel assessed exposure to radiofrequency fields in the various occupations.	Level of exposure assigned from experts.	Birth defects, the total number of CNS and musculoskeletal limb defects, and all categories combined, preterm delivery, low birth weight, sex ratio and perinatal mortality. Relative risks for each exposure category were calculated by approximating odds ratios (OR) with 95% confidence intervals (CI) from logistic regression models.	**Preterm delivery (<37 weeks) - OR (95% CI)**	**Low birth weight (<2,500 g) - OR (95%CI)**	**Early stillbirth (between 16 and 28 weeks) - OR (95% CI)**	**Late stillbirth (after 28 weeks) - OR (95% CI)**	**Male gender - OR (95% CI)**	**Any birth defect - OR (95% CI)**	Calendar year, place of birth and level of education.	Adequate/ negative
			Probably not exposed		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			Possibly exposed		0.99 (0.96-1.02)	1.03 (0.98-1.07)	1.01 (0.91-1.12)	1.01 (0.92-1.11)	1.01 (1.00-1.03)	0.98 (0.94-1.02)		
			Probably exposed		1.08 (1.03-1.15)	1.03 (0.94-1.13)	0.98 (0.79-1.22)	1.09 (0.89-1.29)	0.99 (0.97-1.02)	0.94 (0.86-1.01)		

Table 17 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cohort studies (450-6000 MHz) (continued b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjustments	Comments
20. Divan at al., 2008 and Divan et al. 2011. Denmark. Children born between 1997 and 2002. Cohort study.	41541 children (F and M). Mothers and live-born children constitute 2 fixed cohorts. Child's health status assessed at 7th year of age using an internet-based Questionnaire.	Cell phone and cordless phone use, assessed via four telephone interviews.	Cell phone use among children, among mothers during pregnancy (mother's use of cell phone during pregnancy, use of hands-free equipment during pregnancy (proportion of time) and location of the phone when not in use (handbag or clothing pocket), and for children, current use of cellular and other wireless phones.	Cognitive/language development delays, motor development delays and behavioural problems assessed using the "Strengths and Difficulties Questionnaire". Odds ratios and 95% CI from adjusted logistic regression models.	**Cognitive/language development delay at 6 months-Adjusted OR (95% CI)**	**Motor development delay at 6 months-Adjusted OR (95% CI)**	**Cognitive/language development delay at 18 months-Adjusted OR (95% CI)**	**Motor development delay at 18 months-Adjusted OR (95% CI)**	**Overall Behavioural Problems Score at 7 years-Adjusted OR (95% CI)**	Adjusted for gender of child, combined social-occupational status, mother's age at birth, gestational age, and child's birth weight, child care outside home at 18 months.	Adequate/ Negative Exposure to cell phones prenatally—and, to a lesser degree, postnatally—was associated with behavioral difficulties such as emotional and hyperactivity problems around the age of school entry.
			Prenatal Exposure Only			1.12 (0.97–1.30)		**1.21 (1.05–1.40)**	**1.58 (1.29–1.93)**		
			Postnatal Exposure Only			1.06 (0.92–1.23)		1.02 (0.89–1.18)	1.18 (0.96–1.45)		
			Both Prenatal and Postnatal Exposure			**1.25 (1.07–1.47)**		**1.49 (1.28–1.74)**	**1.80 (1.45–2.23)**		
			Prenatal: Times spoken per day								
			0-1		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			2-3		1.0 (0.7–1.4)	0.8 (0.5–1.0)	0.9 (0.6–1.3)	0.7 (0.5–1.0)	1.33 (0.99–1.79)		
			4+		0.8 (0.4–1.3)	0.6 (0.3–1.0)	0.9 (0.5–1.6)	1.2 (0.8–1.8)	**1.51 (1.02–2.22)**		
			Prenatal: Percentage of time turned on								
			0		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			<50		1.1 (0.6–1.9)	1.3 (0.8–2.7)	1.2(0.7–2.3)	1.1 (0.7–1.8)	0.62 (0.35–1.11)		
			50-99		0.9 (0.5–1.6)	1.1 (0.6–1.8)	1.2 (0.5–2.2)	1.2 (0.8–2.0)	0.93 (0.58–1.48)		
			100		1.0 (0.5–2.0)	1.1 (0.6–2.0)	1.5 (0.7–3.0)	1.3 (0.8–2.3)	1.09 (0.70–1.70)		

Table 17 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cohort studies (450-6000 MHz) (continued c)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)				Any Other Co-Exposure/adjustments	Comments
21. Guxens et al., 2013. Netherlands. 2003-2004 enrollment; 2008-2009 assessment of behavioural problems; 2010-2011 retrospective exposure assessment. Study embedded in a population-based prospective birth cohort study.	8266 pregnant women, 2618 children (F and M). Pregnant women enrolled during their first prenatal visit to an obstetric care provider. Prenatal phone use assessed retrospectively with postal or via web questionnaire at children 7th year, and child behaviour problems assessed at children 5th year.	Cell phones and cordless phones use during pregnancy. Self-assessed exposure from questionnaire. Given the introduction of Universal Mobile Telecommunications System technology in the Netherlands in the beginning of 2004, mobile phone use reports were expected to be nearly exclusively Global System for Mobile Communications (GSM) 900/1800 technology.	Frequency of cell phone calls were set to 75% of the number of calls for those reporting to use the hands-free equipment 'less than half of the calls', to 25% for those reporting to use it 'more than half of the calls', and to 0 for those reporting to use it 'nearly always'.	Children's behaviour (emotional symptoms, conduct problems, hyperactivity/inattention problems, peer relationship problems and pro-social behaviour) reported by primary school teachers and mothers using the Strengths and Difficulties Questionnaire (SDQ) at age 5. Odds ratios and 95% CI from unadjusted and adjusted logistic regression models.	**Teacher-reported child overall behaviour problems, Unadjusted model - OR (95% CI)**	**Teacher-reported child overall behaviour problems, Adjusted model - OR 95% CI)**	**Mother-reported child overall behaviour problems, Unadjusted model - OR (95% CI)**	**Mother-reported child overall behaviour problems, Adjusted model - OR**	Maternal age, maternal educational level, maternal country of birth, maternal parity, maternal pre-pregnancy weight and height, maternal smoking, maternal second-hand smoke at home, maternal alcohol consumption during pregnancy, maternal pregnancy-related anxiety and maternal anxiety and depression during pregnancy, children's birth addresses as indicator of socioeconomic position. .	Adequate/ negative
			Prenatal frequency of cell phone call							
			None		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			<1/day		2.09 (0.95 - 4.62)	2.12 (0.95 - 4.74)	0.95 (0.39 - 2.29)	0.89 (0.36 - 2.20)		
			1–4/day		1.53 (0.69 - 3.42)	1.58 (0.69 - 3.60)	0.78 (0.32 - 1.92)	0.73 (0.28 - 1.85)		
			≥5/day		1.88 (0.82 - 4.34)	2.04 (0.86 - 4.80)	0.77 (0.29 - 2.06)	0.75 (0.27 - 2.09)		
			Prenatal frequency of cordless phone call							
			None		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)		
			<1/day		0.89 (0.57 - 1.39)	1.19 (0.74 - 1.92)	0.27 (0.15 - 0.50)	0.35 (0.18 - 0.67)		
			1–4/day		0.76 (0.48 - 1.22)	1.07 (0.65 - 1.76)	0.55 (0.32 - 0.96)	0.73 (0.41 - 1.33)		
			≥5/day		0.50 (0.23 - 1.09)	0.61 (0.27 - 1.35)	0.40 (0.15 - 1.07)	0.43 (0.15 - 1.21)		

Table 17 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cohort studies (450-6000 MHz) (continued d)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)				Any Other Co-Exposure/adjustments	Comments
22. Choi et al., 2017. South Korea. 2006-2016. Multi-center prospective cohort study (the Mothers and Children's Environmental Health (MOCEH) study).	1198 mother-infant pairs (M and F). Participants were enrolled at ≤20 weeks gestation.	RFR sources of exposure, including cell phone, TV, radio, working on the internet, and mobile phone base stations. Self-assessed exposured from questionnaire regarding average calling frequency (≤2, 3–5, and ≥6 times/day) and average calling time (< 3, 3–10, 10–30, and ≥30 min/day) during pregnancy.	Heavy user defined as calling frequency >6 times per day or calling time >30 min per day. Categories by average calling time (min/day)	MDI: Mental development index, PDI: Psychomotor development index.	**OR (95% CI) for decreasing MDI (6–36 months)**				Occupational exposure to some chemical pesticides, petroleum, solvents, lead and nitrosamines, tobacco consumption.	Inadequate
			Average calling time (min/day)		**All**	**Low Maternal blood lead during pregnancy (< 75%)**	**High Maternal blood lead during pregnancy (<75%)**	**p-interaction**	Maternal blood lead level as main confounding factor	
			<3		0.50 (0.30-0.83)	0.71 (0.42-1.21)	0 (0-Inf)	0.02		
			3-10		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)			
			10-30		0.85 (0.60-1.19)	0.86 (0.57-1.28)	2.11 (0.67-6.68)			
			>30		0.63 (0.37-1.08)	0.76 (0.43-1.34)	0 (0-Inf)			
			P for trend		0.86	0.48	**0.05**			
					OR (95% CI)) for low PDI (6–36 months)					
			Average calling time (min/day)		**All**	**Low Maternal blood lead during pregnancy (< 75%)**	**High Maternal blood lead during pregnancy (<75%)**	**p-interaction**		
			<3		0.47 (0.24-0.94)	0.41 (0.19-0.92)	0.45 (0.23-0.89)	0.44		
			3-10		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)			
			10-30		0.77 (0.49-1.23)	0.81 (0.49-1.35)	1.10 (0.69-1.76)			
			>30		0.64 (0.32-1.29)	0.73 (0.36-1.48)	1.56 (0.74-3.26)			
			P for trend		0.54	0.26	**0.008**			

Table 17 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cohort studies (450-6000 MHz) (continued e)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)			Any Other Co-Exposure/adjustments	Comments
23. Papadopoulou et al., 2017. Norway, 1999 -2008. Norwegian mother and child cohort study (MoBa).	45389 mother-child pairs (M and F), participants of the MoBa, recruited at mid-pregnancy. Information assessed by questionnaires.	Maternal frequency of cell phone use in early pregnancy, assessed by a questionnaire administered at 17th and 30th weeks of gestation.	Frequency of talking on the cell phone: "seldom/never" (no use), "few times a week" (low), "daily" (medium), and "more than an hour daily" (high use).	Child language, communication and motor skills at 3 (45389 mother-child pairs) and 5 years (17310 mother-child pairs). Adjusted OR and 95% C.I. from logistic regression to estimate the associations.	**Risk for lower sentence complexity at 3 years- Adjusted OR (95% C.I.)**			Parity, maternal age, education and year of delivery.	**Adequate /negative**
			Maternal cell phone use in early pregnancy						
			No use		1 (ref)				
			Any use		0.83 (0.77, 0.89)				
			Low		0.87 (0.81, 0.94)				
			Medium		0.78 (0.72, 0.84)				
			High		0.71 (0.62, 0.81)				
			P for trend		**<0.001**				
24. Sudan et al., 2018. Denmark 1996-2002, Spain 2003-2008, South Korea 2006-2011. Data from 3 birth cohorts, part of the Generalized EMF Research using Novel Methods (GERoNiMO) Project.	3089 mother-child pairs participating in the Danish National Birth Cohort (DNBC) (n=1209), the Spanish Environment and Childhood Project (INMA) (n=1383), and the Korean Mothers and Children's Environment Health Study (MOCEH) (n=497).	Maternal cell phone use during pregnancy, assessed during pregnancy (ES and KO) or 7 years after birth (DK).	Frequency of talking on the cell phone: "seldom/never" (no use), "few times a week" (low), "daily" (medium), and "more than an hour daily" (high use). In the DNBC, ABCD, and INMA cohorts, no exposure corresponded to no cell-phone use, low exposure to ≤1 calls/day, intermediate exposure to 2–3 calls/day, and high exposure to ≥4 calls/day. In the MOCEH cohort, no exposure corresponded to no cell-phone use, low exposure to ≤2 calls/day, intermediate exposure to 3–5 calls/day, and high exposure to ≥6 calls/day.	Cognitive performance in children at age 5. Linear regression to compute mean differences (MD) and 95% confidence intervals (CI).	**General cognition, Adjusted OR (95% C.I.)**	**Verbal cognition, Adjusted OR (95% C.I.)**	**Non-verbal cognition, Adjusted OR (95% C.I.)**	Sex of child, age of child, maternal IQ, maternal age, parity, mother's history of psychological distress, maternal education, paternal education, prenatal smoking, prenatal alcohol use, and maternal pre-pregnancy BMI	**Adequate /equivocal**
			Maternal cell phone use in early pregnancy						
			No use		0.78 (-0.76, 2.33)	1.42 (-1.12, 3.96)	0.72 (-0.85, 2.28)		
			Low		1 (ref)	1 (ref)	1 (ref)		
			Medium		0.11 (-0.81, 1.03)	-0.23 (-1.29, 0.83)	-0.12 (-1.60, 1.35)		
			High		-0.41 (-1.54, 0.73)	-0.42 (-1.73, 0.89)	-0.85 (-2.23, 0.53)		

Table 17 - Reproductive/developmental effects in humans: developmental effects, epidemiologic cohort studies (450-6000 MHz) (continued f)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)				Any Other Co-Exposure/adjustments	Comments
25. Tsarna et al., 2019. Denmark 1996-2002, Spain 2003-2008, South Korea 2006-2011. Data from 3 birth cohorts, part of the Generalized EMF Research using Novel Methods (GERoNiMO) Project.	55507 mother-child pairs (M and F) participating in the Danish National Birth Cohort (DNBC), the Spanish Environment and Childhood Project (INMA), and the Korean Mothers and Children's Environment Health Study (MOCEH).	Use of mobile phone s during pregnancy. Retrospective exposure assessment (DNBC and ABCD) or prospective exposure assessment (INMA and MOCEH) were used.	Exposure were classified into 4 categories (none, low, intermediate, and high) based on daily frequency of cell-phone calls during pregnancy.	Preterm/post-term birth, fetal growth (small or large size for gestational age). Modified Wald, χ2, and Fischer exact tests. The calculated adjusted cohort-specific estimates were meta-analysed using random-effects models.	**Preterm birth - Adjusted OR (95% C.I.)**	**Post term birth - Adjusted OR (95% C.I.)**	**SGA birth - Adjusted OR (95% C.I.)**	**LGA birth - Adjusted OR (95% C.I.)**	Maternal age at child's birth (a natural spline term with 3 degrees of freedom), parity, active and passive smoking during pregnancy, alcohol consumption during pregnancy, pre-pregnancy body mass index.	Adequate/ equivocal
			None		0.96 (0.86-1.07)	0.98 (0.89-1.07)	0.94 (0.86-1.03)	0.98 (0.92-1.04)		
			Low		1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	1.00 (ref.)	Stress not considered as confounding	
			Intermediate		1.12 (0.97-1.28)	0.85 (0.75-0.97)	1.03 (0.88-1.21)	0.97 (0.89-1.05)		
			High		1.28 (0.87-1.88)	0.98 (0.83-1.16)	0.94 (0.78-1.13)	0.93 (0.83-1.04)		
			P for trend		**0.003**	0.863	0.872	0.488		
26. Boileau et al., 2020. France, children born in 2014-2017. Prospective, longitudinal, multicenter observational cohort study (NéHaVi cohort)	1378 mothers-child pairs (M and F). Questionnaires completed during face-to-face interviews in the post-partum period during stay at the maternity unit, and the child's and parents' medical records.	Use of mobile phone s during pregnancy. Retrospective exposure assessment (DNBC and ABCD) or prospective exposure assessment (INMA and MOCEH) were used.	Phone time recorded in minutes per day.	Fetal growth, assessed using a personalized AUDIPOG score (growth restriction at birth, defined by an AUDIPOG score ≤ 10th percentile at birth)	**AUDIPOG score ≤10th percentile- Adjusted OR (95% C.I.)**	**P-value**			Socio-professional category variables of the mother likely to influence phone time, smoking, alcohol consumption, history of diabetes or high blood pressure, gestational diabetes, gestational hypertension, and potential confounding factors.	Adequate/ positive
			Phone time (min/day)							
			0-5		1.00 (ref.)					
			5-15		0.98 (0.58-1.65)	0.9423				
			15-30		1.68 (0.99-2.82)	0.0508				
			≥30		**1.54 (1.03-2.31)**	**0.0374**				

Table 18 (summary tables 12-17) - Collected data for epidemiological studies on reproductive/ developmental effects (FR1: 450-6000 MHz)

Total studies	26				
Adequate studies	16				
Type of study	**Observed Effect**	**Total* adequate studies**	**Positive studies**	**Equivocal studies**	**Negative studies**
Reproductive- man fertility	Decline in semen quality	6	6		
Developmental-mother-offspring effects	Miscarriage	2	2		
	Preterm/post-term birth, foetal growth; chromosomal anomalies	8	2	2	4
	Language/communication/ behavioural /cognitive problems	4		2	2

*Some of the studies include more than one outcome.

SUMMARY OF THE COLLECTED DATA FOR EPIDEMIOLOGICAL STUDIES ON REPRODUCTIVE/DEVELOPMENTAL EFFECTS (FR1: 450 to 6000 MHZ) (Table 18)

The epidemiological evidence on possible associations of exposure to RF-EMF with reproductive developmental effects comes from studies of diverse design that have assessed a range of sources of exposure: the populations included people exposed in occupational settings, people exposed through sources in the general environment, e.g. radio-base stations, and people exposed through use of wireless (mobile and cordless) telephones.

In chapter 4 (Limitations) of the present document, general methodological concerns related to the assessment of individual studies are covered. The total number of epidemiological studies selected for the present review for FR1, was 26. After further deep analyses of the 26 original papers, 16 studies proved to be adequate on the basis of exposure assessment, sample size and appropriateness of confounding analyses.

Decline in semen quality, risk of miscarriage, pre-term/post-term birth, foetal growth, language/communication/ behavioural /cognitive problems were analysed in the 16 adequate studies for a possible association with exposure to RF-EMF, related to the use of mobile phone or to environmental/occupational exposure to emissions from radiobase stations. With reference to the numbers given to the studies in the respective abstracts and tables, the association of the different adverse effects to RF-EMF exposure is:

Decline in semen quality: out of 6 adequate studies regarding this outcome, all showed a positive association with RF-EMF exposure (Ref: 2, 3, 5, 7, 11, 12).

Miscarriage: both of the 2 adequate studies regarding this outcome, showed a positive association with RF-EMF exposure (Ref: 13, 14).

Pre-term/post-term birth, foetal growth: out of 8 adequate studies regarding these outcomes, 2 showed a positive association with RF-EMF exposure (Ref: 15, 26), 2 equivocal association /Ref: 24,25) whilewhile 4 were negative (Ref: 19, 20, 21, 23).

Language/communication/ behavioural /cognitive problems: out of 4 adequate studies, 2 showed equivocal evidence of association to RF-EMF exposure (Ref: 20, 24) and 2 were negative (Ref: 21, 23).

We can conclude as follows:

FR1: 450 to 6000 MHZ:

There is sufficient evidence of adverse effects on fertility in man.

There is limited evidence of adverse effects on fertility in woman.

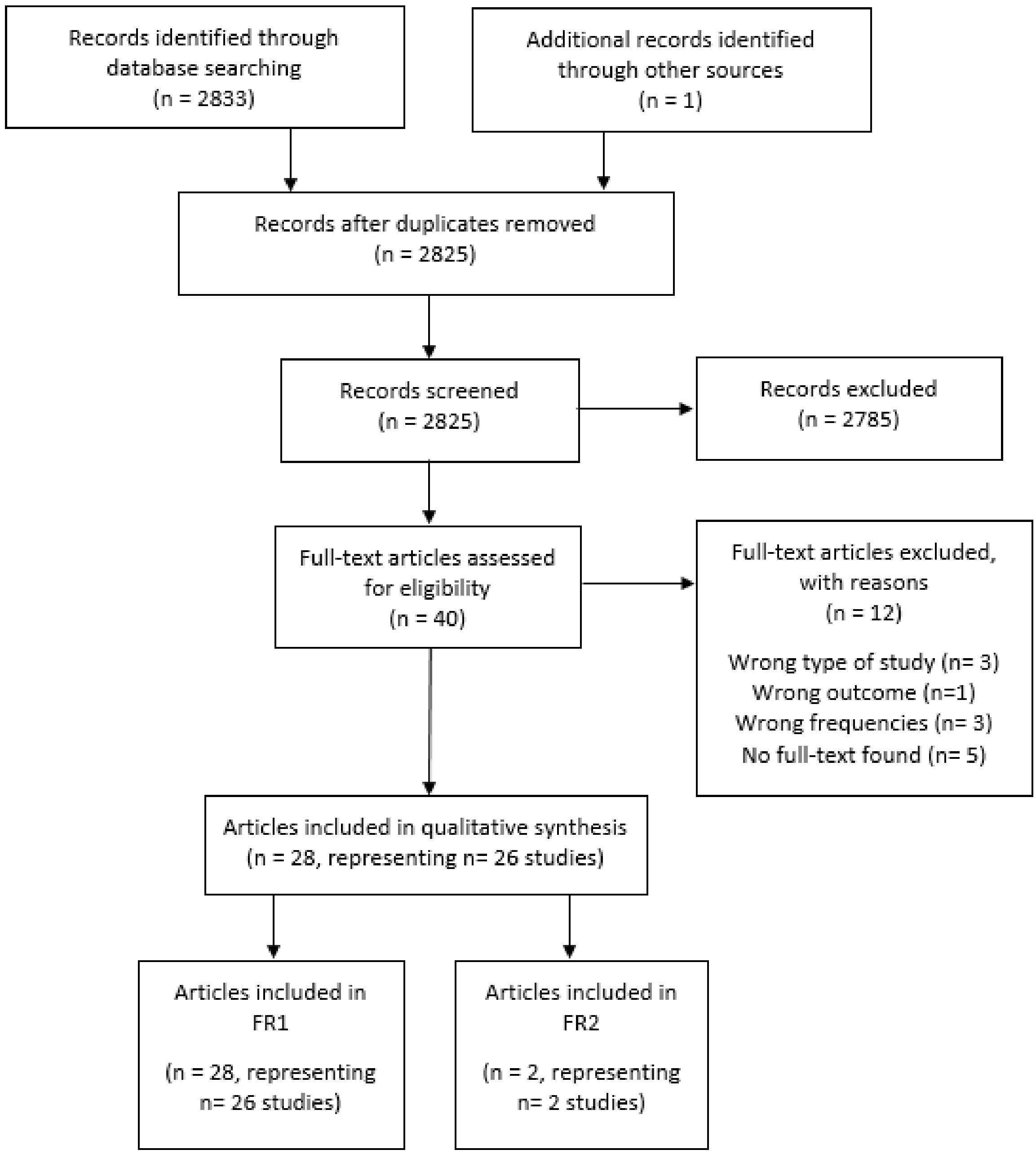
There is limited evidence for adverse effects in pregnant women and their offspring for all developmental end-point examined.

4.2.2 Reproductive/developmental effects in epidemiological studies: Studies evaluating health effects due to RF at a higher frequency range (FR2: 24 to 100 GHz, MMW).

The articles identified through database searching and other sources were 2834. After removing duplicates (9) and excluding non-pertinent articles (2785) based on title and abstracts, 40 articles remained. Based on full-text screening, 12 papers were further excluded, so that the published articles with frequencies appropriate for inclusion in this qualitative synthesis were 28, corresponding to 26 studies. Two papers were published reporting information on the same study (Fig. 14).

At this stage, a selection based on frequency range was also performed: 28 papers/26 studies referred to exposures belonging to the FR1 range, and 2 referred to FR2 as well. These papers reported exposures suitable for both FR1 and FR2, so they don't add up to the overall number of studies included; they are reported twice, once in each frequency range with related outcome.

Figure 14 – Flow diagram. Epidemiological studies on reproductive/developmental effects FR2



MALE FERTILITY

Cross-sectional studies (Table 19 a,b)

1. Baste et al., 2008.

Norway. 2002-2004. Case-control study , occupational exposure.

The authors performed a cross-sectional study among military men employed in the Royal Norwegian Navy, including information about work close to equipment emitting radiofrequency electromagnetic fields, one-year infertility, children and sex of the offspring. Among 10,497 respondents, 22% had worked close to high-frequency aerials to a ''high'' or ''very high'' degree. Infertility increased significantly along with increasing self-reported exposure to radiofrequency electromagnetic fields. In a logistic regression, the odds ratio (OR) for infertility among those who had worked closer than 10 m from high-frequency aerials to a ''very high'' degree relative to those who reported no work near high-frequency aerials was 1.86 (95% confidenceinterval (CI): 1.46–2.37), adjusted for age, smoking habits, alcohol consumption and exposure to organic solvents, welding and lead. Similar adjusted OR for those exposed to a ''high'', ''some'' and ''low'' degree were 1.93 (95% CI: 1.55–2.40), 1.52 (95% CI: 1.25–1.84), and 1.39 (95% CI: 1.15–1.68), respectively. In all age groups there were significant linear trends with higher prevalence of involuntary childlessness with higher self-reported exposure to radiofrequency fields. However, the degree of exposure to radiofrequency radiation and the number of children were not associated. For self-reported exposure both to high-frequency aerials and communication equipment there were significant linear trends with a lower ratio of boys to girls at birth when the father reported a higher degree of radiofrequency electromagnetic exposure.

Comment*: *Self-reported level of exposure. Higher degree of RF-EMF exposure associated to infertility and a lower ratio of boys to girls at birth.

2. Mollerlekken and Moen, 2008.

Norway. 2002. Case-control study, occupational exposure.

The aim of this study was to examine the relationship between workers exposed to electromagnetic fields and their reproductive health. We obtained data using a questionnaire in a cross-sectional study of naval military men, response rate 63% (n¼1487). The respondents were asked about exposure, lifestyle, reproductive health, previous diseases, work and education. An expert group categorized the work categories related to electromagnetic field exposure. We categorized the work categories ''tele/communication,'' ''electronics'' and ''radar/sonar'' as being exposed to electromagnetic fields. Logistic regression adjusted for age, ever smoked, military education, and physical exercise at work showed increased risk of infertility among tele/ communication odds ratio (OR≤1.72, 95% confidence interval 1.04–2.85), and radar/sonar odds ratio (OR≤2.28, 95% confidence interval 1.27–4.09). The electronics group had no increased risk. This study shows a possible relationship between exposure to radiofrequency fields during work with radiofrequency equipment and radar and reduced fertility. However, the results must be interpreted with caution.

Comment*: *Self-reported exposure. Possible increased risk of infertility among telecommunication and radar/sonar operators.

Table 19 - Reproductive/developmental effects in humans: man fertility, epidemiologic case-control studies (24-100 GHz)(a)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)		Any Other Co-Exposure/adjustments	Comments
1. Baste et al., 2008. Norway. 2002-2004. Case-control study	9925 current and former male military employees in the Royal Norwegian Navy, defined by the military employment list (M); mean age 49.	High-frequency aerials, communication equipment, radar. Self-assessed occupational exposure and age categories assessed by mail questionnaire.	Exposure to radiofrequency electromagnetic fields: work closer than 10 m from high-frequency aerials, work closer than 3 m from communication equipment and work closer than 5 m from radar.	Infertility. Odds ratios and 95% CI from adjusted logistic regression models; Mantel–Haenszel test for linear trend.	**Total Infertility - <5 m from radar, OR (95% CI)**	**Test for linear trend (Mantel–Haenszel chi-square)**	Infertility. Odds ratios and 95% CI from adjusted logistic regression models; Mantel–Haenszel test for linear trend.	**Adequate/ Positive for man infertility**
			Age <29					
			Not exposed					
			Low		1.00 (ref.)	0.001		
			Some		0.87 (0.25–2.99)			
			High		2.13 (0.64–7.06)			
			Very high		1.11 (0.20–6.00)			
			Age 30-39		5.09 (1.59–16.30)			
			Not exposed					
			Low		1.00 (ref.)	0.005		
			Some		1.46 (0.99–2.15)			
			High		1.32 (0.87–2.02)			
			Very high		1.79 (1.14–2.82)			
			Age 40-49		1.91 (1.19–3.07)			
			Not exposed					
			Low		1.00 (ref.)	0.002		
			Some		1.22 (0.87–1.71)			
			High		1.24 (0.87–1.79)			
			Very high		1.59 (1.05–2.41)			
			Age >50		1.50 (0.95–2.35)			
			Not exposed					
			Low		1.00 (ref.)	0.001		
			Some		1.11 (0.84–1.46)			
			High		1.58 (1.20–2.09)			
			Very high		1.39 (0.98–1.97)			

Table 19 - Reproductive/developmental effects in humans: man fertility, epidemiologic case-control studies (24-100 GHz)(continued b)

Study information	Population	Type of Exposure and assessment method	Exposure category or level	Health Outcome and measure	Risk estimate (95% CI)					Any Other Co-Exposure/adjustments	Comments
2. Møllerløkken et al., 2008. Norway. 2002. Case-control study.	2265 (M) employees who were currently serving in the Navy, both military and civilians. Mean age of 36 years of age, range 20–62.	Occupational exposure from military communication equipment. Information on occupational history from mail questionnaire. An expert group determined work categories related to electromagnetic field exposure.	Workers in the radar/sonar-, the tele/communication, electronics, other jobs (unexposed).	Infertility, Biological Children, Anomalies, Chromosomal Errors, Preterm and Stillbirths or Infant Deaths. Incidence of outcome by exposure group (%); Chi2 or Fisher Exact Tests to assess significance of differences among groups.	**Infertility - % (p-value from Chi2 tests)**	**Having biological children - % (p-value from Chi2 tests)**	**Children with anomalies or chromosomal errors - % (p-value from Chi2 or Fisher's Exact tests)**	**Children with preterm births - % (p-value from Chi2 or Fisher's Exact tests)**	**Stillbirths and infant deaths within 1 year - % (p-value from Fisher's Exact tests)**	Age, ever smoked, military education, and physical exercise at work.	**Adequate/ Positive for male infertility and developmental parameters in offspring**
			Other jobs (unexposed group)		8.6	62.0	3.5	7.9	2.3		
			Radar/sonar workers (radar)		**17.5 (<0.01)**	70.4 (0.10)	7.1 (0.11)	9.1 (0.37)	2.0 (0.61)		

Table 20 (summary tables 19 a,b) – Collected data for epidemiological studies on reproductive/ developmental effects (FR2: 24-100 GHz).

Total studies*	2				
Adequate studies	2				
Type of study	Observed Effect	Total adequate studies	Positive results	Negative results	Equivocal results
Reproduction- man fertility	Decline in sperm quality	2	2		
Developmental parameters	Children: preterm birth; chromosomal anomalies	1	1		

The epidemiological evidence on possible associations of exposure to RF-EMF with reproductive/ developmental effects comes from studies of diverse design that have assessed a range of sources of exposure. The studied populations for FR2 include people exposed in occupational settings, in particular military employees.

In chapter 4 (Limitations) of the present document, general methodological concerns related to the assessment of individual studies are covered. The total number of epidemiological studies up to 2020, selected for the present review for FR2, was 2, both considered adequate.

SUMMARY OF THE COLLECTED DATA FOR EPIDEMIOLOGICAL STUDIES ON REPRODUCTIVE/DEVELOPMENTAL EFFECTS (FR2: 24-100 GHz) (Table 20)

FR2 (24-100 GHz)

The two analysed studies on FR2 have limits in exposure assessment, so the real RF/ EMFs levels of exposure are uncertain. However, both studies show *sufficient* evidence of adverse effects on male fertility (Ref: 1, 2).

Limited evidence of developmental effects in offspring of exposed military workers is shown in one of the study (Ref: 2).

However, due to the small number of adequate studies available and the uncertainty about exposure assessment, these results do not allow to confirm or denie an association between exposure to FR2 and reproductive developmental outcome (*not classifiable*).

4.2.3 Reproductive/developmental effects in experimental animals: Studies evaluating health effects due to RF at a lower frequency range (FR1: 450 to 6000 MHZ), which also includes the frequencies used in previous generations' broadband cellular networks (1G, 2G, 3G and 4G).

The articles identified through database searching and other sources were 5052. After removing duplicates (77) and excluding non-pertinent articles (4886) based on title and abstracts, 89 articles remained. Based on full-text screening, 43 papers were further excluded, so that the published articles with appropriate frequencies for the inclusion in this qualitative synthesis were 46, corresponding to 39 studies. In three cases, more than one article was published reporting information on the same study for different reproductive/developmental end points (Fig. 15).

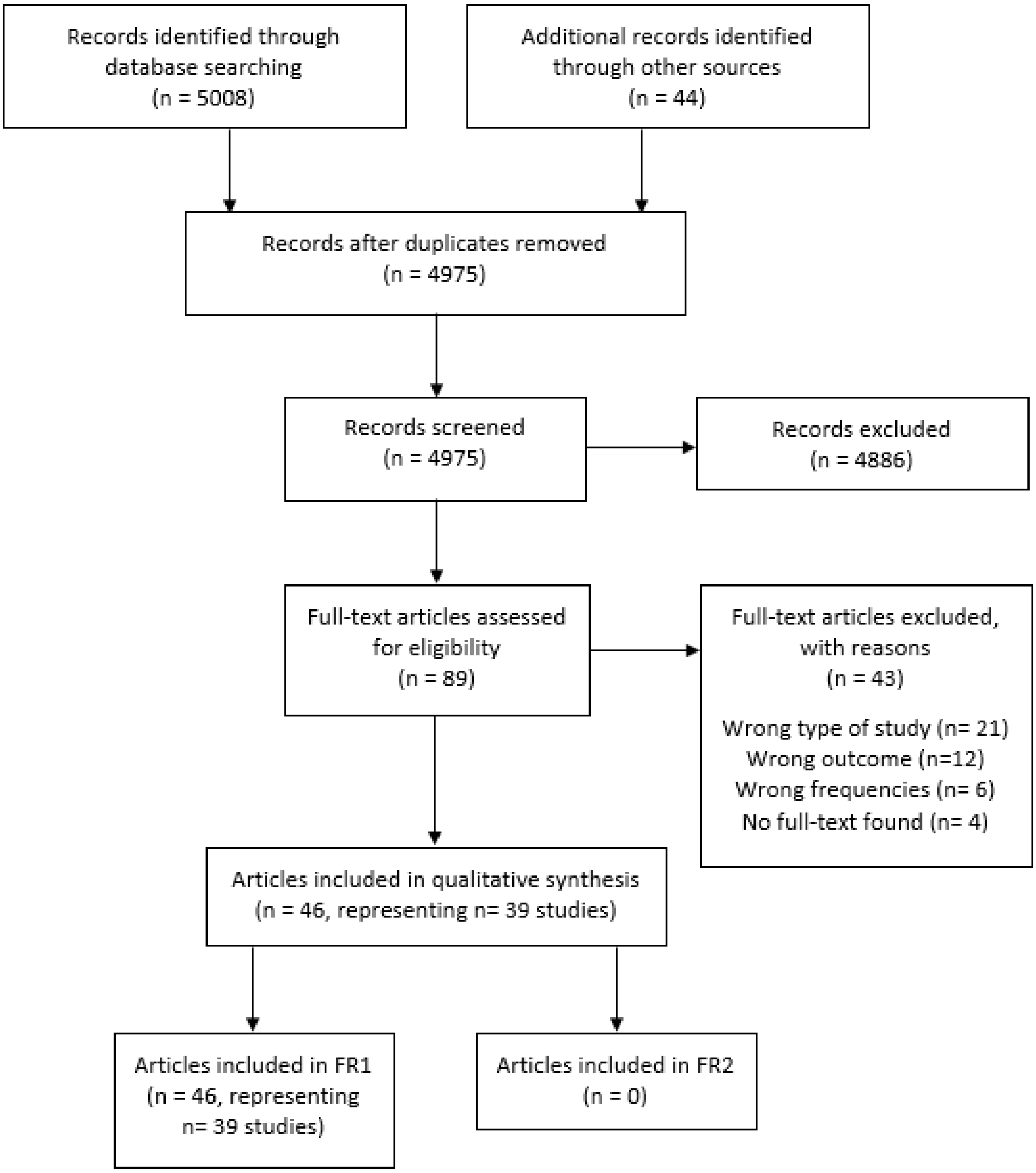
At this stage, a selection based on frequency range was also performed: out of 46 papers/39 studies, all reported exposures to the FR1 range, and none to FR2.

Another selection was based on the guidelines NTP Modified One Generation Study and OECD 443 from 2014 (Foster et al., 2014), which are globally recognised as the gold standard for the planning, conduct and monitoring of experimental bioassays on animals (rodents), aimed at finding effects on developmental pathology, endocrine disruptors, female reproduction, male reproduction, and effects on the reproductive system.

The guideline study design envisages at least 10 animals/sex/group in order to produce statistically robust results. Following this assumption, the papers were distributed by type of study, i.e., male reproduction, female reproduction, developmental pathology.

For each study, the abstract is reported, together with tables summarising the salient information; a senior expert evaluated their adequacy for assessing reproductive and developmental effects (adequate/inadequate), and expressed an overall synthesis of the results (positive/negative/equivocal), following the criteria described in the methodology section.

Figure 15 – Flow diagram. Reproductive/developmental effects in experimental animals FR1



REPRODUCTIVE TOXICITY

Male Mice (Tables 21, a, b)

1. Mugunthan et al., 2012.
India. Mice. Reproductive toxicity.

Mice (n=18) were exposed to 2G ultra-high frequency radiation, 48 minutes per day for a period of 30 to 180 days. The amount of electromagnetic field (EMF) exposed was calculated by the radiation frequency meter. Eighteen mice were exposed to 900-1900 MHz frequency radiation emitted from 2G cell phone and eighteen mice were sham control. The sham control mice (n=18) were exposed to similar conditions without 2G exposure. Each animal's weight was recorded before sacrifice. Three animals each were sacrificed at the end of 30, 60, 90,120,150 and 180 days of exposure in the experimental group after 24 hours of last exposure. Same numbers of control animals were sacrificed on similar period. We collected blood samples to measure plasma testosterone. We measured and analyzed the size, weight and volume of the testis. Testis sections were analysed under the light microscope for structural changes. Results: In 2G exposed group animal weight was lower at first, second and fourth month (p value ≤0.05). The mean testis weight of 2G exposed mice was significantly reduced in all months except fourth month (p value <0.05) and the mean testis volume was significantly reduced in the first three months (p value 0.02). The mean seminiferous tubule density per unit area was significantly lower (p value <0.001) in the 2G exposed testis. The mean seminiferous tubule diameter was significantly reduced in 2G exposed testis (p value is highly significant <0.001) except the second month. The mean number of Sertoli cells and Leydig cells were significantly reduced in 2G radiation exposed mice (p value is highly significant <0.001). While compared with control group, mean serum testosterone level of 2G exposed mice were significantly lower (p value 0.004). The following microscopic changes were found in the testis of 2G cell phone radiation exposed mice. 1. The interstitium appeared wide 2. Sertoli cells and spermatogonia were detached from the basal lamina. 3. Vacuolar degeneration and desquamation of seminiferous epithelium. Most of the peripheral tubules showed maturation arrest in the spermatogenesis. Seminiferous tubules scored between 8 and 9 using Johnson testicular biopsy score count. Chronic exposure to ultra-high frequency radiation emitted from a 2G cell phone could cause microscopic changes in the seminiferous tubules, reduction in the number of Sertoli and Leydig cells and decreased serum testosterone level. Long term use of cell phones could cause male infertility.

Comment*: *Adequate/positive.

2. Shahin et al., 2014.
India. Swiss mice (M). Reproductive toxicity.

Twelve-week-old mice were exposed to non-thermal low-level 2.45-GHz MW radiation (CW for 2/day for 30 days, power density = 0.029812 mW/cm2 and SAR = 0.018 W/Kg). Sperm count and sperm viability test were done as well as vital organs were processed to study different stress parameters. Plasma was used for testosterone and testis for 3b HSD assay. Immunohistochemistry of 3b HSD and nitric oxide synthase (i-NOS) was also performed in testis. We observed that MW irradiation induced a significant decrease in sperm count and sperm viability along with the decrease in seminiferous tubule diameter and degeneration of seminiferous tubules. Reduction in testicular 3b HSD activity and plasma testosterone levels was also noted in the exposed group of mice. Increased expression of testicular i-NOS was observed in the MW-irradiated group of mice. Further, these adverse reproductive effects suggest that chronic exposure to non-ionising MW radiation may lead to infertility via free radical species-mediated pathway.

Comment: Adequate/positive.

3. Zhu et al., 2015.

USA. ICR mice (M, SPF). Reproductive toxicity.

Adult male ICR mice were exposed to continuous wave 900 MHz radiofrequency fields (RF) After 7 days quarantine period, the animals were weighed (20 ± 2 gm) and randomized into three sep-arate groups of 10 mice each for different exposures.a. Continuous wave 900 MHzRf at 1.6 mW/cm2power intensity, 4 h/day for 15days. b. Sham exposure withoutRFtransmission (control mice. c. An acute dose of 2 Gy $_{\gamma}$-radiation (GR, positive controls). At the end of exposure, each mouse was caged with 3 mature virgin female mice for mating. After 7days, each male mouse was transferred to a fresh cage and mated with a second batch of 3 females. This process was repeated for a total of 4 consecutive weeks. Sham exposed male mice and those subjected to an acute 2 Gy -irradiation (GR) were handled similarly and used as un-exposed and positive controls,respectively. All females were sacrificed on the 18th day of gestation and presumptive mating and, the contents in their uteri were examined. The overall observations during the 4 weeks of mating indicated that the unexposed female mice mated to RF-exposed male mice showed no significant differences in the percentage of pregnancies, total implants, live implants and dead implants when compared with those mated with sham-exposed mice. In contrast, female mice mated with GR-exposed males showed a consistent pattern of significant differences in the above indices in each and all 4 weeks of mating. Thus, the data indicated an absence of mutagenic potential of RF exposure in the germ cells of male mice.

Comment*: *Adequate/negative.

4. Pandey et al., 2017.

India. Swiss mice (M). Reproductive toxicity.

Swiss albino mice were exposed to RFR (900 MHz) for 4 h and 8 h duration per day for 35 days. One group of animals was terminated after the exposure period, while others were kept for an additional 35 days post-exposure. RFR exposure caused depolarisation of mitochondrial membranes resulting in destabilized cellular redox homeostasis. Statistically significant increases in the damage index in germ cells and sperm head defects were noted in RFR-exposed animals. Flow cytometric estimation of germ cell subtypes in mice testis revealed 2.5-fold increases in spermatogonial populations with significant decreases in spermatids. Almost fourfold reduction in spermatogonia to spermatid turnover (1C:2C) and three times reduction in primary spermatocyte to spermatid turnover (1C:4C) was found indicating arrest in the premeiotic stage of spermatogenesis, which resulted in loss of post-meiotic germ cells apparent from testis histology and low sperm count in RFR-exposed animals. Histological alterations such as sloughing of immature germ cells into the seminiferous tubule lumen, epithelium depletion and maturation arrest were also observed. However, all these changes showed recovery to varied degrees following the post-exposure period indicating that the adverse effects of RFR on mice germ cells are detrimental but reversible. To conclude, RFR exposure-induced oxidative stress causes DNA damage in germ cells, which alters cell cycle progression leading to low sperm count in mice.

Comment: adequate/positive.

5. Pandey et al., 2018.

India. Swiss mice (M). Reproductive toxicity.

The present study investigated the effect of RFR Global System for Mobile communication (GSM) type, 900 MHz and melatonin supplementation on germ cell development during spermatogenesis. Swiss albino mice were divided into four groups. One group received RFR exposure for 3 h twice/day for 35 days and the other group received the same exposure but with melatonin (N-acetyl-5-methoxytryptamine) (MEL; 5 mg/kg bw/day). Two other groups received only MEL or remain unexposed. Sperm head abnormality, total sperm count, biochemical assay for lipid peroxides, reduced glutathione, superoxide dismutase activity and testis histology were evaluated. Additionally, flow cytometric evaluation of germ cell subtypes and comet assay were performed in testis. Extensive DNA damage in germ cells of RFR-exposed animals along with arrest in pre-meiotic stages of spermatogenesis eventually leading to low sperm count and sperm head abnormalities were observed. Furthermore, biochemical assays revealed excess free radical generation resulting in histological and morphological changes in testis and germ cells morphology, respectively. However, these effects were either diminished or absent in RFR-exposed animals supplemented with melatonin. Hence, it can be concluded that melatonin inhibits pre-meiotic spermatogenesis arrest in male germ cells through its anti-oxidative potential and ability to improve DNA reparative pathways, leading to normal sperm count and sperm morphology in RFR-exposed animals.

Comment*: *Adequate/positive (group treated without any supplement of melatonine).

6. Shahin et al., 2018.

India. Swiss mice. Reproductive toxicity.

The aim of present study was to investigate the underlying detailed pathway of the testicular apoptosis induced by free radical load and redox imbalance due to 2.45 GHz MW radiation exposure and the degree of severity along with the increased exposure duration. Twelve-week old male mice were exposed to 2.45 GHz MW radiation [continuous-wave (CW) with overall average Power density of 0.0248 mW/cm2 and overall average whole body SAR value of 0.0146 W/kg] for 2 hr/day over a period of 15, 30, and 60 days. Testicular histology, serum testosterone, ROS, NO, MDA level, activity of antioxidant enzymes, expression of pro-apoptotic proteins (p53 and Bax), anti-apoptotic proteins (Bcl-2 and Bcl-xL), cytochrome-c, inactive/active caspase-3, and uncleaved PARP-1 were evaluated. Findings suggest that 2.45 GHz MW radiation exposure induced testicular redox imbalance not only leads to enhanced testicular apoptosis via p53 dependent Bax-caspase-3 mediated pathway, but also increases the degree of apoptotic severity in a duration dependent manner.

Comment*: *Adequate/positive.

Female mice (Table 22, a)

7. Gul et al., 2009.

Turkey. Rats (F). Reproductive toxicity.

The aim of this study was to investigate whether there were any toxic effects of microwaves of cellular phones on ovaries in rats. In this study, 82 female pups of rats, aged 21 days (43 in the study group and 39 in the control group) were used. Pregnant rats in the study group were exposed to mobile phones that were placed beneath the polypropylene cages during the whole period of pregnancy. The cage was free from all kinds of materials, which could affect electromagnetic fields. A mobile phone in a standby position for 11 h and 45 min was turned on to speech position for 15 min every 12 h and the battery was charged continuously. On the 21st day after the delivery, the female rat pups were killed and the right ovaries were removed. The volumes of the ovaries were measured and the number of follicles in every tenth section was counted. The analysis revealed that in the study group, the number of follicles was lower than that in the control group. The decreased number of follicles in pups exposed to mobile phone microwaves suggest that intrauterine exposure has toxic effects on ovaries. We suggest that the microwaves of mobile phones might decrease the number of follicles in rats by several known and, no doubt, countless unknown mechanisms.

Comment*: *Adequate/equivocal.

8. Shahin et al., 2017.

India. Swiss mice (F). Reproductive toxicity.

The present study investigated the long-term effects of mobile phone (1800 MHz) radiation in stand-by, dialing and receiving modes on the female reproductive function (ovarian and uterine histo-architecture, andsteroidogenesis) and stress responses (oxidative and nitrosative stress). We observed that mobile phone radiation induces significant elevation in ROS, NO, lipid peroxidation, total carbonyl content and serum corticosterone coupled with significant decrease in antioxidant enzymes in hypothalamus, ovary and uterus of mice. Compared to control group, exposed mice exhibited reduced number of developing and mature follicles as well as corpus lutea. Significantly decreased serum levels of pituitary gonadotrophins(LH, FSH), sex steroids (E2 and P4) and expression of SF-1, StAR, P-450scc, 3beta-HSD, 17beta-HSD, cytochromeP-450 aromatase, ER-alfa and ER-beta were observed in all the exposed groups of mice, compared to control.These findings suggest that mobile phone radiation induces oxidative and nitrosative stress, which affects the reproductive performance of female mice.

Comment*: *Adequate/positive.

Male Rats (Tables 23, a-c)

9. Ozguner et al., 2005.

China. Sprague-Dawley rats (M). Reproductive toxicity.

The aim of this experimental study was to determine the biological and morphological effects of 900 MHz radiofrequency (RF) EMF on rat testes. The study was performed in the Physiology and Histology Research Laboratories of Süleyman Demirel University, Faculty of Medicine, Isparta, Turkey in May 2004. Twenty adult male Sprague-Dawley rats weighing 270 - 320 gm were randomized into 2 groups of 10 animals: Group I (control group) was not exposed to EMF and Group II (EMF group) was exposed to 30 minutes per day, 5 days a week for 4 weeks to 900 MHz EMF. Testes tissues were submitted for histologic and morphologic examination. Testicular biopsy score count and the percentage of interstitial tissue to the entire testicular tissue were registered. Serum testosterone, plasma luteinising hormone (LH) and follicle stimulating hormone (FSH) levels were assayed biochemically. Results: The weight of testes, testicular biopsy score count and the percentage of interstitial tissue to the entire testicular tissue were not significantly different in EMF group compared to the control group. However, the diameter of the seminiferous tubules and the mean height of the germinal epithelium were significantly decreased in EMF group ($p<0.05$). There was a significant decrease in serum total testosterone level in EMF group ($p<0.05$). Therefore, there was an insignificant decrease in plasma LH and FSH levels in EMF group compared to the control group ($p>0.05$). The biological and morphological effects resulting from 900 MHz RF EMF exposure lends no support to suggestions of adverse effect on spermatogenesis, and on germinal epithelium. Therefore, testicular morphologic alterations may possibly be due to hormonal changes.

Comment*: *Adequate/positive.

10. Lee et al., 2010.

Korea. Sprague Dawley rats (M). Reproductive toxicity.

We examined the histological changes by radiofrequency (RF) fields on rat testis, specifically with respect to sensitive processes such as spermatogenesis. Male rats (20 x group) were exposed to 848.5 MHz RF for 12 weeks. The RF exposure schedule consisted of two 45-min RF exposure periods, separated by a 15-min interval. The whole-body average specific absorption rate (SAR) of RF was 2.0 W/kg. We then investigated correlates of testicular function such as sperm counts in the cauda epididymis, malondialdehyde concentrations in the testes and epididymis, frequency of spermatogenesis stages, germ cell counts, and appearance of apoptotic cells in the testes. We also performed p53, bcl-2, caspase 3, p21, and PARP immunoblotting of the testes in sham- and RF-exposed animals. Based on these results, we concluded that subchronic exposure to 848.5 MHz with 2.0 W/kg SAR RF did not have any observable adverse effects on rat spermatogenesis.

Comment*: *Adequate/negative.

11. Imai et al., 2011.

Japan. Sprague-Dawley rats (M). Reproductive toxicity.

In recent years concern has arisen whether carrying a cellular phone near the reproductive organs such as the testes may cause dysfunction and particularly decrease in sperm development and production, and thus fertility in men. The present study was performed to investigate the effects of a 1.95 GHz electromagnetic field on testicular function in male Sprague-Dawley rats. Five week old animals were divided into 3 groups of 24 each and a 1.95-GHz wide-band code division multiple access (W-CDMA) signal, which is used for the freedom of mobile multimedia access (FOMA), was employed for whole body exposure for 5 hours per day, 7 days a week for 5 weeks (the period from the age of 5 to 10 weeks, corresponding to reproductive maturation in the rat). Whole-body average specific absorption rates (SAR) for individuals were designed to be 0.4 and 0.08 W/kg respectively. The control group received sham exposure. There were no differences in body weight gain or weights of the testis, epididymis, seminal vesicles, and prostate among the groups. The number of sperm in the testis and epididymis were not decreased in the electromagnetic field (EMF) exposed groups, and, in fact, the testicular sperm count was significantly increased with the 0.4 SAR. Abnormalities of sperm motility or morphology and the histological appearance of seminiferous tubules, including the stage of the spermatogenic cycle, were not observed. Thus, under the present exposure conditions, no testicular toxicity was evident.

Comment*: *Adequate/negative.

12. Meo et al., 2011.
Saudi Arabia. Wistar rats. Reproductive toxicity.

Forty male Wistar albino rats were divided in three groups. First group of eight served as the control. The second group [group B, n=16] was exposed to mobile phone radiation for 30 minutes/day and the third group [group C, n=16] was exposed to mobile phone radiation for 60 minutes/day for a total period of 3 months. Morphological changes in the testes induced by mobile phone radiations were observed under a light microscope. Exposure to mobile phone radiation for 60 minutes/day caused 18.75% hypospermatogenesis and 18.75% maturation arrest in the testis of albino rats compared to matched controls. However, no abnormal findings were observed in albino rats that were exposed to mobile phone radiation for 30 minutes/day for a total period of 3 months. Long-term exposure to mobile phone radiation can cause hypospermatogenesis and maturation arrest in the spermatozoa in the testis of Wistar albino rats.

Comment*: *Adequate (smaller no. of animals as controls)/equivocal.

13. Al-Damegh, 2012.
Saudi Arabia. Wistar rats (M). Reproductive toxicity.

The aim of this study was to investigate the possible effects of electromagnetic radiation from conventional cellular phone use on the oxidant and antioxidant status in rat blood and testicular tissue and determine the possible protective role of vitamins C and E in preventing the detrimental effects of electromagnetic radiation on the testes. The study population comprised 120 male Wistar albino rats, distributed at least 10xgroup. The treatment groups were exposed to an electromagnetic field, electromagnetic field plus vitamin C (40 mg/kg/day) or electromagnetic field plus vitamin E (2.7 mg/kg/day). All groups were exposed to the same electromagnetic frequency for 15, 30, and 60 min daily for two weeks. There was a significant increase in the diameter of the seminiferous tubules with a disorganized seminiferous tubule sperm cycle interruption in the electromagnetism-exposed group. The serum and testicular tissue conjugated diene, lipid hydroperoxide, and catalase activities increased 3-fold, whereas the total serum and testicular tissue glutathione and glutathione peroxidase levels decreased 3-5 fold in the electromagnetism-exposed animals. Results indicate that the adverse effect of the generated electromagnetic frequency had a negative impact on testicular architecture and enzymatic activity. This finding also indicated the possible role of vitamins C and E in mitigating the oxidative stress imposed on the testes and restoring normality to the testes.

Comment*: *Adequate/positive.

14. Celik et al., 2012.
Turkey. Wistar rats (M). Reproductive toxicity.

Wistar-Kyoto male rats were placed into either a control group or a group that was exposed to an electromagnetic field (EMF). Two cell phones with Specific Absorbation Rate values of 1.58 were placed and left off in cages that housed 15 rats included in the control group, and four cell phones were placed and left on in cages that housed 30 rats included in the experimental group. After 3 months, weights, seminiferous tubule diameters, and spermatogenic cell conditions of all testes of the rats were evaluated. One half of each testis was examined also under an electron microscope. No significant differences were observed between the testis weights, seminiferous tubule diameters, and histopathological evaluations between rats that had and had not been exposed to EMF. Electron microscope analysis revealed that the membrana propria thickness and the collagen fiber contents were increased and the capillary veins extended in the experimental group. Common vacuolisation in the cytoplasm of the Sertoli cells, growth of electron-dense structures, and existence of large lipid droplets were noted as the remarkable findings of this study. Although the cells that had been exposed to long-term, low-dose EMF did not present any findings that were contrary to the control conditions, the changes observed during ultrastructural examination gave the impression that significant changes may occur if the study period were to be extended. Longer studies are needed to better understand the effects of EMFs on testis tissue.

Comment: Adequate/negative.

15. Lee et al., 2012.

Korea. Sprague Dawley rats (M). Reproductive toxicity.

The effects of combined exposure to radiofrequency electromagnetic fields (RF-EMF) on rat testicular function, specifically with respect to sensitive processes such as spermatogenesis were examined. Male rats (20 x group) were exposed to single code division multiple access (CDMA) and wideband code division multiple access (WCDMA) RF signals for 12 weeks. The RF exposure schedule comprised 45 min/day, 5 days/week for a total of 12 weeks. The whole-body average specific absorption rate (SAR) of CDMA and WCDMA was 2.0 W/kg each or 4.0 W/kg in total. The correlates of testicular function such as sperm count in the cauda epididymis, testosterone concentration in the blood serum, malondialdehyde concentrations in the testes and epididymis, frequency of spermatogenesis stages, and appearance of apoptotic cells in the testes were investigated. Immunoblot for p53, bcl2, GADD45, cyclin G, and HSP70 in the testes of sham- and combined RF-exposed animals were performed. Based on the results, we concluded that simultaneous exposure to CDMA and WCDMA RF-EMFs at 4.0 W/kg SAR did not have any observable adverse effects on rat spermatogenesis.

Comment: Adequate/negative.

16. Ozlem-Nisbet et al., 2012.

Turkey. Wistar rats (M). Reproductive toxicity.

Male albino Wistar rats (2 days old) were exposed toexposure on reproduction in growing male rats. Male albino Wistar rats (2 days old) were exposed to EMF 1800 and 900 MHz for 2 h continuously per day for 90 days. Sham control was kept under similar conditions except that the field was not applied for the same period. After blood samples were collected, the animals were sacrificed 24 h after the last exposure and the tissues of interest were harvested. The mean plasma total testosterone showed similarity among the two study groups and was significantly higher than the sham control rats. The percentage of epididymal sperm motility was significantly higher in the 1800 MHz group ($P < 0.05$). The morphologically normal spermatozoa rates were higher and the tail abnormality and total percentage abnormalities were lower in the 900 MHz group ($P < 0.05$). Histopathologic parameters in the 1800 MHz group were significantly higher ($P < 0.05$). In conclusion, the present study indicated that exposure to electromagnetic wave caused an increase in testosterone level, epididymal sperm motility (forward), and normal sperm morphology of rats. As a consequences, 1800 and 900 MHz EMF could be considered to be a cause of precocious puberty in growing rats.

Comment: Adequate/positive.

17. Bin-Meferijand El-kott, 2015.

Saudi Arabia. Sprague Dawley rats (M). Reproductive toxicity.

The purpose of this study was to explore the capability of polyphenolic-rich Moringa oleifera leaf extract inprotecting rat testis against EMR-induced impairments based on evaluation of sperm count, viability, motility, sperm cell morphology, anti-oxidants (SOD and CAT), oxidative stress marker, testis tissue histopathology and PCNA immunohistochemistry. The sample consisted of sixty male Wistar rats which were divided into four equal groups. The first group (the control) received only standard diet while the second group was supplemented daily and for eight weeks with 200 mg/kg aqueous extract of Moringa leaves. The third group was exposed to 900 MHz fields for one hour a day and for (7) days a week. As for the fourth group, it was exposed to mobile phone radiation and received the Moringa extract. The results showed that the EMR treated group exhibited a significantly decrease sperm parameters. Furthermore, concurrent exposure to EMR and treated with MOE significantly enhanced the sperm parameters. However, histological results in EMR group showed irregular seminiferous tubules, few spermatogonia, giant multinucleated cells, degenerated spermatozoa and the number of Leydig cells was significantly reduced. PCNA labelling indices were significant in EMR group versus the control group. Also, EMR affects spermatogenesis and causes to apoptosis due to the heat and other stress-related EMR in testis tissue. This study concludes that chronic exposure to EMR marked testicular injury which can be prevented by Moringa oleifera leaf extract.

Comment*: *Adequate/positive.

18. Liu et al., 2015.

China. Sprague-Dawley rats (M) .Reproductive toxicity.

Twenty four rats were exposed to 900 MHz electromagnetic radiation with a special absorption rate of 0.66 ± 0.01 W/kg for 2 h/d. After 50d, the sperm count, morphology, apoptosis, reactive oxygen species (ROS), and total antioxidant capacity (TAC), representing the sum of enzymatic and nonenzymatic antioxidants, were investigated. Western blotting and reverse transcriptase PCR were used to determine the expression levels of apoptosis-related proteins and genes, including bcl-2, bax, cytochrome c, and capase-3. Results: In the present study, the percentage of apoptotic sperm cells in the exposure group was significantly increased by 91.42 % compared with the control group. Moreover, the ROS concentration in exposure group was increased by 46.21 %, while the TAC was decreased by 28.01 %. Radiation also dramatically decreased the protein and mRNA expression of bcl-2 and increased that of bax, cytochrome c, and capase-3. Conclusion: RF-EMR increases the ROS level and decreases TAC in rat sperm. Excessive oxidative stress alters the expression levels of apoptosis-related genes and triggers sperm apoptosis through bcl-2, bax, cytochrome c and caspase-3 signaling pathways.

Comment*: *Adequate/positive.

19. Saygin et al., 2015.

Turkey. Sprague Dawley rats. Reproductive toxicity.

The aim of this study was to investigate electromagnetic radiation (EMR) transmitted by wireless devices (2.45 GHz), which may cause physiopathological or ultrastructural changes, in the testes of rats. We addressed if the supplemental gallic acid (GA) may reduce these adverse effects. Six-week-old male Sprague Dawley rats were used in this study. Forty eight rats were equally divided into four groups, which were named: Sham, EMR only (EMR, 3 h day21 for 30 days), EMR1GA (30 mg/kg/daily), and GA (30 mg/kg/daily) groups. Malondialdehyde (MDA) and total oxidant status (TOS) levels increased (p50.001 for both) in EMR only group. TOS and oxidative stress index (OSI) levels decreased in GA treated group significantly (p50.001 and p50.045, respectively). Total antioxidant status (TAS) activities decreased in EMR only group and increased in GA treatment group (p50.001 and p50.029, respectively). Testosterone and vascular endothelial growth factor (VEGF) levels decreased in EMR only group, but this was not statistically significant. Testosterone and VEGF levels increased in EMR1GA group, compared with EMR only group (p50.002), and also increased in GA group compared with the control and EMR only group (p50.044 and p50.032, respectively). Prostaglandin E2 (PGE2) and calcitonin gene releated peptide (CGRP) staining increased in tubules of the testes in EMR only group (p<0.001 for both) and decreased in tubules of the testes in EMR1GA group (p<0.001 for all parameters). In EMR only group, most of the tubules contained less spermatozoa, and the spermatozoon counts decreased in tubules of the testes. All these findings and the regenerative reaction, characterized by mitotic activity, increased in seminiferous tubules cells of the testes in EMR1GA group (p<0.001). Long term EMR exposure resulted in testicular physiopathology via oxidative damage and inflammation. GA may have ameliorative effects on the prepubertal rat testes physiopathology.

Comment*: *Adequate/positive.

20. Bilgici et al., 2018.

Turkey. Wistar rats (M). Reproductive toxicity.

Inflammatory effect and testicular damage on rats exposed to low level of electromagnetic fields (EMF) at 2.45GHz microwave radiation were investigated. Twenty two Wistar rats were divided into two groups. Group 1 was the control group and not exposed to EMF. Group 2 was exposed to low level EMF (average E-field 3.68 ± 0.36 V/m, whole body average SAR, 0.0233 W/kg, in 10 g tissue) at 2.45GHz for 1 hour/day for 30 consecutive days. At the end of the study, interleukin-6 (IL-6), interleukin-10 (IL-10), interleukin-32 (IL-32), C-reactive protein (CRP) were measured in rat serum and IL-6, IL-10, IL-32 were measured in rat testis tissue.Furthermore, testicular tissues were evaluated histopathologically in terms of spermatogenesis and coagulation necrosis. Serum IL-6 and CRP levels were found to be significantly different in the study group compared to the control group (p<.05), but no significant difference was found in serum IL-10, IL-32 levels and testis tissue IL-6, IL-10, IL-32 levels compared to the control group (p>.05). On the other hand, histopathological evaluation of testicular tissue revealed a significant difference in necrosis and spermatogenesis when compared with the control group (p<.05). It may be concluded that low level EMF at 2.45GHz increases inflammation and testicular damage and negative impact on male reproductive system function.

Comment*: *Adequate/positive.

21. Guo et al., 2019.

China.Sprague-Dawlwy rats. Reproductive toxicity.

Under some occupational conditions, workers are inevitably exposed to high-intensityradiofrequency (RF) fields. In this study, we investigated the effects of one-month exposure to a220 MHz pulsed modulated RF field at the power density of 50 W/m2on the sperm quality in maleadult rats. The sperm quality was evaluated by measuring the number, abnormality and survivalrate of sperm cells. The morphology of testis was examined by hematoxylin–eosin (HE) staining. Thelevels of secreting factors by Sertoli cells (SCs) and Leydig cells (LCs) were determined by enzymelinked immunosorbent assay (ELISA). The level of cleaved caspase 3 in the testis was detected byimmunofluorescence staining. Finally, the expression levels of the apoptosis-related protein (caspase 3,BAX and BCL2) in the testis were assessed by Western blotting. Compared with the sham group, thesperm quality in the RF group decreased significantly. The levels of secreting factors of SCs and themorphology of the testis showed an obvious change after RF exposure. The level of the secretingfactor of LCs decreased significantly after RF exposure. The levels of cleaved caspase 3, caspase 3,and the BAX/BCL2 ratio in the testis increased markedly after RF exposure. These data collectivelysuggested that under the present experimental conditions, 220 MHz pulsed modulated RF exposure could impair sperm quality in rats, and the disruption of the secreting function of LCs and increased apoptosis of testis cells induced by the RF field might be accounted for by this damaging effect.

Comment*: *Adequate/positive.

22. Yu et al., 2020.

China. Sprague Dawley rats. Reproductive toxicity (exp.1 and 2).

The correlation between long-term exposure to SRF-EMR and the decline in male fertility is gradually receiving increasing attention fromthe medical society.While male reproductive organs are often exposed to SRF-EMR, little is currently known about the direct effects of long-termSRF-EMR exposure on the testes and its involvement in the suppression of male reproductive potential. The present study was designed to investigate this issue by using 4G SRF-EMR in rats. A unique exposure model using a 4G smartphone achieved localized exposure to the scrotum of the rats for 6 h each day (the smartphone was kept on active talk mode and received an external call for 1 min over 10min intervals). Results showed that SRF-EMR exposure for 150 days decreased spermquality and pupweight, accompanied by testicular injury. However, these adverse effectswere not evident in rats exposed to SRF-EMR for 50 days or 100 days. Sequencing analysis and western blotting suggested Spock3 overexpression in the testes of rats exposed to SRF-EMR for 150 days. Inhibition of Spock3 overexpression improved sperm quality decline and alleviated testicular injury and BTB disorder in the exposed rats. Additionally, SRF-EMR exposure suppressed MMP2 activity, while increasing the activity of the MMP14–Spock3 complexes and decreasing MMP14–MMP2 complexes; these results were reversed by Spock3 inhibition. Thus, long-term exposure to 4G SRF-EMR diminished male fertility by directly disrupting the Spock3–MMP2–BTB axis in the testes of adult rats. To our knowledge, this is the first study to show direct toxicity of SRF-EMR on the testes emerging after long-term exposure.

***Comment*: *Adequate/positive*.**

DEVELOPMENTAL TOXICITY

Hamsters (Table 24, a)

23. Lerchl 2008a, 2008b, 2008c.

Germany. Djiungarian Hamsters. Developmental toxicity.

In three experiments, adult male Djungarian hamsters (Phodopus sungorus) were exposed 24 hr/day for 60 days to radio frequency electromagnetic fields (RF-EMF) at 383, 900, and 1800 MHz, modulated according to the TETRA (383 MHz) and GSM standards (900 and 1800 MHz), respectively. A radial waveguide system ensured a well defined and uniform exposure at whole-body averaged specific absorption rates of 80 -mW/kg, which is equal to the upper limit of whole-body exposure of the general population in Germany and other countries. For each experiment, using two identical waveguides, hamsters were exposed (n = 120) and sham-exposed (n = 120) in a blind fashion. In all experiments, pineal and serum melatonin levels as well as the weights of testes, brain, kidneys, and liver were not affected. At 383 MHz, exposure resulted in a significant transient increase in body weight up to 4%, while at 900 MHz this body weight increase was more pronounced (up to 6%) and not transient. At 1800 MHz, no effect on body weight was seen. The results corroborate earlier findings which have shown no effects of RF EMF on melatonin levels in vivo and in vitro. The data are in accordance with the hypothesis that absorbed RF energy may result in metabolic changes which eventually cause body weight increases in exposed animals. The data support the notion that metabolic effects of RF-EMFs need to be investigated in more detail in future studies.

Comment: Adequate/negative.

Mice (Table 25, a-c)

24. Finnie et al. a, b (2006, 2009)
    BALB/c mice. Developmental toxicity.

To determine whether whole of gestation exposure of fetal mouse brain to mobile telephone radiofrequency fields produces a stress response detectable by induction of heat shock proteins (HSPs). Using a purpose-designed exposure system at 900 MHz, pregnant mice were given a single, far-field, whole body exposure at a specific absorption rate of 4 W/kg for 60 min/day from day 1 to day 19 of gestation. Control mice were sham-exposed or freely mobile in a cage to control for any stress caused by restraint in the exposure module. Immediately prior to parturition on day 19, fetal brains were collected, fixed in 4% paraformaldehyde and paraffin-embedded. Three coronal sections encompassing a wide range of anatomical regions were cut from each brain and any stress response detected by immunostaining for HSP25, 32 and 70. Results There was no induction of HSP32 or 70 in any brains, while HSP25 expression was limited to two brainstem nuclei and occurred consistently in exposed and non-exposed brains.

Comment*: *Adequate/negative.

25. Lee et al., 2009.

    Korea. ICR mice. Developmental toxicity (teratogenesis).

The murine fetus is a very sensitiveindicator of the effects of stress or stimuli in the environment.Therefore, we investigated the teratogenic effects of multi-signal radiofrequency electromagnetic fields (RF EMFs) on mouse fetuses. Pregnant mice were simultaneously exposed to two types of RF signals, single code division multiple access (CDMA) and wideband code division multiple access (WCDMA). Mice received two 45-min RF-field exposures, separated by a 15-min interval, daily throughout the entire gestation period. The whole-body average specific absorption rate (SAR) of CDMA or WCDMA was 2.0 W/kg. The animals were killed humanely on the 18th day of gestation and fetuses were examined for mortality, growth retardation, changes in head size and other morphological abnormalities. From the results, we report for the first time that simultaneous experimental exposure to CDMA and WCDMA RF EMFs did not cause any observable adverse effects on mouse fetuses.

Comment*: *Adequate (short daily exposure)/negative.

26. Fragopoulou et al., 2010.
    Greece. Balb/c mice. Developmental toxicity.

This study focuses on foetal development following mild daily exposure of pregnant mice to near field electromagnetic radiation emitted by a mobile phone.The investigation was motivated by the fact that the potentially hazardous electromagnetic radiation emitted by mobile phones is currently of tremendous public interest. Physically comparable pregnant mice were exposed to radiofrequency radiation GSM 900MHz emitted by a mobile phone.Within 5 h after birth most cubs were fixed followed by double staining in toto, and conventional paraffin histology. Other cubs remained with their mothers until teeth eruption. Structural development was assessed by examining newborns for the presence of anomalies and/or variations in soft tissues and skeletal anatomy. Electromagnetic radiofrequency exposed newborns, externally examined, displayed a normal phenotype. Histochemical and histological studies, however, revealed variations in the exposed foetuses with respect to control ones concerning the ossification of cranial bones and thoracic cage ribs, as well as displacement of Meckelian cartilage. Littermates examined after teeth eruption displayed normal phenotypes. It is concluded that mild exposure to mobile phone radiation may affect, although transiently, mouse foetal development at the ossification level. The developmental variations observed could be explained by considering the different embryonic origin and mode of ossification of the affected skeletal elements.

Comment*: *Adequate/positive.

27. Sambucci et al., 2011.
Italy. C57BL/6 newborns mice (M and F). Developmental toxicity (immunotoxicology).

The development of the immune system begins during embryogenesis, continues throughout fetal life, and completes its maturation during infancy. Exposure to immune-toxic compounds at levels producing limited/transient effects in adults, results in long-lasting or permanent immune deficits when it occurs during perinatal life. Potentially harmful radiofrequency (RF) exposure has been investigated mainly in adult animals or with cells from adult subjects, with most of the studies showing no effects. Is the developing immune system more susceptible to the effects of RF exposure? To address this question, newborn mice were exposed to WiFi signals at constant specific absorption rates (SAR) of 0.08 or 4 W/kg, 2 h/day, 5 days/week, for 5 consecutive weeks, starting the day after birth. The experiments were performed with a blind procedure using sham-exposed groups as controls. No differences in body weight and development among the groups were found in mice of both sexes. For the immunological analyses, results on female and male newborn mice exposed during early post-natal life did not show any effects on all the investigated parameters with one exception: a reduced IFN-g production in spleen cells from microwaves (MW)-exposed (SAR 4 W/kg) male (not in female) mice compared with sham-exposed mice. Altogether our findings do not support the hypothesis that early post-natal life exposure to WiFi signals induces detrimental effects on the developing immune system.

***Comment**: Adequate/negative, except for reduced IFN-g production in spleen cells from microwaves exposed (SAR 4 W/kg) male (not in female) mice compared with sham-exposed mice.*

28. Zhang et al., 2015.
China. CD1 mice. Developmental toxicity (behavioral study).

The recent rapid development of electronic communication techniques is resulting in a marked increase in exposure of humans to electromagnetic fields (EMFs). This has raised public concerns about the health hazards of long-term environmental EMF exposure for fetuses and children. Some studies have suggested EMF exposure in children could induce nervous system disorders. However, gender-dependent effects of microwave radiation exposure on cognitive dysfunction have not previously been reported. Here we investigated whether in utero exposure to 9.417-GHz microwave throughout gestation (Days 3.5–18) affected behavior, using the open field test (OFT), elevated-plus maze (EPM), tail suspension test (TST), forced swimming test (FST) and Morris water maze (MWM). We found that mice showed less movement in the center of an open field (using the OFT) and in an open arm (using the EPM) after in utero exposure to 9.417-GHz radiation, which suggested that the mice had increased anxiety-related behavior. Mice demonstrated reduced immobility in TST and FST after in utero exposure to 9.417-GHz radiation, which suggested that the mice had decreased depression related behavior. From the MWM test, we observed that male offspring demonstrated decreased learning and memory, while females were not affected in learning and memory, which suggested that microwaves had gender-dependent effects. In summary, we have provided the first experimental evidence of microwaves inducing gender-dependent effects.

***Comment**: Adequate/ positive (gender dependent effects).*

29. Fatehi et al., 2018.
Iran. NMRI-mice. Developmental toxicity.

Two hundred male and female NMRI-mice were used. One hundred males divided in five groups (n = 20) as control and exposed groups. Those irradiated with cell-phone RF in "Standby-mode" 1, 5 and 10 h daily named groups II, III and IV; respectively. Group V irradiated with cell-phone on "Active-mode" one hour daily. After 30 days irradiation, 50 males and 50 females were kept 24 h to assess their embryos. Fifty males were scarified to evaluate both in vitro and in vivo parameters, and 50 females received PMSG and HCG for both quantitative and qualitative evaluation. Comparing groups III, IV and V with control-group showed significantly decreased in the number of two-cell embryos (p = .000); however, a significant increase was found in the number of dead embryos (p = .000). Furthermore, 5 h daily irradiation significantly decreased grade-A embryos (p = .015); while, it significantly increased grade-B, C and D embryos (p-values = 0.026, 0.007, 0.006; respectively). Moreover, comparing groups IV and V to control-group, significant increase was found in pregnancy duration (p = .005, p = .009; respectively). However, in the mentioned groups a significant decrease was seen in number of newborn mice (p = .001, p = .004; respectively). In conclusion, findings showed that the cell-phone radiation can affect development of embryos as well as the number of newborn and pregnancy duration in NMRI-mouse, which might be a significant cause of reproductive failure .

Comment* : *Adequate/positive.

Rats (Table 26, a)

30. Nelson et al., 1991, 1994, 1997, 1997. USA. Sprague-Dawley rats. Developmental toxicity (synergistic effects).

Concurrent exposures to chemical and physical agents occur in the workplace; exposed workers include those involved with microelectronics industry, plastic sealers and electrosurgical units. Previous animal research indicates that hyperthermia induced by an elevation in ambient temperature can potentiate the toxicity and teratogenicity of some chemical agents. We previously demonstrated that combined exposure to radiofrequency (r.f.; 10 MHz) radiation, which also induces hyperthermia and is teratogenic to exposed animals, and the industrial solvent 2-methoxyethanol (2ME) produces enhanced teratogenicity in rats. A subsequent study replicated and extended that research by investigating the interactive dose-related teratogenicity of r.f. radiation (sham exposure or maintaining colonic temperatures at 42.0 degrees C for 0, 10, 20 or 30 min by r.f. radiation absorption) and 2ME (0, 75, 100, 125 or 150 mg/kg) on gestation days 9 or 13 of rats. The purpose of the present research is to determine the effects of r.f. radiation (sufficient to maintain colonic temperatures at 42.0 degrees C for 10 min) on a range of doses of 2ME (0, 20, 40, 60, 80, 100, 120 and 140 mg kg-1) administered on gestation day 13 of rats. Focusing on characterising the dose-response pattern of interactions, this research seeks to determine the lowest interactive effect level. Day 20 fetuses were examined for external and skeletal malformations. The results are consistent with previous observations. Dose-related developmental toxicity was observed for 2ME both in the presence and absence of r.f. radiation. However, concurrent RF radiation exposure changed the shape of the dose-effect curve of 2ME. These data indicate that combined exposure effects should be considered when developing exposure guidelines and intervention strategies.

Comment*: *Inadequate (thermal effects are considered for studying synergistic effects).

31. Nelson et al., 2001.

USA. Sprague-Dawley rats. Developmental toxicity ((synergistic effects).

The purpose of the present research is to investigate if the interactive effects noted for RF radiation and 2ME are unique to these agents, or if similar interactions might be seen with other chemicals. Because methanol is widely used as a solvent as well as fuel additive, and, at high levels, is teratogenic in animals, we selected methanol as a chemical to address generalisability. Based on the literature and our pilot studies, 0, 2, or 3 g/kg methanol (twice, at 6-hour intervals) were administered on gestation day 9 or 13 to groups of 10 Sprague-Dawley rats. Dams treated on day 9 were given methanol and exposed to RF radiation sufficient to maintain colonic temperature at 41 degrees C for 60 minutes (or sham). Those treated on day 13 were given methanol plus either 0 or 100 mg/kg 2ME. Because we observed that methanol produced hypothermia, some groups were given the initial dose of methanol concurrently with the RF or 2ME, and others were given the first dose of methanol 1.5 hours prior to RF or 2ME. Dams were sacrificed on gestation day 20, and the fetuses were examined for external malformations. The results indicate that RF radiation or methanol on day 9 increased the incidence of resorbed fetuses, but no interactive effects were observed. The resorptions were highest in groups given the experimental treatments 1.5 hours apart. The higher dose of methanol also reduced fetal weights. Administration of 2ME or methanol on day 13 increased the rate of malformations, and there was evidence of a positive interaction between 2ME and methanol. Fetal weights were reduced by 2ME and methanol alone, but no interaction was observed. Also, separation of the dosing with the teratogens did not affect the results. These results point out that interactions in developmental toxicology, such as those of RF radiation, 2ME, and methanol that we have studied, are complex, and such interactions cannot be fully understood or predicted without more research. It is important that combined exposure effects be considered when developing both physical agent and chemical agent exposure guidelines and intervention strategies.

Comment*: *Inadequate (thermal effects are considered for studying synergistic effects).

32. Ogawa et al., 2009.

Japan. Sprague-Dawley rats (F), 10 days. Developmental toxicity.

The present study was designed to evaluate whether gestational exposure to an EMF-targeting the head region, similar to that from cellular phones, might affect embryogenesis in rats. A 1.95-GHz wideband code division multiple access (W-CDMA) signal, which is one applied for the International Mobile Telecommunication 2000 (IMT-2000) system and used for the freedom of mobile multimedia access (FOMA), was employed for exposure to the heads of four groups of pregnant CD(SD) IGS rats (20 per group) for gestational days 7–17. The exposure was performed for 90 min/day in the morning. The spatial average specific absorption rate (SAR) for individual brains was designed to be 0.67 and 2.0 W/kg with peak brain SARs of 3.1 and 7.0 W/kg for low (group 3) and high (group 4) exposures, respectively, and a whole-body average SAR less than 0.4 W/kg so as not to cause thermal effects due to temperature elevation. Control and sham exposure groups were also included. At gestational day 20, all dams were killed and fetuses were taken out by cesarean section. There were no differences in maternal body weight gain. No adverse effects of EMF exposure were observed on any reproductive and embryotoxic parameters such as number of live (243–271 fetuses), dead or resorbed embryos, placental weights, sex ratios, weights or external, visceral or skeletal abnormalities of live fetuses.

Comment*: *Adequate/negative.

33. Sommer et al., 2009.

Germany, C57BL mice (M, F). Multi-generation study. Developmental toxicity.

Male and female mice (C57BL) were chronically exposed (life-long, 24 h/day) to mobile phone communication electromagnetic fields at approximately 1966 MHz (UMTS). Their development and fertility were monitored over four generations by investigating histological, physiological, reproductive and behavioral functions. Exposure of 24 h/day, 7 days/week, using 128 M and 256 F over four generations. The mean whole-body SARs, calculated for adult animals at the time of mating, were 0 (sham), 0.08, 0.4 and 1.3 W/kg. Power densities were kept constant for each group (0, 1.35, 6.8 and 22 W/m(2)), resulting in varying SARs due to the different numbers of adults and pups over the course of the experiment. The experiment was done in a blind fashion. The results show no harmful effects of exposure on the fertility and development of the animals. The number and the development of pups were not affected by exposure. Some data, albeit without a clear dose-response relationship, indicate effects of exposure on food consumption that is in accordance with some data published previously. In summary, the results of this study do not indicate harmful effects of long-term exposure of mice to UMTS over several generations.

Comment*: *Adequate/negative.

34. Ozorak et al., 2013.

Turkey. Wistar rats. Developmental toxicity.

The present study was designed to determine the effects of both Wi-Fi (2.45 GHz)- and mobile phone (900 and 1800 MHz)-induced electromagnetic radiation (EMR) on oxidative stress and trace element levels in the kidney and testis of growing rats from pregnancy to 6 weeks of age. Thirty-two rats and their 96 newborn offspring were equally divided into four different groups, namely, control, 2.45 GHz, 900 MHz, and 1800 MHz groups. The 2.45 GHz, 900 MHz, and 1, 800MHz groups were exposed to EMRfor 60min/day during pregnancy and growth. During the fourth, fifth, and sixth weeks of the experiment, kidney and testis samples were taken from decapitated rats. Results from the fourth week showed that the level of lipid peroxidation in the kidney and testis and the copper, zinc, reduced glutathione (GSH), glutathione peroxidase (GSH-Px), and total antioxidant status (TAS) values in the kidney decreased in the EMR groups, while iron concentrations in the kidney as well as vitamin A and vitamin E concentrations in the testis increased in the EMR groups. Results for fifth-week samples showed that iron, vitamin A, and β-carotene concentrations in the kidney increased in the EMR groups, while the GSH and TAS levels decreased. The sixth week results showed that iron concentrations in the kidney and the extent of lipid peroxidation in the kidney and testis increased in the EMR groups, while copper, TAS, and GSH concentrations decreased. There were no statistically significant differences in kidney chromium, magnesium, and manganese concentrations among the four groups. In conclusion, Wi-Fi- and mobile phone-induced EMR caused oxidative damage by increasing the extent of lipid peroxidation and the iron level, while decreasing total antioxidant status, copper, and GSH values.Wi-Fi- and mobile phone-induced EMR may cause precocious puberty and oxidative kidney and testis injury in growing rats.

Comment: Adequate, positive (testes injuries too).

35. Poulletier de Gannes et al., 2013.

France. Wistar rats (M, F). Developmental toxicity.

For the first time, we evaluated the effects of exposure to the 2450 MHz Wi-Fi signal (1 h/day,6 days/week) on the reproductive system of male and female Wistar rats, pre-exposed to Wi-Fi during sexual maturation. Thirty-six Wistar Han male and female rats were purchased (Janvier, France) at 6 and 7 weeks of age, respectively and exposed 1 h/day, 6 days/week, 12 animals per group Exposure lasted 3 weeks (males) or 2 weeks (females), then animals were mated and couples exposed for 3 more weeks. On the day before delivery, the fetuses were observed for lethality, abnormalities, and clinical signs. In our experiment, no deleterious effects of Wi-Fi exposure on rat male and female reproductive organs and fertility were observed for 1 h per days. No macroscopic abnormalities in fetuses were noted, even at the critical level of 4 W/kg.

Comment: Adequate/negative.

36. Celik et al., 2016.

Turkey. Wistar rats. Developmental toxicity (neuro).

The study investigates the effects of Wi-Fi-induced EMR on the brain and liver antioxidant redox systems in the rat during pregnancy and development. Sixteen pregnant rats and their 48 newborns were equally divided into control and EMR groups. The EMR groups were exposed to 2.45 GHz EMR (1 h/day for 5 days/week) from pregnancy to 3 weeks of age. Brain cortex and liver samples were taken from the newborns between the first and third weeks. In the EMR groups, lipid peroxidation levels in the brain and liver were increased following EMR exposure; however, the glutathione peroxidase (GSH-Px) activity, and vitamin A, vitamin E and b-carotene concentrations were decreased in the brain and liver. Glutathione (GSH) and vitamin C concentrations in the brain were also lower in the EMR groups than in the controls; however, their concentrations did not change in the liver. In conclusion, Wi-Fi-induced oxidative stress in the brain and liver of developing rats was the result of reduced GSH-Px, GSH and antioxidant vitamin concentrations. Moreover, the brain seemed to be more sensitive to oxidative injury compared to the liver in the development of newborns.

Comment: Adequate/positive.

37. Shirai et al., 2016.

Japan. Sprague-Dawley rats. Developmental toxicity.

To evaluate the possible adverse effects of multifrequency RF-EMFs, an experiment in which pregnant rats and their delivered offspring were simultaneously exposed to eight different communication signal EMFs (two of 800 MHz band, two of 2 GHz band, one of 2.4 GHz band, two of 2.5 GHz band and one of 5.2 GHz band) was performed. Thirty six pregnant Sprague-Dawley (SD) 10-week-old rats were divided into three groups of 12 rats: one control (sham exposure) group and two experimental (low- and high-level RF EMF exposure) groups. The whole body of the mother rats was exposed to the RF EMFs for 20 h per day from Gestational Day 7 to weaning, and F1 offspring rats (46–48 F1 pups per group) were then exposed up to 6 weeks of age also for 20 h per day. The parameters evaluated included the growth, gestational condition and organ weights of the dams; the survival rates, development, growth, physical and functional development, memory function, and reproductive ability of the F1 offspring; and the embryotoxicity and teratogenicity in the F2 rats. No abnormal findings were observed in the dams or F1 offspring exposed to the RF EMFs or to the F2 offspring for any of the parameters evaluated. Thus, under the conditions of the present experiment, simultaneous whole-body exposure to eight different communication signal EMFs at frequencies between 800 MHz and 5.2 GHz did not show any adverse effects on pregnancy or on the development of rats.

Comment*: *Adequate/negative.

38. Stasinopouloua et al., 2016.

Greece. Wistar rats. Developmental toxicity (neuro).

In the present study, to evaluate the effects of wireless 1880–1900 MHz Digital Enhanced CommunicationTelephony (DECT) base radiation on fetal and postnatal development, Wistar rats (80 dams in 4 groups) were exposed at an average electric field intensity of 3.7 V/m, 12 h/day, during pregnancy. After parturition, a group of dams and offspring were similarly exposed for another 22 days. Controls were sham-exposed. The data showedthat DECT base radiation exposure caused heart rate increase in the embryos on the 17th day of pregnancy.Moreover, significant changes on the newborns' somatometric characteristics were noticed. Pyramidalcell loss and glia fibrilliary acidic protein (GFAP) over-expression were detected in the CA4 region of thehippocampus of the 22-day old pups that were irradiated either during prenatal life or both pre- and postnatally. Changes in the integrity of the brain in the 22-day old pups could potentially be related to developmental behavioral changes during the fetal period.

Comment*: *Adequate/positive.

39. Othman et al., 2017.

Tunisia. Wistar rats. Developmental toxicity (neuro).

The present work investigated the effects of prenatal exposure to radiofrequency waves of conventional WiFi devices on postnatal development and behavior of rat offspring. Ten Wistar albino pregnant rats were randomly assigned to two groups (n =5). The experimental group was exposed to a 2.45 GHz WiFi signal for 2 h a day throughout gestation period. Control females were subjected to the same conditions as treated group without applying WiFi radiations. After delivery, the offspring was tested for physical and neurodevelopment during its 17 postnatal days (PND), then for anxiety (PND 28) and motricity (PND 40-43), as well as for cerebral oxidative stress response and cholinesterase activity in brain and serum (PND 28 and 43). Our main results showed that the in-utero WiFi exposure impaired offspring neurodevelopment during the first seventeen postnatal days without altering emotional and motor behavior at adult age. Besides, prenatal WiFi exposure induced cerebral oxidative stress imbalance (increase in malondialdehyde level (MDA) and hydrogen peroxide (H2O2) levels and decrease in catalase (CAT) and superoxide dismutase (SOD) activities) at 28 but not 43 days old, also the exposure affected acethylcolinesterase activity at both cerebral and seric levels. Thus, the current study revealed that maternal exposure to WiFi radiofrequencies led to various adverse neurological effects in the offspring by affecting neurodevelopment, cerebral stress equilibrium and cholinesterase activity.

Comment*: *Adequate/positive.

Table 21 – Reproductive/developmental effects in experimental animals: reproductive toxicity in male mice (450-6000 MHz) (a)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
1. Mugunthan et al., 2012, Swiss albino mice (M), 30 to 180 days	2G ultra-high frequency radiation (900 - 1900 MHz); the highest SAR value for this standard handset was 1.69W/Kg	48 minutes/day; 18 mice/group	Exposed animal weight was lower at first, second and fourth month ($p<0.05$). The mean testis weight of exposed mice was significantly reduced in all months except fourth month ($p<0.05$) and the mean testis volume was significantly reduced in the first three months ($p < 0.05$). Mean seminiferous tubule density per unit area was significantly lower in exposed testis ($p< 0.01$). The mean seminiferous tubule diameter was significantly reduced in exposed testis ($p < 0.01$) except the second month. The mean number of Sertoli cells and Leydig cells were significantly reduced in exposed mice ($p < 0.01$). Mean serum testosterone level of exposed mice were significantly lower ($p < 0.01$). The following microscopic changes were found in the testis of RFR exposed mice. 1. The interstitium appeared wide 2. Sertoli cells and spermatogonia were detached from the basal lamina. 3. Vacuolar degeneration and desquamation of seminiferous epithelium. Most of the peripheral tubules showed maturation arrest in the spermatogenesis. Seminiferous tubules scored between 8 and 9 using Johnson testicular biopsy score count.	**Adequate/positive**
2.Shahin et al., 2014, Swiss mice (M), 30 days	2.45-GHz; SAR: 0.018 W/Kg	2 h/day; 20 mice group, 40 in total	RFR induced a significant decrease in sperm count and sperm viability along with the decrease in seminiferous tubule diameter and degeneration of seminiferous tubules. Reduction in testicular 3ß HSD activity and plasma testosterone levels was also observed in the exposed group of mice. Increased expression of testicular i-NOS was observed in the MW-irradiated group of mice ($p < 0.01$)	**Adequate/positive**
3. Zhu et al., 2015, ICR mice (SPF) (M adult), [12 virgin females per each male were used for mating], 15 days	900 MHz; 1.6 mW/cm2, whole body average SAR 0.731 W/kg; acute 2 Gy irradiation from Co60 source, at a dose rate of 1 Gy per minute, as positive control	4 h/day; 10 male mices per exposure group. After exposures, each male mouse was kept in a separate cage with 3 virgin females for mating. After 7 days, each male was separated from the females and transferred to a fresh cage with a new batch of 3 virgin females for mating in the second, third and fourth weeks (in total: 12 females per each male).	Not any statistically significant effect on average body weight, testes weight in male mice exposed to RFR. Comparison between the females mated to RF- and sham-exposed mice: non-significant differences in percentages of pregnancies, live and dead implants. There were no significant differences in calculated total implants, live and dead implants per pregnant female ($p > 0.05$).	**Adequate/negative**

Table 21 – Reproductive/developmental effects in experimental animals: reproductive toxicity in male mice (450-6000 MHz) (continue b)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
4. Pandey et al., 2017, Swiss albino mice (M), 35 days	900 MHz (GSM), 0.0054 - 0.0516 W/kg	4 or 8 h/day, 7 days/week, 15/group	Increased damage index in germ cells, sperm head defects, decreased sperm count, arrest in pre-meiotic stage of spermatogenesis, loss of immature germ cells into the seminiferous tubule lumen, epithelium depletion and maturation arrest (p<0.05)	**Adequate/positive**
5.Pandey et al., 2018, Swiss albino mice (M), 35 days	900 MHz (GSM), (Melatonin 5 mg/kg bw/day), 0.0054 - 0.0516 W/kg	6 h/day, 7 days/week, 15/group	Decreased sperm count, sperm head abnormalities, extensive DNA damage in germ cells, arrest in pre-meiotic stages of spermatogenesis, excess free radical generation resulting in histological and morphological changes in testis and germ cells morphology (p<0.05)	**Adequate/positive** **(group treated without any supplement of melatonine)**
6. Shahin et al., 2018, Swiss albino mice (M), 15, 30, and 60 days	2.45 GHz MW, whole body SAR 0.0146 W/kg	2 h/day; 10 mice/group	Exposure to 2.45 GHz MW leads to altered testicular histoarchitecture, decreased seminiferous tubule diameter, sperm count, sperm viability, and serum testosterone level. Duration dependent increment in total ROS, NO, and MDA level was observed in the testes of exposed animals. Exposure to RFR leads to altered expression of p53, Bax, Bcl-xL, Bcl-2, pro-caspase-3, active-caspase-3, and PARP-1. The expression of cytochrome c was found to be increased significantly in duration dependent manner in the testes of all RFR exposed mice as compared with controls. ($p < 0.05$)	**Adequate/positive**

Table 22 – Reproductive/developmental effects in experimental animals: reproductive toxicity in female mice (450-6000 MHz) (a)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
7. Gul et al., 2009, Swiss mice (F), 21 days	NR (mobile phone in standby position for 11 h and 45 min, and in call position for 15 min), NR	12 h/day, 7 days/week, 30/group	Decreased number of follicles in mice ovaries, decreased ovarian volume (p<0.01)	**Adequate/equivocal**
8.Shahin et al., 2017, Swiss albino mice (F), 4 months (120 days)	1800 MHz, Nokia 100 (2G, GSM) dual-band mobile phones, in different operative modes (dialing, receiving, stand-by and switched-off)	3 h/day; 24 mice/group, 2 experiments of 12mice/group, 48 female mice in total each.	Exposure caused significant elevation in ROS, NO, lipid peroxidation, total carbonyl content and serum corticosterone coupled with significant decrease in antioxidant enzymes in hypothalamus, ovary and uterus of mice. Compared to controls, exposed mice exhibited reduced number of developing and mature follicles as well as corpus lutea. Significantly decreased serum levels of pituitary gonadotrophins (LH, FSH), sex steroids (E2 and P4) and expression of SF-1, StAR, P-450scc, 3ß-HSD, 17ß-HSD, cytochrome P-450 aromatase, ER-α and ER-α were observed in all the exposed groups of mice, compared to control ($p < 0.01$)	**Adequate/positive**

Table 23 – Reproductive/developmental effects in experimental animals: reproductive toxicity in male rats (450-6000 MHz) (a)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
9. Ozguner et al., 2015, Sprague-Dawley rats (M), 4 weeks	900 MHz, 2 watts peak power, average power density 1 ± 04 mW/cm^2	30 minutes/day, 5 days/week; 10 rats/group, 20 in total	The weight of testes, testicular biopsy score count and the percentage of interstitial tissue to the entire testicular tissue were not significantly different in RFF group compared to the controls. The diameter of the seminiferous tubules and the mean height of the germinal epithelium were significantly decreased in RFF group (p<0.05). There was a significant decrease in serum total testosterone level in RFR group (p<0.05). Therefore, there was an insignificant decrease in plasma LH and FSH levels in RFF group compared to the control group (p>0.05).	**Adequate/positive**
10.Lee et al., 2010, Sprague-Dawley rats, 12 weeks	848.5 MHz, 2.0 W/kg (CDMA)	90 min/day, 5 days/week, 20/group	Not any statistically significant alteration (NS) for testicular function and spermatogenesis (p>0.05)	**Adequate/ negative**
11. Imai et al., 2011, Sprague-Dawley rats, 5 weeks	1950 MHz (CDMA), 0.4 W/kg, 0.08 W/kg	5 h/day, 7 days/week, 24/group	Not any statistically significant alteration (NS) for testicular function (p>0.05).	**Adequate/negative**
12. Meo et al., 2011, Wistar rats, 12 weeks	900, 1800 GHz (GSM). Intensities: NR	30 minutes/day, 60 minutes/day, 7 days/week 16/group (control group: 8)	Hypospermatogenesis and maturation arrest in the testis (Significance: NR)	**Adequate/equivocal**
13. Al-Damegh, 2012, Wister albino rats (M), 14 consecutive days	900/1800/1900 MHz (GSM), 0.9 W/kg, vitamin C (40 mg/kg/day) or vitamin E (2.7 mg/kg/day)	15, 30, and 60 min/day; 30/group of exposed rats; 10/group of control rats	There was a significant increase in the diameter of the seminiferous tubules with a disorganized seminiferous tubule sperm cycle interruption in RFR-exposed group. The serum and testicular tissue conjugated diene, lipid hydroperoxide, and catalase activities increased 3-fold, whereas the total serum and testicular tissue glutathione and glutathione peroxidase levels decreased 3-5 fold in RFR-exposed animals (p<0.05)	**Adequate/positive**
14. Celik et al., 2012, Wistar-Kyoto rats (M), 3 months	NR, cell phone radiations, SAR 1.58 W/kg	24 h/day (30 M exposed, 15 M controls)	No significant differences in testis weights, seminiferous tubule diameters, and histopathological evaluations (p>0.05). Electron microscope analysis: membrana propria thickness and collagen fiber contents were increased, and the capillary veins extended in exposed animals. Common vacuolisation in the cytoplasm of the Sertoli cells, growth of electron-dense structures, and existence of large lipid droplets are the remarkable findings of this study.	**Inadequate**
15.Lee et al., 2012, Sprague-Dawley rats, 12 weeks	848.5 MHz (CDMA), 1950 MHz (WCDMA), 4.0 W/kg	45 min/day, 5 days/week, 20/group (cage control group: 5)	Not any statistically significant alteration (NS) for testicular function and spermatogenesis (p>0.05)	**Adequate/negative**
16.Ozlem-Nisbet et al., 2012, Albino Wistar rats (M), 90 days	1800 and 900 MHz, SAR: 3.00, 2.7, 2.2, 1.2 mW/kg for 900 MHz for 10, 20, 50, 70 days old rats; 0.053, 0.046, 0.011, 0.011 mW/kg for 1800 MHz for 10, 20, 50, 70 days old rats	2 h/day; 11 rats/group	The mean plasma total testosterone showed similarity among the two study groups and was significantly higher than the sham control rats. The percentage of epididymal sperm motility was significantly higher in the 1800 MHz group (P < 0.05). The morphologically normal spermatozoa rates were higher and the tail abnormality and total percentage abnormalities were lower in the 900 MHz group (P < 0.05). Histopathologic parameters in the 1800 MHz group were significantly higher (P < 0.05).	**Adequate/positive**

Table 23 – Reproductive/developmental effects in experimental animals: reproductive toxicity in male rats (450-6000 MHz) (continued b)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
17. Bin-Meferij El-kott et al., 2015, Sprague-Dawley rats, 8 weeks	900 MHz for GSM, NR intensity, 200 mg/kg aqueous extract of Moringa oleifera leaves	1 h/day (15 M exposed to RF+MO extract; 15 M exposed to RF; 15 M exposed to MO extract; 15 M controls)	Statistically significant decrease of epididymal sperm counts in the exposed group (P < 0.001). Significant decrease of sperm motility. Significant (P < 0.001) increase in the frequency percentage of dead spermatozoa in exposed animals. Overall, hypospermatogenesis and maturation arrest in spermatozoa were observed in the testes of exposed rats compared to their matched control.	**Adequate/ positive**
18. Liu et al., 2015, Sprague-Dawley rats (M), 50 days (from 10 weeks of age)	900 MHz, SAR 0.66 W/kg	2 h/day (24 M exposed; 24 M controls)	Significant increase of the percentage of apoptotic sperm cells by 91.42% in exposed animals; Significant increase of the ROS concentration by 46.21%; Significant decrease of the TAC by 28%; Significant decrease of the protein and mRNA expression of bcl-2 and increase of bax, cytochrome c, and capase-3 (p<0.05)	**Adequate/ positive**
19. Saygin et al., 2015, Sprague-Dawley rats (young M), 30 days	2.45 GHz, whole body SAR 3.21 W/kg, Gallic acid (GA) ,30 mg/kg/daily	3h/day; 12 rats/ group, 48 in total	Malondialdehyde and total oxidant status (TOS) levels increased (p<0.01) in RFR only group. TOS and oxidative stress index levels decreased in GA treated group significantly (p<0.05). Total antioxidant status activities decreased in RFR only group and increased in GA treatment group (p<0.05). Testosterone and vascular endothelial growth factor levels decreased in RFR only group, but this was not statistically significant. Testosterone and VEGF levels increased in RFR+GA group, compared with RFR only group (p<0.01) and also increased in GA group compared with the control and RFR only group (p<0.05). Prostaglandin E2 and calcitonin gene releated peptide staining increased in tubules of the testes in RFR only group (p<0.01) and decreased in tubules of the testes in RFR+GA group (p<0.01). In RFR only group, most of the tubules contained less spermatozoa, and the spermatozoon counts decreased in tubules of the testes. All these findings and the regenerative reaction, characterized by mitotic activity, increased in seminiferous tubules cells of the testes in RFR+GA group (p<0.01).	**Adequate/ positive**
20. Bilgici et al., 2018, Wistar rats (M), 30 days	2.45 GHz, whole body average SAR 0.0233 W/kg	1 h/day (11 M exposed, 11 M controls)	Serum IL-6 and CRP levels were significantly different in in exposed animals (p<0.05). Significant difference in necrosis and spermatogenesis in exposed animals (p<0.05)	**Adequate/ positive**
21. Guo et al., 2019, Sprague-Dawley rats, 1 month	220 MHz (pulsed modulated), 0.030 W/kg	1h/day, 7 days/week, 20/group	Decreased sperm count and survival rate of sperm (p<0.05), increased sperm abnormalities (NS), increased expression in testes of cleaved caspase 3 (p < 0.05), caspase 3 (p<0.01), and the BAX/BCL2 ratio (p<0.01), decreased serum T level (p<0.05)	**Adequate/ positive**

Table 23 – Reproductive/developmental effects in experimental animals: reproductive toxicity in male rats (450-6000 MHz) (continued c)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
22. Yu et al., Experiment 1, 2020, Sprague-Dawley rats (M adults), 50, 100 0r 150 days	smartphone emitting SRF-EMR, 2575–2635 MHz (TD-LTE), 1.05 W/kg.	6 h/day (smartphone was kept on active talk mode and received an external call for 1 min over 10min intervals for 10 cycles); 135 rats (9 groups of 15 rats each).	After 150 days of SRF-EMR exposure, sperm concentration, motility, viability, and normal morphology were comparatively lower in the SRF group than in the control group. Mating experiment in rats exposed to SRF-EMR for 150 days: the pup weight was comparatively lower in the SRF group than in the controls. Testicular morphologic injury: after 150 days, increased disorder in spermatogenesis, as well as significant germ cell loss, and decreased epithelium height were observed, together with lower epithelium height, lower Johnsen score, and higher Cosentino score. Oxidative stress in testes: After 100 days of exposure, only CAT and GSH content was found to be significantly lower in the SRF group. After 150 days, also the levels of MDA, 4-HNE and LPO were comparatively higher, while GSH, SOD and CAT content were lower in the SRF group. Apoptosis in the testes: after 100 days, only cleaved-caspase 8 was significantly upregulated in the SRF group. After 150 days, only the level of Bcl-2 was lower, while the levels of Bax, cleaved-caspase-3, Fas, FasL and cleaved-caspase-8 were significantly higher in the SRF group ($p < 0.01$)	**Adequate/ positive**
Experiment 2, 2020, Sprague-Dawley rats (M adults), 150 days	smartphone emitting SRF-EMR, 2575–2635 MHz (TD-LTE), 1.05 W/kg.	6 h/day (smartphone was kept on active talk mode and received an external call for 1 min over 10min intervals, for 10 cycles); 10 to 15 rats/ group, 91 rats in total (7 groups)	Transcriptional profile changes: 1663 differentially expressed genes including 1446 up-regulated and 217 down-regulated. Spock3 level was higher in rats exposed to SRF-EMR for 150 days. Inhibition of Spock3 overexpression improved sperm quality decline and alleviated testicular injury and BTB disorder in the exposed rats. SRF-EMR exposure suppressed MMP2 activity, while increasing the activity of the MMP14–Spock3 complexes and decreasing MMP14–MMP2 complexes; these results were reversed by Spock3 inhibition ($p < 0.01$).	**Adequate/ positive**

Table 24 – Reproductive/developmental effects in experimental animals: : developmental toxicity in hamster in male rats (450-6000 MHz) (a)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
23. Lerchl et al., 2008 a, b, c, Djungarian hamsters (M), 60 days	a: 383 MHz (TETRA), b: 900 and c: 1800 MHz (GSM), SAR 0.08 W/kg	24 h/day (120 M exposed; 120 M sham)	a: Pineal and serum melatonin levels as well as the weights of testes, brain, kidneys, and liver were not affected; Significant transient increase in body weight up to 4%; b: Pineal and serum melatonin levels as well as the weights of testes, brain, kidneys, and liver were not affected; Significant non transient increase in body weight up to 6%; c: Pineal and serum melatonin levels as well as the weights of testes, brain, kidneys, and liver were not affected; no effect on body weight;	**Adequate/negative**

Table 25 – Reproductive/developmental effects in experimental animals: developmental toxicity in mice (450-6000 MHz) (a)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
24. Finnie et al. a, b (2006), c (2009), BALB/c mice (F)	900 MHz, 4 W/kg	1h/day, 7 days/week, 10/group	Not any statistically significant alteration (NS) in: (a): blood-brain barrier permeability in the immature brain of fetal heads, (b): immediate early gene c-fos expression as a marker of neural stress (c): stress response by induction of heat shock proteins	**Adequate/negative**
25. Lee et al., 2009, ICR mice (F breeders; F and M fetuses), Day 1-17 of gestation	CDMA (849 MHz) and WCDMA (1.95 GHz), SAR 2.0 W/kg for 2 exposure periods (total 4 W/kg)	2 exposures 45-min/day, separated by a 15-min interval (14 F sham; 17 F CDMA-exposed; 20 F sham CDMA+WCDMA controls; 20 F CDMA+WCDMA exposed). Short daily exposure	Simultaneous experimental exposure to CDMA and WCDMA RF EMFs did not cause any observable adverse effects (mortality, growth retardation, changes in head size and other morphological abnormalities) on mouse fetuses.	**Adequate/ negative**
26. Fragopoulou et al., 2010, Balb/c Mus musculus (F breeders; M and F offspring), 5 days before pregnancy; days 1-21 of gestation	GSM 900MHz, SAR 0.6–0.94 W/kg	0 (5 F control breeders, 7 M and F offspring) ; 6 min/day (7 F exposed, 20 M and F offspring); 30 min/day (7 F exposed, 20 M and F offspring)	Statistically significant variations in the ossification of cranial bones and thoracic cage ribs, and displacement of Meckelian cartilage, in exposed animals (both groups). Littermates examined after teeth eruption displayed normal phenotypes.	**Adequate/ positive**

Table 25 – Reproductive/developmental effects in experimental animals: developmental toxicity in mice (450-6000 MHz) (continued b)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
27. Sambucci et al., 2011, C57BL/6 newborns mice (M and F), 5 consecutive weeks, starting the day after birth	Wi-Fi at 2.45 GHz, 0.08 or 4 W/kg SAR	2 h/day, 5 days/week; 16 newborns/group, each with 4 adoptive mothers assigned (48 pups in total)	No differences in body weight and development among the groups were found in mice of both sexes. For the immunological analyses, results on female and male newborn mice exposed during early post-natal life did not show any effects on all the investigated parameters ($p>0.05$), with one exception: a reduced IFN-γ production in spleen cells from microwaves (MW)-exposed (SAR 4 W/kg) male (not in female) mice compared with sham-exposed mice ($p<0.05$).	**Adequate/negative**
28. Zhang et al., 2015, CD1 mice (M and F), in utero exposure, throughout gestation (Days 3.5–18)	9.417 GHz, SAR: 2.0 W/kg	12 h/day; 4 pregnant female mice per group. Previously, to obtain pregnancies: 12 breeding cages were set up, each containing one CD1 female mouse and two CD1 male mice, all aged 6 weeks.	Mice did not differ in motor ability by open field test (OFT); however, frequency of entries into and duration of time spent in the center zone for the treated group were lower compared to controls. Exposed mice had increased anxiety-related behavioral elevated-plus maze test (EPM). Tail suspension test (TST) and forced swimming test (FST) showed that RFR exposure significantly decreased immobility time, demonstrating that the offspring of exposed mice had decreased depression-related behavior. By Morris water maze (MWM), treated mice showed a progressive decline in escape latency. On the fourth and fifth days of MWM, only male mice in Radiation group spent more time trying to find the platform, indicating reduced spatial learning ability ($p < 0.01$).	**Adequate/ positive**
29. Fatehi et al., 2018, NMRI mice (M and F offspring), 30 days	900 MHz, intensity NR	Cell phone in "Standby-mode": 1, 5 and 10 h/day (group 2,3,4); cell-phone on "Active-mode": 1 h/day (group 5); 20 mice/group	Irradiated mice (at any exposure duration) had significant increases in pregnancy duration. Furthermore, when the cellphone changed from off mode to active mode, a significant delay was seen in pregnancy duration. RFR exposure leads to a significant decrease in the number of newborn mice compared to the control group. The results also demonstrated that the increase of the exposure time from 1 h per day (group 2) to 10 h per day (group 4) in the Standby mode caused a significant difference in the number of the newborns ($p < 0.05$).	**Adequate/positive**

Table 25 – Reproductive/developmental effects in experimental animals: developmental toxicity in mice (450-6000 MHz) (continued c)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
30. Nelson et al., 1991, 1994, 1997, 1997; Sprague-Dawley rats (F); 10, 20, 30 minutes	10 MHz (2-methoxyethanol at 20, 40, 60, 75, 80, 100, 120, 125, 140 or 150 mg/kg), 0.8-6.6 W/Kg . Thermal effects (temp. 42C°)	10, 20, 30 minutes; 10-27/group	Synergism between RFR and 2ME administration in the induction of teratogenic effects: increased incidence of external malformation of fetuses ($p<0.05$)	**Inadequate**
31. Nelson et al., 2001, Sprague-Dawley rats (F), 60 minutes	10 MHz (Methanol 2, 3 g/kg); 0.8-6.6 W/Kg Thermal effects (temp. 42C°)	60 minutes; 10/group	Increased incidence of resorbed fetuses ($p<0.05$). No synergistic effects.	**Inadequate**
32. Ogawa et al., 2009, Sprague-Dawley rats (F), 10 days	1950 MHz CDMA, 0.4 W/kg	90 min/day, 7 days/week, 20/group	Not any statistically significant alteration (NS) for: landmarks of sexual maturity, viable litter size/live birth index, neonatal growth, neonatal survival indices, sex ratio in progeny, physiologic endpoints revealing unique toxicities of pregnancy and lactation ($p>0.05$).	**Adequate/negative**
33. Sommer et al., 2009, C57BL mice (M, F), Multi-generation study	1966 MHz (UMTS), 0.08, 0.4, 1.3 W/kg	24 h/day, 7 days/week, 128 M and 256 F over four generations (1M and 2F per cage)	Not any statistically significant alteration (NS) for: viable litter size/live birth index, neonatal growth, neonatal survival indices, prenatal mortality, assessment of sperm quality, weight and morphology of reproductive organs, mating and fertility indices and reproductive outcome, landmarks of sexual maturity, sexual behavior ($p<0.05$)	**Adequate/negative**
34. Ozorak et al., 2013, Wistar albino rat offspring (and F pregnant adult), from pregnancy to 6 weeks of age	Wi-Fi (2.45 GHz) and mobile phone (900 and 1800 MHz) RFR, whole body SAR 0.1 W/kg	1 h/day, 5 days/week; 24 rats/group, 96 in total	Results from the fourth week showed that the level of lipid peroxidation in the kidney and testis and the copper, zinc, reduced glutathione (GSH), glutathione peroxidase, and total antioxidant status (TAS) values in the kidney decreased in the RFR groups, while iron concentrations in the kidney as well as vitamin A and vitamin E concentrations in the testis increased in the RFR groups. Results for fifth-week samples showed that iron, vitamin A, and β-carotene concentrations in the kidney increased in the RFR groups, while the GSH and TAS levels decreased. The sixth week results showed that iron concentrations in the kidney and the extent of lipid peroxidation in the kidney and testis increased in the RFR groups, while copper, TAS, and GSH concentrations decreased ($p<0.05$). There were no statistically significant differences in kidney chromium, magnesium, and manganese concentrations among the four groups ($p>0.05$).	**Adequate/positive**
35. Poulletier de Gannes et al., 2013, Wistar rats (M, F), 5 weeks F, 6 weeks M	2450 MHz (Wi-Fi signal), 0.08, 4 W/kg	1 h/day, 6 days/week, 12/group	Not any statistically significant alteration (NS) for: number of live and dead fetuses per uterine horn, number and location in each uterine horn of early and late resorption sites, distribution of implantation sites on each uterine horn (Significance: NR).	**Adequate/negative**

Table 26 – Reproductive/developmental effects in experimental animals: developmental toxicity in rats (450-6000 MHz) (a)

Reference, Strain, Species (Sex), Exposure duration	Frequency, Intensity Any other co-exposure	Exposure time, Number of animals	Observed effects	Comments
36. Celik et al., 2016, Wistar albino rats (F breeders, M offspring), from gestation to 21 days of age	2.45 GHz EMR with 217 Hz pulses, SAR 0.1 W/kg	1 h/day for 5 days/week (8 F exposed breeders, 24 M exposed offspring; 8 F control breeders, 24 M control offspring)	Oxidative stress was observed in the brain and liver of developing rats, due to reduced GSH-Px, GSH and antioxidant vitamin concentrations. Moreover, the brains were more sensitive to oxidative injury compared to the liver in the development of newborns (p<0.05).	**Adequate/positive**
37. Shirai et al., 2016, Sprague–Dawley rats (F adults and their offspring), Mothers: from Gestational Day 7 to weaning; F1 offspring rats from birth up to 6 weeks of age	Eight different communication signal RFR (two of 800 MHz band, two of 2 GHz band, one of 2.4 GHz band, two of 2.5 GHz band and one of 5.2 GHz band), 0.4 W/kg, each frequency contributing for 0.05 W/kg	20 h/day; mothers: 12 rats/group; 46–48 F1 pups per group.	No abnormal findings were observed in the dams or F1 offspring exposed to the RFR or to the F2 offspring for any of the parameters evaluated (p>0.05).	**Adequate/negative**
38. Stasinopoulou et al., 2016, Wistar rats (F adults and their offspring), Pregnant rats throughout the pregnancy, and a group of dams and their offspring for further 22 days	1880–1900 MHz, whole body SAR ranging from 0.016 to 0.020 W/kg	12 h/day; 40 rats/group	RFR exposure caused heart rate increase in the embryos on the 17th day of pregnancy. Significant changes on the newborns' somatometric characteristics were noticed. Pyramidal cell loss and glia fibrilliary acidic protein over-expression were detected in the CA4 region of the hippocampus of the 22-day old pups that were irradiated either during prenatal life or both pre- and postnatally (p>0.05).	**Adequate/positive**
39. Othman et al., 2017, Albino Wistar rats, Gestation period (19–20 days)	2.45 GHz from Wi-Fi, Intensity NR (Wi-Fi: Exposed group was placed at distance of 25 cm from the Antennas. D-Link DWL-3200 AP with 802.11 g mode and WPA2 net-work protection)	2 h/day; 63 control offsprings and 37 treated offspring, 5 adult pregnant exposed rats/group	In-utero WiFi exposure impaired offspring neurodevelopment during the first 17 postnatal days without altering emotional and motor behavior at adult age. Besides, prenatal WiFi exposure induced cerebral oxidative stress imbalance (increase in malondialdehyde level and hydrogen peroxide levels and decrease in catalase and superoxide dismutase activities) at 28 but not 43 days old, also the exposure affected acethylcolinesterase activity at both cerebral and seric levels (p<0.05)	**Adequate/positive**

Table 27 (summary tables 21-26) (a, b) – Collected data for experimental studies on reproductive/developmental effects (FR1: 450-6000 MHz)

Total studies	39								
Adequate studies	37								
Type of study	Mouse					Rat			
	Observed effects	**Total adequate studies***	**Positive results**	**Equivocal results**	**Negative results**	**Total adequate studies***	**Positive results**	**Equivocal results**	**Negative results**
Reproductive-male fertility	Semen quality Histopathological alterations Fertility	9	6		3	14	10	1	3
Reproductive-female fertility	Fertility Gestation period Number of pups Weight of litters	2	1	1					
Development-Female-litters	Neuro/behavioural effects Foetal growth Litter haematochemical characteristics	10	4		6	4	3		1

*Some of the studies include more than one outcome. One study (Ref. 23) was performed on Djungarian hamster, and was considered adequate/negative.

SUMMARY OF THE RESULTS OF REPRODUCTIVE/DEVELOPMENTAL EFFECTS IN EXPERIMENTAL ANIMALS STUDIES (FR1: 450 to 6000 MHZ)(Table 27)

From the present review, 39 studies on reproductive/developmental effects in experimental animals were selected. 20 studies were performed on mice, 18 were performed on rats, 1 on hamsters. Various end points were studied in both mice and rats in adequate studies. Summaries of the results are presented in Table 27.

Out of the 37 adequate studies, the results were:

Reproduction, male fertility (Semen quality, Histopathological alterations, Fertility).

Twentythree adequate studies were performed to investigate possible non-thermal adverse effects on reproduction in male rats and mice. In mice, 6 of 6 adequate studies, showed a positive association between exposure and adverse effects (Ref: 1, 2, 4, 5, 6, 8) and 1 was negative (Ref: 3). In rats, out of 14 studies,10 were positive (Ref: 9, 13, 16, 17, 18, 19, 20, 21, 22, 23), 1 showed equivocal outcomes (Ref: 12), 3 were negative (Ref: 10, 11, 15).

The most convincing evidence regards the statistically significant decline of sperm quality, in both rats and mice. For this outcome there is *sufficient* evidence of association between RF-EMF exposure and the decline of sperm quality.

Reproduction, female fertility (Fertility, gestation period, number of pups, weight of litters).

Only 2 studies on mice were considered adequate for the present review. One of them (Ref. 8) showed positive evidence for the association of adverse effects with RF-EMF exposure, one was equivocal (Ref: 7). Female fertility was not enough investigated, so, although statistically significant effects were found, evidence is *limited* to allow for any conclusive evaluation.

Development - Dams and litters (litter hematochemical characteristics, neuro/behavioural effects, foetal growth, etc)

Fourteen adequate studies were analysed for developmental outcomes. Out of 14, 10 were performed on mice, 4 on rats. In mice, 4 showed a positive association with exposure (Ref: 26, 28, 29, 34) and 6 were negative (Ref: 24, 25, 27, 32, 33, 35). In rats, out of 4 adequate studies, 3 were positive (Ref: 36, 38, 39) and 1 negative.

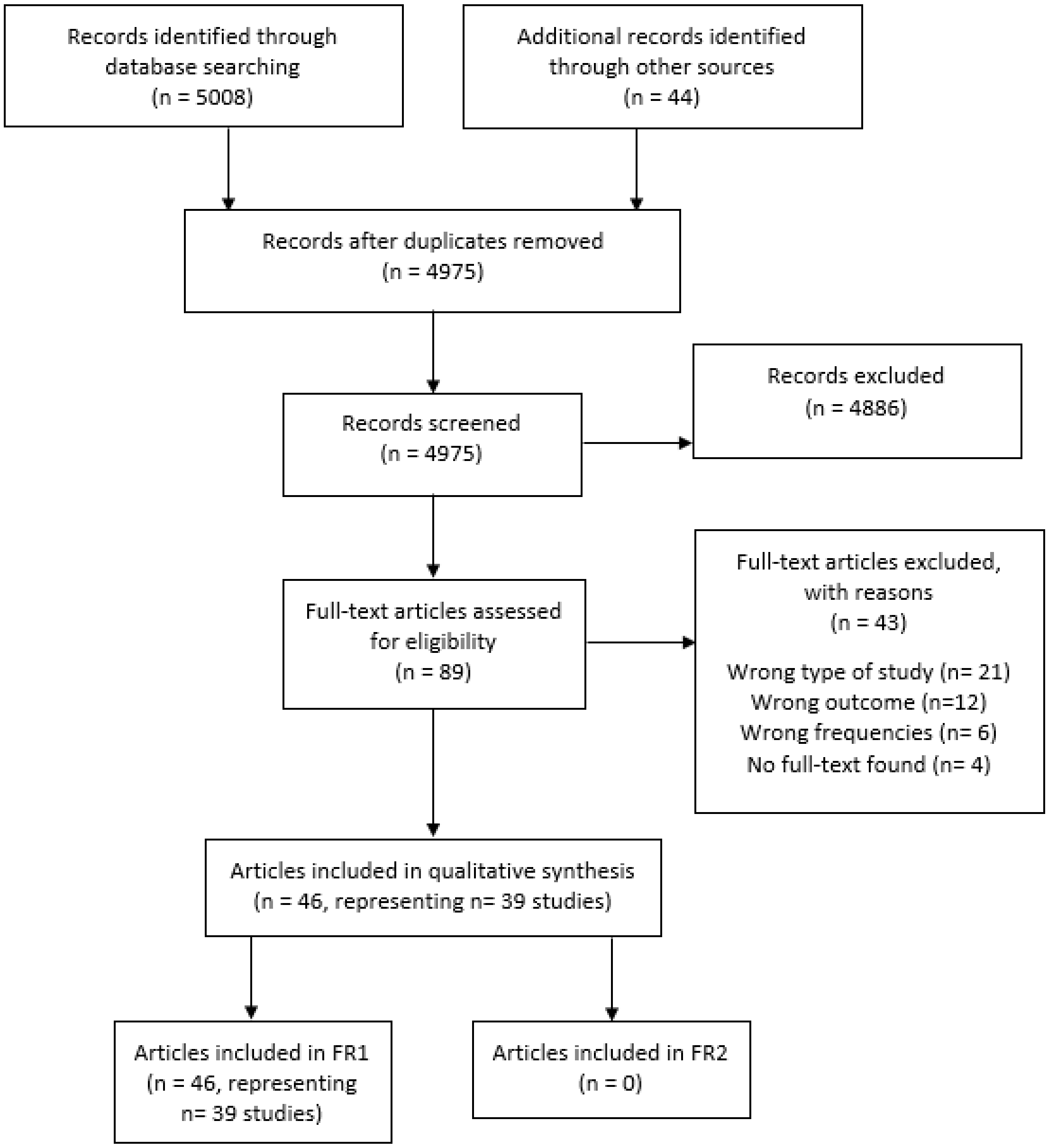
The results on this end point are mixed (conflicting) and the evidence of a possible association of developmental adverse effects with the exposure to RF-EMF is *limited.*

4.2.4 Reproductive/developmental effects in experimental animals: Studies evaluating health effects due to RF at a higher frequency range (FR2: 24 to 100 GHz, MMW) .

The articles identified through database searching and other sources were 5052. After removing duplicates (77) and excluding non-pertinent articles (4886) based on title and abstracts, 89 articles remained. Based on full-text screening, 43 papers were further excluded, so that the published articles with frequencies appropriate for inclusion in this qualitative synthesis were 46, corresponding to 39 studies. In three cases, more than one article was published reporting information on the same study for different reproductive/developmental end points (Fig. 16).

At this stage, a selection based on frequency range was also performed: out of 46 papers/39 studies, all reported exposures to the FR1 range, and none to FR2.

Figure 16 – Flow diagram. Reproductive/developmental effects in experimental animals (FR2)



5. Discussion

In its latest publication ICNIRP states that: "(…) reported adverse effects of RF-EMFs *on health need to be independently verified, be of sufficient scientific quality and consistent with current scientific understanding, in order to be taken as "evidence" and used for setting exposure restrictions. Within the guidelines, "evidence" will be used within this context, and "substantiated effect" used to describe reported effects that satisfy this definition of evidence. The reliance on such evidence in determining adverse health effects is to ensure that the exposure restrictions are based on genuine effects, rather than unsupported claims* (…)" (ICNIRP, 2020a).

Both in humans and in animal models, effects that ICNIRP defines as "*unsupported claims*" have been observed; and, some of them represent "*substantiated effects*", i.e. objective and relevant observations from epidemiological and experimental studies, including those on cancer and adverse effects on reproduction and development.

Epidemiological studies, when conducted with adequate information on the exposure scenarios and correct methodology, can provide strong evidence of "substantiated effects" of an agent, factor or situation. However, epidemiological studies can often have several limitations in small sample size, low statistical power, and confounding factors. These limitations include: i) Small exposed or follow up populations which may be insufficient to provide adequate statistical power; ii) The nature, amount and timing of exposures to the hazardous agent may lead to exposure misclassifications and false negative results; iii) Clear results due to confounding factors may be difficult to derive; iv) Methodological factors, such as recall bias, or publication bias, may also prevent clear results; v) The inherent delay in establishing robust epidemiological results due to the long period of tumour latency in humans (ie from first exposure to tumour indentification) on average can be 10-40 years; iv) Wide spread and diffuse exposure to other hazardous agents which may have synergistic or protective effects in combination with the agent being studied; vii) Widespread exposures to EMF creates difficulties in finding a large enough unexposed control group: which then may require the use of lowest exposure groups for comparison as the controls, which can be less robust.

The main direction of bias from many of these methodological and other limitations of human studies tends to produce "false negatives", i.e. results that exonerate the agent from being harmful but which later turn out to be wrong (Grandjean, 2013).

While sufficient evidence of carcinogenicity from RF-EMF was observed in studies on experimental animals, the following reasons suggest that the findings are important/relevant for risk assessment in humans. Animal studies (bioassays) have few limitations, and when adequately conducted to the high standards recommended (OECD, 2018b) can therefore, by comparison to human studies, provide relatively rapid and robust evidence of the association of exposure with the specific outcome.

Since the period of latency is proportional to the average lifespan of an organism, latency is proportionally shorter in the rodents that are commonly used in the laboratories. A latency time of one year in rats is equivalent to slightly more than 30 years of latency in humans, so animal bioassays, even over the rats full life time of approximately 2.5 years, allow cancer identification within a relatively short time compared to human studies.

Animal bioassays can therefore provide important information on the human risk of cancer from exposure to different agents. These data can enhance our confidence in the evidence on human cancer risks from epidemiological data.

Many human carcinogens have first been reliably identified in adequately tested laboratory animals, often many years before the human evidence was established (Huff, 1999; Huff, 2013; Maronpot et al., 2004).

There can also be consistent evidence between well conducted (OECD, 2016) animal and human studies on reproductive and developmental adverse effects.

The importance of experimental bioassays for safeguarding human health also emerges from risk assessments for chemicals as based on well conducted animal studies. Thus, animal studies are used to find the Lowest-Observed-Adverse-Effect Level (LOAEL i.e the lowest concentration of the chemical agent; or sometimes the No-Observed-Adverse-Effect Level- NOAEL) causing adverse alteration of morphology, functional capacity, growth, development, or life span of the target organism distinguishable from unexposed animals/organisms of the same species and strain under the same exposure conditions (Gaylor, 1999).

With RF-EMF, the epidemiological study results have so far only provided "*limited evidence*" of an association with cancer, largely because of the above limitations of epidemiological studies, and the absence of sufficient independent funding of such research.

In studies on laboratory animals, however, where confounding factors and other limitations are minimal, the evidence for RF-EMF having a carcinogenic effect , particularly on peripheral and central nervous system cells, is more robust than in 2011, following publications by the US- NTP and the Ramazzini Institute in 2018/19, and now attains "*sufficiency*" of animal evidence as per IARC evidence evaluation (IARC, 2019).

5.1 Cancer and lower telecommunication frequencies (FR1: 450 to 6000 MHz)

In 2011, in view of the limited evidence in humans and in experimental animals, the Working Group of IARC classified RF-EMF as "possibly carcinogenic to humans" (Group 2B). This evaluation was supported by a large majority of Working Group members. The overall evaluation was: *Radiofrequency electromagnetic fields are possibly carcinogenic to humans* (Group 2B).

Almost 10 years later many new studies have been published and an update is necessary. An Advisory Group of 29 scientists from 18 countries met at the International Agency for Research on Cancer (IARC) in March 2019 to recommend priorities for the IARC Monographs programme during 2020–2024, and among them there are RF-EMF (IARC, 2019).

5.1.1 RF-EMF (FR 1: 450 to 6000 MHz) and cancer in humans

Our review of the literature up to 2020 has found that several new epidemiological studies have been published on the association between RF-EMF and cancer since the publication of IARC Monograph 102 (IARC, 2013), yet the evidence remains mixed (conflicting results). In the Million Women Study cohort, there was no evidence of increased risk of glioma or meningioma. There was an increased risk of vestibular Schwannoma (neurinoma of the acoustic nerve) with long-term use and a significant dose–response relationship (Benson et al., 2013).

Updated follow-up in the Danish nationwide subscribers study did not find increased risks of glioma, meningioma, or vestibular schwannoma, even among those with subscriptions of 10 years or longer (Frei et al., 2011; Schüz et al., 2011).

New reports from case–control studies that assessed long-term use also found mixed results; for example, increased risks of glioma and acoustic neuroma were reported by Hardell and Carlberg, (2015) and Hardell et al., (2013 a, b), but no evidence of increased risks for these tumours was reported by Yoon et al., (2015) and Pettersson et al., (2014).

Several large-scale studies are still in progress and should yield results within the next few years. Mobi-Kids is a multicentre case–control study of brain tumours in those aged 10–24 years. Cohort Study of Mobile Phone Use and Health (COSMOS) is a new European cohort of adult cell phone users. There will also be updated results from the Million Women Study (IARC, 2019).

Some authors state that the elevated risk of brain cancer and neurinoma evidenced by various epidemiological studies do not mirror the observed incidence time trends, which are considered informative on this specific topic. This is not what we found in the recent available literature.

Concerning malignant tumours of the central nervous system (CNS), in 2019 the Global Burden of Diseases, Injuries, and Risk Factors (GBD) Study 2016 (GBD 2016, published on Lancet Neurol, 2019) reports a 4.63 per 100 000 person-years global incidence of malignant CNS tumours, which represents a 17.3% increase from 1990 to 2016. The top three countries with the highest number of incident cases were China, the USA, and India.

An increase in the incidence of glioblastoma multiforme in the frontal and temporal lobes and cerebellum was also reported in USA (Little et al., 2012; Zada et al., 2012).

A register based study in Sweden (Hardell and Carlberg, 2017) showed increasing rates of tumours of unknown type in the brain with higher rate during 2007–2015, in both sexes (Fig. 17 and 18).

Figure 17 – The Swedish National Inpatients Registry (source: Hardell and Carlberg, 2017): men

Joinpoint regression analysis of number of patients per 100,000 inhabitants according to the Swedish National Inpatient Register for men, all ages during 1998–2015 diagnosed with D43 = tumour of unknown type in the brain or CNS (http://www.socialstyrelsen.se/statistik/statistikdatabas/diagnoserislutenvard).

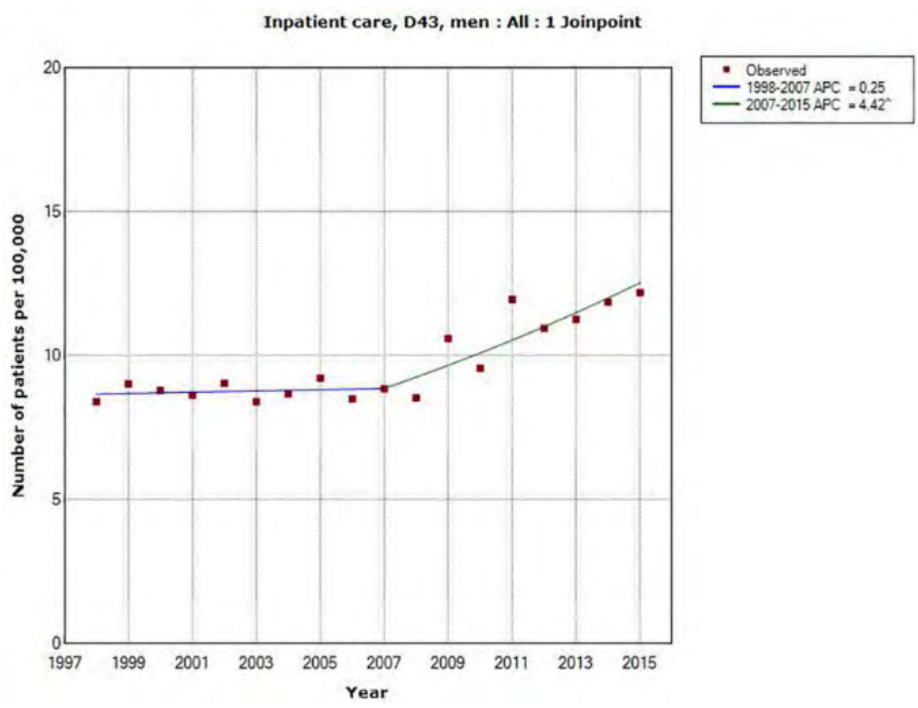
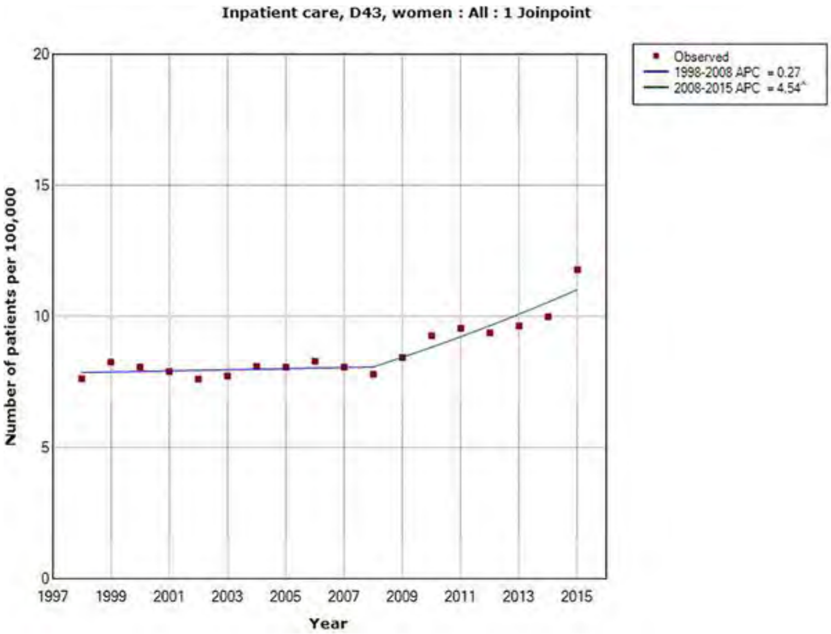


Figure 18 – The Swedish Nnl. Inpatients Registry (source: Hardell and Carlberg, 2017): women

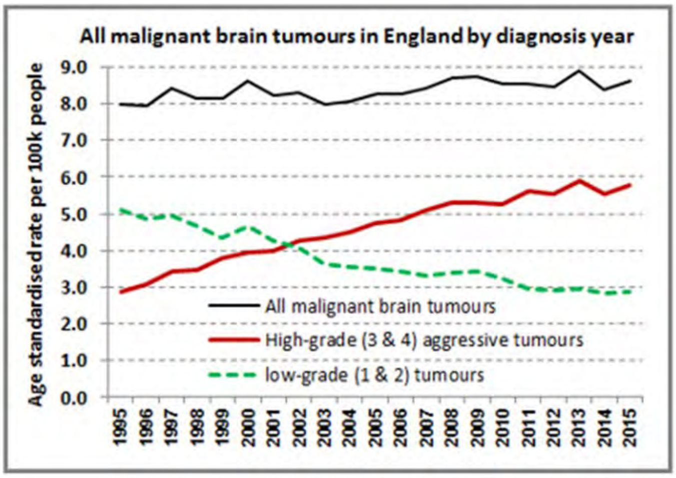
Joinpoint regression analysis of number of patients per 100,000 inhabitants according to the Swedish National Inpatient Register for women, all ages during 1998–2015 diagnosed with D43 = tumour of unknown type in the brain or CNS. (http://www.socialstyrelsen.se/statistik/statistikdatabas/diagnoserislutenvard).



Furthermore, ANSES (2019), in the volume "Estimations nationales de l'incidence et de la mortalité par cancer en France métropolitaine entre 1990 et 2018" reports the trend of the incidence (new cases by year) of glioblastomas (malignant tumours of the brain), histologically confirmed. Between 1990 and 2018 the number of new cases by year, both in men and women, increased: this is essentially attributable to the (environmental, occupational) increase in risks related to this type of cancer (ANSES, 2019)

In a UK study of national incidence data on malignant brain tumours, there was a rise in the rates of the more aggressive type identified in the epidemiological case control studies (Fig. 19). The authors looked at the incidence of brain tumours in three "major cancer registries" over a 15-year period (1992-2006). The study showed "decreased rates of primary brain tumours in all sites with the notable exception of increased incidence of glioblastoma multiforme (GBM) in the frontal lobes, temporal lobes and cerebellum. The increase in GBMs in the temporal lobe (the region of the brain closest to the ear and potentially to a phone) was seen in all three registries, ranging from approximately 1.3% to 2.3% per year, a finding that is statistically significant (Philips et al., 2018).

Figure 19 – Trends in the incidence of of all malignant brain tumours in England
(Philips et al., 2018)



http://www.saferemr.com/2018/03/brain-tumor-incidence-trends.html

In conclusion, referred to our research on FR1, positive *limited* associations have been observed in the literature between exposure to RF-EMF from wireless phones and glioma, and acoustic neuroma in humans.

5.1.2 RF-EMF (FR1: 450 to 6000 MHz) and cancer in experimental animals

New data in experimental animals for exposure to RF-EMF (FR1) have been published since the previous IARC Monographs evaluation in 2011 (IARC, 2013).

The large study by the United States National Toxicology Program (NTP) found an increased risk of malignant schwannomas of the heart in male rats with high exposure to radiofrequency radiation at frequencies used by cell phones, as well as possible increased risks of certain types of tumour in the brain and adrenal glands, and equivocal increased risks in mice or female rats (NTP, 2018a, b).

The Ramazzini Institute (RI) study also found a statistically significant increase in schwannomas of the heart in highly exposed (50 V/m) male rats and an increase in gliomas in female rats (Falcioni et al., 2018). In the Lee et al. study (2011) on Eμ-piml transgenic mice, prone to getting lymphomas, any increase of tumour incidence was observed. Lerchl et al. (2015), in a promotion study found that tumours of the lung and liver in exposed animals were significantly higher than in sham-exposed controls. In addition, lymphomas were also found to be significantly elevated by exposure, suggesting a promotion effect of RF-EMF.

The $30 million NTP study includes both mice and rats. It took more than 10 years to complete and is one of the most comprehensive assessments to date of health effects in animals exposed to RF-EMF, mice and rats. The FDA called for this research in 1999.

In this study, in the far GSM-exposed mice, the NTP found skin tumours and lung tumours in males, and malignant lymphomas in females. Far CDMA-exposed mice showed an increase of liver hepatoblastomas in males and malignant lymphomas in females. The results were labelled as equivocal (a marginal increase of neoplasms that may be test agent related even if the increased incidence of the tumours were statistically significant).

The long term study on rats (NTP, 2018a) found that exposure to high levels of RF-EMF, like that used in 2G and 3G cell phones, was associated with:

- Clear evidence of tumours in the hearts of male rats (malignant schwannomas).

- Some evidence of tumours in the brains of male rats (malignant gliomas).

- Some evidence of tumours in the adrenal glands of male rats (pheochromocytomas).

An expert peer-review panel concluded that the NTP studies were well designed, and that the results demonstrated that both GSM- and CDMA-modulated RFR were carcinogenic to the heart (schwannomas) and brain (gliomas) of male rats (Final evaluation: *Clear evidence of carcinogenicity*) (NTP, 2018c).

The RI in Italy performed a life-span carcinogenicity study on Sprague-Dawley rats to evaluate the carcinogenic effects of RF-EMF in the far field situation, reproducing the environmental exposure to RF-EMF generated by 1.8 GHz GSM antennae at radio-base stations for mobile phones. This is the largest long-term study ever performed in rats on the health effects of RF-EMF, including 2,448 animals. The authors reported the final results regarding brain and heart tumours, confirming and strengthening the same observation as NTP on rats: a statistically significant increase in Schwannomas of the heart in males and an increase in glial malignant tumour in females.

The recent NTP and RI RF-EMF studies presented similar findings in heart schwannomas and brain gliomas, strengthening the reciprocal results. Both NTP and RI studies were well performed, no bias affecting the results. Blinding was applied in both NTP and RI experiments, following their respective Standard Operating Procedures (SOPs) or specifications. It is quite common to have a different response in carcinogenesis for mice and rats, and gender differences in the response to carcinogens are common in both experimental animals and humans. Schwannomas are tumours arising from the Schwann cells, which are peripheral glial cells that cover and protect the surface of all nerves diffused throughout the body; so vestibular (acoustic nerve) and heart schwannomas have the same tissue of origin. In rats, increases in malignant heart schwannomas, malignant glial tumours of the brain and Schwann cell hyperplasia (a pre-malignant lesion) are rare. However, these lesions were observed in exposed animals in two independent laboratories, in a wide range of RF-EMF exposures studied. As a consequence, the findings of the two laboratories could not be interpreted as occurring "by chance". The NTP and the RI studies show that the assumption that RF radiation is incapable of causing adverse health effects other than by tissue heating is not scientifically based.

It's noteworthy that both NTP and the RI in the last 40 years strongly contributed with their results to the risk assessment of various chemical and physical agents. Their results were often predictive for human health. The NTP is the world's largest toxicology program; as far as number of agents studied, the RI is second only to NTP. The NTP and RI two-year carcinogenicity studies and their publications are also considered as the "gold standard" of cancer studies due to their high quality, their utility in evaluating human health hazards, and the rigour, transparency, and independency they bring to the evaluation of the data.

In conclusion, for FR1 exposed experimental animals, positive associations, with *sufficient* evidence, have been observed between exposure to RF-EMF and glioma and neuromas (synonymous with shwannoma).

5.2 Cancer and higher telecommunication frequencies (FR2: 24 to 100 GHz)

5.2.1 RF-EMF (FR2: 24 to 100 GHz) and cancer in humans

Very few studies were performed on frequencies between 24 to 100 GHz (FR2). The largest part of them regarded occupational exposure in workers involved in radar telecommunication. The exposure was self-reported or related to job title, and based on the distance from the source of RF emissions. In conclusion, while there are weak suggestions of a possible increase in risk of brain cancers and of lymphomas and leukaemias in workers occupationally exposed, exposure misclassification and insufficient attention to possible confounders limit the interpretation of the findings. In IARC Monograph 102 the conclusion was:

Tumours of the brain: *"exposure misclassification and insufficient attention to possible confounding limit the interpretation of findings. Thus, there is no clear indication of an association of occupational exposure to RF radiation with risk of cancer of the brain"* (IARC, 2013).

"Leukaemia/Lymphoma: *In summary, while there were weak suggestions of a possible increase in risk of leukaemia or lymphoma associated with occupational exposure to RF radiation, the limited exposure assessment and possible confounding make these results difficult to interpret"* (IARC, 2013).

Other kinds of tumour emerged as potentially associated with exposure to high frequencies (uveal melanoma, cancer of the testis, breast, lung, and skin), but many of the studies showed methodological limitations and the results were inconsistent (IARC, 2013).

The present review confirms the IARC remarks, where the highest 5G frequency (FR2) is concerned, there are no adequate epidemiological studies upon which to assess the impact on health.

5.2.2 RF-EMF (FR2: 24 to 100 GHz) and cancer in experimental animals

Seventy six studies were examined for cancer in experimental animals. No available literature regarding the possible association between experimental carcinogenicity and RF radiation, at the range 24 to 100 GHz (FR2), was found.

5.3 Adverse effect on reproduction/development and lower telecommunication frequencies (FR1: 450 to 6000 MHz)

5.3.1 RF-EMF (450 to 6000 MHz) and adverse effects on reproduction /development in humans.

About 2800 studies in this review conformed to pre-set inclusion criterion. Additional records identified through reviewed articles revealed some further eligible articles. However, only a total of 40 articles were used for data extraction, and 26 epidemiological studies were reviewed as being adequate in methodology. The result of the review are presented in Table 18.

- **Man fertility**

In recent years, we have observed a general increasing percentage of male infertility. It has been attributed to an array of environmental, health and lifestyle factors.

Sperm count, motility, DNA integrity, sperm viability and morphology were the most affected parameters when men are exposed to RF-EMF.

FR1 (450 to 6000 MHz): There is sufficient evidence of the association between RF-EMF exposure and adverse effect on fertility in man.

- **Pregnant women exposure**

Miscarriage and pre-term birth among women heavily using mobile-phones during pregnancy was described as possibly associated to the exposure of the embryo/foetus during gestation; the studies are too limited in number and inadequate for exposure assessment in order to reach definitive conclusions. An association can neither be excluded nor confirmed.

FR1 (450 to 6000 MHz): There is limited evidence of the association between RF-EMF exposure and adverse effect on fertility woman.

- **Developmental effects in offspring**

In offspring, behavioural difficulties and motor/cognitive/language delay were examined by epidemiological cross-sectional and cohort studies; the results are mixed (conflicting) and not conclusive. An association can neither be excluded nor confirmed.

FR1 (450 to 6000 MHz): There is limited evidence of the association between RF-EMF exposure and adverse effect on offspring health.

5.3.2 RF-EMF (450 to 6000 MHz) and adverse effects on reproduction /development in experimental animals.

An important aspect of safety assessment of chemical and physical agents is determining their potential reproductive and developmental toxicity. A number of guidelines have outlined a series of separate reproductive and developmental toxicity studies from fertilisation through adulthood and in some cases to second generation.

The OECD Test Guideline 443 is designed to provide an evaluation of reproductive and developmental effects that may occur as a result of pre- and postnatal chemical exposure as well as an evaluation of systemic toxicity in pregnant and lactating females and young and adult offspring. This Test Guideline is designed to provide an evaluation of reproductive and developmental effects that may occur as a result of pre- and postnatal chemical exposure as well as an evaluation of systemic toxicity in pregnant and lactating females and young and adult offspring.

The Extended One-Generation Reproductive Toxicity Study (EOGRTS) is the most recent and comprehensive guideline in this series. EOGRTS determines toxicity during preconception, development of embryo/fetus and newborn, adolescence, and adults, with specific emphasis on the nervous, immunological, and endocrine systems, EOGRTS also assesses maternal and paternal toxicity.

The objective of the prenatal developmental toxicity study is to provide general information concerning the effects of prenatal exposure on the pregnant test animal and on the developing organism. More specifically, the developmental toxicity study aims to identify direct and indirect effects on embryonic and foetal development resulting from exposure to the agent; identify any maternal toxicity; establish the relationship between observed responses and dose in both dam and offspring; establish NOAELs (no observed adverse for maternal toxicity and pup development).

We selected and analysed animal studies considering their compliance with the guidelines mentioned, though our approach tended to be inclusive when the number of animals, exposure assessment and procedure were considered acceptable.

Table 27 summarises the results. Among the different adverse effects of FR1, the most evident was the impairment of sperm quality.

Structural and/or physiological analyses of the testes showed degenerative changes, reduced testosterone level, increased apoptotic cells, and increased production of reactive oxygen species (ROS).

For all other parameters results were limited and they do not allow conclusive evaluation.

➢ **Male fertility**

As regards RF-EMF exposure, sperm count, motility, DNA integrity, sperm viability and morphology were the most affected parameters when experimental animals are exposed to RF-EMF.

FR1 (450 to 6000 MHz): There is sufficient evidence of the association between RF-EMF exposure and adverse effect on fertility in male experimental animals.

➢ **Female fertility**

The studies are too limited in number in order to reach definitive conclusions. The two adequate studies examined, show adverse effects, but an association cannot be denied, nor confirmed.

FR1 (450 to 6000 MHz): There is limited evidence of the association between RF-EMF exposure and adverse effect on fertility in female experimental animals.

➢ **Developmental effects in offspring**

In offspring, gestation duration, foetal growth, litter characteristics, neurobehavioural effects were examined by experimental bioassays in rodents. Some studies were positive, but results are often conflicting for different studies and limitations were observed in exposure assessment. So, results were not conclusive. An association cannot be denied, nor confirmed.

FR1 (450 to 6000 MHz): There is limited evidence of the association between RF-EMF exposure and adverse effect on developmental parameters both in dams and offspring.

5.4 Adverse effect on reproduction/development and higher telecommunication frequencies (FR2: 24 to 100 GHz)

5.4.1 Adverse effect on reproduction/development in humans (FR2: 24 to 100 GHz)

The few available epidemiological studies we have analysed were performed on occupationally exposed men (Table 20). Adverse effects on sperm fertility were reported. However, the two available cross-sectional studies have the limit of self-reported exposure or assessment done by job title. An association cannot be denied, or confirmed. From our search, developmental adverse effects on these higher frequencies were not adequately studied in the human population.

FR2 (24 to 100 GHz): No adequate studies were performed on this band of higher frequencies.

5.4.2 Adverse effect on reproduction/development in experimental animal studies (FR2: 24 to 100 GHz)

In the few studies designed for the higher frequencies, only thermal adverse effects were adequately studied.

FR2 (24 to 100 GHz): No adequate studies were performed on this band of higher frequencies.

6. Conclusions

6.1 Telecommunication frequencies FR1 450 MHz – 6000 MHz

6.1.1 Cancer in humans

There is limited evidence in humans for the carcinogenicity of radiofrequency radiation. Starting from 2011, positive associations have again been observed between exposure to radiofrequency radiation from wireless phones and glioma and acoustic neuroma, but the evidence is not yet sufficiently strong to establish a direct relationship.

6.1.2 Cancer in experimental animals

There is sufficient evidence in experimental animals for the carcinogenicity of radiofrequency radiation.

6.1.3 Reproductive/developmental effects in humans

There is sufficient evidence of adverse effects on the fertility of men. There is *limited* evidence of adverse effects on fertility in women. There is *limited* evidence on developmental effects in offspring of mothers who were heavy users of mobile phones during pregnancy.

6.1.4 Reproductive/developmental effects in experimental animals

There is sufficient evidence of adverse effects on male rat and mouse fertility. There is *limited* evidence of adverse effects on female mouse fertility. There is *limited* evidence of adverse effects on the development in offspring of rats and mice exposed during embryo life.

6.2 Telecommunication frequencies FR2: 24 to 100 GHz

6.2.1 Cancer in humans

The few inadequate data available do not allow any evaluation.

6.2.2 Cancer in experimental animals

No available data.

6.2.3 Reproductive/developmental effects in humans

No available data.

6.2.4 Reproductive/developmental effects in experimental animals

No available data.

6.3 Overall evaluation

6.3.1 Cancer

FR1 (450 to 6000 MHz): As a synthesis of what we have managed to analyse in the available scientific literature, in both human and animal studies, we can say that RF-EMF at FR1 frequencies exposure probably cause cancer, and in particular gliomas and acoustic neuromas in humans.

FR2 (24 to 100 GHz): No adequate studies were performed on non thermal effects of the higher frequencies.

6.3.2 Reproductive developmental effects

FR1(450 to 6000 MHz): These frequencies *clearly* affect male fertility. These frequencies *possibly* affect female fertility. They *possibly* have adverse effects on the development of embryos, foetuses and newborns.

FR2 (24 to 100 GHz): *No adequate* studies were performed on non-thermal effects of the higher frequencies.

7. Policy options

The policy options resulting from the present report – applying to the 5G frequencies (700 MHz, 3600 MHz, 26 GHz) and bearing in mind that the 2G, 3G and 4G frequencies will continue to be used for many years – are reported below.

7.1 Opting for novel technology for mobile phones that enables RF exposures to be reduced

The source of RF emissions that seems at present to pose the greatest threat is the mobile phone. Though transmitting installations (radiobase masts) are perceived by some people as providing the greatest risk, actually the greatest burden of exposure in humans generally derives from their own mobile phones, and epidemiological studies have observed a statistically significant increase in brain tumours and Schwann cell tumours of the peripheral nerves, mainly among heavy cell-phone users.

We accordingly need to ensure that increasingly safer telephone devices are manufactured, emitting low energy and if possible only working when at a certain distance from the body. The cable earpiece solves much of the problem, but is inconvenient and hence puts users off; on the other hand, it is not always possible to use a speakerphone mode.

The option of lowering RF-EMF exposure as much as possible in connection with telephones still applies whatever the frequencies, from 1G to 5G. Countries such as the USA and Canada, which enforced stricter mobile phone SAR limits than Europe, were still able to build efficient 2G, 3G and 4G communications (Madjar, 2016). Since 5G aims to be more energy-efficient than the previous technologies, adopting stricter limits in the EU for mobile phone devices will be simultaneously a sustainable and a precautionary approach.

7.2 Revising the exposure limits for the public and the environment in order to reduce RF exposures from cell towers

Recently European policies (European Commission, 2019) have promoted the sustainability of a new economic and social development model which uses new technologies to constantly monitor the planet's state of health, including climate change, the energy transition, agro-ecology and the preservation of biodiversity. Using the lowest frequencies of 5G and adopting precautionary exposure limits such as those used in Italy, Switzerland, China and Russia, among others, and which are significantly lower than those recommended by ICNIRP, could help achieve these European sustainability objectives.

What epidemiological studies already showed in 2011 (IARC, 2013) has been confirmed by studies on laboratory animals, especially concerning the connection between exposure to RF-EMF and the carcinogenic effect in the nervous system. The safety level currently allowed in Europe is 61 V/m (ICNIRP, 2020a). The lowest dose at which those effects have been experimentally observed for far-field exposure is 50 V/m. In the same experimental study (Falcioni et al, 2018) any carcinogenic effect was observed at 5 V/m.

In light of this result, one policy option might be to revise residential and public exposure maxima throughout Europe. Levels could be reduced by at least 10 times, i.e. to around 6 V/m, which is an exposure level at which no cancer effects in experimental animals have been observed. 6 V/m seems also to be the precautionary limit where no adverse effects on fertility are concerned. It may sound impracticably low if we are to expand telecommunications by 5G, but it is not so.

In Italy, for example, the law sets a top limit of 20V/m, though wherever people are constantly exposed for over four hours (homes, workplaces, schools, centres of congregation, etc.) the critical value is set at 6 V/m. This limit is very close to the 5 V/m we mentioned before as being safe for experimental animals. NOAEL values ("*No Observed Adverse Effect Level*") in experimental studies are commonly used in risk assessments and research (Gaylor, 1999).

In many Italian towns, including Bologna, 5G has already been operating at a frequency of 3600 MHz. Monitoring data show that the mean exposure in the municipality of Bologna was 1.97 V/m for 2019 (peaking at 4.62 V/m in one specific instance). Statistics for 2020 are still being processed, but in no cases have the values prescribed by Italian law been exceeded. For the moment, then, it does seem possible to develop new installations whilst keeping within the legal limit.

Another example is Paris. The city has reached an agreement with France's four main mobile network operators aimed at introducing stricter network radiation norms. The RF-EMF exposure limit was lowered to 5 V/m from the previous 7 V/m for indoor spaces, representing a 30 percent reduction at the frequency reference of 900 MHz, setting a lower limit than the one adopted in Brussels (6 V/m) or Rome (6 V/m). The agreement, approved by the municipality of Paris in 2017, also includes plans for a new monitoring service to help measure EMF levels within buildings. Brussels is a third example of the adoption of a 6 V/m lower limit.

7.3 Adopting measures to incentivise the reduction of RF-EMF exposures

Much of the remarkable performance of new wireless 5G technology can also be achieved by using optic-fibre cables and by adopting engineering and technical measures to reduce exposures from 2-4G systems (Keiser, 2003; CommTech Talks, 2015; Zlatanov, 2017). This would minimise exposure, wherever connections are needed at fixed sites. For example, we could use optic fibre cables to connect schools, libraries, workplaces, houses, public buildings, all new buildings etc. Public gathering places could be 'no RF-EMF' areas (as we have for cigarette smoking) so as to avoid the passive exposure of people not using a mobile phone or long-range transmission technology, thus protecting many vulnerable elderly or immune-compromised people, children, and those who are electro-sensitive.

7.4 Promoting multidisciplinary scientific research to assess the long-term health effects of 5G and to find an adequate method of monitoring exposure to 5G

The literature contains no adequate studies by which to exclude the risk that tumours and adverse effects on reproduction and development may occur upon exposure to 5G MMW, or to exclude the possibility of some synergistic interactions between 5G and other frequencies that are already being used. This makes the introduction of 5G fraught with uncertainty concerning both health issues and forecasting/monitoring the actual exposure of the population: these gaps in knowledge are invoked to justify the call for a moratorium on 5G MMW, pending adequate research being completed.

In light of these uncertainties, one policy option is to promote multidisciplinary team research into various factors concerning exposure assessment and also into the biological effects of 5G MMW, both on humans and on the flora and fauna of the environment, non-human vertebrates, plants, fungi and invertebrates, at frequencies between 6 and 300 GHz. The results of these studies could form the basis for developing evidence-based policies regarding RF-EMF exposure of human and non-human organisms to 5G MMW frequencies. Further studies are needed to better and independently explore the health effects of RF-EMF in general and of MMW in particular.

REACH aims to improve the protection of human health and the environment through better and earlier identification of the intrinsic properties of chemical substances. EU REACH regulates the registration, evaluation, authorisation and restriction of chemicals. It also aims to enhance innovation and competitiveness of the EU chemicals industry. EU REACH is based on the principle, "*no data no market*", placing responsibility on industry to provide safety information on substances. Manufacturers and importers are required to gather information on the properties of their chemical substances, which will allow their safe handling, and to register the information in a central database at the European Chemicals Agency (ECHA) in Helsinki. One policy option can be to apply the same approach used for chemical agents to all types of technological innovation.

7.5 Promoting information campaigns on 5G

Unfortunately, there is a lack of information on the potential harms of RF-EMF. The information gap creates scope for deniers as well as alarmists, giving rise to social and political tension in many EU countries (OECD, 2017). Campaigns to inform the citizens should be therefore a priority.

Information campaigns should be carried out at all levels, beginning with schools. They should show the potential health risks, but also the opportunities for digital development, what infrastructural alternatives exist for 5G transmission, the safety measures (exposure limits) taken by the EU and Member States, and the correct use of the mobile phone. Only by sound and accurate information can we win back citizen trust and reach a shared agreement over a technological choice which, if properly managed, can bring great social and economic benefits.

8. References

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Recent decades have experienced an unparalleled development in wireless communication technologies (mobile telephony, Wi-Fi). The imminent introduction of 5G technology across the EU is expected to bring new opportunities for citizens and businesses, through faster internet browsing, streaming and downloading, as well as through better connectivity. However, 5G, along with 3G and 4G, with which it will operate in parallel for several years, may also pose threats to human health. This STOA report aim to take stock of our present understanding of health effects of 5G.

QA-09-21-134-EN-N

This is a publication of the Scientific Foresight Unit (STOA)
EPRS | European Parliamentary Research Service

ISBN 978-92-846-8030-6 | doi: 10.2861/657478 | QA-09-21-134-EN-N

ENVIRONMENTAL HEALTH TRUST

Environmental Health Trust et al. v The FCC

What evidence of people injured by wireless radiation was ignored by the FCC in their 2019 Order?

Note: This evidence referenced here is all contained in the Environmental Health Trust et al. v The FCC submitted evidence found in Volume 1, Volume 2, Volume 3, Volume , Volume 5, Volume 6, Volume 7, Volume 8, Volume 9, Volume 10, Volume 11, Volume 12, Volume 13, Volume 14, Volume 15, Volume 16, Volume 17, Volume 18, Volume 19, Volume 20, Volume 21, Volume 22, Volume 23, Volume 24: Volume 25, Volume 26, Volume 27

Answer: Evidence of over 180 people injured by wireless radiation was submitted to the FCC and the FCC ignored it.

The Court found that the FCC did not adequately review record evidence of people harmed by wireless radiation. More than 180 people submitted evidence to the FCC of illness from wireless radiation as detailed in our opening brief. Examples include Wood, Hertz, Sheehan, Burke, Seward, Finley and the numerous personal declarations in one of the EMF Safety Network Submissions. Medical experts also submitted testimony with case histories such as Dr. Jetler's testimony with case histories of children, Susan Foster's documentation of injuries to firefighters and the American Academy of Environmental Medicine Recommendations Regarding Electromagnetic and Radiofrequency Exposure. The FCC also ignored the scientific documentation on electromagnetic sensitivity submitted to the record such as Belyaev 2015.pdf, McCarty 2011, Isaac Jamieson's Presentation and the Electromagnetic Hypersensitivity Summary by Dr Erica Mallery-Blythe.

The Court found the FCC ignored the scientific evidence indicating harmful biological impacts. The record contained hundreds of science-based submissions documenting genetic damage, brain damage, headaches, sleep impacts, reproductive effects and more. These are referenced in our opening brief and all of these documents are downloadable in 27 Appendices.

The FCC was sent extensive research compilations by the BioInitiative, Dr. Moskowitz, Powerwatch, EHT, Environmental Working Group, Dr. Henry Lai, EMR Policy Institute and numerous other scientific experts. The BioInitiative Charts documenting effects at intensities from cell tower, Wi-Fi, wireless laptop and 'smart' meters were submitted in numerous filings.

Several U.S. government/military reports documenting biological effects from decades ago—when the U.S. had robust funded research—were also included such as EPA's 1984

Report on Biological Effects, a Navy 1969 Report Reviewing Soviet and Eastern European Research and a Navy 1971 Report on Biological Effects. A 2012 review on biological effects by a National Institute of Environmental Health Sciences scientist cautioned that studies showing harm at low levels should not be ignored until there was "sufficient proof that the effects of microwaves on the brain and central nervous system are not detrimental to the health and well-being of our people."
A 1965 Report by Ford Motor Company on the record details numerous effects on the central nervous system as well as changes to blood sugar and sleep "which by no means can be attributed to the effect of heat."

In addition, the full text of numerous individual scientific papers were placed on the record. For example, Belpomme 2018 documents the science on cognitive and neurobehavioral problems in children, microwave illness, impacts of combined exposures, oxidative stress and genetic and epigenetic mechanisms. Nittby 2009 documents blood-brain barrier impacts. Yakymenko 2015 finds more than 90% of studies show oxidative impacts. Pall 2015 reviews neuropsychiatric effects. Dr. Lai summarized research on neurological effects published from 2007 to 2017 and DNA breaks.

What scientific research on impacts to reproduction was ignored by the FCC?

The court specifically noted the FCC did not explain why it ignored the issue of impacts to reproduction. Numerous FCC submissions documented effects to sperm, testes and the ovaries. Submissions include a comprehensive research list on reproductive effects by the Bioinitiative for the European Union as part of Cindy Sage's submission, studies compiled for Canadian Parliament, research compilations by Pong, Dr. Dart, individual studies such as found in a compilation of research on Wi-Fi and review papers on reproductive impacts such as Yahyazadeh 2018, Atasoy 2012, Adams 2014 and Asghari 2016.. Altun 2018 co-authored by EHT's Dr. Davis reviews mechanistic pathways of the effects on fertilization, oogenesis and spermatogenesis and evaluates metabolomic effects on the male and female reproductive systems in recent human and animal studies.

Science showing harm from long term exposures to low levels such as cell tower radiation.

The FCC noted that the FCC ignored science on long term exposures which would include the research on people living near cell towers. Submissions include Shahbazi-Gahrouei 2013(headache, dizziness, depression, sleep disturbance, memory loss), Zothansiama 2017 (DNA changes in blood), Thamilselvan, Meo 2015 (diabetes) and numerous compilations of dozens of studies on cell tower radiation. The FCC was sent a study on how cell towers near schools is a human rights issue (Roda and Perry 2013), and Dr. Paul Dart's PPT presentation and scientific research compilation. Dr. Henry Lai and Blake Levitt submitted a written letter with research compilations of studies showing harmful effects from wireless levels far far lower than FCC limits as well as the full text of their publication on chronic exposure to cell towers and low intensity wireless radiation.

Numerous submissions document how FCC limits were not developed to protect from biological impacts nor effects from long term low level exposures. The paper "Origins of US Safety Limits for Microwave Radiation" details the post cold war research and development of limits to protect against over heating, but not biological effects. A 1993 EPA Letter from the EPA to the FCC on the record states that "it is clear" that the limit is based on short term exposures and not on research considering chronic long term exposures.

The FCC record also has the unfortunate history of how the EPA was defunded from researching the issue. Submissions include a 1984 letter by the U.S. Science Advisory Board that recommends that the EPA develop radiation protection guidance to protect the public. EHT's submission (page 173) shares the presentations the EPA made about they would develop safety limits to protect against biological effects. However in 1996, the EPA was fully defunded from the issue of non ionizing electromagnetic radiation and the US adopted limits by groups dominated by industry military and scientists with longstanding industry ties. Lloyd Morgan's "US Exposures Limits:A History of Their Creation" documents how these standards setting groups were aware of biological effects decades ago.

EHT submitted hundreds of pages of science to the FCC record and continues to submit evidence to 13-84 and 19-226 in anticipation of a new record review (See EHT submissions).
What expert recommendations were ignored by the FCC?
Numerous groups of scientists and medical experts directly wrote the FCC. The American Academy of Pediatrics called on the FCC to strengthen limits to protect children. Public health organizations such as Black Women for Wellness, Breast Cancer Fund, Center for Environmental Health, Center for Health, Environment & Justice, Consumer Federation of California, Environmental Working Group, the Empire State Consumers Project, Healthy Child Healthy World, Product Policy Institute, Science and Environmental Health Network and Teens Turning Green signed a letter urging the FCC to strengthen limits- especially for children.
The FCC record contained the hundreds of scientists and doctors who have signed onto the EMF Scientists Appeal and the European Union 5G Appeal. The FCC record contained the resolution of the California Medical Association, the recommendations of the Vienna Medical Association, the Porto Alegre 2009 resolution and the 1997 Boston Physicians petition calling to halt a new wireless network in Boston due to "voluminous medical studies". A list of governments and policy actions worldwide had medical/scientific appeals going back decades.
What evidence of harmful effects to wildlife and the environment from wireless radiation was ignored by the FCC?

When the FCC adopted safety guidelines in 1996, they were only designed for humans, not wildlife or trees and plants. When the FCC opened it's inquiry in 2013, it specifically asked for information on the adequacy of the limits to protect human health and the environment. In turn numerous studies finding harmful environmental effects were submitted to the FCC record, yet the FCC fully ignored all of them when they decided to affirm the 1996 limits in 2019. Examples of research sent to the FCC include Balmori 2015 (RF threat to wildlife), Haggerty 2010 (harms Aspen), Halgamuge 2016 (review on plants), and Waldmann-Selsam 2016 (field study on trees). Cucurachi 2012 reviewed 113 studies and found 65% showed ecological effects with high as well as at low dosages.

The Court ruling highlighted the 2014 letter by the Department of Interior which stated that, "There is a growing level of anecdotal evidence linking effects of non-thermal, non-ionizing electromagnetic radiation from communication towers on nesting and roosting wild birds and other wildlife…. "However, the electromagnetic radiation standards used by the Federal Communications Commission (FCC) continue to be based on thermal heating, a criterion now nearly 30 years out of date and inapplicable today. " and "third-party peer-reviewed studies need to be conducted in the U.S. to begin examining the effects from radiation on migratory birds and other trust species."

EHT submitted a compilation of research on impacts to insects and wildlife which found the induction of piping signal (a stress response), decline in colony strength and impacts to navigation. Thielens 2018 documents how bees and insects can intensely absorb the higher frequencies of 5G leading to behavior changes.

The record contained images of trees harmed by cell antennas such as "Trees in radiation field of 65 mobile phone base stations" and the review article "Impacts of radio-frequency electromagnetic field (RF-EMF) from cell phone towers and wireless devices on biosystem and ecosystem.

Reports on environmental effects were on the FCC record such as India's interministerial report on wildlife impacts, a compilation of impacts to birds, and Bees Birds and Mankind: Destroying Nature by 'Electrosmog by Ulrich Warnke.

The scientific documentation and testimony on impacts to birds and wildlife by former US Fish and Wildlife Service biologist Albert Manville was on the FCC record as well as Dr. Cindy Russell's Wireless Silent Spring published in the Santa Clara County Medical Association Bulletin.

A submission by Ed Friedman of a letter from the Global Union Against Radiation Deployment from Space stated the potential environmental and human health hazards from 5G necessitates a comprehensive NEPA review...specifically, a formal Environmental Impact Statement which should include a full review of environmental effects, as well as human health and safety.

EHT continues to strongly advocate for a full environmental review of 5G before continued deployment.

What evidence on children and wireless radiation did the FCC ignore?

The FCC ignored extensive medical recommendations and published research such as letters from the American Academy of Pediatrics (AAP) which recommended the FCC launch a review of the limits to ensure children were protected due to the mounting research showing children's unique vulnerability to wireless. The FCC ignored numerous research studies documenting serious impacts to the younger developing brain and the testimony of parents with injured children.

Here are some examples of submissions on the FCC record that the FCC ignored.

- The 2012 AAP Letter to the FCC asking the agency for a formal review because children's use "has skyrocketed" at"much younger ages" and "concerns have been raised that long-term RF exposure at this level affects the brain…" The letter states "Children, however, are not little adults and are disproportionately impacted by all environmental exposures, including cell phone radiation."
- The 2013 AAP Letter to the FCC record stating that RF regulations should; 1. account for children's unique vulnerability, 2. Reflect the way children use phones and wireless devices close to their body 3. Inform consumers with information about potential risks and RF exposure, 4. Reconsider the compliance test metric for exposure because it is "not an accurate predictor of actual exposure. The AAP also raised the importance of ensuring RF limits addressed impacts to pregnancy because "pregnant women may carry their phones for many hours per day in a pocket that keeps the phone close to their uterus."
- Dr. Suleyman Kaplan's FCC submission (Letter and Slides) documenting several of his published experimental studies showing prenatal and postnatal exposure can damage to the brain (Bas et al., 2009, Odaci, et al., 2008, Sonmez et al., 2010, Bas, et al., 2009) concluding that "Over the past few decades, several experimental studies have emerged which indicate electromagnetic fields could affect brain activity and neurons at the cellular level.
- List of published studies showing prenatal neurological impacts from Dr. Hugh Taylor, Chief of Obstetrics at Yale, a medical resource list from Dr. Shetraet-Klein and research list by Dr. Davis for the Pediatric Academic Societies Conference.
- Published research showing children have proportionately deeper penetration of wireless into specific brain regions associated with learning and memory such as the cerebellum and hippocampus (Morris et al., 2015, Ghandi 2015, Ferreira and de Salles 2015, Fernendez et al 2015, Cyprus Committee on Children Presentation, Fernandez et al. 2018, Mohammed 2017 in Dr. Moskowitz submission).
- Submissions documenting how the 1996 test systems did not account for children's exposures but were based on a 220-pound man's head and how the standards used to set FCC's limits did not have information on children (Ghandi 2012, EHT 2013).
- Research that shows that stem cells - which are more active in children- are more sensitive to microwave radiation (Belyaev 2010)
- Publications focused on impacts to the nervous system Lissak 2018, memory (Foerster 2018), behavioral problems (Divan 2008), links to autism (Herbert and Sage 2013), impacts to myelin sheath Redmayne and Johanssen 2014.
- Recommendations by scientists and doctors calling to reduce children's exposure (Council of Europe 1815 Resolution, Mobilewise Case for Action to Protect Children

Report, Russian government recommendations for children, Yale Doctor Report, Compilation of research on Wi-Fi, Recommendation by Dr. Joel Moskowtiz)

- Doctor's letters to schools calling on them to reduce Wi-Fi including Dr. Herbert, Dr. Carpenter, Dr. Havas, Dr. Powell, Dr. Blank and Dr. Sinatra, EHT's 2015 Letter to Secretary of Education, Medical Recommendations for Schools, and the Santa Clara Medical Association article on health risks from Wi-F in School.

FAQs on EHT et. al v FCC

EHT webpage on Environmental Health Trust et. al v the FCC
Court Documents

- Final Court Decision 8/13/2021
- Link to 11,000 Pages of Evidence- - 447 exhibits in 27 Volumes- Volume 1, Volume 2, Volume 3, Volume , Volume 5, Volume 6, Volume 7, Volume 8, Volume 9, Volume 10, Volume 11, Volume 12, Volume 13, Volume 14, Volume 15, Volume 16, Volume 17, Volume 18, Volume 19, Volume 20, Volume 21, Volume 22, Volume 23, Volume 24: Volume 25, Volume 26, Volume 27
- EHT Factsheet on EHT et al. v FCC
- November 30, 2021 Filing
- March 11, 2022 Filing

Amicus Briefs

- Amicus of NRDC: Natural Resources Defense Council
- Amicus of Attorney Joe Sandri including the declaration of Dr. Linda Birnbaum, former Director of the National Institute of Environmental Health Sciences
- Amicus of Catherine Kleiber
- Amicus of the Building Biology Institute

Important Video Resources

- Video of Oral Arguments
- Transcript of Oral Argument
- EHT Video Analysis Oral Arguments With Clips
- EHT Press Conference after Historic Court Ruling

Court Documents

- Final Court Decision 8/13/2021
- Official Mandate to the FCC 10/5/2021
- Full Opening Brief of Petitioners, 8/14/2020
- FCC Reply Brief 9/22/2020
- Petitioner's Reply to the FCC and Addendum 10/19/2020
- Post oral argument FCC Submission, EHT/petitioner's response
- Link to 11,000 Pages of Evidence- - 447 exhibits in 27 Volumes-
- EHT Factsheet on EHT et al. v FCC

2021 November 30, 2021 FCC Filing
Part 1: Scientific and Policy updates
Part 2: Letters

November 24, 2021

The Honorable Jessica Rosenworcel, Commissioner
Acting Chairwoman
Federal Communications Commission
445 12th Street, S.W.
Washington, DC 20554

Dear Chairwoman Rosenworcel,

We write to you as scientists and public health experts deeply committed to protecting public health and the environment. As authors of numerous publications and reports in the field we urge that the FCC ensure a robust review of the latest science and expert recommendations in the FCC's upcoming reexamination of its Inquiry on human exposure limits for wireless radiation. The major scientific developments of the last two years must be included in the FCC review- especially in the new 5G environment where wireless is ubiquitous.

We request the FCC reopen Docket #13-84 "Reassessment of FCC Radiofrequency Exposure Limits and Policies" and Docket #03-137 'Proposed Changes to the Commission Rules Regarding Human Exposure to Radiofrequency Electromagnetic Fields" in order to refresh the record before issuing a final response to the recent August 13, 2021 judgment by the U.S. Court of Appeals for the District of Columbia Circuit, in Environmental Health Trust et al. v. the FCC.

Furthermore, as the FCC does not have expertise in interpreting scientific studies, it relies on input from federal health agencies and knowledgeable expert organizations to evaluate the scientific evidence and the adequacy of FCC limits. However the relevant US health and safety agencies have not reviewed the research on impacts to flora and fauna; long-term exposures from cell towers; children's unique vulnerability; and health effects such as damage to the brain and reproduction. The court noted that the "silence" of federal agencies such as the National Cancer Institute, the Environmental Protection Agency, the Centers for Disease Control and Prevention, and the National Institute for Occupational Safety and Health does not mean these agencies agree with the FCC's 1996 limits. In fact, none of these agencies has systematically reviewed the totality of science in their respective area of expertise both to develop safety standards and to offer an analysis of the adequacy of FCC's 1996 wireless exposure limits.

Accordingly, we recommend that the FCC record be reopened with ample time to allow for new substantive comments. U.S. safety limits for cell phones and cell towers must rest on sound science to ensure the public and wildlife are protected.

Importantly, we also recommend a full environmental impact review to evaluate 5G and the rapid proliferation of 4G wireless antennas in the USA. A three part review published in Reviews in Environmental Health found the scientific evidence showing adverse effects is sufficient to trigger new regulatory action to protect wildlife, yet the US does not have regulations that were ever designed to protect flora and fauna (1). Instead, the FCC is fast tracking small cell deployment and opening new spectrum disregarding recent research which finds, for example, that the higher frequencies of 5G can result in higher absorption rates into the bodies of pollinators.

In addition, experts are warning that 5G will contribute to climate change and have documented the exponentially increasing energy demands of 5G networks, "smart" wireless devices, and other new communication technologies. As the FCC has projected hundreds of thousands of new wireless facilities, we recommend a full environmental assessment for the 5G rollout and 4G wireless network densification.

The scientific evidence has substantially increased over the last two years (2). In 2020 scientists of the National Institute of Environmental Health Sciences National Toxicology Program published their animal-study findings of "significant increases in DNA damage" in groups of mice and rats after just 14 to 19 weeks of exposure to cell phone radiation (3). A 2021 analysis published by the Environmental Working Group concluded FCC limits should be 200 to 400 times more protective than the whole-body exposure limit set by the FCC in 1996 (4). Unaware of the scientists calling for caution, school districts nationwide are deploying high-capacity Wi-Fi networks in school buildings, testing out 5G networks with students, and signing leases with companies to install cell towers on school property, relying on these outdated FCC limits. As the American Academy of Pediatrics and numerous other specialists have noted, children are uniquely vulnerable to wireless radiation (5).

Health risks should be assessed by experts with no conflicts of interest. The FCC should not rely on the International Commission on Non-Ionizing Radiation Protection (ICNIRP), a small 14 member privately constituted invite only Commission lacking in transparency whose self-appointed membership has conflicts of interest and industry ties (6). ICNIRP has rejected the NTP and Ramazzini Institute animal studies with unfounded criticisms (7). Further, ICNIRP has not shown any systematic review of the totality of the research such as impacts to the developing brain and damage to reproduction. It has never conducted a comprehensive evaluation of human health and environmental risks associated with RF radiation. Their exposure guidelines are based solely on protecting against heating effects, with no change of concept since 1998, two years after the FCC adopted human exposure guidelines in 1996.

Broadband internet provides the connectivity that enables Americans to do their jobs, to participate equally in school learning and health care, and to create a fairer playing field by eliminating the digital divide. The United States must bridge the digital divide with a "future-proof" broadband infrastructure with wired *rather than wireless* connections to and through homes, schools and businesses that is affordable, reliable, high-speed, and sustainable.

Wherever possible, we urge that the broadband system rely on wired connections, rather than wireless connections. Wired connections are safer, faster, more secure, more energy efficient, and more reliable. Wired connections are especially important for schools and other institutions where they will save money and reduce exposure to wireless radiation.

Our experts stand ready to provide more detailed information to you on this important issue, including elaborating on materials and assistance with evaluating the science and impacts on humans, climate, animals, and wilderness.

Sincerely,

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November 19, 2021

The Honorable Jessica Rosenworcel
Chairwoman
Federal Communications Commission
445 12th Street, SW
Washington, D.C. 20554

Dear Chairwoman Rosenworcel,

The Environmental Working Group, a nonprofit public health research and advocacy organization with offices in Washington, D.C, Minneapolis, and Sacramento, Calif., requests that the Federal Communications Commission reopen Docket #13-84, "Reassessment of FCC Radiofrequency Exposure Limits and Policies," and Docket #03-137, "Proposed Changes to the Commission Rules Regarding Human Exposure to Radiofrequency Electromagnetic Fields," to allow robust review and consideration of scientific evidence published in the past two years and in response to the court ruling in *Environmental Health Trust et al. v. the FCC*.

Since 2009, the Environmental Working Group has extensively researched the topic of the human and environmental health impacts of radiofrequency radiation emitted from wireless communication devices. EWG also closely follows regulatory approaches and recommendations on radiofrequency radiation made by authoritative health agencies around the world. The World Health Organization states on its website:

> *… during the 20th century, environmental exposure to man-made sources of EMF steadily increased due to electricity demand, ever-advancing wireless technologies and changes in work practices and social behaviour. Everyone is exposed to a complex mix of electric and magnetic fields at many different frequencies, at home and at work, and concern continues to grow over possible health effects from overexposure.*[1]

Extensive research literature points to the potential health risks of radiofrequency radiation, particularly for the developing child. Peer-reviewed studies show that the

[1] World Health Organization, web page not dated, "Supporting the development of national policies on electromagnetic fields". https://www.who.int/activities/supporting-the-development-of-national-policies-on-electromagnetic-fields Accessed Nov. 16, 2021.

bodies of children absorb more radiofrequency radiation, compared to adults, putting children at greater health risk as a result to such exposure.[2]

Scientists and public health advocates have raised concerns for decades about the adverse health effects of exposure to electromagnetic radiation. Recent research publications highlight the severity of these impacts, especially among vulnerable populations, and the need for more stringent health-based exposure standards. In 2011, the International Agency for Research on Cancer (IARC), an agency of the World Health Organization, classified radiofrequency electromagnetic fields as "possibly carcinogenic to humans."[3]

For today's generation of children, exposure to radiofrequency radiation from wireless communication devices starts from the fetal development period as a result of wireless devices in the pregnant person's everyday environment. Following birth, today's children will be exposed to radiofrequency radiation throughout their lives – an exposure scenario that is drastically different from the very limited consumer use and exposure to wireless radiation of the 1980s and 1990s, when the basis for current FCC standards was established.

This comment letter highlights two key considerations that point to the need for the FCC to reassess existing radiofrequency exposure limits and policies:

1. A 2021 peer-reviewed publication we authored that uses Environmental Protection Agency methodology to determine protective health-based exposure limits for radiofrequency radiation, based on the U.S. government's landmark 2018 laboratory study; and
2. Recent literature that documents a range of effects of non-ionizing electromagnetic radiation on different body systems that current FCC standards do not take into account.

1. Health-based limits developed with consideration for children's health

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[2] Fernández C, de Salles AA, Sears ME, Morris RD, Davis DL. Absorption of wireless radiation in the child versus adult brain and eye from cell phone conversation or virtual reality. Environ Res. 2018; 167:694-699. https://doi.org/10.1016/j.envres.2018.05.013; Gandhi OP, Morgan LL, de Salles AA, Han YY, Herberman RB, Davis DL. Exposure limits: the underestimation of absorbed cell phone radiation, especially in children. Electromagn Biol Med. 2012; 31(1):34-51. https://doi.org/10.3109/15368378.2011.622827

[3] International Agency for Research on Cancer. IARC classifies radiofrequency electromagnetic fields as possibly carcinogenic to humans. Press Release N: 208. 2011. https://www.iarc.who.int/wp-content/uploads/2018/07/pr208_E.pdf Accessed Nov. 16, 2021.

A peer-reviewed article published by our organization in 2021 (Uche & Naidenko, 2021)[4] documented how the current FCC exposure limit for radiofrequency radiation is not sufficient to protect the general population, especially children, against the adverse impacts associated with radiofrequency radiation exposure. The current limit, last revised a quarter-century ago – well before wireless devices became ubiquitous – needs to be updated with the latest science to be fully health protective for all users of wireless communication technologies.

Our study, published in the journal *Environmental Health*, recommends strict, lower health-based exposure standards for both children and adults for radiofrequency radiation emitted from wireless devices. This recommendation draws on data from a landmark 2018 study from the National Toxicology Program, one of the largest long-term laboratory studies on the health effects of radiofrequency radiation exposure.[5]

EWG's study used an approach similar to the methodology that the U.S. EPA developed to assess human health risks arising from toxic chemical exposures. EWG study recommends a whole-body specific absorption rate (SAR) limit of 0.2 to 0.4 mW/kg for children, which is 200 to 400 times lower than the current federal whole-body exposure limit. For adults, EWG recommends a whole-body specific absorption rate limit of 2 to 4 mW/kg, which is 20 to 40 times lower than the federal limit (Uche & Naidenko, 2021).[4]

EWG's analysis and recommendation for a much stricter limit for radiofrequency radiation exposure is a step toward advancing a re-evaluation of the existing federal limit for radiofrequency radiation exposure while reviewing the latest research on radiofrequency radiation exposure.

2. Wide range of potential impacts of non-ionizing electromagnetic radiation on human health not accounted for in the current FCC standard

[4] Uche UI, Naidenko OV. Development of health-based exposure limits for radiofrequency radiation from wireless devices using a benchmark dose approach. Environ Health. 2021; 20(1):84. https://doi.org/10.1186/s12940-021-00768-1

[5] National Toxicology Program. 595: NTP Technical Report on the Toxicology and Carcinogenesis Studies in Hsd: Sprague Dawley SD Rats Exposed to Whole-Body Radio Frequency Radiation at a Frequency (900 MHz) and Modulations (GSM and CDMA) Used by Cell Phones. National Toxicology Program, US Department of Health and Human Services. 2018. https://ntp.niehs.nih.gov/ntp/htdocs/lt_rpts/tr595_508.pdf?utm_source=direct&utm_medium=prod&utm_campaign=ntpgolinks&utm_term=tr595

The current FCC standard was based on the 1986 recommendations of the National Council on Radiation Protection and Measurements[6] and 1991 recommendations of the Institute of Electrical and Electronics Engineers,[7] which chose an exposure level based on behavioral changes observed in laboratory animals exposed to radiofrequency radiation for a duration of minutes to hours in studies conducted in the 1970s and 1980s. With extensive current research linking radiofrequency exposure to adverse impacts, even at exposure levels below the current federal limit, the FCC needs to review the latest science and update the allowable exposure limits.

Among the reported biological effects of electric and magnetic fields are harm to fetal growth and development (Ozgur et al., 2013);[8] changes in brain activity (Wallace and Selmaoui, 2019);[9] changes in heart rate variability (Wallace et al., 2020);[10] DNA damage (Smith-Roe et al., 2020);[11] cognitive effects (Azimzadeh and Jelodar);[12] and increased risk of cancer, including gliomas,[3] parotid gland tumors (Sadetzki et al., 2008),[13] thyroid cancers (Luo et al., 2019).[14] These adverse health effects may be associated with different mechanistic pathways, such as changes in the activity of voltage-gated calcium

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[6] National Council on Radiation Protection and Measurements. Biological effects and exposure criteria for radiofrequency electromagnetic fields: NCRP Report No. 86; 1986. Available from: https://ncrponline.org/shop/reports/report-no-086-biological-effects-and-exposure-criteria-for-radiofrequency-electromagnetic-fields-1986/

[7] Institute of Electrical and Electronics Engineers. (Revision of ANSI C95.1–1982). IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz. IEEE Std C95. 1991. https://doi.org/10.1109/IEEESTD.1992.101091

[8] Ozgur E, Kismali G, Guler G, Akcay A, Ozkurt G, Sel T, et al. Effects of prenatal and postnatal exposure to GSM-like radiofrequency on blood chemistry and oxidative stress in infant rabbits, an experimental study.
Cell Biochem Biophys. 2013;67(2):743–51. https://doi.org/10.1007/s12013- 013- 9564-1

[9] Wallace J, Selmaoui B. Effect of mobile phone radiofrequency signal on the alpha rhythm of human waking EEG: a review. Environ Res. 2019; 175:274–86. https://doi.org/10.1016/j.envres.2019.05.016

[10] Wallace J, Andrianome S, Ghosn R, Blanchard ES, Telliez F, Selmaoui B.Heart rate variability in healthy young adults exposed to global system for mobile communication (GSM) 900-MHz radiofrequency signal from mobile phones. Environ Res. 2020; 191:110097. https://doi.org/10.1016/j.envres.2020.110097

[11] Smith-Roe SL, Wyde ME, Stout MD, Winters JW, Hobbs CA, Shepard KG, et al. Evaluation of the genotoxicity of cell phone radiofrequency radiation in male and female rats and mice following subchronic exposure. Environ Mol Mutagen. 2020; 61(2):276–90. https://doi.org/10.1002/em.22343

[12] Azimzadeh M, Jelodar G. Prenatal and early postnatal exposure to radiofrequency waves (900 MHz) adversely affects passive avoidance learning and memory. Toxicol Ind Health. 2020;36(12):1024–30. https://doi.org/10.1177/0748233720973143

[13] Sadetzki S, Chetrit A, Jarus-Hakak A, Cardis E, Deutch Y, Duvdevani S, et al. Cellular phone use and risk of benign and malignant parotid gland tumors – a nationwide case-control study. Am J Epidemiol. 2008;167(4):457–67. https://doi.org/10.1093/aje/kwm325

[14] Luo J, Deziel NC, Huang H, Chen Y, Ni X, Ma S, et al. Cell phone use and risk of thyroid cancer: a population-based case–control study in Connecticut. Ann Epidemiol. 2019; 29:39–45. https://doi.org/10.1016/j.annepidem.2018.10.004

channels (Blackman et al., 1991);[15] changes in the concentrations of reactive oxygen species and redox homeostasis (Ertilav et al., 2018);[16] changes in intracellular enzymes and gene expression (Fragopoulou et al.,2018);[17] and changes in membrane permeability (Perera et al., 2018).[18]

Table 1. Extensive research points to effects of non-ionizing electromagnetic radiation on individual body systems that are not considered by the current FCC standards for cell phone radiation.

Reported health effects	**Key studies**
Elevated risk of brain cancer, breast cancer, parotid gland tumors, and thyroid cancer	Choi YJ, Moskowitz JM, Myung SK, Lee YR, Hong YC. Cellular Phone Use and Risk of Tumors: Systematic Review and Meta-Analysis. Int J Environ Res Public Health. 2020; 17(21):8079. West JG, Kapoor NS, Liao SY, Chen JW, Bailey L, Nagourney RA. Multifocal Breast Cancer in Young Women with Prolonged Contact between Their Breasts and Their Cellular Phones. Case Rep Med. 2013; 2013:354682 Sadetzki S, Chetrit A, Jarus-Hakak A, Cardis E, Deutch Y, Duvdevani S, et al. Cellular phone use and risk of benign and malignant parotid gland tumors – a nationwide case-control study. American journal of epidemiology 2008; 167(4):457-67. Luo J, Li H, Deziel NC, Huang H, Zhao N, Ma S, et al. Genetic susceptibility may modify the association between cell phone

[15] Blackman C, Benane S, House D. The influence of temperature during electric-and magnetic-field-induced alteration of calcium-ion release from in vitro brain tissue. Bioelectromagnetics. 1991;12(3):173–82. https://doi.org/10.1002/bem.2250120305
[16] Ertilav K, Uslusoy F, Ataizi S, Nazıroğlu M. Long term exposure to cellphone frequencies (900 and 1800 MHz) induces apoptosis, mitochondrial oxidative stress and TRPV1 channel activation in the hippocampus and dorsal root ganglion of rats. Metab Brain Dis. 2018;33(3):753–63. https://doi.org/10.1007/s11011-017-0180-4
[17] Fragopoulou AF, Polyzos A, Papadopoulou MD, Sansone A, Manta AK, Balafas E, et al. Hippocampal lipidome and transcriptome profile alterations triggered by acute exposure of mice to GSM 1800 MHz mobile phone radiation: an exploratory study. Brain Behavior. 2018; 8(6):e01001. https://doi.org/10.1002/brb3.1001
[18] Perera PGT, Nguyen THP, Dekiwadia C, Wandiyanto JV, Sbarski I, Bazaka O, et al. Exposure to high-frequency electromagnetic field triggers rapid uptake of large nanosphere clusters by pheochromocytoma cells. Int J Nanomed. 2018;13:8429. https://doi.org/10.2147/IJN.S183767

	use and thyroid cancer: A population-based case-control study in Connecticut. Environmental Research. 2020; 182:109013.
Eye strain, damage to eye tissues cataracts	Bormusov E, P Andley U, Sharon N, Schächter L, Lahav A, Dovrat A. Non-thermal electromagnetic radiation damage to lens epithelium. Open Ophthalmol J. 2008; 2:102-6
Cardiomyopathy, heart rate variability	National Toxicology Program. 2018. Technical Report on the Toxicology and Carcinogenesis Studies in Hsd: Sprague Dawley SD Rats Exposed to Whole-Body Radio Frequency Radiation at a Frequency (900 MHz) and Modulations (GSM and CDMA) Used by Cell Phones. Wallace J, Andrianome S, Ghosn R, Blanchard ES, Telliez F, Selmaoui B. Heart rate variability in healthy young adults exposed to global system for mobile communication (GSM) 900-MHz radiofrequency signal from mobile phones. Environmental Research 2020; 191:110097
Damage to sperm, decreased male fertility	Kesari KK, Agarwal A, Henkel R. Radiations and male fertility. Reprod Biol Endocrinol. 2018; 16(1):118
Changes in brain activity Changes in blood-brain barrier	Volkow ND, Tomasi D, Wang G-J, Vaska P, Fowler JS, Telang F, et al. Effects of cell phone radiofrequency signal exposure on brain glucose metabolism. JAMA 2011; 305(8):808-13 Wallace J, Selmaoui B. Effect of mobile phone radiofrequency signal on the alpha rhythm of human waking EEG: A review. Environmental research. 2019; 175:274-86
Changes in the immune system function	Piszczek P, Wójcik-Piotrowicz K, Gil K, Kaszuba-Zwoińska J. Immunity and electromagnetic fields. Environ Res. 2021; 200:111505.

As documented in Table 1, exposure to non-ionizing electromagnetic fields can harm a variety of organs and body systems, highlighting the urgency of a public-health-focused reassessment of existing exposure limits for radiofrequency radiation. Further, exposure to non-ionizing electromagnetic fields during pregnancy has been associated with an increased risk of miscarriage (Li et al., 2017)[19] and an increased frequency of hyperactivity and inattention during early childhood (Birks et al., 2017).[20]

In conclusion, the Environmental Working Group urges the FCC to open its record for a more comprehensive evaluation of radiofrequency radiation and update its standard to ensure the safety of wireless radiation devices for everyone, especially young children.

Submitted on behalf of the Environmental Working Group,

Uloma Igara Uche, Ph.D.
Environmental Health Science Fellow
Environmental Working Group

Olga V. Naidenko, Ph.D.
Vice President, Science Investigations
Environmental Working Group

[19] Li DK, Chen H, Ferber JR, Odouli R, Quesenberry C. Exposure to Magnetic Field Non-Ionizing Radiation and the Risk of Miscarriage: A Prospective Cohort Study. Sci Rep. 2017; 7(1):17541. https://doi.org/10.1038/s41598-017-16623-8

[20] Birks L, Guxens M, Papadopoulou E, Alexander J, Ballester F, Estarlich M, Gallastegi M, Ha M, Haugen M, Huss A, Kheifets L, Lim H, Olsen J, Santa-Marina L, Sudan M, Vermeulen R, Vrijkotte T, Cardis E, Vrijheid M. Maternal cell phone use during pregnancy and child behavioral problems in five birth cohorts. Environ Int. 2017; 104:122-131. https://doi.org/10.1016/j.envint.2017.03.024

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November 9, 2021

The Honorable Jessica Rosenworcel, Commissioner
Acting Chairwoman
Federal Communications Commission
445 12th Street, S.W.
Washington, DC 20554

Dear Chairwoman Rosenworcel,

I am writing to request that the FCC re-open Docket #13-84 "Reassessment of FCC Radiofrequency Exposure Limits and Policies" and Docket #03-137" Proposed Changes to the Commission Rules Regarding Human Exposure to Radiofrequency Electromagnetic Fields- in order to refresh the record before responding to the mandate of the August 13, 2021 judgment by the U.S. Court of Appeals for the District of Columbia Circuit, in Environmental Health Trust et al. v. the FCC.

I am Professor and Chair Emeritus at the University of New Hampshire Department of Electrical & Computer Engineering and served on the New Hampshire State Commission on 5G Technology. After a year of investigation we issued our final report on November 1, 2020.

I want to ensure the fifteen recommendations of the expert New Hampshire State Commission are considered by the FCC. If the FCC does not re-open the record, the Report will not be available to the Commission as it was finalized in 2020.

Sincerely

Kent Chamberlin

Digitally signed by Kent Chamberlin
Date: 2021.11.09 21:21:17 -05'00'

Kent Chamberlin, PhD
Professor & Chair Emeritus

New Hampshire State Commission on 5G Technology Final Report Recommendations

RECOMMENDATION 1

Propose a resolution of the House to the US Congress and Executive Branch to require the Federal Communication Commission (FCC) to commission an independent review of the current radiofrequency (RF) standards of the electromagnetic radiation in the 300MHz to 300GHz microwave spectrum as well as a health study to assess and recommend mitigation for the health risks associated with the use of cellular communications and data transmittal.

RECOMMENDATION 2

Require that the most appropriate agency (agencies) of the State of New Hampshire include links on its (their) website(s) that contain information and warnings about RF-radiation from all sources, but specifically from 5G small cells deployed on public rights-of-way as well as showing the proper use of cell phones to minimize exposure to RF-radiation, with adequate funding granted by the Legislature. In addition, public service announcements on radio, television, print media, and internet should periodically appear, warning of the health risks associated with radiation exposure. Of significant importance are warnings concerning the newborn and young as well as pregnant women.

RECOMMENDATION 3

Require every pole or other structure in the public rights of- way that holds a 5G antenna be labeled indicating RF-radiation being emitted above. This label should be at eye level and legible from nine feet away.

RECOMMENDATION 4

Schools and public libraries should migrate from RF wireless connections for computers, laptops, pads, and other devices, to hardwired or optical connections within a five-year period starting when funding becomes available.

RECOMMENDATION 5

Signal strength measurements must be collected at all wireless facilities as part of the commissioning process and as mandated by state or municipal ordinances. Measurements are also to be collected when changes are made to the system that might affect its radiation, such as changes in the software controlling it. Signal strength is to be assessed under worst-case conditions in regions surrounding the tower that either are occupied or are accessible to the public, and the results of the data collection effort is to be made available to the public via a website. In the event that the measured power for a wireless facility exceeds radiation thresholds, the municipality is empowered to immediately have the facility taken offline. The measurements are to be carried out by an independent contractor and the cost of the measurements will be borne by the site installer.

RECOMMENDATION 6

Establish new protocols for performing signal strength measurements in areas around wireless facilities to better evaluate signal characteristics known to be deleterious to human health as has been documented through peer-reviewed research efforts. Those new protocols are to take into account the impulsive nature of high-data-rate radiation that a growing –body of evidence shows as having a significantly greater negative impact on human health than does continuous radiation. The protocols will also enable the summative effects of multiple radiation sources to be measured.

RECOMMENDATION 7

Require that any new wireless antennas located on a state or municipal right-of-way or on private property be set back from residences, businesses, and schools. This should be enforceable by the municipality during the permitting process unless the owners of residences, businesses, or school districts waive this restriction.

RECOMMENDATION 8

Upgrade the educational offerings by the NH Office of Professional Licensure and Certification (OPLC) for home inspectors to include RF intensity measurements.

RECOMMENDATION 9

The State of New Hampshire should begin an effort to measure RF intensities within frequency ranges throughout the state, with the aim of developing and refining a continually updated map of RF exposure levels across the state using data submitted by state-trained home inspectors.

RECOMMENDATION 10

Strongly recommend all new cell phones and all other wireless devices sold come equipped with updated software that can stop the phone from radiating when positioned against the body.

RECOMMENDATION 11

Promote and adopt a statewide position that would strongly encourage moving forward with the deployment of fiber optic cable connectivity, internal wired connections, and optical wireless to serve all commercial and public properties statewide.

RECOMMENDATION 12

Further basic science studies are needed in conjunction with the medical community outlining the characteristics of expressed clinical symptoms related to radio frequency radiation exposure.The majority of the Commission feels the medical community is in the ideal position to clarify the clinical presentation of symptoms precipitated by the exposure to radio frequency radiation consistent with the Americans with Disabilities Act (ADA) which identifies such a disability. The medical community can also help delineate appropriate protections and protocols for affected individuals. All of these endeavors (basic science, clinical assessment, epidemiological studies) must be completely independent and outside of commercial influence.

RECOMMENDATION 13

Recommend the use of exposure warning signs to be posted in commercial and public buildings. In addition, encourage commercial and public buildings, especially healthcare facilities, to establish RF-radiation free zones where employees and visitors can seek refuge from the effects of wireless RF emissions.

RECOMMENDATION 14

The State of New Hampshire should engage agencies with appropriate scientific expertise, including ecological knowledge, to develop RF-radiation safety limits that will protect the trees, plants, birds, insects, and pollinators.

RECOMMENDATION 15

The State of New Hampshire should engage our Federal Delegation to legislate that under the National Environmental Policy Act (NEPA) the FCC do an environmental impact statement as to the effect on New Hampshire and the country as a whole from the expansion of RF wireless technologies.

November 24, 2021

The Honorable Jessica Rosenworcel
Federal Communications Commission
445 12th Street, S.W.
Washington, DC 20554

Dear Chairwoman Rosenworcel,

I am a physician in France and for the past fifteen years I have been working on the documented health issues related to cell phone radiation as well as the cell phone SAR test procedures.

In regards to the recent U.S. DC Circuit Court of Appeals' ruling in EHT v FCC, we are writing to request that the FCC re-open Dockets #13-84 and #03-137 to allow new, significant policy developments and research be included for consideration because of it's relevance to the FCC examining its cell phone SAR testing procedures.

I am President of the Phonegate Alerte Association, formed in 2018 and our efforts to ensure transparency have led to the French government's actions to withdraw or update at least 23 models of cell phones from different manufacturers (Xiaomi, Nokia, Huawei, Wiko, Alcatel, etc.) because they were found to exceed European Union regulatory SAR limits for human exposure to radiofrequency radiation.

Similar to the FCC's regulations on cell phone test procedures, European Union regulations allow manufacturers to test cell phones at 5 mm separation distance from the body. They do not force companies to test cell phones or wireless devices at positions that are directly against the body (0 mm separation distance) *despite the reality that billions of people are using cell phones close to the body.*

The French Government is Requesting 0 mm Cell Phone Radiation Testing

In late 2019, the French government health agency ANSES issued a report[1] on the possible health effects associated with high radiation from mobile telephones carried close to the body and recommended that cell phones be tested at 0 millimeters, instead of 5 mm as the European Commission regulations require. Subsequently, France submitted a formal objection[2] to the European Commission in regards to the

[1] https://www.anses.fr/en/content/exposure-mobile-telephones-carried-close-body
[2] https://ec.europa.eu/docsroom/documents/43448

current compliance test separation distance requirements of only 5 mm. The authorities have requested that compliance test distances be revised to 0 mm

> "*Developments in the use of mobile telephones have led to a wide variety of situations in which telephones are no longer exclusively held close to a person's ear in order to hold a conversation, since they are now also used to send and receive data through various applications for listening to music, playing video games or making video calls, which means that the equipment is used in ways which were not previously foreseen. There is also a growing trend for telephones to be networked with numerous connected objects, such as headsets or watches, which tend to result in lengthy connections between a telephone and the mobile network without the telephone being held in the hand, since it is often carried in clothing and is therefore closer to – or in contact with – the trunk.*
>
> *For this reason, the French authorities believe that it is necessary to revise the harmonised standard EN 50566: 2017 concerning measurements of the SAR of devices that are hand-held or body-mounted in close proximity to the human body so that a maximum distance of 0 mm from the body is taken into consideration."*

The FCC should ensure that cell phones are tested in body contact positions at 0 mm.

For background, in 2016, the French National Frequency Agency (ANFR) officially tested various models of cell phones and found that the majority exceeded regulatory limits when tested in body contact positions - with 0 mm between the phone and simulated body testing device (aka "phantom").

Cell Phones Violate Radiation Limits

Since December 4, 2019 ANFR has posted *143 new cell phone SAR test reports*. Despite the fact that the European Union strengthened their requirements to ensure cell phones were tested at 5 mm from the body, many cell phone models are still violating the limit of 2.0 W/kg for trunk SAR when tested by ANFR (10 g of tissue). All of the test results are posted online[3].

Examples of smartphones that **violated the EU limits of 2.0 W/kg as well as the FCC limit of 1.6 W/kg when SAR radiation tested by the ANFR at 5mm include:**

- February 26, 2020: Sony Xperia 5 violated the limit at 2.64 W/kg.
- November 12, 2020: Essential Heyou 40 violated the limit at 2.54 W/kg[4]
- September 9, 2020: Essential Heyou 60 violated the limit at 2.86 W/kg[5]
- February 26, 2020: Xiaomi Mi Note 10 violated the limit at 2.45 W/kg[6]

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3 https://data.anfr.fr/explore/dataset/das-telephonie-mobile/table/?disjunctive.marque&disjunctive.modele&dataChart=eyJxdWVyaWVzIjpbeyJjb25maWciOnsiZGF0YXNldCI6ImRhcy10ZWxlcGhvbmllLW1vYmlsZSIsIm9wdGlvbnMiOnsiZGlzanVuY3RpdmUubWFycXVlIjp0cnVlLCJkaXNqdW5jdGl2ZS5tb2RlbGUiOnRydWV9fSwiY2hhcnRzIjpbeyJ0eXBlIjoibGluZSIsImZ1bmMiOiJBVkciLCJ5QXhpcyI6ImRhc190ZXRlX25vcm1lX25mX2VuXzUwMzYwIiwic2NpZW50aWZpY0Rpc3BsYXkiOnRydWUsImNvbG9yIjoiIzY2YzJhNSJ9XSwieEF4aXMiOiJkYXRlX2R1X2NvbnRyb2xlX3Bhcl9sX2FuZnIiLCJtYXhwb2ludHMiOiIiLCJ0aW1lc2NhbGUiOiJ5ZWFyIiwic29ydCI6IiJ9XX0%3D&sort=das_tronc_au_contact

4 https://www.anfr.fr/das/COM054200035

5 https://www.anfr.fr/das/COM054200035

6 https://www.anfr.fr/das/COM006200006/

Examples of smartphones **that would be compliant with the EU limit but would violate the FCC limits of 1.6 W/kg when SAR radiation tested by the ANFR at 5mm include:**

- September 16, 2020 Logicom Le Fleep 178 violated FCC's limit at 1.94 W/kg[7]
- September 16, 2020: Sky 55 Konrow violated FCC's limit at 1.91 W/kg[8]
- September 30, 2020: Wiki Lubi 5 Plus violated FCC's limit at 1.9 W/kg [9]
- September 29, 2020: Nokia 5.1 violated FCC's limit at 1.82 W/kg[10]
- April 8, 2021: Wiko F 300 violated FCC's limit at 1.8 W/kg[11]

As European Union and FCC test procedures utilize different averaging volumes, one cannot directly compare the measurements. However, FCC test procedures could result in even higher SAR violations (Gandhi 2019)[12].

Unfortunately ANFR no longer tests cell phones in body contact positions with 0 mm distance from the phone to the body phantom. If they did, far more of the 143 cell phones tested in the last two years would violate FCC and EU limits because every millimeter can significantly increase exposure. Further, due to the averaging volume differences between the FCC and EU limits, several of the phones that ANFR finds are compliant with the 1.6 W/kg limit would violate the FCC's test procedures.

The FCC presently allows manufacturers to SAR test cell phones with a separation distance between the phone and body (which can be up to approximately one inch from the body in some models of phones still in use in the USA) inaccurately measuring SAR levels into the body. Actual SAR exposure in direct body contact positions would be much higher than FCC test measurements.

New Research on Metal and Radiation Levels

Studies on SAR in human tissue published since 2019 related to cell phone test procedures need to be included in the FCC re-examination. Metal can reflect and refocus cellular radiation, resulting in much higher absorption rates. The FCC, states, "Electrically conductive objects in or on the body may interact with sources of RF energy in ways that are not easily predicted. Examples of conductive objects in the body include implanted metallic objects. Examples of conductive objects on the body include eyeglasses, jewelry, or metallic accessories."

- In January 2021 the study "Experimental Validation for Temperature Rise in Human Tissue Due to Implanted Metal Plates with Screw Holes Using Translucent Solid Phantom" was published in 2020 International Symposium on Antennas and Propagation (ISAP), Osaka, Japan IEEE, 2021 and found increases in SAR enhancement due to the implanted metallic plates observed at specific frequencies. [13]
- On December 2020, the study The effect of metal objects on the SAR and temperature increase in the human head exposed to dipole antenna (numerical analysis) published in Case Studies in Thermal Engineering found "the presence of metal objects in proximity to the head alters SAR and temperature increase within the tissues. In most cases, metal objects redistribute the EM

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7 https://www.anfr.fr/das/COM044200035
8 https://www.anfr.fr/das/COM044200036
9 https://www.anfr.fr/das/COM046200002
10 https://www.anfr.fr/das/COM085200003
11 https://www.anfr.fr/das/COM057210009
12 https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8688629
13 https://ieeexplore.ieee.org/document/9391129

> field incident upon them to a smaller region increasing power absorption, thereby increasing SAR and temperature in that region. The power absorption in head layers is found to be sensitive to metal object's size and shape, and distance of the antenna from the objects".[14]

These are just *a few* of the published studies on radiation levels will not be included in the FCC's examination of cell phone test procedures *unless the FCC refreshes the record.*

Investigative Reports on Telecom Influence

In September 2020, the editor-in-chief of the Program 66 minutes interviewed Chicago Tribune journalist and Pulitzer Prize winner Sam Roe and myself discussing how FCC's cell phone test procedures allow violations of FCC limits because they do not requite cell phones to be tested at 0 mm.[15]

On November 12, 2020, France Télévisions Complément d'Investigation "5G A Wave of Doubt" directed by investigative journalist Nicolas Vescovacci was broadcast on France 2[16]. The investigation described how cell phones exceed radiation thresholds when tested against the body and how cell phones are being taken off the market in response. Importantly, the industry ties of members of International Commission on Non-Ionizing Radiation Protection (ICNIRP) were revealed. In June 2020, a report released by European Members of Parliment Michèle Rivasi (Europe Écologie) and Dr. Klaus Buchner (Ökologisch-Demokratische Partei) found that ICNIRP has long ignored the science on non thermal effects[17].

This 2020 investigative research must be included in the FCC's record review so that the FCC does not inadvertently allow the wireless industry to influence its review of the record and decision.

There is Not a 50-Fold Safety Factor for Cell Phone Local SAR

Furthermore, we would like to importantly note that after we questioned ICNIRP President Rodney Croft and Vice President Eric Van Rongen, we received confirmation that there is not a 50 fold safety factor when it comes to ICNIRP's cell phone local SAR limit.

Here is what Mr. Van Rongen wrote about this:

> "Anyone who states that a reduction factor of 50 applies to local exposures obviously misinterprets the guidelines, although the 1998 guidelines might not have been very clear in that respect the 2020 ones provide more clear information."

On December 17, 2019 Environmental Health Trust and Phonegate Association write members of Congress a letter[18] and Background and Facts document[19] on the urgent need for a hearing regarding cell phone radiation test procedures, due to the excessive radiation the phone can expose the user to in body contact positions.

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[14] https://www.sciencedirect.com/science/article/pii/S2214157X20305311?via%3Dihub
[15] Phonegate : entretien avec le journaliste américain et prix Pulitzer Sam Roe
[16] https://www.francetvinfo.fr/replay-magazine/france-2/complement-d-enquete/complement-d-enquete-5g-londe-dun-doute_4152949.html
[17] https://ehtrust.org/wp-content/uploads/ICNIRP-report-FINAL-JUNE-2020.pdf
[18] https://ehtrust.org/wp-content/uploads/Signed-Letter-to-US-Congress-phonegate-.pdf
[19] Background and Facts Documenting PhoneGate and Our Call for Congressional Action https://ehtrust.org/wp-content/uploads/Background-and-Facts-on-PhoneGate-1-1.pd

We have a significant amount of new data on SAR test methods from 2020 and 2021 to share with the FCC in order to ensure the protection of cell phone users, especially children. SAR tests are thermally based and they are an inadequate measurement to ensure safety. Stronger regulations which protect users from thermal and non-thermal effects are needed.

New Law To Require Radiation Testing of Wi-Fi Laptops, Router and Electronics

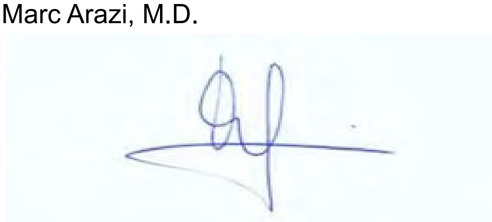
In addition, there has been new legislation regarding transparency on wireless radiation in France. Starting in July 2020, the wireless industry must label tablets, laptops, Wi-Fi routers, DECT phones and other wireless connected electronics with the radiofrequency radiation SAR exposure levels for consumers **at point of sale and for all advertising**. This includes the SAR for the head, trunk and extremities. All equipment used close to the head, hand-held or carried close to the body is potentially covered. From the SAR Regulation Guide provided by ANFR, you can find a non-exhaustive list of equipment qualified as radio equipment that required SAR testing.

Note: For years France law[20] has ensured cell phones were SAR radiation labeled, banned the sale of cell phones designed for young children, prohibited advertising to children under 14 years of age[21] and warned[22] users to keep devices away from the body.

It is imperative that the two above-mentioned dockets are re-opened to allow recent developments to be submitted for a proper assessment of FCC's testing protocol.

Sincerely,

Marc Arazi, M.D.



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A book on Phonegate was published by Massot Editions on this international health scandal. An English version is planned and we will be sure to send it to you when it is released in the United States.

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[20] Article 183 - LOI n° 2010-788 du 12 juillet 2010 portant engagement national pour l'environnement (1)
[21] **Law on sobriety, transparency, information and consultation for exposure to electromagnetic waves**
[22] **Order of November 15, 2019 relating to the display of the specific absorption rate of radioelectric equipment and to consumer information NOR: SSAP1834792A**

November 18, 2021

The Honorable Jessica Rosenworcel, Commissioner
Acting Chairwoman
Federal Communications Commission
445 12th Street, S.W.
Washington, DC 20554

Dear Chairwoman Rosenworcel,

We are writing to request that the FCC re-open the relevant Dockets to ensure the latest science be included in the FCC's reexamination of the adequacy of its human exposure limits and regulations for radiofrequency radiation exposures.

We urge the Commission to look at new scientific evidence published since December 4, 2019. Of 39 new genetic effect studies, 79 % (31 studies) showed effects and 21 % (8 studies) did not show significant effects. Of 33 new neurological effect studies, 85 % (28 studies) showed effects and 15 % (5 studies) did not show significant effects. Of 30 new oxidative effect studies, 93% (28 studies) showed effects and 7 % (2 studies) did not show significant effects. The preponderance of scientific research on RFR continues on an upward trend.

There is a broad consensus among those in the scientific research community who are knowledgeable on the published literature, that new, biologically-based public safety limits for chronic exposure to radiofrequency radiation (RFR) are warranted now. The available evidence for health risks due to low intensity radiofrequency radiation exposures from wireless technology applications is sufficient and compelling. Research published over the last two years has added significant additional weight to the body of evidence which indicates that FCC public safety exposure limits are grossly inadequate to protect public health given the proliferation of RFR-emitting devices now in common usage.

The evidence for health risks comes directly from hundreds of published scientific and public health studies reporting that low-intensity RFR is capable of producing health harm across very large populations of exposed people.

The BioInitiative Working Group has been gathering and evaluating hundreds of such studies since 2006, and has published two large reports detailing this evidence. The group concluded that the scientific evidence was more than sufficient in 2007, and certainly in 2012 (www.bioinitiative.org) to establish new biologically-based exposure safety standards. Further, we have submitted numerous comments to the FCC since 2013 advising that the Commission has not struck the right balance between the wireless technologies rollout and managing resulting health impacts for Americans, particularly for children. The increased risk for cancers, neurological diseases, fertility and reproduction, immune disfunction, memory and learning impairment, and other serious medical problems associated with exposure to low-intensity RF are documented and analyzed for the Commission to review at: https://bioinitiative.org/research summaries/

When the cumulative body of evidence is assessed over the last decades of research, the overall picture for studies on radiofrequency radiation effects shows clear and consistent patterns of effects on living tissues. Chronic RFR exposures at environmental levels common today can reasonably be presumed to produce health harm at and below current FCC safety limits for humans and should be substantially lowered.

Genetic effects: Effect= 67% (259 studies); No Effect= 33% (129 studies) (literature up to November 12, 2021)

Neurological effects: Effect= 74% (271 studies); No Effect= 26% (97 studies) (literature up to November 12, 2021)

Oxidative effects: Effect= 92% (258 studies); No Effect= 8% (23) studies) (literature up to November 12, 2021)

Respectfully submitted on behalf of the BioInitiative Working Group by**:**

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Consumers for Safe Cell Phones

November 24, 2021

The Honorable Jessica Rosenworcel
Federal Communications Commission
445 12th Street, S.W.
Washington, DC 20554

Dear Chairwoman Rosenworcel,

As one of the petitioners who recently sought the DC Circuit Court of Appeal's review of the FCC's December 4th, 2019 decision to maintain their outdated 25 year old wireless exposure guidelines, we write to urge the Commission to follow the Court's directive to properly review the evidence that had been submitted into Dockets #13-84 and #03-137. A proper review requires that the two dockets be re-opened to allow newly published research and documents (made public over the past 2 years) to be included in the analysis. This will provide the FCC with up-to-date information to use in undertaking the Court's required thorough analysis.

The Court's ruling stated that the Commission "*must, in particular, (i) provide a reasoned explanation for its decision to retain its testing procedures for determining whether cell phones and other portable electronic devices comply with its guidelines*…"

Of particular concern to the Court is the failure of the FCC to review the evidence in the record related to assessing their inadequate cell phone testing guidelines. Since the GAO released their 2012 report[1] stating, "*The Federal Communications Commission's (FCC) RF energy exposure limit may not reflect the latest research, and testing requirements may not identify maximum exposure in all possible usage conditions… Some consumers may use mobile phones against the body, which FCC does not currently test, and could result in RF energy exposure higher than the FCC limit."* - we have been calling on the FCC to test phones directly against the body with zero separation to simulate the manner in which they are typically used by consumers.

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1 "Telecommunications: Exposure and Testing Requirements for Mobile Phones Should Be Reassessed" - GAO-12-77: Published: Jul 24, 2012

FCC's current testing protocol allows a separation distance between the phone and the torso simulating use in a holster or belt clip, enabling a phone to pass the FCC compliance test when in fact, the exposure from phones used in real life usage positions will likely exceed the federal "safety" limit. This is because it is commonplace for today's consumer to carry a transmitting phone in a pants or breast pocket or tucked into a bra with no separation between the antennas and the body.

Here are some examples of the RF warnings for wireless devices currently on the market in 2021:

- The Apple iPhone 13 Pro Max RF Exposure statement[2] reads, *"iPhone is evaluated in positions that simulate uses against the head, with no separation, and when worn or carried against the torso of the body, with 5mm separation."* [Users will likely carry and use transmitting phones in pockets and bras against their body unaware because the RF "safety" warning is located in the small print of the legal section deep within menus on the phone where it is not likely to be found.]
- The Miku Pro Smart Baby Monitor manual states[3], *"RF EXPOSURE WARNING: ….This equipment should be installed and operated with minimum distance 20cm between the radiator and your body."* [Yet many parents will locate these RF transmitting monitors close to the crib or in a child's playroom unaware that these RF warnings are in the manual.]
- The AT&T DECT 6.0 Home Cordless Phone manual[4] states, "*The telephone base shall be installed and used such that parts of the user's body other than the hands are maintained at a distance of approximately 20 cm (8 inches) or more*." [Yet many people install the base unit on the desk just inches from their head or on their bedside table unaware of these instructions.]

Key evidence has been published in the past two years that indicates cell phones directly in body contact (as when worn and used in a pants or shirt pocket or sports bra) are associated with an increased risk for breast tumors and sperm damage.

As examples, these 2020 and 2021 published studies referenced below must be included in a thorough FCC assessment of their cell phone testing protocol in order to perform a more "reasonable analysis" of the testing protocol:

I. "The Association Between Smartphone Use and Breast Cancer Risk Among Taiwanese Women: A Case-Control Study" - Cancer Manag Res 2020 Oct 29;12:10799-10807 doi: 10.2147/CMAR.S267415.

> Results: "*Participants who carried their smartphone near their chest or waist-abdomen area had significantly increased 5.03-fold and 4.06-fold risks of breast cancer*"

II. "Effects of mobile phone usage on sperm quality - No time-dependent relationship on usage: A systematic review and updated meta-analysis" - 2021 Nov; 202:111784. doi: 10.1016/j.envres.2021.111784. Epub 2021 Jul 30

> Results: "*Exposure to mobile phones is associated with reduced sperm motility, viability, and concentration*." 18 studies were evaluated including 4280 samples.

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[2] https://www.apple.com/legal/rfexposure/iphone14,3/en/

[3] https://cdn.shopify.com/s/files/1/2621/9254/files/mikucare.com_quick_setup-guide.pdf?v=1589825520

[4] https://att.vtp-media.com/products/CL/CL82X07/CL82X07_WEBCIB_i5.0_20201217.pdf

If the past two years of important research and evidence are not allowed to be included in the re-assessment of the FCC's cell phone testing protocol, it is certain that the public's distrust of the safety of phones and other wireless consumer devices will become even more widespread. The public's trust is dependent upon the FCC's thorough evaluation of the current, up to date body of research, especially with the advent of the novel and more powerful exposures expected with 5G.

Respectfully submitted,

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ISSN (Online): 2350-0530
ISSN (Print): 2394-3629

International Journal of Research -GRANTHAALAYAH
November 2020, Vol 8(11), 7 – 14
DOI: https://doi.org/10.29121/granthaalayah.v8.i11.2020.2151

DOES ENHANCED ELECTROMAGNETIC RADIATION DISTURB HONEYBEES' BEHAVIOUR? OBSERVATIONS DURING NEW YEAR'S EVE 2019

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DOI: https://doi.org/10.29121/granthaalayah.v8.i11.2020.2151

Article Type: Research Article

Article Citation: Daniel Favre, and Olle Johansson. (2020). DOES ENHANCED ELECTROMAGNETIC RADIATION DISTURB HONEYBEES' BEHAVIOUR? OBSERVATIONS DURING NEW YEAR'S EVE 2019. International Journal of Research - GRANTHAALAYAH, 8(11), 7-14. https://doi.org/10.29121/granthaalayah.v8.i11.2020.2151

Received Date: 26 October 2020

Accepted Date: 20 November 2020

Keywords:
Honeybees
Sounds
Worker Piping
RF-EMF
New Year's Eve
Anthropogenic Electrosmog

ABSTRACT

Insects, and especially honeybees, are under major threat everywhere around the globe. Current studies lack in the consideration of potential effects which may directly affect other organisms or ecosystems, because of the verPy limited attention which is usually received by the potential adverse ecological effects of radiofrequency electromagnetic fields. Here, it is hypothesized that planetary enhancement of electromagnetic radiation produces a disturbing pollution for honeybees. In order to test this hypothesis, a bi-directional wide frequency range microphone was placed during the New Year's Eve night 2019 in a honeybee hive, in order to detect and analyze potential changes in the acoustic behaviour of the bees due to increased phone induced RF- EMF radiation. It was observed that the honeybees produced strong worker piping signals. Such signals are typically produced shortly before takeoff of a swarm, or as the sign of a disturbed colony. It is therefore hypothesized that planetary enhancement of electromagnetic radiation produces a disturbing pollution for honeybees, such as during the New Year's Eve night. Evidence of proof of such electromagnetic waves taking place at New Year's Eve should be investigated worldwide during forthcoming similar events based on a global network of long term EM measurements.

1. INTRODUCTION

Honeybees are under major threat everywhere around the globe [1], [2]. The so-called colony collapse disorder (CCD) is a recent phenomenon [3]. Current theories about the potential cause(s) of CCD essentially include increased losses due to the invasive varroa mite, pesticide poisoning, potential immune-suppressing stress on bees, drought, monocultural practices, migratory stress due the moving of the bees in long distances, and increased transmission of pathogens [4], [5]. Furthermore, radiation from mobile phones and mast antennas could also have contributed to the dramatic decline in insect populations, as revealed by a recent meta-analysis; indeed, increased exposure to electromagnetic radiation is "probably having a negative impact on the insect world", according to a recent study [6].

Thielens et al. [7] studied the effects of radio-frequency electromagnetic fields (RF-EMFs) on the Western honeybee. They showed that a relatively small shift of 10% of environmental incident power density from frequencies below 3 GHz to higher frequencies will lead to a relative increase in absorbed power of a factor higher than 3. In 2011, I have shown that active mobile phone handsets have a dramatic impact on the behaviour of bees, namely by inducing the worker piping signal [8]. These initial observations were substantiated by additional experiments that were performed with the controlled enhancement of the local RF-EMF signals [9]. In natural conditions, worker piping either announces the swarming process of the bee colony or is a signal of a disturbed bee colony [10], [11].

In order to assess, whether the increased radiofrequency electromagnetic radiation in the environment has an impact on the behaviour of honeybees, a broad spectral frequency microphone was placed in a hive during the New Year's Eve night of 2019, to investigate whether and to what degree the increased amount of local wireless communications might have an effect on the honeybees' behaviour around midnight, local time.

2. MATERIALS AND METHODS

The recording of a honeybee colony during the New Year's Eve 2019 took place in a rural area of Switzerland, close to the city of Montreux and at an altitude of 960 m above sea level. This location is surrounded by small mountains (Les Pléiades, Le Folly and Le Cubly, at 1362, 1730 and 1187 m above sea level, respectively). There is only one local emitting antenna in direct view (CH1093+ / LV95 ; https://www.bakom.admin.ch/bakom/en/homepage/frequencies-and-antennas/location-of-radio-transmitters.html), located more than 800 m away from the hive (Fig. 1a). The device employed for the recording of the honeybees' sounds consisted of a bidirectional compact microphone (Olympus ME-31) with frequency response from 70 to 15,000 Hz connected to a vocal recorder (Olympus LS-11). The microphone was placed in the bottom part of the hive (Figs. 1b and c). The vocal recorder was connected to an external battery (Panasonic LC-R123R4P; https://na.industrial.panasonic.com/) via a 12V-to-4.5V voltage converter (Dupertuis Electronique S.A., Lausanne, Switzerland) (Fig. 1d).

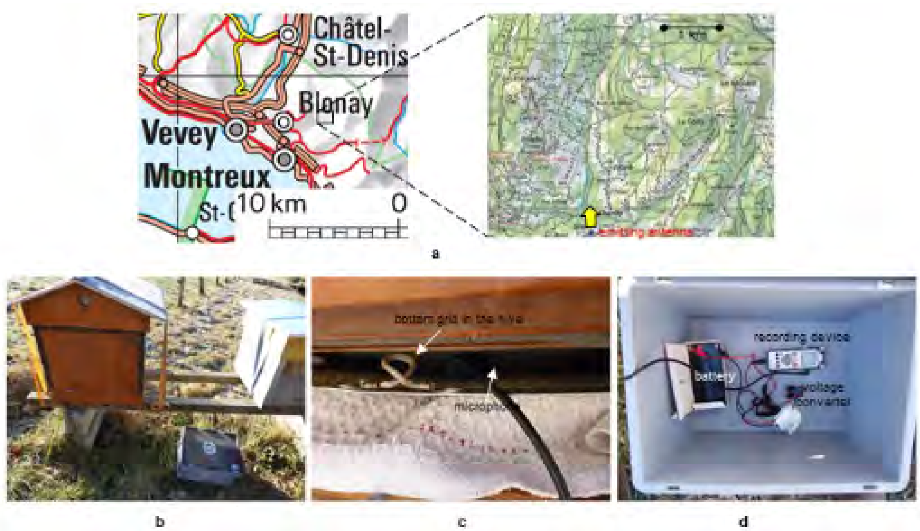

Figure 1: Location of the honeybee colony and experimental setup**. a**, Overview of the measurement location (source : Swiss Federal Office of Topography, https://shop.swisstopo.admin.ch/en/products/maps/overview/municipality_map ; geodata © swisstopo). The rural location at 1000 m above sea level is lying within mountains (Les Pléiades, Le Folly and Le Cubly); there is only one emitting antenna mast (for 2G, 3G and 4G) in direct view, more than 800 m away from the honeybee colony. **b**, Experimental setup, with positioning of the microphone under the bottom grid in the hive, above which is the honeybee colony. **c**, Microphone positioning in the back side of the hive (Dadant-Blatt model). **d**, Set up of the recording device. Electric current is provided by a 12 Volts battery and the voltage necessary for the recording device is set to 4.5 Volts with the help of a voltage converter.

The recorded signal was digitized as a Waveform audio file format sound file with 44,1 kHz recording mode. The open source, cross platform audio software Audacity (https://www.audacityteam.org/) was employed for the manual analysis of the sound files and for the generation of the audiograms (also called sonograms) and spectrograms (oscillograms). The computer program FFT Properties 5.0 (Dew Research LLC, SLO-3210 Slovenske Konjice, Slovenia) was employed for the generation and the analysis of the orbital phase (which is a visualization of the signal strength during a given period). Intensity values of audiograms might slightly vary throughout the whole recordings in the hive, depending on the clustering of the bees in the hive during winter. The sound files are freely available at https://doi.org/10.5061/dryad.5mkkwh748. In the geographic area where the recordings took place, the bees (*Apis mellifera carnica*) usually begin to forage to collect nectar and pollen in early March, depending on the weather conditions. All applicable national guidelines for the care and use of honeybees were followed.

3. RESULTS AND DISCUSSIONS

The fundamental frequency of *Apis mellifera carnica* was in the range of 70 to 100 Hertz (Hz). Dramatic changes in the fundamental intensity and frequency patterns of the sounds produced in the hive were recorded before, during and after the local New Year's Eve. It was indeed observed based on the recorded signals that the honeybees were significantly disturbed around midnight (local time), since the colony emitted a strong and long lasting (about 15 minutes) worker piping signal (Fig. 2).

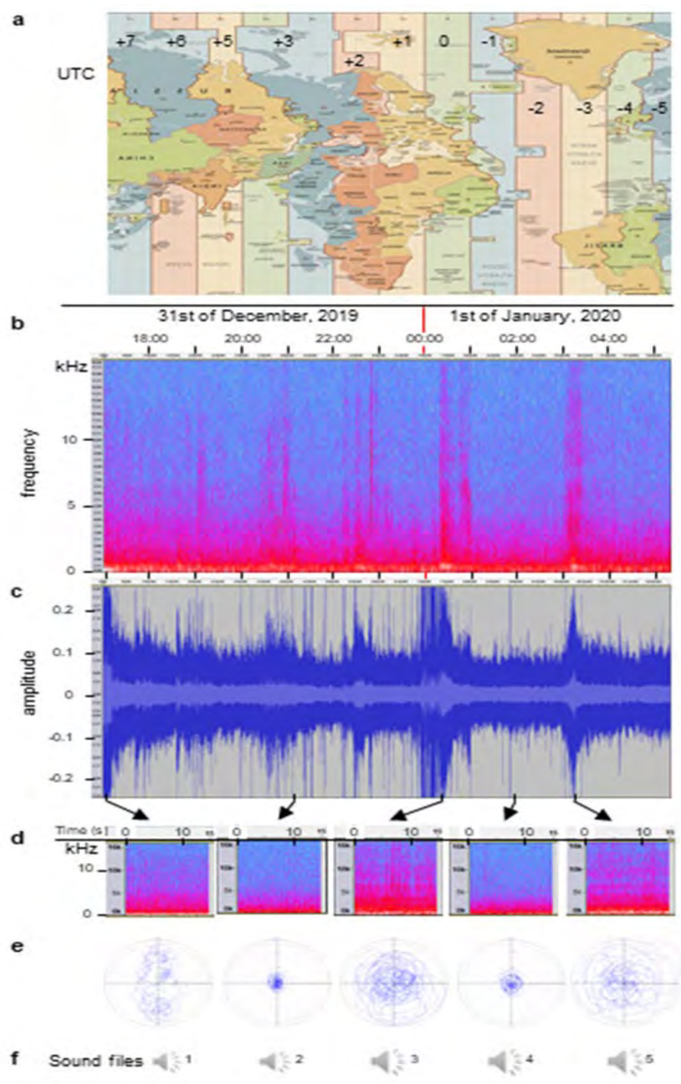

Figure 2: World time zones correlated with spectrogram and audiogram of hive sounds. **a**, World time zones (source: Map of current official time zones, US Central Intelligence Agency,

https://en.wikipedia.org/wiki/File:World_Time_Zones_Map.png from the freely licensed media file repository Wikimedia Commons) with Coordinated Universal Time (UTC). The map is flipped horizontally in order to reflect the progression of the New Year's Eve around the terrestrial globe. **b**, Spectrogram of honeybee colony sounds. Spectrogram is reported in kiloHertz (kHz). Local time is reported horizontally, from the left to the right. Local New Year's Eve at 00:00 (24-hour clock) is indicated with a vertical red line. **c**, Audiogram of honeybee colony sounds. Audiogram is normalized (-0.25 to 0.25). Local time is corresponding to Panel **b**. **d**, Spectrograms from five different time points. Spectrograms are reported in kiloHertz (kHz). Sounds lasting fifteen seconds each and starting at 17:03:00, 21:40:00, 01:22:55, 03:53:50 and 05:16:35 (hh.mm.ss) were analyzed. **e**, Orbital phase analyses of honeybees' sounds (see panel **d**). **f**, Sound files (see panel **d**).

Very surprisingly, the bees seemed to have also been disturbed on several other occasions before and after local midnight, as seen with the increase of the sound intensities and also the frequencies produced by the honeybee colony (Figs. 2a and 2b, respectively). These sounds might be correlated to the succeeding locations of the New Year's Eve celebrations around the globe : about seven (China), five (India), three and a half (Iran), three (Center of Russia, Saudi Arabia, East of Africa, Madagascar), two (Finland, Baltic States, Ukraine, Turkey, Bulgaria, Romania, etc.) hours before, and about one (United Kingdom) and three (Brazil, Argentina) hours after the local New Year's Eve, respectively. Listening to the sound files themselves further substantiates these observations (Figs. 2d and 2e) which to the best of these authors' knowledge, cannot be explained by natural causes.

For controls, twelve additional and similar recordings were performed with the same hive throughout the following weeks until mid-February. This revealed that the patterns of the sounds and frequencies produced by the honeybee colony did not show the peaks that were observed during the night of the New Year's Eve (Fig. 3).

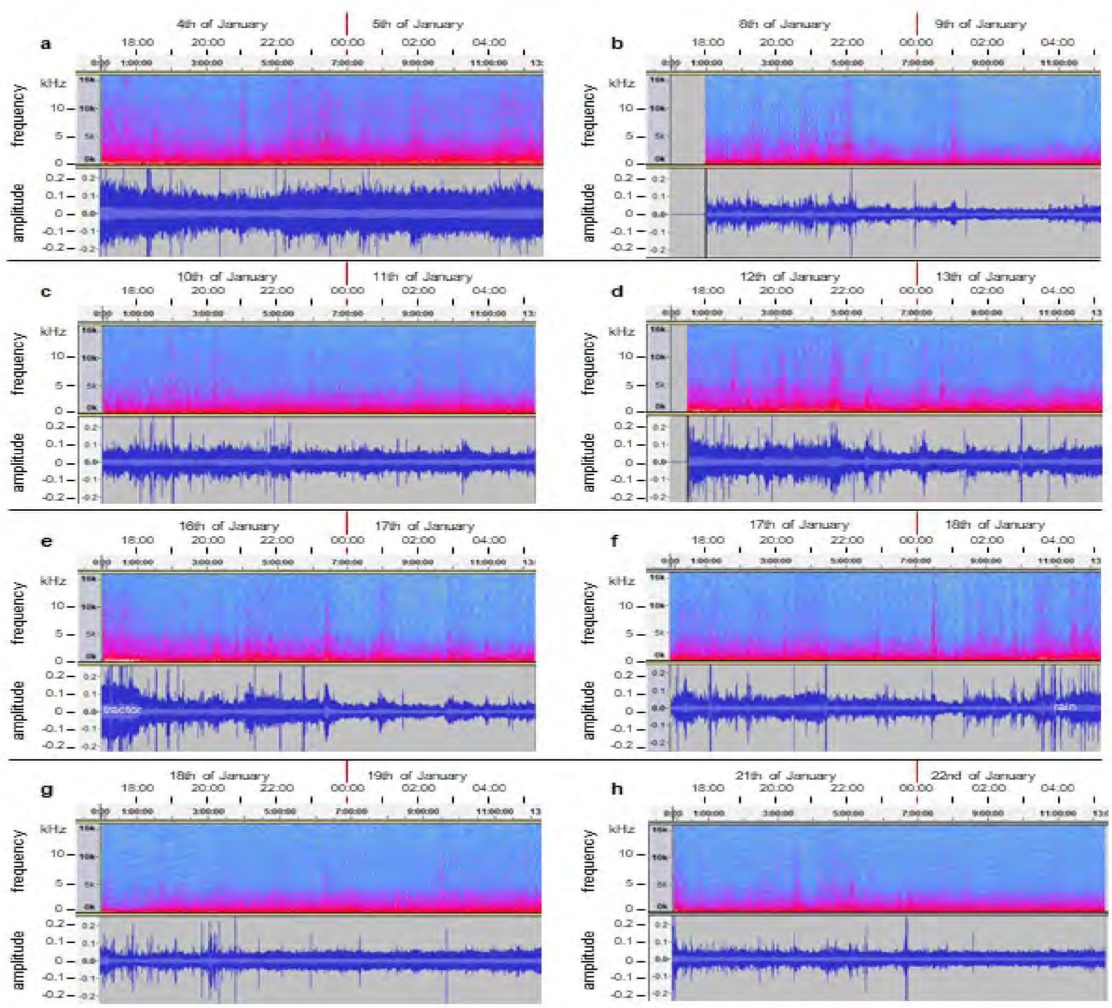

Figure 3: Spectrograms and audiograms of hive sounds. Spectrograms are reported in kiloHertz (kHz). Audiograms are normalized (-0.2 to 0.2). Local time is reported horizontally, from the left to the right. Local

midnight (00:00 ; 24-hour clock) is indicated with a vertical red line. **a**, 4 to 5 of January. **b**, 8 to 9 of January. **c**, 10 to 11 of January. **d**, 12 to 13 of January. **e**, 16 to 17 of January. A tractor was noisy in the surroundings. **f,** 17 to 18 of January. Rain in the early morning was audible. **g**, 18 to 19 of January. **h**, 21 to 22 of January. All dates are in the year 2020.

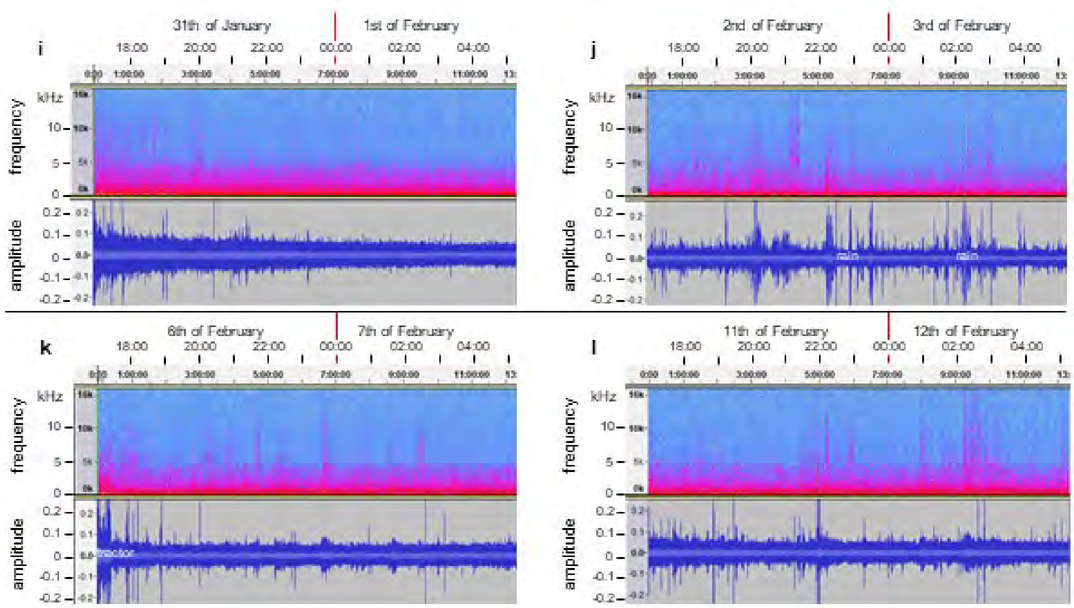

Figure 3 (continued): Spectrograms and audiograms of hive sounds. Spectrograms are reported in kiloHertz (kHz). Audiograms are normalized (-0.2 to 0.2). Local time is reported horizontally, from the left to the right. Local midnight (00:00 ; 24-hour clock) is indicated with a vertical red line. **i**, 31 of January to 1 of February. **j**, 2 to 3 of February. Rain during the night. **k**, 6 to 7 of February. **l**, 11 to 12 of February. All dates are in the year 2020.

It is hypothesized here that the honeybees were subjected not only to local but to global anthropogenic environmental RF-EMFs exposure occurring from New Year's Eve festivities around the globe. Indeed, the worker piping signals produced by honeybees is usually a signal that is produced shortly before takeoff of a swarm [10], or is associated with disturbance of the hive by, for example, intruders or jarring [11]. The induction of honeybee worker piping by enhanced electromagnetic fields might have dramatic consequences in terms of colony losses due to unexpected swarming. It is therefore time to assess the planetary electromagnetic pollution, since the Internet of Things and 5G will add millions more radiofrequency transmitters around and radiating with unprecedented increased power density above us, and since radio frequency electromagnetic fields (RF-EMF) have increased by several orders of magnitude over the last 50 years [12]. Current studies lack in the consideration of potential effects which may directly affect other organisms or ecosystems, because of the very limited attention which is usually received by the adverse ecological effects of RF-EMF [13]. Hallmann et al. have observed a seasonal decline of 76%, and mid-summer decline of 82% in flying insect biomass over the 27 years of their study [14]. These authors showed that this decline was apparent regardless of habitat type, while changes in weather, land use, and habitat characteristics cannot explain this overall decline.

It is obvious that in the future, thorough independent scientific investigations must be conducted in order to confirm or refute the working hypothesis : do RF-EMFs emitted not only locally, but worldwide, have the ability to disturb the behavior of honeybees ? Several critical parameters should be concomitantly analysed in the close vicinity of the honeybees participating in these studies, such as : i) the permanent measurement of the levels of exposure to radiofrequency electromagnetic radiations (around various frequency bands) ; ii) the analysis of the environmental electric and magnetic fields, and their variations ; iii) the examination of the putative involvement of natural atmospheric events such as, for example, the variations in the radio atmospheric signals, the so-called spherics [15].

There might be an unknown planetary electromagnetic mechanism for the generation of the observed sound effects in a bee colony. Indeed, honeybees have magnetic remanence [16] and can be trained to respond to very small changes in geomagnetic-field intensity, with the detection of an anomaly of 0.06% of background [17]. Honeybees do possess a magnetoreception system [18] and have been shown capable of detecting weak electric fields [19]. Evidence of proof of such electromagnetic waves taking place at New Year's Eve should be investigated worldwide during forthcoming similar events based on a global network of long term EM measurements. Protocols and methodologies are available for thoroughly performing such investigations [20], [21], [22].

Further verification of the above working hypothesis by implementing such measurements in a global monitoring network will be important for a mechanistic understanding of the interaction of RF fields with ecosystems [23].

4. CONCLUSIONS & RECOMMENDATIONS

The present study has revealed disturbing behaviour by honeybees which were very likely caused by increased wireless phone EM radiation during New Year's Eve celebrations around the globe. To the best of these authors' knowledge, this behaviour could not be explained by natural causes.

The forthcoming deployment of the 5G (fifth generation) wireless network, including 5G from space satellites, will increase exposure to radio frequency (RF) radiation on top of the 2G, 3G and 4G networks for telecommunications already in place. These RF radiations might be harmful for the biosphere. There is therefore an urgent need to address the so-called anthropogenic electrosmog [12]. The risk assessment and regulation of anthropogenic electromagnetic fields should be carefully evaluated and coordinated under international scrutiny.

Increasing RF-EM radiation power worldwide and the upcoming 5G rollout may present a serious challenge not only for honeybees but public health in general [24].

APPENDICES

Supplementary Materials: The original sound files are available online at https://doi.org/10.5061/dryad.5mkkwh748

Appendix A

Audio file 1. Recording of honey bees during the New Year's Eve 2019. Recording is starting at 5:03:00 AM and is lasting 15 seconds

Audio file 2. Recording of honey bees during the New Year's Eve 2019. Recording is starting at 9:40:00 AM and is lasting 15 seconds

Audio file 3. Recording of honey bees during the New Year's Eve 2019. Recording is starting at 00:22:55 PM and is lasting 15 seconds

Audio file 4. Recording of honey bees during the New Year's Eve 2019. Recording is starting at 01:53:50 PM and is lasting 15 seconds

Audio file 5. Recording of honey bees during the New Year's Eve 2019. Recording is starting at 03:16:35 PM and is lasting 15 seconds

Large audio file entitled "Honeybees New Year's Eve 2019 Favre". Full recording of the honeybees in the hive, starting 17.00 local time the 31st of December, 2019.

AUTHOR CONTRIBUTIONS

The first author is Dr. in Biology, teacher, independent researcher, apiary adviser in the canton de Vaud (Switzerland), president (since 2010) of the not-for-profit association Alerte Romande aux Rayonnements Artificiels (A.R.R.A., formerly A.R.A; www.alerte.ch), and member of the scientific advisory board of the not-for-profit association FreeTheBees (www.freethebees.ch). The second author is an Associate Professor, retired from the Karolinska Institute (in Nov 2017, still active), Department of Neuroscience, head of The Experimental Dermatology Unit, Stockholm, Sweden, and Adjunct Professor, previously at the Royal Institute of Technology, Stockholm, Sweden.

SOURCES OF FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

CONFLICT OF INTEREST

The authors have declared that no competing interests exist.

ACKNOWLEDGMENT

This work was performed under the full responsibility of the two authors. Daniel Favre is very grateful to Jean-Claude Perez, Ph.D. (Bordeaux, France) for his support in the correction of the manuscript. The International 5G Appeal (https://www.5gspaceappeal.org/) gave us the final inspiration for undertaking this current research study.

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EXCERPTS FROM EMAILS TO AND FROM A MOTHER AND AN FCC LAWYER

Key findings: The FCC could not find any recent reports by the WHO on 5G safety. It could not find any reports on long term effects of wireless and cell tower radiation to children.
Oct 27, 2021 FCC lawyer states, “If anyone has “studied what might happen to children if a cell tower is placed in front of their bedroom window,” it’s not here or anywhere else I’m aware of.”

In January of 2023 the mother wrote the FDA wanting to know about the safety of the cell tower on her street and Ellen Flannery of the Director of the Office of Policy Center for Devices and Radiological Health of the FDA stated, “We have reviewed the questions that you listed below. The Food and Drug Administration (FDA) does not regulate cell towers or cell tower radiation. Therefore, FDA has no studies or information on cell towers to provide in response to your questions.”

Links

- October 25, 2021 at 10:26:41 PM PDT shows the FCC lawyer realizing that the WHO has not put forward any updated report on RFR.
- Oct 24, 2021, at 9:55 PM there’s no updated WHO study to send to you.
- Oct 27, 2021 FCC lawyer states, “If anyone has “studied what might happen to children if a cell tower is placed in front of their bedroom window,” it’s not here or anywhere else I’m aware of.”
- October 19, 2021 Mother asks for Research and reports that the FCC was unable to provide to her showing safety
- January 7, 2022 FCC lawyer refuses to answer question about how he has determined FCC cell tower limits are safe.
- January 11, 2022 Ellen Flannery of the Director of the Office of Policy Center for Devices and Radiological Health of the FDA responds that the FDA does not regulate cell towers.
- January 18, 2022 at 5:48:46 AM PST FDA sends form letter saying the FCC regulates cell phone towers.
- January 24, 2022 FDA writes another email stating the FDA cannot provide infirmation
- **Mother repeatedly writes asking for a response- Note- all of these emails are not included in this document as there are several**
- March 1, 2022 at 9:36:28 AM PST Abiy Desta CDRH Ombudsman writes to state her “continued emails on issues that have already been addressed have exceeded the limits of what the FDA can do in response.”
- Mar 1, 2022, 5:43 PM Mother writes Mr. Abiy Desta CDRH Ombudsman with 3 questions
-

Mar 1, 2022, 5:43 PM Mother writes Mr. Abiy Desta CDRH Ombudsman with 3 questions

Dear Mr. Abiy Desta CDRH Ombudsman,

Thank you so much for writing. I truly appreciate that the FDA is reading my letters. However I simply cannot understand how the FDA would refuse to answer these simple questions related to its posted information on cell phone radiation. After all, transparency is the most important aspect of good government.

I ensured my questions simply need a yes or no response or a page number so I respectfully ask that you at least provide a response. After all, I have a cell tower in my front yard and so far, no federal entity can provide me the safety assurances any mother or neighborhood would want. They all point to the FCC, who points to the FDA so in fact you are the correct agency. If you are not them you should clarify that you have not done any risk evaluations in regards to cell towers and then send me to the agency that I should look to for expertise please.

I am making an inquiry because:

1. I wrote the FCC who expressly sent me to you - the FDA
   I received an email from Ellen Flannery on January 11, 2022 stating that, "We have reviewed the questions that you listed below. The Food and Drug Administration (FDA) does not regulate cell towers or cell tower radiation. Therefore, FDA has no studies or information on cell towers to provide in response to your questions."
2. I asked follow up questions that any mother and neighborhood would want to know the answer to but the FDA has not responded. My questions are the following:

So here are my 3 easy questions and I would like them responded to please.

1. Is the FDA literature review (link here) that you refer to in your emails to in your a proper “risk analysis” or “health effects evaluation” for wireless cell tower and cell phone radiation? (It looks like it just summarizes studies so im not sure how you calculated risk.) **Please respond yes or no.**

2. Are you saying this FDA literature review (according to your emails to me which repeatedly present this literature review) is an official “safety determination by the FDA” in regards to cell tower radiation? Cell towers create nonstop day and night full body exposures. Please confirm this literature review is or is not a safety evaluation. (and--- If it is just an evaluation for cell phones, please clarify, if it is for both phones and towers please clarify both. **Please answer simply yes or no.**

3. If it is a proper FDA safety evaluation or risk or hazard evaluation or determination of protection from FCC limits, please show me in the literature review where there is any evaluation of FCC human exposure limits for cell towers. What page please? I simply need you to share with me where the FDA evaluates this as again, the only report you have is a literature review but I see not comparison of the studies or any way you actually show you looked at the various studies and weighted them and calculated risk. **Please simply send the page number in the literature review (where you show an evaluation of the FCC cell tower maximum permissible levels and compare this to the scientific research findings).**

I ask these 3 important questions because the FDA attorney stated in its response to my question, “What US health agency has reviewed the totality of the research to ensure safety for my children?” that “As stated above EPA, NIOSH, OSHA, NCI and FDA post on their webpage each agency’s determination of the safety or radiofrequency energy exposure based on the available scientific evidence.” however the EPA, NIOSH, OSHA and NCI have not don any research review. In fact the FDA is the only agency that has any sort of documentation of even looking at the science. However all I see online is that literature review- now well outdated. Therefore I think it is only fair the FDA would answer me a simple yes or no answer.

March 1, 2022 at 9:36:28 AM PST Abiy Desta CDRH Ombudsman writes to state her "continued emails on issues that have already been addressed have exceeded the limits of what the FDA can do in response."

From CDRH Ombudsman <CDRHOmbudsman@fda.hhs.gov>

Date: March 1, 2022 at 9:36:28 AM PST

To: Lindley Residents <lindleyresidents4869@gmail.com>

Cc: CDRH Ombudsman <CDRHOmbudsman@fda.hhs.gov>

Subject: RE: [EXTERNAL] Re: No response 5g tower e-mail

Dear Ms. K and others,

First please allow me to introduce myself, my name is Abiy Desta, and I am the Ombudsman for the Center for Devices and Radiological Health (CDRH). In my role as Ombudsman for CDRH, I have reviewed your communications with various FDA officials over the past several months and I have concluded the FDA has made every attempt to respond to your questions. However, your continued emails on issues that have already been addressed have exceeded the limits of what the FDA can do in response.
I have requested FDA staff to forward future communication without response to the Office of the Ombudsman. You may continue to communicate with the CDRH Ombudsman office by email (CDRHOmbudsman@fda.hhs.gov); however, please be advised only messages that contain inquiries that have not been previously addressed and are relevant to FDA's regulatory authority will receive a reply.

Best regards,
Abiy Desta

Abiy Desta
CDRH Ombudsman
Center for Devices and Radiological Health
Office of Policy
U.S. Food and Drug Administration

Mother repeatedly writes asking for a response- Note- all of these emails are not included in this document as there are several

To Whom it may concern,

This is beyond frustrating that over 30 people are on this e-mail from government agencies and NO one can answer a pleading neighborhood for answers.

We are begging for answers:

1. Is the FDA literature review (link here) you refer to a risk analysis or health effects evaluation for wireless cell tower and cell phone radiation? (It looks like it just summarizes studies so im not sure how you calculated risk.)

2. Are you saying this FDA literature review makes an official "safety determination by the FDA" in regards to cell tower radiation? Cell towers create nonstop day and night full body exposures. Please confirm this literature review **is** or **is not** a safety evaluation. (and--- If it is just an evaluation for cell phones, please clarify, if it is for both phones and towers please clarify both.

3. If it is a proper FDA safety evaluation or risk or hazard evaluation or determination of protection from FCC limits, **please show me in the literature review where there is any evaluation of FCC human exposure limits for cell towers. What page please?**

Sincerely,
Natalie K.

On Jan 24, 2022, at 6:09 AM, Flannery, Ellen <Ellen.Flannery@fda.hhs.gov> wrote:

Subject: RE: [EXTERNAL] Re: NO Response: 5g Tower e-mail

Dear Ms. K.

Please find the responses to your questions to FDA below:

"… which U.S. health and safety agency does have accountability on this issue- cell towers, small cells and 5G networks".
The Food and Drug Administration (FDA) is responsible for protecting the public from hazardous or unnecessary radiation exposure from radiation emitting electronic products. More information on FDA's radiological health program can be found here. The Federal Communication Commission (FCC) has jurisdiction over all radiofrequency transmitting structures in the United States (for additional information please see link here). The FCC is the U.S. government agency that is responsible for making sure radiofrequency transmitting structures meet radiofrequency energy exposure guidelines it adopted. The exposure guidelines are based on thresholds for known biological effects, and they incorporate prudent margins of safety. In adopting the current radiofrequency energy exposure guidelines, the FCC obtained input from the Environmental Protection Agency (EPA), the National Institute for Occupational Safety and Health (NIOSH), the Occupational Safety and Health Administration (OSHA) and FDA. EPA (link here), NIOSH (link here), OSHA (link here) and FDA (link here) all maintain websites to inform the public on the safety of radiofrequency energy exposure. In addition The National Cancer Institute also maintains a website on the safety of radiofrequency energy exposure (link here).

"What US health agency has reviewed the totality of the research to ensure safety for my children?"
As stated above EPA, NIOSH, OSHA, NCI and FDA post on their webpage each agency's determination of the safety or radiofrequency energy exposure based on the available scientific evidence.

"*Does the FDA issue a scientific literature review on cell phones and radiofrequency radiation (RFR) and cancer apply to cell towers?"*
While FDA's primary focus has been on devices emitting radiofrequency energy close to sensitive organs such as the human brain, FDA has reviewed a number of the animal studies that looked at life time exposure to radiofrequency energy. The length of radio frequency energy exposure in these studies is similar to exposure one may get from radiofrequency energy transmitting structures.

"…FDA's doctors, scientists and engineers monitor the scientific studies and public health data for evidence that radiofrequency energy from cell phones could cause adverse health effects." Where are the reports of such monitoring? Which studies do you look at? When you say monitor what does this mean? Do you have meetings or presentations? If so, where can I find the details of such monitoring?"
Please see FDA's review of published the literature between 2008 and 2018. This review was conducted in 2019 and published in February 2020 https://www.fda.gov/media/135043/download. This is the most current publication the FDA has put out on the safety of radio frequency energy.

"…*There is no consistent or credible scientific evidence of health problems caused by the exposure to radiofrequency energy emitted by cell phones." Please share with me where you and the FDA staff substantiate such a conclusion? Does the FDA have a report of the studies they evaluated to develop this conclusion of no evidence?"*
Please see report referenced above. Please note the conclusions reached by the FDA are consistent with the conclusions reached by other health agencies that have evaluated the available scientific literature.

"…Also why are these towers placed on our street without our knowledge? How is this acceptable?"
FDA does not have regulatory authority over the placement of radio frequency emitting structures. For additional information please see FCC's website on the topic here.

Ellen J. Flannery, J.D.
Deputy Center Director for Policy
Director, Office of Policy

Center for Devices and Radiological Health
Office of Policy
U.S. Food and Drug Administration
Tel: 301-796-5900
Ellen.Flannery@fda.hhs.gov

FDA U.S. FOOD & DRUG ADMINISTRATION

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https://www.research.net/s/cdrhcustomerservice?ID=5000&S=E

January 18, 2022 at 5:48:46 AM PST FDA sends form letter saying the FCC regulates cell phone towers.

From: DICE@fda.hhs.gov
Date: January 18, 2022 at 5:48:46 AM PST
To: lindleyresidents4869@gmail.com
Subject: Support at FDA/DICE Re:Re: NO Response: 5g Tower e-mail [ref:_00Dd0fegA._500t0wJKwF:ref]

Dear Ms. XXXREDACTED

Thank you for contacting the Division of Industry and Consumer Education (DICE) at FDA's Center for Devices and Radiological Health (CDRH) DICE@fda.hhs.gov e-mail account.

You are inquiring about cell phones and specifically cell towers.

The Federal Communications Commission (FCC) regulates systems such as cell phone towers. Exposure levels from cell phone towers must comply with the FCC's radiofrequency (RF) radiation exposure guidelines, which were developed to protect the public from RF-related health risks. You can find more information about cell phone tower siting on the FCC Tower and Antenna Siting Issues page.

Additionally, the FDA has some resources available for you related to cell phones online:

Cell Phones
https://www.fda.gov/radiation-emitting-products/home-business-and-entertainment-products/cell-phones

Scientific Evidence for Cell Phone Safety
https://www.fda.gov/radiation-emitting-products/cell-phones/scientific-evidence-cell-phone-safety

Reducing Radio Frequency Exposure from Cell Phones
https://www.fda.gov/radiation-emitting-products/cell-phones/reducing-radio-frequency-exposure-cell-phones

Radio Frequency Radiation and Cell Phones
https://www.fda.gov/radiation-emitting-products/cell-phones/radio-frequency-radiation-and-cell-phones

Sincerely,
Consumer Team
Division of Industry and Consumer Education
Office of Communication and Education
Center for Devices and Radiological Health
U.S. Food and Drug Administration

January 11, 2022 Ellen Flannery of the Director of the Office of Policy Center for Devices and Radiological Health of the FDA responds that the FDA does not regulate cell towers.

January 11, 2022 at 3:59 PM
From Ellen.Flannery@fda.hhs.gov to XXX Mother readcted

Dear Ms. XXX Redacted

I have read your emails, and I appreciate your questions and concern for your family and neighbors.

We have reviewed the questions that you listed below. The Food and Drug Administration (FDA) does not regulate cell towers or cell tower radiation. Therefore, FDA has no studies or information on cell towers to provide in response to your questions.

Howard Griboff of the FCC previously explained to you (November 21) that RF exposure from a cell phone is higher than from a cell phone tower, which is why you are finding that studies focus on cell phone RF exposure.

As you are aware, FDA issued a scientific literature review on cell phones and radiofrequency radiation (RFR) and cancer, which can be found here: https://www.fda.gov/media/135043/download In that review, FDA stated: "Based on the studies that are described in detail in this report, there is insufficient evidence to support a causal association between RFR exposure and tumorigenesis. There is a lack of clear dose response relationship, a lack of consistent findings or specificity, and a lack of biological mechanistic plausibility."

Additionally, the FDA's doctors, scientists and engineers monitor the scientific studies and public health data for evidence that radiofrequency energy from cell phones could cause adverse health effects. There is no consistent or credible scientific evidence of health problems caused by the exposure to radiofrequency energy emitted by cell phones.

The people who are experiencing the symptoms you mentioned might wish to consult a physician about how best to address those symptoms.

Thank you for contacting FDA.

Sincerely,
Ellen

Ellen J. Flannery, J.D.
Deputy Center Director for Policy
Director, Office of Policy

Center for Devices and Radiological Health

Office of Policy

U.S. Food and Drug Administration

Tel: 301-796-5900

Ellen.Flannery@fda.hhs.gov

U.S. FOOD & DRUG ADMINISTRATION

Excellent customer service is important to us. Please take a moment to provide feedback regarding the customer service you have received:
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January 10, 2022 Letter from XXX mother to FDA

Kassiday, Daniel F. H. <Daniel.Kassiday@fda.hhs.gov>; Shuren, Jeff <Jeff.Shuren@fda.hhs.gov>; Flannery, Ellen <Ellen.Flannery@fda.hhs.gov>

Dear Mr. Shuren and Mr. Kassiday,

This my 2nd attempt to get some answers. I wrote with NO response!

I hope you can help desperate mothers/fathers looking for help! I have been looking for answers for the last two years with every instituion transferring me over from place to place. With No answers or help!

Howard Griboff who works at the FCC, says you will be able to help me with the answers my neighborhood is seeking. If you can NOT then I want to understAnd your logic for allowing 5g towers in residential areas where children sleep and play. Will you take the liability if children get sick? I am also astonished you are allowing these up during an ongoing pandemic!

The FCC has stated that you are ensuring FCC limits are safe. However I do not see any reports on cell tower radiation on your website or on long term exposure of radiofrequency. I had some specific questions

1. Does the FDA have authority over cell tower radiation and "small" cells? If so please share where I can find this in the law.
2. Where is the FDA report that reviewed the research on cell tower radiation and included science beyond cancer- such as impacts to children's developing brains, DNA damage, fertility effects, headaches and oxidative stress.
3. Where is the FDA report that has reviewed FCC limits as all I see is a literature review on cell phones and cancer, but this is not an FCC limit review for cell tower network emission limits. Please send me the link.
4. Can you share research studies on cell phone towers and people that show long term exposure is safe please. Do any studies exist?
5. If the FDA is not the agency that ensures protections from cell tower radiation --then which U.S. health and safety agency does have accountability on this issue?
6. What US health agency has reviewed the totality of the research?
7. Who do I contact about the headaches and nosebleeds? Where do I submit a report on these symptoms clearly related to the cell antennas?

Thanks for your immediate help,
Sincerely,

XXX Mother

On Jan 7, 2022, at 1:41 PM, FCC lawyer redacted @fcc.gov> wrote:

XXX Redacted – we've covered your questions in multiple emails over the past year. Please ask the FDA your questions related to the FDA. I'm unable to engage in this back-and-forth further without new engineering data showing that the small cell on Lindley exceeds the maximum permissible exposure limits currently in effect for the transmitted frequencies, and will not further reply.

Have a great weekend –
XXX FCC Lawyer redacted

From: Mother-redacted
Sent: Friday, January 7, 2022 12:37 PM
To:FCC lawyer @fcc.gov>
Cc includes: ellen.flannery@fda.hhs.gov; Tonya.Wilbon@fda.hhs.gov; Michael Owens <michael.owens@lacity.org>; brad.sherman@mail.house.gov; garnet.hanley@fcc.gov; Donald Johnson <Donald.Johnson@fcc.gov>; Terri.Garvin@fda.hhs.gov; asa4@cdc.gov; CMcCurley@cdc.gov; KPollard@cdc.gov; jdbO@cdc.gov; Daniel.Kassiday@fda.hhs.gov; Bakul.Patel@fda.hhs.gov; Brian.Beard@fda.hhs.gov; Michael.OHara@fda.hhs.gov; Mary.Pastel@fda.hhs.gov; Robert.Ochs@fda.hhs.gov; Jeff.Shuren@fda.hhs.gov; byw3@cdc.gov; Mark@keepcellantennasaway.org; Eric <enk21@yahoo.com>
Subject: Re: Your latest email

Hi XXX redacted FCC Lawyer

Thank you for the response. However, the tower will never exceed the 10,000,000 m2 the U.S allows, because it is set so high. I have spoken to many engineers. Is that why you place the standards so high so you never have to look into these towers?

Why are our radiation set higher then any other country? Now, you have told me in numerous e-mails that you have NO data supporting the fact that these towers are safe?

How do you allow yourself as a LAWYER for the FCC to take the liabilty if you have NO research to back up that it safe for my kids to sleep near one of these?

Howard, you do NOT know me, but as a Mother, I will NOT stop and will get as many people involved till you prove to me this is safe (which you have NOT) and remove it!

You said"the Lindley small cell does not exceed the FCC's maximum permissible exposure limits that have been deemed by the FDA not to show adverse health effects in humans"

However the FDA has not reviewed the limit for cell towers.. or has it? You said their was NO report? So how can you be so sure? How can mothers sleep at night if you have no report to back up your statements?

Is NOSE BLEEDS, Headaches, people moving, nauticious not enough for you? What else would you need? Why wouldn't the FCC take the time to check this tower? Isn't that your job to keep us safe?

Can you please share:

1. Where the FDA has authority over cell tower radiation
2. The FDA report that reviewed the research (including)on cell tower radiation
3. The FDA report that has reviewed FCC limits.

Does the FCC have these FDA reports? **-as you are alluding to such FDA reports?**

Many from the FDA are on this e-mail.

If you do NOT have answers you should NOT allow these on residential streets. Howard I am not sure if you are a father but where is the empathy for us mothers who have to fight these towers while our kids are home 24/7 during a pandemic?

Have a great day,
-Mother Redacted

On Nov 9, 2021, at 6:21 AM, [FCC Lawyer@fcc.gov]> wrote:
[REDACTED NAME] –

Since base station exposure levels typically are much lower than the exposure from cell phones, the bulk of research in this area is on the cell phones. Thus, the lack of US government reports on the base stations.

In any case, debating what studies say and whether particular reports exist does not change the fact that the radiated power from the Lindley small cell does not exceed the FCC's maximum permissible exposure limits that have been deemed by the FDA not to show adverse health effects in humans. Unless you can show that the Lindley small cell is operating higher than the FCC's maximum permissible exposure specifications, we have no legal authority or ability to help you. That's the information we need to continue this conversation.

I'm sorry I can't engage in this back-and-forth any further without new engineering data.

Take care,
[FCC Lawyer@fcc.gov]

From: [REDACTED NAME] K. <[REDACTED EMAIL]>
Sent: Monday, November 8, 2021 11:35 AM
To: [FCC Lawyer@fcc.gov]>
Subject: [EXTERNAL]: Re: Wait wait wait. I need to correct a few things here before I sign off for good.

CAUTION: This email originated from outside of the Federal Communications Commission. Do not click on links or open attachments unless you recognize the sender and trust the content to be safe. If you suspect this is a phishing attempt, please use the 'Report Message' feature in Microsoft Outlook or forward the email to the NSOC.

[FCC Lawyer@fcc.gov],

Thank you for always taking the time to answer my questions. Hope you had a great weekend and Shabbat. I will get an engineer shortly to measure the tower again in the meanwhile I have a few unanswered questions:

1) First you are dismissing the European Parliament report because it focuses **more on cell phones**, yet the FDA report suffers from the same problem. Why not say the same thing about the FDA report? The FDA report says it is focused on cell phones but then generalizes to Radiofrequency in general.

Plusthe FDA report pages 89 DO NOT SHOW CELL TOWERS are safe .What is your point? These are little rat /mice/ and rabbit studies that did short term exposures. My neighborhood is getting long term exposure??

Where is the US government report that focuses on cell towers? That is what I have been asking for and the FCC should have access to such a thing right?

A carcinogen is bad if my family is saturated day and night. Even at a low level, it is non stop.
I am looking for any US report that shows safety if a cell tower is feet away from the home.

2. Both CDMA and GSM caused cancer in the NIH rats! Are you saying there is a difference? If so then how you even for a heartbeat say 4G and 5G are safe as they are new technologies???

Please help me [FCC Lawyer@fcc.gov],
MY neighbors and I have NOT slept in weeks worrying about this!!

Thanks,
[REDACTED NAME] K.

On Nov 5, 2021, at 3:01 PM, [FCC Lawyer@fcc.gov]> wrote:

Hi [REDACTED NAME] – that was a large document to digest – thank you for bringing it to our attention.

The document isn't quite on point to our discussion, as the bulk of the studies and discussion is concerned with wireless phones – not the small cell infrastructure in the wireless network that's the source of your concern. For example, see section 7.1 ("The source of RF emissions that seems at present to pose the greatest threat is the mobile phone. Though transmitting installations (radiobase masts) are perceived by some people as providing the greatest risk, actually the greatest burden of exposure in humans generally derives from their own mobile phones, and epidemiological studies have observed a statistically significant increase in brain tumours and Schwann cell tumours of the peripheral nerves, mainly among heavy cell-phone users.").

The only study related to base stations that I can find in the document, in section 5.1.2, is a study on 2448 rats reproducing the environmental exposure to RF-EMF generated by 1.8 GHz GSM antenna at radio-base stations. However, there's no detail on the data points we've discussed (the distance of the rats from the base station transmitter, the power of the transmitter, the MPE limits involved), and in any case, GSM is a European standard, not used in the U.S. with the proliferation of CDMA and LTE here, so there's no way to apply any of the GSM results to the U.S. standards. [Note that the U.S. carriers are planning to phase out CDMA in 2022]

As to your questions about the FDA report, I was referring you to the entirety of pages 89 through 113 (the entire list of References), not just pages 89 and 113.

Regarding the "cell towers or this 5G technology that I hear uses millimeter waves," you are referring to as-yet unused frequencies for wireless services. See Section 6.2 of the document you sent stating that there's little literature exploring the possible adverse effects on health from use of the millimeter wave frequencies. These would not be the frequencies operating at the Lindley small cell.

Finally, although I'm glad to see you're doing your own research, sending studies to us will not change our ability to legally have the small cell on Lindley shut off. Again: if you can send us new engineering data showing that the small cell on Lindley exceeds the maximum permissible exposure limits currently in effect for the transmitted frequencies, I/we will be able to respond accordingly. I've enjoyed the challenge of thinking about and answering your questions while I've had the time to do so; now I need to focus on newly-assigned projects.

[FCC Lawyer@fcc.gov]

On Oct 27, 2021, at 2:14 PM, [REDACTED NAME] K. <[REDACTED EMAIL]> wrote:
Wait [FCC Lawyer@fcc.gov]. Page 89 of the FDA report literally nothing about cell towers or this 5G technology that I hear uses millimeter waves.
pls page 113 has a Swedish and Netherlands Report Why are you sending me this? I am looking for USA reviews by top experts.

Do you know what I just found! a report from the European Parliament saying this radio frequencies probably cause cancer! PROBABLY See it here please Health Impact of 5G!
https://www.europarl.europa.eu/RegData/etudes/STUD/2021/690012/EPRS_STU(2021)690012_EN.pdf

Our children should be safe and our government should be looking at this with its top health experts. What do I do now? If the EPA sends me to you. The FDA has nothing on cell towers?
I appreciate your help but there is a cell tower outside my children's bedroom window. How do I keep them safe? Please tell me your thoughts? I am assuming you are a father, what would you do?

Please tell me who to contact at the FCC please.

Thanks,
[REDACTED NAME] K.

On Oct 27, 2021, at 12:47 PM, [FCC Lawyer@fcc.gov]> wrote:
YOU asked me about the EPA so I recommended you reach out there, since we don't speak for another agency. If they send you back to the FCC, that means they rely on our expertise. You should too.

I sent you what we have from the FDA, a federal health and safety agency. Read the entire 113 page report. Review pages 89-113 for citations to all of the relevant studies on your topic. If what you're looking for isn't there, then the FDA doesn't have one.

We searched broadly at your request and did not find anything else beyond what we sent you >> it's entirely possible there's nothing else to find, and you need to be at peace with that.

We are not a health agency and we are not responsible for answering on behalf of a health agency. Stop asking us to do so.

I assure you that my supervisor knows less about this than I do, as my working with you has educated me on these issues more than any attorney in the Office of Engineering and Technology. For that, I thank you.

From: [REDACTED NAME] K. <[REDACTED EMAIL]>
Sent: Wednesday, October 27, 2021 2:52 PM
To: [FCC Lawyer@fcc.gov]>
Subject: [EXTERNAL]: Re: We've come to an end of our discussion

[FCC Lawyer@fcc.gov],

You have been amazing and very patient. I appreciate that. Even though I do not personally know you, I feel grateful for that! I hope to meet you one day!

[FCC Lawyer@fcc.gov], you need to understand before anything I am a mother and that comes before my other priorities. I am here to protect my children. As your mother did for U!

[FCC Lawyer@fcc.gov], I just wrote you an email stating that the EPA- **which you sent me to-** says to go to the FCC.
I asked you for a report by a federal health and safety agency on cell tower radiation and you so far have not been able to find it. Why is that??

Your agency- the FCC- is allowing this tower in front of my home and **its radiation emissions are penetrating into my home and my children's rooms-** so your agency is RESPONSIBLE to answer my questions as to what health agency has reviewed the science on safety.

If you cannot answer my questions on where the safety report is **then please tell me to whom I can write? Surely someone at the FCC can answer this question! Maybe your manager- who do you report to!? I have asked a few times!!!**

Thanks [FCC Lawyer@fcc.gov],
Appreciate the help
[REDACTED NAME] K

Oct 27, 2021 FCC lawyer states

"If anyone has "studied what might happen to children if a cell tower is placed in front of their bedroom window," it's not here or anywhere else I'm aware of."

On Oct 27, 2021, at 10:43 AM, [FCC Lawyer@fcc.gov]> wrote:
Well [REDACTED NAME], I've patiently sent you everything I possibly could to answer your questions. My colleagues and I have spent numerous hours, gone well beyond the FCC's files for you, and sent multiple documents and web pages, including detailed engineering studies and health policy statements, with experts backing up everything I have relayed to assure you that the FCC is on top of the issues, so that you'd know you and your neighborhood are safe from the small cell on Lindley. Read all of that material in its entirety. Research the

supporting footnotes.   Anyone who refers this issue to us (for example, apparently the EPA) does so because our engineers can be relied on to protect the public. If anyone has "studied what might happen to children if a cell tower is placed in front of their bedroom window," it's not here or anywhere else I'm aware of. As you surmise, there may not be such studies. But it's now up to you. And based on all of the facts you have presented, and electrical engineering science in general, the FCC has no legal basis to have the small cell on Lindley turned off.

I won't waste any more of your time. Please stop contacting me or anyone else at the FCC unless you have ***new engineering data*** showing that the small cell on Lindley exceeds the maximum permissible exposure limits currently in effect for the transmitted frequencies. Then we'll have something to talk about. Otherwise, I will not be responding to your emails from hereon.

Good luck with your crusade,
[FCC Lawyer@fcc.gov]

From: [REDACTED NAME] K. <[REDACTED EMAIL]>
Sent: Wednesday, October 27, 2021 11:48 AM
To: [FCC Lawyer@fcc.gov]>
Subject: Re: Hi [REDACTED NAME] -

[FCC Lawyer@fcc.gov],

I think we have discovered something. No one studied what might happen to children if a cell tower is placed in front of their bedroom window! **What happened to the US government! Surely this CANNOT BE! How can my family and neighborhood feel safe, please tell ME????**

[FCC Lawyer@fcc.gov], **the EPA website just sends me to the FCC!**
See what the EPA says on their websites below- "go to FCC" . **So that's why I'm going to you.**Surely someone at the FCC knows where a report is by an American agency !

The FDA has no information on cell towers [FCC Lawyer@fcc.gov]! The EPA sends me to the FCC!
So exactly what US agency IS watching the research!

The EPA sends me to the FCC and you are an FCC expert! - And you can't even find a single report by a United States Agency to show cell towers are safe!!!!!!
Where is a report that looks at published science FROM THIS CENTURY on cell tower day and night radiation and kids brain development?

Where is the US government review of cell tower radiation?

Surely for me and my family, the FCC has a report by some American health agency that looked at children health and cell towers? Are you telling me you don't know where to find one? There is a 5G cell tower IN FRONTof my home and the US government has zero safety studies on 5G and on cell towers?

EPA website: "Where can I find information about living near a cell phone tower?"
https://www.epa.gov/radiation/where-can-i-find-information-about-living-near-cell-phone-tower
says--"The Federal Communications Commission (FCC) regulates systems such as cell phone towers. Exposure levels from cell phone towers must comply with the FCC's radiofrequency (RF) radiation exposure guidelines, which were developed to protect the public from RF-related health risks. You can find more information about cell phone tower siting on the FCC Tower and Antenna Siting Issues page."
EPA Website: "Where can I find information about cell phone safety concerns?"
https://www.epa.gov/radiation/where-can-i-find-information-about-cell-phone-safety-concerns
says--- "The Federal Communications Commission (FCC) has adopted exposure limits to RF energy with which all

cell phones legally sold in the United States must comply. These limits are expressed in Specific Absorption Rate (SAR), which is a measure of the amount of RF energy absorbed by the body while using a mobile phone. For more information, please visit the FCC Wireless Phone FAQs and the FCC Wireless Devices Health Concerns Consumer Facts webpage."
Why are you sending me *another* World Health Organization webpage! *They have not done any researc*h and not even looked at this issue or at least you can't find any report by them! If they are not scientifically studying this issue they certainly can't have an opinion. All I see are these cute little WHO webpages - like the 2006 page you sent- **but no research to back it up!!**

[FCC Lawyer@fcc.gov] at this point with everything that my engineer and I have presented, as I know you have the authority, if you don't please send me to SOMEONE who does? All agencies point to the FCC. I called the WH0 yesterday and they told me to contact the FCC. Please stop waisting my time- i have children to take care of. Once again Please turn this off Immediately. You have 0 research on the side affects and long term affects it will have on my children and grandchildren.

Thanks,

[REDACTED NAME] K.

Email October 25, 2021 at 10:26:41 PM PDT- FCC lawyer admits WHO has not reviewed research with any report he could find.

From: [FCC Lawyer@fcc.gov]>
Date: October 25, 2021 at 10:26:41 PM PDT
To: "[REDACTED NAME] K." <[REDACTED EMAIL]>
Subject: RE: Hi [REDACTED NAME] -

[REDACTED NAME], correction: I am an attorney. I am not an engineer.

I received your voicemail.

To answer the questions from your most recent email:

- **There is no currently-released WHO research report. The WHO is completing a study with a 2022 release date.**
- **I forwarded a pdf of the FDA report last week. That document, comprising 113 pages, reviews the published literature between 2008 and 2018 of relevance to radiofrequency radiation and cancer.**
- **I do not have any contacts at the WHO. I refer you to two links on its public website: https://www.who.int/about/contact-us; https://www.who.int/about/collaborations-and-partnerships/who-office-at-the-united-nations.**
- **The WHO uses ICNIRP material as well as IEEE material for the information presented on its website Q&A on the issue. I sent you a pdf of the ICNIRP's guidelines last night, which is in the *National Institute of Health* library. I also sent a pdf of IEEE's review paper.**
- **The ICNIRP material has references to health studies used to arrive at its guidelines.**
- **You may find the ICNIRP guidelines' discussion of protections for children, pregnant women, sick and elderly people informative.**

[REDACTED NAME], the FCC is not a health agency. You need to contact the other agencies directly for information on the specific investigations or public health reports you seek, if any.

The FCC is a technology and engineering agency. My colleagues and I have tried to help you understand how the FCC applied the data from your submitted engineering study to our rules. Unless you present us with new engineering data showing that the small cell on Lindley is operating above the maximum permissible exposure limits, there is nothing else I can do for you.

Good luck,
[FCC Lawyer@fcc.gov]

From: [REDACTED NAME] K. <[REDACTED EMAIL]>
Sent: Monday, October 25, 2021 2:18 PM
To: [FCC Lawyer@fcc.gov]>
Subject: Re: Hi [REDACTED NAME] -

Hi [FCC Lawyer@fcc.gov],

Thanks for writing, and as always thanks for your help. However, I feel as though mine and my engineers questions were NOT answered.

[FCC Lawyer@fcc.gov] I believe you are an engineer for the FCC
So [FCC Lawyer@fcc.gov], as I read your information yesterday, you are telling me there are no reports by the World Health Organization and FDA that you could find? No research reviews? I do not want an engineer report! I want public health reports. ***Are you telling me the WHO and FDA have not looked at this?***

- **I asked you "Can you please tell me where the study is that the World Health Organization did to make a determination on safety and to conclude there is no harm? "and you said "** ***let's go back to the WHO Q&A for "Radiation: 5G mobile networks and health," https://www.who.int/news-room/q-a-detail/radiation-5g-mobile-networks-and-health (link provided here again for your convenience). See the last question, which says "WHO is conducting a health risk assessment from exposure to radiofrequencies, covering the entire radiofrequency range, including 5G, to be published by 2022." So there's no updated WHO study to send to you. " [FCC Lawyer@fcc.gov]. How can the World Health Organization say on its website that cell towers are safe when they do not have a research report on the radiation?. Does this make sense to you? Is there anyone I can contact there? I need this done ASAP as time is of the essence.***
- **I asked you, "Can you share with me a US government report that shows they looked at risk to children? You say there are studies that show safety, but where is the big research report - a risk assessment- where they looked at the research to see if radiation can increase our children's risk of cancer and brain damage?" and you did not respond.** ***Is there an FDA or EPA investigation into cell tower radiation or children..or any US government report please that looked at brain damage to kids?***

Please Explain? As the lack of knowledge is very concerning.

Thank you,
[REDACTED NAME] K.

Oct 24, 2021, at 9:55 PM there's no updated WHO study to send to you.

On Oct 24, 2021, at 9:55 PM, [FCC Lawyer@fcc.gov]> wrote:
Hi [REDACTED NAME] –

Not hard to access. Hard to find time among my other projects.

First off, this link to a Dec 2020 report from Deloitte provides an excellent lay-person's summary of the issues that we've been discussing:
https://www2.deloitte.com/xe/en/insights/industry/technology/technology-media-and-telecom-predictions/2021/5g-radiation-dangers-health-concerns.html.

Next, let's go back to the WHO Q&A for "Radiation: 5G mobile networks and health," https://www.who.int/news-room/q-a-detail/radiation-5g-mobile-networks-and-health (link provided here again for your convenience). See the last question, which says "WHO is conducting a health risk assessment from exposure to radiofrequencies, covering the entire radiofrequency range, including 5G, to be published by 2022." So there's no updated WHO study to send to you.

So we look at the answer to the prior question on the Q&A, which notes "Two international bodies produce exposure guidelines on electromagnetic fields. Many countries currently adhere to the guidelines recommended by: The International Commission on Non-Ionizing Radiation Protection (*ICNIRP*) and The Institute of Electrical and Electronics Engineers (*IEEE*), through the International Committee on Electromagnetic Safety."

***ICNIRP:* I'm sending the attached ICNIRP March 2020 guidelines for limiting exposure to electromagnetic field for the protection of humans exposed to radiofrequency electromagnetic fields in the range 100 kHz to 300 GHz. These guidelines cover many applications such as 5G technologies, WiFi, Bluetooth, mobile phones and base stations, and apply to any possible frequencies used by the small cell on Lindley. ICNIRP works with the WHO and this guidelines release is an example of the studies that WHO relies on for its answers on the above-referenced Q&A page. The ICNIRP homepage provides further information: https://www.icnirp.org/en/activities/news/news-article/rf-guidelines-2020-published.html. Moreover, the Frequently Asked Questions related to the ICNIRP RF Guidelines 2020 answer many of your questions, including protections for children, pregnant women, sick and elderly people. https://www.icnirp.org/en/rf-faq/index.html. It's important to point out here that ICNIRP acknowledges that non-ionizing radiation *can* harm humans and the purpose of the guidelines is to set the limits where no harm would occur through exposure. The FCC's limits are conservative and do not cause harm under these guidelines.**

***IEEE:* I already sent you the latest info from IEEE's Committee on Man and Radiation, but here is a link to the Aug 2020 published version of the article (I had sent you a pre-published version): https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7337122/. I'm attaching a new pdf for easy reading. As you see, this article appears on the website of the National Center for Biotechnology Information (NCBI), under PubMed Central® (PMC), an archive of biomedical and life sciences journal literature at the U.S. National Institutes of Health's National Library of Medicine (NIH/NLM).**
[REDACTED NAME], there's no more I can do for you here at the FCC. I have sent you more than enough information from various reputable sources to support the FCC's application of the RF exposure limits to your situation. Please take the time to carefully review with your engineers everything I've sent.

Kind regards,
[FCC Lawyer@fcc.gov]

October 19, 2021 Mother asks for Research and reports

From: [REDACTED NAME] K. <[REDACTED EMAIL]>
Sent: Tuesday, October 19, 2021 11:42 AM
To: [FCC Lawyer@fcc.gov]>
Subject: Re: Hi [REDACTED NAME] -

[FCC Lawyer@fcc.gov],

Good Morning! Thank you for always being kind and answering my questions. The engineer that I am working with has been explaining to me this new technology- always tells me that cancer is on the rise especially in young children because of these cell towers so close in proximity to the home. Please clarify where I can find and show him the below information:

1. **Can you please tell me where the study is that the World Health Organization did to make a determination on safety and to conclude there is no harm? Do they have a report like the FDA where they look at studies? If NOT how can we be sure these "small cells" are safe in close proximity to our homes?**
2. **Can you share with me a US government report that shows they looked at risk to children? You say there are studies that show safety, but where is the big research report - a risk assessment- where they looked at the research to see if radiation can increase our children's risk of cancer and brain damage? Research is key when making an argument [FCC Lawyer@fcc.gov]. You keep pointing me back to the FCC website- their research is from 1996, which in my opinion since it is 25 years old should be null and void!**

Please share that information as I am only reading reports of the harm it does. I want to see a physical report like LADWP can share when questions are asked. Please share as soon as you can as I really looking for some answers before pursuing my next move.

As always thank you,
[REDACTED NAME] K.
From: [FCC Lawyer@fcc.gov]>
Date: October 18, 2021 at 7:50:04 PM PDT
To: "[REDACTED NAME] K." <[REDACTED EMAIL]>
Subject: RE: Hi [REDACTED NAME] -
Hi [REDACTED NAME],

Yes, the county council has approved small cells to be installed throughout my neighborhood. I'm not concerned.

As friends do, we'll have to agree to disagree regarding the extent of my empathy and the months-long efforts of many FCC staff from different bureaus who have answered your questions respectfully - in some cases, multiple times - to no avail. G-d prefers I help you and your neighbors by unravelling the misinformation from the facts. For example, in the link you sent today, the doctors have no basis in fact or science to connect 5G small cells to "microbots" and radiation emitting from vaccinated people. In comparison, we refer you to the medical expertise of the World Health Organization, https://www.who.int/news-room/q-a-detail/radiation-5g-mobile-networks-and-health (from Sept 2020) ("[t]o date, and after much research performed, no adverse health effect has been causally linked with exposure to wireless technologies"). More info from 2020 is attached, from the Institute of Electrical and Electronics Engineers' Committee on Man and Radiation, and the FDA's Center for Devices & Radiological Health. As you see, there is plenty of recent peer-reviewed data generated worldwide that supports the FCC's current

approach.

So, as before, based on the facts and data you've presented, and the rules currently in effect, we have no legal grounds to have the small cell site on Lindley turned off. If, after all of your emails with the FCC through today, you still want to pursue your agenda, you'll need to continue with your next path.

...
[FCC Lawyer@fcc.gov]

From: [REDACTED NAME] K. <[REDACTED EMAIL]>
Sent: Monday, October 18, 2021 12:45 AM
To: [FCC Lawyer@fcc.gov]>
Subject: Re: Hi [REDACTED NAME] -

Hi [FCC Lawyer@fcc.gov],

I just thought of something since I consider you a friend I wanted to know if you have a small cell tower near your home? My neighbors feels like a higher up like yourself should live near one before us civilians do. Why should be expected to live near one and our children be guinea pigs?

Please look below, more evidence of doctors saying the exact symptoms my neighbors are getting. [FCC Lawyer@fcc.gov] please do the right thing? I would hope because you are big believer in G-D that HASHEM would lead you to make the right decision.
https://rumble.com/vnvarf-doctors-call-for-an-immediate-stop-of-5g.html

Thanks,
[REDACTED NAME] K

From: [REDACTED NAME] K. <[REDACTED EMAIL]>
Sent: Saturday, October 16, 2021 1:37 PM
To: [FCC Lawyer@fcc.gov]>
Subject: Re: Hi [REDACTED NAME] -

[FCC Lawyer@fcc.gov],

...

[FCC Lawyer@fcc.gov] who is your supervisor I would like to make the FCC aware of how I am turning blue in the face with NO care from the FCC. I would like my neighborhood heard. Who can i talk to? If you say NO one I will be sure to find someone on my own.

I am really upset that the FCC can care less that my neighbors are having symptoms and your only response is "I am sorry" [FCC Lawyer@fcc.gov], as a Federal organization , that reports to the Government that should not be allowed "ooo I am sorry" your neighbors are sick basically Tuff luck! What??? How is that acceptable?? You tell me?? Are you for the people or do you discriminate and are only for corporations that pay the FCC big $$$$? I am confused! Because Michael Owens from Bob Blumfield kept saying the same thing? He will also be held accountable for all the time of mine he waisted during an ongoing pandemic.

The FCC lost a lawsuit and refuse to take action, so someone in my eyes needs to be held accountable till the FCC can produce more up to date information? I am not arguing, I am explaining to you what I will use in

my court case.

I will continue with my next path…unless you will turn this site off till you can produce up to date knowledge on how it is safe?

[FCC Lawyer@fcc.gov] looking for a response immediately.

I hope you have a wonderful weekend,
[REDACTED NAME] K.

Review Article

Lennart Hardell* and Michael Carlberg

Lost opportunities for cancer prevention: historical evidence on early warnings with emphasis on radiofrequency radiation

https://doi.org/10.1515/reveh-2020-0168
Received December 16, 2020; accepted January 30, 2021;
published online February 15, 2021

Abstract: Some historical aspects on late lessons from early warnings on cancer risks with lost time for prevention are discussed. One current example is the cancer-causing effect from radiofrequency (RF) radiation. Studies since decades have shown increased human cancer risk. The fifth generation, 5G, for wireless communication is about to be implemented world-wide despite no comprehensive investigations of potential risks to human health and the environment. This has created debate on this technology among concerned people in many countries. In an appeal to EU in September 2017, currently endorsed by more than 400 scientists and medical doctors, a moratorium on the 5G deployment was required until proper scientific evaluation of negative consequences has been made (www.5Gappeal.eu). That request has not been taken seriously by EU. Lack of proper unbiased risk evaluation of the 5G technology makes adverse effects impossible to be foreseen. This disregard is exemplified by the recent report from the International Commission on non-ionizing radiation protection (ICNIRP) whereby only thermal (heating) effects from RF radiation are acknowledged despite a large number of reported non-thermal effects. Thus, no health effects are acknowledged by ICNIRP for non-thermal RF electromagnetic fields in the range of 100 kHz–300 GHz. Based on results in three case-control studies on use of wireless phones we present preventable fraction for brain tumors. Numbers of brain tumors of not defined type were found to increase in Sweden, especially in the age group 20–39 years in both genders, based on the Swedish Inpatient Register. This may be caused by the high prevalence of wireless phone use among children and in adolescence taking a reasonable latency period and the higher vulnerability to RF radiation among young persons.

Keywords: asbestos; cancer prevention; DDT; dioxins; early warnings; glyphosate; phenoxyacetic acids; radiofrequency radiation; tobacco.

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E-mail: lennart.hardell@environmentandcancer.com
Michael Carlberg, The Environment and Cancer Research Foundation, Örebro, Sweden,
E-mail: michael.carlberg@environmentandcancer.com

Introduction

The International Agency for Research on Cancer (IARC) at the World Health Organization (WHO) initiated in 1969 a program to evaluate human cancer risks of chemicals. It was later expanded to include chemical mixtures, radiation and viruses. So far, this program has resulted in 125 Monographs. Mostly, as the history shows, it has taken a long time between the first reports of increased cancer risk and cancer classification of the agent. Thereby preventive measures have not been taken in due time with high costs to society as a consequence in terms of increased numbers of cases with diseases leading to suffering and costs for treatment, loss of professional activity and eventually premature deaths [1–3]. Thus, early warnings should not be neglected. In fact, false positives on environmental risks are extremely rare [4]. In the following some historical examples are discussed, followed by a review of the current controversy on radiofrequency (RF) radiation and cancer. These examples serve as lessons for early warnings [5, 6].

No doubt the reports from the European Environment Agency on late lessons from early warnings may serve as important documents for the precautionary approach. Volume 1 was published in 2001 [5]. It dealt with 12 key lessons on health and environmental hazards. The 2013 volume on late lessons was grouped into five parts including e.g., health, ecosystems, justice, and governance [6]. Both volumes give examples on action that could have been taken to prevent harm. In the following some examples are discussed partly based on our own research experiences.

Examples of early warnings on cancer risks

The first history on occupational diseases was written by the Italian physician Bernardini Ramazzini in his book “De morbis artificum” (Diseases of Workers) printed in Modena, Italy 1700. He is regarded to be the ‘father of occupational medicine’. A second extended version was printed in Padua 1713. In the book 53 chapters deal with different occupations and diseases occurring in these occupations [7].

Regarding specific occupational exposures the English physician Percival Pott was the first to describe that men working as chimneysweeps, and thereby exposed to soot, had an increased risk for scrotal cancer. He published his findings in 1775 [8]. This disease was known as chimney-sweepers’ cancer. It is regarded to be the first report of an environmental factor causing cancer. It took a long time of campaigning to stop little boys being used to clean chimneys by climbing up them. More than 200 years later soot was classified as a human carcinogen Group 1 (carcinogenic) by IARC in 1985 [9].

Asbestos

Another both occupational and environmental toxic substance is asbestos. Already in 1899, a UK Factor Inspector observed the sharp glass-like jagged nature of asbestos particles [10]. The author noted asbestos dust in the air of the factory rooms and that “*the effects have been found to be injurious”*. Numerous reports have since then described increased risks primarily of lung cancer and mesothelioma. Already in 1935, a man with asbestosis and lung cancer was reported [11]. In 1953 it was reported that a man who had worked with asbestos died of pleural mesothelioma [12]. South African researchers published in 1960 a report on increased risk for mesothelioma for both occupational and environmental exposure to asbestos [13]. The American physician Dr. Irving Selikoff gave to a broader public insight into a dramatic increased cancer mortality among American insulation workers exposed to asbestos. Also, that environmental exposure increased the risk of mesothelioma [14]. This started a long-standing battle between a multinational industry defending its product, and public health and regulatory bodies [15, 16]. Asbestos was in 1977 evaluated by IARC to be carcinogenic to humans, Group 1 [17]. This was almost 20 years since the clear evidence of cancer risks was published in the early 1960s. Years were lost for prevention and yielded increased numbers of deaths.

Tobacco

Tobacco has a long history of reported adverse health effects. When first introduced in Europe smoking was recommended for medical purposes, in fact as prophylaxis for many diseases. In 1604 King James I of United Kingdom wrote against the use of tobacco [18]. Sömmering stated in a thesis in 1795 that tobacco pipes induced an increased risk for lip cancer [19]. Cancer of the tongue was described some 100 years later in 1890 [20]. A high proportion of diseases including lung cancer among cigar makers and sellers, waiters, and innkeepers was reported in 1914 [21]. A clearly increased incidence of lung cancer was first reported by Müller in 1940 [22]. This evidence and other cancer studies in the 1940s in Germany [23] and in the Netherlands [24] were mainly disregarded thereby omitting the possibility of early prevention. It was not until the 1950s when more studies showed health risks from tobacco, primarily for diseases such as cancer of the lung, myocardial infarction, peripheral vascular diseases, and chronic obstructive lung disease. Tobacco was in 1986 classified by IARC as a human carcinogen, Group 1 [25]. No doubt the history of smoking shows that early warnings were mainly neglected. Greenwashing by industry and its allied experts has a history of counteracting preventive measurements [26].

DDT

The marine biologist Rachel Carson was the first to write a general picture of chemical damage to the environment, human and animal health in her book Silent Spring published in 1962 [27]. She gave the first comprehensive description of the bioaccumulation of the insecticide DDT (*para,para'*-DDT –1,1′-(2,2,2-trichloro-ethylidene)bis (4-chloro benzene)). DDT was discovered in 1939 by the Swiss researcher Paul Müller. For that he received the Nobel Prize in medicine in 1948. No doubt the book by Rachel Carson was opposed by the chemical industry that even tried to stop the publication. In fact, DDT was defended by the American Medical Association and the US Nutrition Foundation unified with 54 companies in the food, chemical and allied industries [28]. The main human studies on human carcinogenicity of DDT and its main metabolite DDE (1,1’-(2,2-dichloroethenylidene)- bis(4-chlorobenzene)) were performed from the 1990s and onward [29].

The Stockholm Convention on Persistent Organic Pollutants was adopted in 2001. It provided initially evidence for the elimination of 12 chemicals, one of which was DDT [30]. The use of DDT was banned in most countries in the 1970s [31]. In 1972, the US EPA issued a cancellation order for DDT [32]. DDT was evaluated by IARC in 2018 to be probably carcinogenic to humans, Group 2A [29]. It had previously been evaluated as a possibly human carcinogen, Group 2B [33]. One of the main toxic issues is the bioaccumulation of DDT and its metabolites with long half-time in the environment [27]. DDT is still used in some countries, e.g. for malaria control. Due to its chemical behavior its metabolites can be found in human tissue [34, 35].

Phenoxyacetic acids

In 1977, a report was published on a series of patients who had been spraying phenoxy herbicides for the Swedish Forestry and who subsequently developed soft-tissue sarcoma [36]. Herbicides of this type include 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). 2,4,5-T was contaminated by 2,3,7,8,tetrachlorodibenzo-p-dioxin (TCDD), one of the most toxic chemicals in the world. This clinical observation was the first to indicate a possible increased cancer risk for these chemicals. Based on that report an increased risk for soft-tissue sarcoma was found both for these phenoxy herbicides and the chemically related chlorophenols, mostly exposure to pentachlorophenol, in a following case-control study [37]. These results were corroborated in further studies by our research group and others, for an overview see [2].

Another set of studies included malignant lymphoma, also initiated by a clinical observation [38]. This clinical observation resulted in further studies. An increased risk was found for both non-Hodgkin lymphoma (NHL) and Hodgkin's disease for persons exposed to phenoxy herbicides or chlorophenols [39]. Also, the increased lymphoma risk was confirmed in other studies, for overview see [2, 40].

One of the main types of chlorophenols, pentachlorophenol, was classified by IARC in 2019 to be carcinogenic to humans, Group 1 [41]. The phenoxy herbicide 2,4-D was in 2018 classified by IARC as possibly carcinogenic to humans, Group 2B [29]. It was the same classification as in 1977 including also 2,4,5-T [42].

Dioxins

The phenoxy herbicides 2,4-D, 2,4,5-T and chlorophenols were contaminated with dioxins. Of large concern was TCDD that contaminated 2,4,5-T and trichlorophenol. The initial Swedish results on cancer risks from this group of chemicals were followed by studies in other countries that confirmed the findings, for overview see [2,40]. Vietnam veterans exposed to the defoliating agent Agent Orange, including 2,4-D and 2,4,5-T, with TCDD contamination suffering from soft-tissue sarcoma or malignant lymphoma were in 1991 judged to be eligible for service-related compensation [43].

In 1976 an accident occurred in a chemical plant at Seveso, Italy producing 2,4,5-trichlorophenol. Thereby the surrounding area was contaminated with dioxins and the general population was exposed to TCDD. In the aftermath an increased incidence in malignant diseases, notably soft-tissue sarcoma and hematolymphatic malignancies was found in the population [40, 44].

Various *ad hoc* explanations were postulated by the chemical industry and its allied experts to discredit the cancer risks [2]. However, in 1997 IARC classified TCDD as a human carcinogen, Group 1 [45]. It had previously been evaluated in 1977 by IARC to be a possibly human carcinogen, Group 2B [42]. This was about two decades after the first epidemiological publications on increased cancer risk for TCDD contaminated herbicides.

Glyphosate

In the case-control studies by the Hardell group on risk factors for NHL exposure to all types of herbicides was assessed. In addition to phenoxyacetic acids also glyphosate turned out to increase the risk [46, 47]. Hairy cell leukemia (HCL) is regarded to be a subtype of NHL. In a separate study on HCL glyphosate was a risk factor also for that malignancy [48]. Similar results were also found in other studies [49, 50].

Glyphosate was in 1970 tested as herbicide and was patented by Monsanto [51]. It was registered for use in USA in 1974 with the trade name 'Roundup'. Since the patent has expired it is produced nowadays by many manufactures. In 1996 genetically engineered glyphosate tolerant crops were introduced (Roundup Ready) and since then the global use has increased 15-fold. Glyphosate has in recent years been the most widely used pesticide [52].

IARC at WHO evaluated glyphosate in March 2015 and classified it as a Group 2A, a probable human carcinogen [53, 54]. This was based on "limited" evidence of cancer in humans (from real-world exposures that occurred) and "sufficient" evidence of cancer in experimental animals (from studies of "pure" glyphosate). IARC also concluded that there was “strong” evidence for genotoxicity, both for “pure” glyphosate and for glyphosate formulations.

The European Food Safety Authority (EFSA) is the EU agency for risk assessment regarding food safety. In October 2015, that is seven months after the IARC evaluation, EFSA published its own evaluation [55]. In summary EFSA dismissed without clear explanation any association of glyphosate with cancer. All findings on carcinogenesis in animal studies were incorrectly discarded as chance findings. Mechanistic evidence on genotoxicity was ignored. Oxidative stress was confirmed but dismissed as a ground for carcinogenesis [56]. It should be noted that EFSA did not reveal the names of the authors of the chapters and references were redacted.

Monsanto, the main glyphosate producer, hired a panel of scientists to defend glyphosate. Thus, in 2016 a 17-page article was published in Critical Reviews in Toxicology, known to be an industry friendly product defense journal [57]. It was concluded that “*In summary, the totality of the evidence, especially in light of the extensive testing that glyphosate has received, as judged by the Expert Panels, does not support the conclusion that glyphosate is a “probable human carcinogen” and, consistent with previous regulatory assessments, the Expert Panels conclude that glyphosate is unlikely to pose a carcinogenic risk to humans.*”

This review was made by four expert panels. In the initial publication no conflicts of interest were stated. All but six of the 16 authors appeared with their university or hospital affiliation. During lawsuits in USA on glyphosate exposure and NHL it was revealed that the authors were not independent, and that Monsanto was deeply involved in organizing, reviewing and editing the review. In fact, Monsanto paid the authors through a consulting firm, *Intertek* [58].

As a consequence Critical Reviews in Toxicology was forced to make a Corrigendum two years later: “*When this article was originally published on 28th September 2016, the contributions, contractual status and potential competing interests of all authors and non-author contributors were not fully disclosed to Critical Reviews in Toxicology. Specifically, the Acknowledgments and Declaration of Interest were not complete. After further clarification from the authors, these sections are corrected to reflect the full contributions, contractual status and, potential competing interests of all authors and non-author contributors and read as follows … This overview paper (paper) is part of a supplement, the preparation of which was coordinated by Intertek Scientific & Regulatory Consultancy (Intertek) under the leadership of Ashley Roberts. It was prepared subsequent to completion of the four manuscripts as an overview and presented the opinions and conclusions of four groups of the expert panel. The expert panels were organized and supported administratively by Intertek. Funding was provided to Intertek by Monsanto Company, which is a primary producer and marketer of glyphosate and related products. All the expert panelists other than John Acquavella and Larry D. Kier were compensated through a contract with Intertek. John Acquavella and Larry D. Kier were compensated through existing consulting contracts with Monsanto Company*” [59].

Product defense by downplaying risk seems to have been one of Monsanto’s strategies [60].

The German chemical company Bayer purchased Monsanto in 2018. It is facing a magnitude of lawsuits on NHL and glyphosate exposure. So far in three lawsuits about 200 million USD have been awarded by the juries [58]. No doubt the use of glyphosate is of large economic importance both for the producers and the agriculture. In 2017 the EU Commission extended the use of glyphosate until 2022 [61].

Radiofrequency radiation

In 2011 radiofrequency electromagnetic fields (RF-EMF) in the frequency range 30 kHz–300 GHz were evaluated by IARC at WHO to be possibly carcinogenic to humans, Group 2B [62, 63]. This was based on evidence of increased risk for glioma and acoustic neuroma in human epidemiology studies on use of mobile and/or cordless phone (DECT) [64–69]. The increased cancer risk was supported by laboratory studies [70, 71].

Extremely low frequency (ELF)-EMF was in 2001 evaluated by IARC to be a possible human carcinogen, Group 2B [72]. This was the first time that non-ionizing radiation at low intensity levels can be a possible cause of cancer. It predated the IARC finding for RF-EMF by a decade.

Since then the evidence on RF-EMF carcinogenesis has strengthened based on further human studies on use of wireless phones, as reviewed [73, 74]. Also animal studies show increased cancer risk, both near field RF-EMF exposure [75–77] and far field exposure [78, 79]. Mechanistic studies show increase of reactive oxygen species (ROS) [80] as well as DNA damage [81]. These results give support to the increased cancer risk in humans and laboratory tested animals for RF radiation. In fact, RF-EMF may now be classified as a human carcinogen, Group 1 [82, 83]. However, such classification can only be made by IARC.

Of course, these well documented health hazards from RF-EMF are not well accepted by the telecom industry and its allied experts. Several methods are used to create doubt.

Studies are discredited, only partly cited, or even not cited at all [84–86]. Thereby the uniformed reader gets the wrong information on actual risks. This includes also regulatory agencies and policy makers. Even agencies aimed at setting exposure guidelines may include pro-industry and biased scientists that obscure the true risks [87, 88].

ICNIRP

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is a private non-governmental (NGO) organization registered in Munich, Germany. ICNIRP appoints its own members and is closed to transparency. It was started in 1992 with the biophysicist Michael Repacholi as the first chairman, now emeritus member. ICNIRP has published three articles with guidelines on RF-EMF exposure [86, 89, 90]. Only thermal (heating) effects from RF radiation are recognized, thereby excluding all studies showing harmful effects at lower non-thermal intensities. In contrast to ICNIRP, some other expert panels such as European Academy of Environmental Medicine [91], the Bioinitiative group [92], and the Russian Commission for Protection from Non-Ionizing Radiation [93], take into account non-thermal RF effects and suggest much lower guidelines for RF exposure.

ICNIRP has managed to get collaborative status with WHO, as discussed previously [88]. The aim is to harmonize the RF-radiation guidelines all over the world. For that purpose ICNIRP has been successful. The guidelines are set to allow very high exposure levels so that the deployment of this technology is not hampered, in favor for industry but at disadvantage to human health and environment. In fact, the ICNIRP guidelines have never been challenged by industry in peer-reviewed articles, which must be taken as a green card for acceptance by industry.

Attributable fraction

The attributable fraction (AF), sometimes also called the etiologic fraction, is the number of cases in which exposure played an etiologic role. This is the preventable fraction if exposure would not be present. In Belpomme et al. [73] we published meta-analyses for longest cumulative use of mobile phones with odds ratio (OR) and 95 % confidence interval (CI), both for total and for ipsilateral wireless phone use. Note that only the Hardell group assessed also use of cordless phones (DECT). We present here AF based on statistically significant increased risks in the meta-analyses. AF is the proportion of cases that can be attributed to the particular exposure. This is calculated as the exposed case fraction multiplied by [(OR-1)/OR].

As displayed in Table 1 the AF for glioma was calculated to 4.88%, 95% CI = 2.44–6.57%, corresponding to 211 preventable cases, 95% CI = 105–284 cases in the longest time for all cumulative use of wireless phones. Regarding ipsilateral use of the wireless phone AF was 6.03%, 95% CI = 4.51–7.12%, yielding 150 cases; 95% CI 112–177 to be preventable.

For meningioma AF = 1.75%, 95% CI = 0.39–2.73 corresponded to 39 cases, 95 % CI = 9–61 cases for ipsilateral use of the wireless phone was calculated. Calculation of AF for acoustic neuroma yielded 4.63%, 95% CI = 3.07–5.63% corresponding to 42 cases, 95% CI = 28–51 cases for ipsilateral use of the phone.

Table 1: Attributable fraction (AF) based on meta-analyses of case-controls studies on use of wireless phones with statistically significant increased risk. For details see Belpomme et al. [73]. Odds ratio (OR), 95% confidence interval (CI), and numbers (n) are given.

	Cases		Meta-analysis		AF		AF, corresponding cases	
	Total n	Exposed n	OR	95% CI	AF, %	95% CI (%)	N	95 % CI
Glioma[a]								
Longest[b] cumulative use ≥ 1640 h	4,319	445	1.90	1.31–2.76	4.88	2.44–6.57	211	105–284
Longest[b] cumulative use, ipsilateral ≥ 1640 h	2,484	247	2.54	1.83–3.52	6.03	4.51–7.12	150	112–177
Meningioma[a]								
Longest[b] cumulative use, ipsilateral ≥ 1640 h	2,241	119	1.49	1.08–2.06	1.75	0.39–2.73	39	9–61
Acoustic neuroma[c]								
Longest cumulative use, ipsilateral ≥ 1640 h	899	66	2.71	1.72–4.28	4.63	3.07–5.63	42	28–51

[a]Based on Interphone [67], Coureau et al. [101], Hardell and Carlberg [104], Carlberg and Hardell [102]. [b]Coureau et al. [101] ≥896 h. [c]Based on Interphone [68], Hardell et al. [108].

Rates of brain tumors in the Swedish National Inpatient Register ICD-code D43

Rates of brain tumors of unknown type, D43, were studied using the Swedish Inpatient Register (IPR) without any personal identification information [94]. It was established in 1964 and has complete national coverage since 1987 [95]. Register data on D43 are available from 1998. Currently more than 99% of hospital discharges are registered. For outpatients the data are less reliable due to missing information. The reporting of outpatients has increased during more recent years so these time trends may give spurious results, thus we omitted outpatients from the analysis.

Data were analyzed for the time period 1998–2019. Age-standardized rates are not available in the register. Instead numbers of patients per 100,000 inhabitants are reported. The Joinpoint Regression Analysis program version 4.1.1.1 was used to examine numbers of patients per 100,000 in inpatient care and incidence per 100,000 person-years in the Swedish Inpatient Register, by fitting a model of 0–3 joinpoints using permutation tests with Bonferroni correction for multiple testing to calculate the number of joinpoints that best fits the material [96]. When joinpoints were detected annual percentage changes (APC) and 95% CIs were calculated for each linear segment. Average annual percentage changes (AAPC) were also calculated for the whole time period using the average of the APCs weighted by the length of the segment. To be able to calculate APC and AAPC the data was log-transformed prior to analysis. Thus, it was not possible to perform joinpoint regression analysis when there were years with no cases during that time period. Since the data do not include any personal identification no ethical approval was needed.

In men AAPC increased during 1998–2019 with +1.77%, 95% confidence interval (CI) −0.02, +3.58%, Table 2; Figure 1. The increase was highest in the age group 20–39 years, +2.90%, 95% CI +1.66, +4.16 %, Figure 2. AAPC increased statistically significant in all age groups, except 0–19 years.

Similar results were found in women with AAPC +1.70%, 95% CI +0.38, +3.05% during 1998–2019, Table 3; Figure 3. Also in women the highest increase of AAPC was found in the age group 20–39 years, +2.89%, 95% CI + 1.54, +4.27%, Figure 4. AAPC increased statistically significant in all age groups except 0–19 years and 80+ years. Especially high increase of APC was seen in women aged 60–79 years during 2005–2019, and women aged 80+ years during 2010–2019.

Table 2: Joinpoint regression analysis of brain tumor rates (numbers per 100,000) in men in the Swedish Inpatient Register 1998–2019, ICD-10 code D43 (https://sdb.socialstyrelsen.se/if_par/val.aspx).

ICD-10	Joinpoint location	APC 1 (95% CI)	APC 2 (95% CI)	APC 3 (95% CI)	AAPC (95% CI)
D43					
All men (n=10,540)	2008; 2011	+0.13 (−0.85, +1.12)	+8.95 (−3.99, +23.64)	+1.22 (−0.16, +2.63)	+1.77 (−0.02, +3.58)
0–19 years (n=662)	No joinpoint detected	–	–	–	+1.83 (−0.13, +3.82
20–39 years (n=1,117)	No joinpoint detected	–	–	–	+2.90 (+1.66, +4.16)
40–59 years (n=2,799)	No joinpoint detected	–	–	–	+1.61 (+0.88, +2.36)
60–79 years (n=4,867)	No joinpoint detected	–	–	–	+1.67 (+0.99, +2.36)
80+ years (n=1,095)	No joinpoint detected	–	–	–	+1.40 (+0.11, +2.70)

APC, annual percentage change (APC 1, time from 1998 to first joinpoint; APC 2, time from first joinpoint to 2019 or to second joinpoint; APC 3, time from second joinpoint to 2019); AAPC, average annual percentage change

Discussion

No doubt there are historical examples of late lessons from early warnings on health risks whereby preventive measurements have been neglected. Some of the examples here clearly show that if the scientific evidence on cancer risks had been taken seriously lives could have been saved.

Tobacco is a good example of cancer risks that were disregarded for decades since clear evidence of increased risk. It was not until 1986 that IARC classified tobacco as a human carcinogen, Group 1 [25]. The strategies by the tobacco industry to sow doubt on the risks include e.g., to fund research that supports their position, to hide their involvement, to promote 'no risk' studies, to criticize research that shows risk, and to disseminate data and their interpretation of the results to the press and layman, for further details see Bero [98].

In fact, these strategies by the tobacco industry to obscure scientific facts seem to be textbook examples on product defense that may be used by different industries.

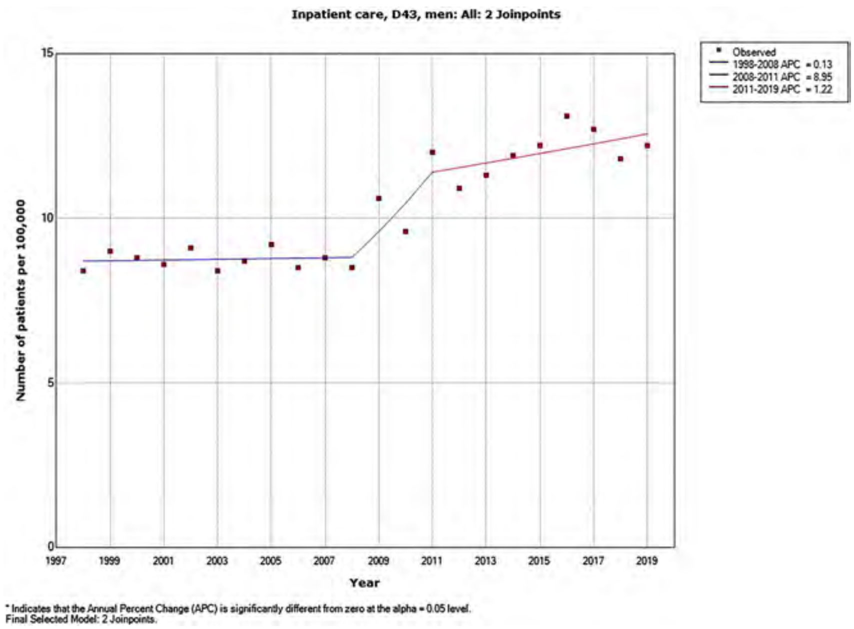

Figure 1: Joinpoint regression analysis of number of patients per 100,000 inhabitants. According to the Swedish National Inpatient Register for men, all ages during 1998–2019 diagnosed with D43 = tumour of unknown type in the brain or CNS. Note that in Sweden 1G (NMT, Nordic mobile telephone System) operated during 1981–2007. 2G (GSM) started 1991, 3G UMTS) started 2003, 4G started 2015, and DECT started 1988 [97].

One current controversy is cancer risks from RF radiation. No lessons on prevention of cancer risks seem to have been learned in spite of decades of publications on adverse health risks. In fact, early prevention is usually very cost effective [2, 99]. The issue on RF radiation risks is on-going and in fact increasing despite decades of research showing adverse effects on human health, plants, insects and birds. It seems as if the industry view of no risk dominates on national level [84], among many countries [85], also at EU level (www.5gappeal.eu), and even within WHO [88]. Notably such industry organizations and nations have the power and economic resources to suppress scientific evidence on risks and have access to mainstream media to propagate their views, may it be for political or economic reasons.

RF radiation is a current controversy regarding cancer risks. The 2011 IARC evaluation on carcinogenesis [62, 63] has been downplayed and detracted by industry and captured agencies from the very beginning in spite of increasing evidence on harmful effects. However, IARC has decided that a new evaluation of cancer risks is top priority within a few years [100].

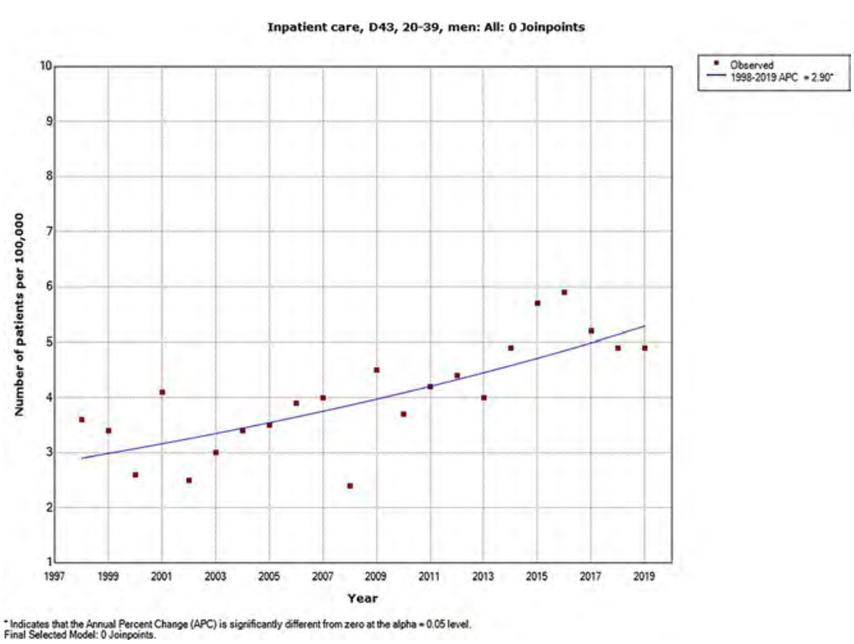

Figure 2: Joinpoint regression analysis of number of patients per 100,000 inhabitants. According to the Swedish National Inpatient Register for men aged 20–39 years during 1998–2019 diagnosed with D43 = tumour of unknown type in the brain or CNS.

Table 3: Joinpoint regression analysis of brain tumour rates (numbers per 100,000) in women in the Swedish Inpatient Register 1998–2019, ICD-10 code D43 (https://sdb.socialstyrelsen.se/if_par/val.aspx).

ICD-10	Joinpoint location	APC 1 (95% CI)	APC 2 (95% CI)	APC 3 (95 % CI)	AAPC (95% CI)
D43					
All women (n=9,611)	2008; 2017	+0.24 (−0.75, +1.24)	+4.77 (+3.32, +6.24)	−4.35 (−15.82, +8.68)	+1.70 (+0.38, +3.05)
0–19 years (n=570)	No joinpoint detected	–	–	–	+0.86 (−0.55, +2.28
20–39 years (n=907)	No joinpoint detected	–	–	–	+2.89 (+1.54, +4.27)
40–59 years (n=2,509)	No joinpoint detected	–	–	–	+1.91 (+0.80, +3.02)
60–79 years (n=4,307)	2005	−0.95 (−4.07, +2.27)	+3.45 (+2.30, +4.62)	–	+1.96 (+0,73, +3.21)
80+ years (n=1,318)	2010	−0.66 (−3.11, +1.84)	+5.49 (+1.51, +9.63)	–	+1.93 (−0.11, +4.02)

APC, annual percentage change (APC 1, time from 1998 to first joinpoint; APC 2, time from first joinpoint to 2019 or to second joinpoint; APC 3, time from second joinpoint to 2019); AAPC, average annual percentage change.

In this article we give some further data on the RF carcinogenesis. The attributable fraction gives the number of cases that could have been prevented if no risk exists for a specific exposure. Based on results in case-control studies from three study groups that have shown statistically significant increased risk for glioma and acoustic neuroma 211 glioma cases (all exposure) and 42 acoustic neuroma cases (ipsilateral exposure) would have been preventable in the longest cumulative exposure group. The preventable fraction was 4.88 and 4.63%, respectively. Highest preventable fraction was found for glioma with ipsilateral wireless phone use, 6.03% corresponding to 150 cases. Lower AF was calculated for meningioma, 1.75%, yielding 39 preventable cases (ipsilateral exposure). As displayed in Belpomme et al. [73] these results were based on Interphone [67], Coureau et al. [101], and Carlberg, Hardell [102], each without statistically significant increased risk. However, meta-analysis of these studies yielded, OR = 1.49, 95% CI = 1.08–2.06.

We have previously published results on increasing rates of tumors of unknown type in the brain or CNS both in the Swedish Inpatient Register and Causes of Death Register during 1998–2013 [103]. There was a clear increasing trend in both genders during that time period, especially during more recent years with AAPC +1.78 %, 95% CI + 0.76, 2.81% for both genders combined. A joinpoint was found in men in 2007; time period 2007–2013 APC +4.95%, 95% CI +1.59, +8.42%. Similarly, in women a joinpoint was detected in 2008; time period 2008–2013 APC +4.08%, 95% CI +1.80, +6.41%.

We have now extended the time period up to 2019. Thus, we report increasing AAPC in both genders during 1998–2019 of similar magnitude as previously. In men the result was of borderline significance although the AAPC

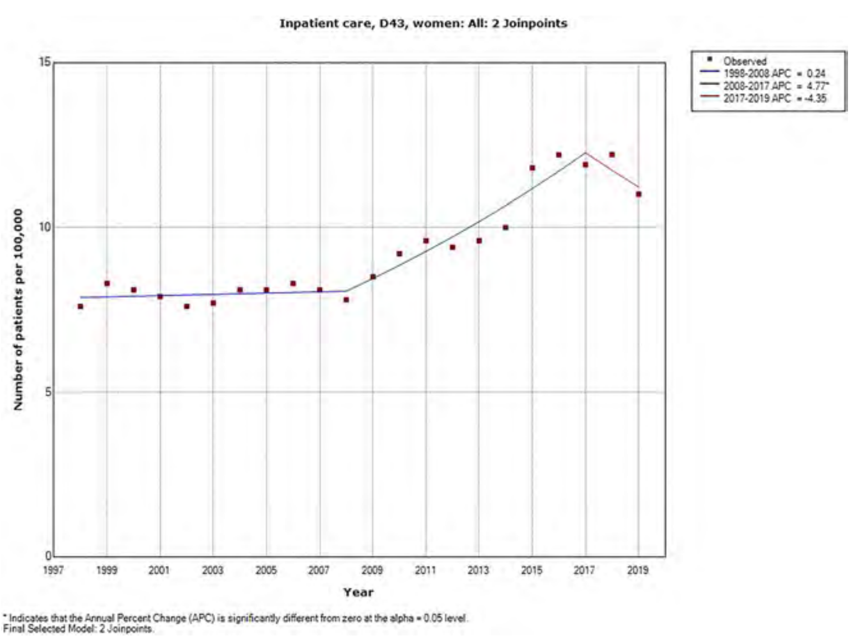

Figure 3: Joinpoint regression analysis of number of patients per 100,000 inhabitants. According to the Swedish National Inpatient Register for women, all ages during 1998–2019 diagnosed with D43 = tumour of unknown type in the brain or CNS. Note that in Sweden 1G (NMT; Nordic mobile telephone System) operated during 1981–2007. 2G (GSM) started 1991, 3G (UMTS) started 2003, 4G started 2015, and DECT started 1988 [97].

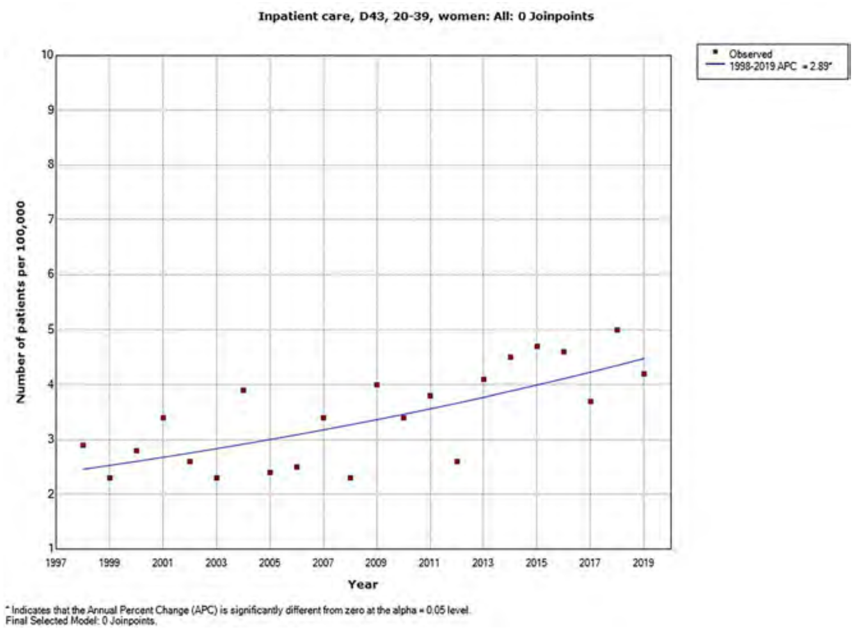

Figure 4: Joinpoint regression analysis of number of patients per 100,000 inhabitants. According to the Swedish National Inpatient Register for women aged 20–39 years during 1998–2019 diagnosed with D43 = tumour of unknown type in the brain or CNS.

overlapped previous findings. Lower APC was found during more recent years in both men and women, see Figures 1 and 3. This may reflect a better diagnostic procedure and thus decreasing numbers of unknown brain tumor type. A delay in reporting to the register during recent years may also have an impact on the results.

It is noteworthy that we found highest AAPC in the age group 20–39 years in both men and women, Tables 2 and 3. We found in our case-control study on glioma a median latency period for use of mobile phone of 9.0 years (mean 10.1 years). The corresponding results for cordless phones (DECT) were 7.0 and 8.0 years, respectively [104]. In a population-based study during 2005–2006 on use of mobile and cordless phones among Swedish children aged 7–14 years 79.1% reported access to mobile phone and use of cordless phone was reported by 83.8% [105]. Thus, our current findings with increasing numbers of brain tumors in the age group 20–39 years may be consistent with use of wireless phones taking a reasonable latency period. Moreover, our previous results showed highest risk for subjects that started the use of mobile or cordless phone before 20 years of age [104]. That age groups would also be more vulnerable to RF radiation [106]. In legends to Figures 1 and 3 we report the history for wireless phone use in Sweden. Figure 5 displays the number of out-going mobile phone minutes in millions during 2000–2019 in

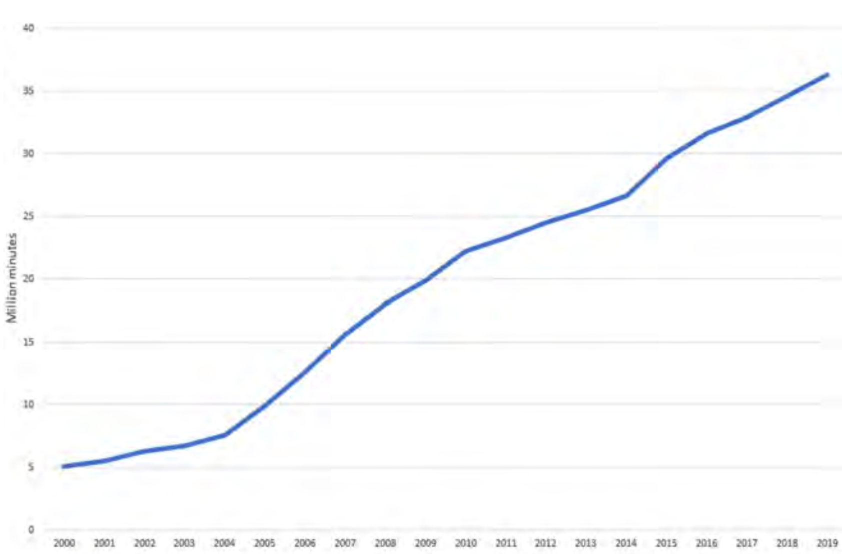

Figure 5: Number of out-going mobile phone minutes in millions during 2000–2019 in Sweden according to post-och Tele-styrelsen [The Swedish post and telecom Authority (PTS)]. Available from: https://statistik.pts.se/svensk-telekommarknad/tabeller/mobila-samtals-och-datatjanster/tabell-13-trafikminuter-utgaende/.

Sweden. The major increase is since early 21st century and may be associated with our findings of increasing numbers of brain tumors of unknown type considering a reasonable latency time.

As we have discussed elsewhere the Swedish Cancer Register is not reliable to study the incidence of brain tumors [103, 107]. The register is mainly based on reporting of cases with histopathological diagnosis. Now diagnosis may be based on CT and/or MRI without further investigations especially of patients with poor outcome. Biopsy or operation may be difficult to perform due to tumor location, age and co-morbidity. In the Swedish Cancer Register about 90% of the cases are diagnosed with cytology or histology, a number that has increased somewhat during recent years [107]. This fact indicates that brain tumors of unknown type are under-reported to the Cancer Register.

This review gives insight into missed opportunities for cancer prevention exemplified by asbestos, tobacco, certain pesticides and now RF radiation. No doubt economic considerations are favored instead of cancer prevention. The cancer victim is the loser in terms of suffering, life quality and shorter life expectancy. Also the life for the next-of-kin is affected. A strategy to sow doubt on cancer risks was established decades ago and is now adopted and implemented in more sophisticated way by the telecom industry regarding RF-EMF risks to human beings and the environment. Industry has the economic power, access to politicians and media whereas concerned people are unheard.

Acknowledgments: The authors want to thank The Electromagnetic Safety Alliance, Inc. USA for general support.
Research funding: None declared.
Author contributions: LH and MC contributed to the conception, design and writing of the manuscript. Both authors read and approved the final manuscript. MC made the statistical analyses.
Competing interests: Authors state no conflict of interest.
Informed consent: Informed consent is not applicable.
Ethical approval: Not applicable.

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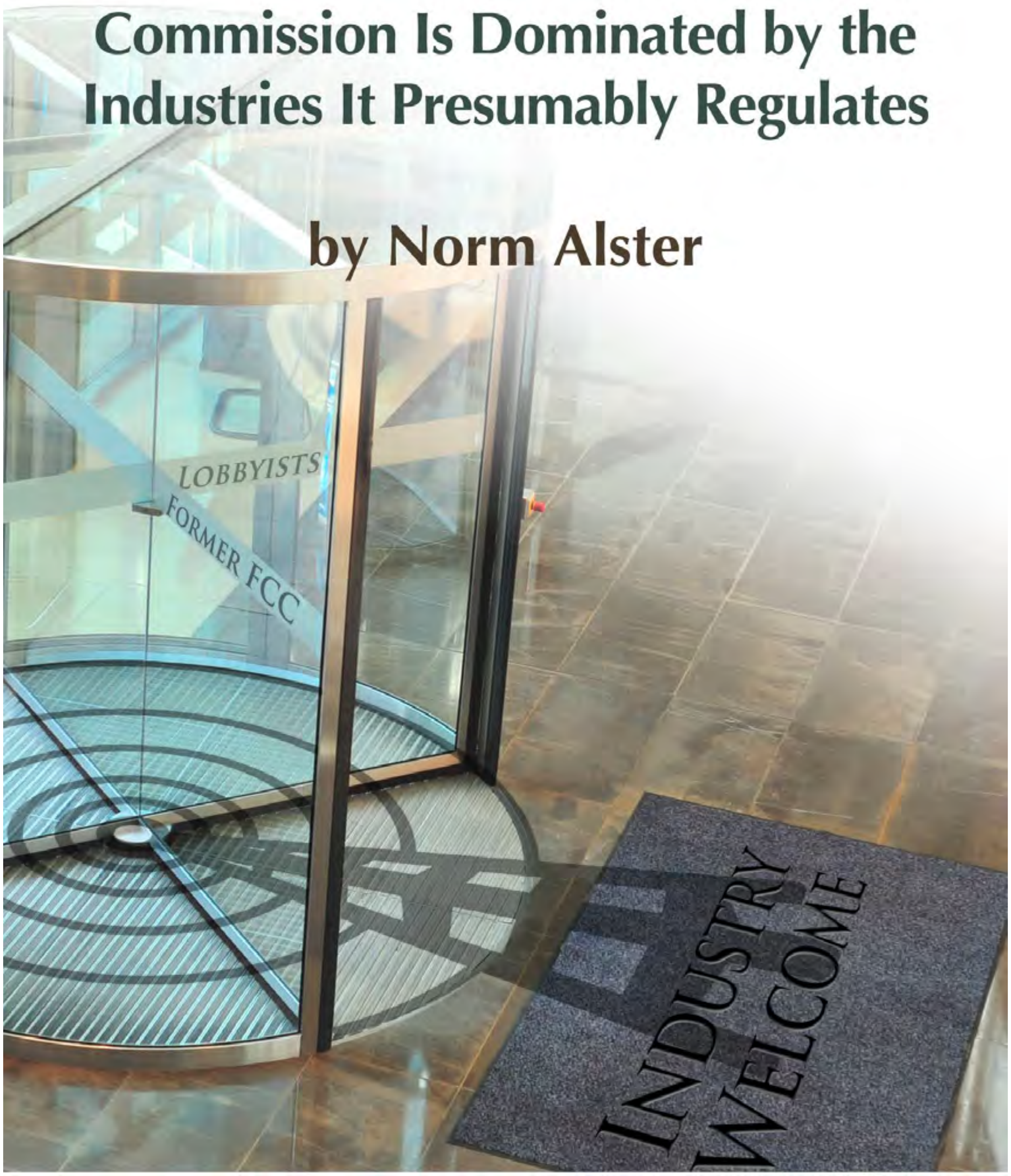
Captured Agency:

How the Federal Communications Commission Is Dominated by the Industries It Presumably Regulates



by Norm Alster

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Published by:
Edmond J. Safra Center for Ethics
Harvard University
124 Mount Auburn Street, Suite 520N
Cambridge, MA 02138 USA
http://www.ethics.harvard.edu/

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Chapter One: The Corrupted Network

Renee Sharp seemed proud to discuss her spring 2014 meeting with the Federal Communications Commission.

As research director for the non-profit Environmental Working Group, Sharp doesn‘t get many chances to visit with the FCC. But on this occasion she was able to express her concerns that lax FCC standards on radiation from wireless technologies were especially hazardous for children.

The FCC, however, should have little trouble dismissing those concerns.

Arguing that current standards are more than sufficient and that children are at no elevated risk from microwave radiation, wireless industry lobbyists don‘t generally have to set up appointments months in advance. They are at the FCC‘s door night and day.

Indeed, a former executive with the Cellular Telecommunications Industry Association (CTIA), the industry‘s main lobbying group, has boasted that the CTIA meets with FCC officials ―500 times a year."[1]

Sharp does not seem surprised. ―There‘s no question that the government has been under the influence of industry. The FCC is a captured agency," she said.[2]

Captured agency.

That‘s a term that comes up time and time again with the FCC. Captured agencies are essentially controlled by the industries they are supposed to regulate. A detailed look at FCC actions—and non-actions—shows that over the years the FCC has granted the wireless industry pretty much what it has wanted. Until very recently it has also granted cable what it wants. More broadly, the FCC has again and again echoed the lobbying points of major technology interests.

Money—and lots of it—has played a part. The National Cable and Telecommunications Association (NCTA) and CTIA have annually been among Washington‘s top lobbying spenders. CTIA alone lobbied on at least 35 different Congressional bills through the first half of 2014. Wireless market leaders AT&T and Verizon work through CTIA. But they also do their own lobbying, spending nearly $15 million through June of 2014, according to data from the Center for Responsive Politics (CRP). In all, CTIA, Verizon, AT&T, T-Mobile USA, and Sprint spent roughly $45 million lobbying in 2013. Overall, the Communications/Electronics sector is one of Washington‘s super heavyweight lobbyists, spending nearly $800 million in 2013-2014, according to CRP data.

But direct lobbying by industry is just one of many worms in a rotting apple. The FCC sits at the core of a network that has allowed powerful moneyed interests with limitless access a variety of ways to shape its policies, often at the expense of fundamental public interests.

As a result, consumer safety, health, and privacy, along with consumer wallets, have all been overlooked, sacrificed, or raided due to unchecked industry influence. The cable industry has consolidated into giant local monopolies that control pricing while leaving consumers little choice over content selection. Though the FCC has only partial responsibility, federal regulators have allowed the Internet to grow into a vast hunting grounds for criminals and commercial interests: the go-to destination for the surrender of personal information, privacy and identity. Most insidious of all, the wireless industry has been allowed to grow unchecked and virtually unregulated, with fundamental questions on public health impact routinely ignored.

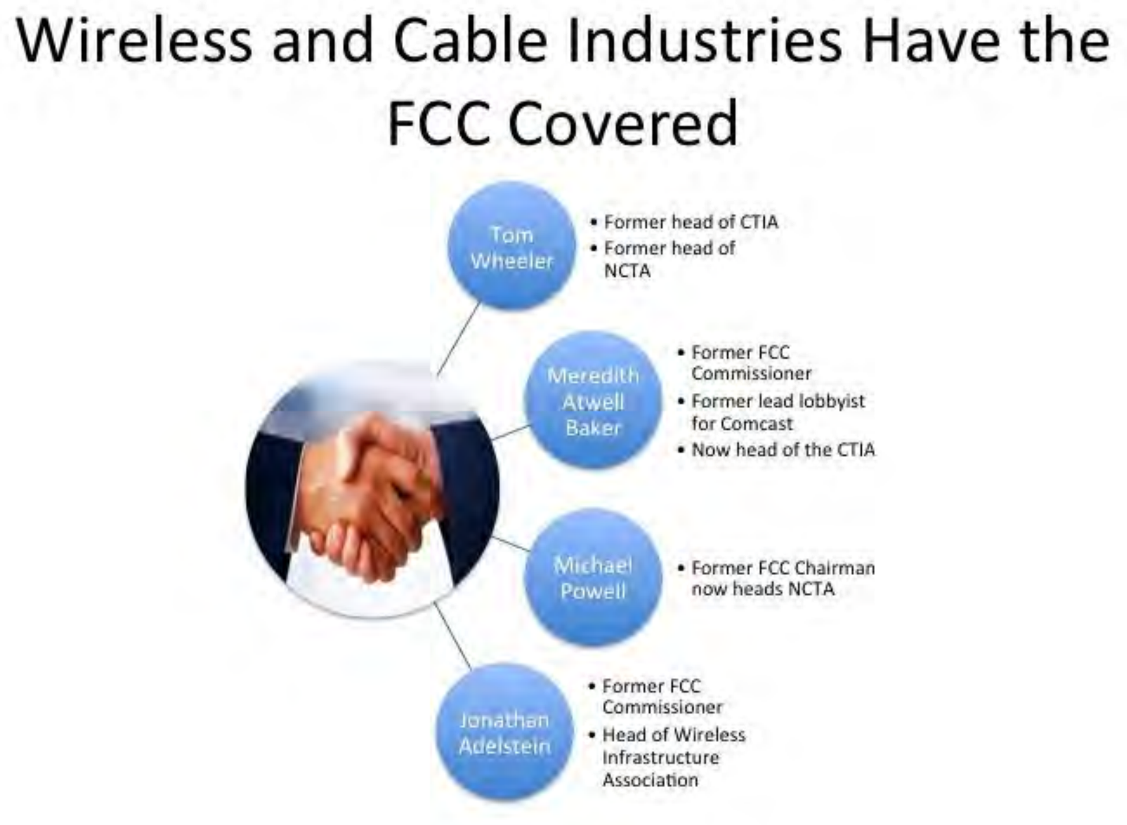
Industry controls the FCC through a soup-to-nuts stranglehold that extends from its well-placed campaign spending in Congress through its control of the FCC‘s Congressional oversight committees to its persistent agency lobbying. ―If you‘re on a committee that regulates industry you‘ll be a major target for industry," said Twaun Samuel, chief of staff for Congresswoman Maxine Waters.[3] Samuel several years ago helped write a bill aimed at slowing the revolving door. But with Congress getting its marching orders from industry, the bill never gained any traction.

Industry control, in the case of wireless health issues, extends beyond Congress and regulators to basic scientific research. And in an obvious echo of the hardball tactics of the tobacco industry, the wireless industry has backed up its economic and political power by stonewalling on public relations and bullying potential threats into submission with its huge standing army of lawyers. In this way, a coddled wireless industry intimidated and silenced the City of San Francisco, while running roughshod over local opponents of its expansionary infrastructure.

On a personal level, the entire system is greased by the free flow of executive leadership between the FCC and the industries it presumably oversees. Currently presiding over the FCC is Tom Wheeler, a man who has led the two most powerful industry lobbying groups: CTIA and NCTA. It is Wheeler who once supervised a $25 million industry-funded research effort on wireless health effects. But when handpicked research leader George Carlo concluded that wireless radiation did raise the risk of brain tumors, Wheeler‘s CTIA allegedly rushed to muffle the message. ―You do the science. I‘ll take care of the politics," Carlo recalls Wheeler saying.[4]

Wheeler over time has proved a masterful politician. President Obama overlooked Wheeler‘s lobbyist past to nominate him as FCC chairman in 2013. He had, after all, raised more than $700,000 for Obama‘s presidential campaigns. Wheeler had little trouble earning confirmation from a Senate whose Democrats toed the Presidential line and whose Republicans understood Wheeler was as industry-friendly a nominee as they could get. And while Wheeler, at the behest of his Presidential sponsor, has taken on cable giants with his plans for net neutrality and shown some openness on other issues, he has dug in his heels on wireless.

Newly ensconced as chairman of the agency he once blitzed with partisan pitches, Wheeler sees familiar faces heading the industry lobbying groups that ceaselessly petition the FCC. At CTIA, which now calls itself CTIA - The Wireless Association, former FCC commissioner Meredith Atwell Baker is in charge.



And while cell phone manufacturers like Apple and Samsung, along with wireless service behemoths like Verizon and AT&T, are prominent CTIA members, the infrastructure of 300,000 or more cellular base stations and antenna sites has its own lobbying group: PCIA, the Wireless Infrastructure Association. The President and CEO of PCIA is Jonathan Adelstein, another former FCC commissioner. Meanwhile, the cable industry‘s NCTA employs former FCC chairman Michael Powell as its president and CEO. Cozy, isn‘t it?

FCC commissioners in 2014 received invitations to the Wireless Foundation‘s May 19th Achievement Awards Dinner. Sounds harmless, but for the fact that the chief honoree at the dinner was none other than former wireless lobbyist but current FCC Chairman Tom Wheeler. Is this the man who will act to look impartially at the growing body of evidence pointing to health and safety issues?

The revolving door also reinforces the clout at another node on the industry-controlled influence network. Members of congressional oversight committees are prime targets of industry. The cable industry, for example, knows that key legislation must move through the Communications and Technology Subcommittee of the House Energy and Commerce Committee. Little wonder then that subcommittee chairman Greg Walden was the second leading recipient (after Speaker John Boehner) of cable industry contributions in the last six years (through June 30, 2014). In all, Walden, an Oregon Republican, has taken over $108,000 from cable and satellite production and distribution companies.[5] But he is not alone. Six of the top ten recipients of cable and satellite contributions sit on the industry's House oversight committee. The same is true of senators on the cable oversight committee. Committee members were six of the ten top recipients of campaign cash from the industry.[6]

Cable & Satellite Campaign Contributions

Top House Recipients Funded

Recipient	Amount
John A. Boehner	$135,425
Greg Walden	$108,750
Bob Goodlatte	$93,200
John Conyers Jr.	$84,000
Mike Coffman	$82,137
Fred Upton	**$73,500**
Lee Terry	**$65,916**
Henry A. Waxman	**$65,000**
Cory Gardner	**$64,500**
Anna G. Eshoo	**$60,500**

Cellular Industry Campaign Contributions

Top House Recipients Funded

Recipient	Amount
Henry A. Waxman	**$41,500**
Scott H. Peters	$40,300
Greg Walden	**$35,750**
Fred Upton	**$32,250**
Bob Goodlatte	$31,250
Lee Terry	**$29,600**
Anna G. Eshoo	**$27,000**
Doris O. Matsui	**$25,500**
John Shimkus	**$24,000**
Peter J. Roskam	$21,100

Cable & Satellite Campaign Contributions

Top Senate Recipients Funded

Recipient	Amount
Edward J. Markey	**$320,500**
Kirsten E. Gillibrand	$194,125
Mitch McConnell	$177,125
Harry Reid	$175,600
Charles E. Schumer	$175,450
Mark L. Pryor	**$172,950**
Michael F. Bennet	$159,000
Richard Blumenthal	**$148,800**
Claire McCaskill	**$138,185**
Mark Udall	$136,625

Cellular Industry Campaign Contributions

Top Senate Recipients Funded

Recipient	Amount
Edward J. Markey	**$155,150**
Mark R. Warner	$74,800
Harry Reid	$73,600
Mark L. Pryor	**$71,900**
Roy Blunt	**$57,400**
John McCain	$56,261
Charles E. Schumer	$53,300
Roger F. Wicker	$51,300
Barbara Boxer	$49,578
Kelly Ayotte	$43,333

The compromised FCC network goes well beyond the revolving door and congressional oversight committees. The Washington social scene is one where money sets the tone and throws the parties. A look at the recent calendar of one current FCC commissioner shows it would take very disciplined and almost saintly behavior on the part of government officials to resist the lure of lavishly catered dinners and cocktail events. To paraphrase iconic investigative journalist I.F. Stone, if you‘re going to work in Washington, bring your chastity belt.

All that free liquor, food and conviviality translates into the lobbyist‘s ultimate goal: access. —They have disproportionate access," notes former FCC commissioner Michael Copps. —When you are in a town where most people you see socially are in industry, you don‘t have to ascribe malevolent behavior to it," he added.[7]

Not malevolent in motive. But the results can be toxic. And blame does not lie solely at the feet of current commissioners. The FCC‘s problems predate Tom Wheeler and go back a long way.

Indeed, former Chairman Newton Minow, enduringly famous for his 1961 description of television as a —vast wasteland," recalls that industry manipulation of regulators was an issue even back then. —When I arrived, the FCC and the communications industry were both regarded as cesspools. Part of my job was to try to clean it up."[8]

More than 50 years later, the mess continues to pile up.

Chapter Two: Just Don’t Bring Up Health

Perhaps the best example of how the FCC is tangled in a chain of corruption is the cell tower and antenna infrastructure that lies at the heart of the phenomenally successful wireless industry.

It all begins with passage of the Telecommunications Act of 1996, legislation once described by South Dakota Republican senator Larry Pressler as ―the most lobbied bill in history.” Late lobbying won the wireless industry enormous concessions from lawmakers, many of them major recipients of industry hard and soft dollar contributions. Congressional staffers who helped lobbyists write the new law did not go unrewarded. Thirteen of fifteen staffers later became lobbyists themselves.[9]

Section 332(c)(7)(B)(iv) of the Act remarkably—and that adverb seems inescapably best here—wrests zoning authority from local governments. Specifically, they cannot cite health concerns about the effects of tower radiation to deny tower licenses so long as the towers comply with FCC regulations.

Congress Silences Public

Section 332(c)(7)(B)(iv) of the Communications Act provides:

> No State or local government or instrumentality thereof may regulate the placement, construction, and modification of personal wireless service facilities on the basis of the environmental effects of radio frequency emissions to the extent that such facilities comply with the Commission's regulations concerning such emissions.

In preempting local zoning authority—along with the public‘s right to guard its own safety and health— Congress unleashed an orgy of infrastructure build-out. Emboldened by the government green light and the vast consumer appetite for wireless technology, industry has had a free hand in installing more than 300,000 sites. Church steeples, schoolyards, school rooftops, even trees can house these facilities.

Is there any reason to believe that the relatively low level radiofrequency emissions of these facilities constitute a public health threat? Certainly, cell phones themselves, held close to the head, have been the focus of most concern on RF emissions. Since the impact of RF diminishes with distance, industry advocates and many scientists dismiss the possibility that such structures pose health risks.

But it‘s not really that simple. A troubling body of evidence suggests exposure to even low emission levels at typical cellular frequencies between 300 MHz and 3 GHz can have a wide range of negative effects.

In a 2010 review of research on the biological effects of exposure to radiation from cell tower base stations, B. Blake Levitt and Henry Lai found that ―some research does exist to warrant caution in infrastructure siting.”[10] They summarized the results on one 2002 study that compared the health of 530 people living at various distances within 300 meters of cell towers with a control group living more than 300 meters away. ―Results indicated increased symptoms and complaints the closer a person lived to a tower. At <10 m, symptoms included nausea, loss of appetite, visual disruptions, and difficulties in moving. Significant differences were observed up through 100 m for irritability, depressive tendencies, concentration difficulties, memory loss, dizziness, and lower libido.”[11]

A 2007 study conducted in Egypt found similar results. Levitt and Lai report, ―Headaches, memory changes, dizziness, tremors, depressive symptoms, and sleep disturbance were significantly higher among exposed inhabitants than controls.”[12]

Beyond epidemiological studies, research on a wide range of living things raises further red flags. A 2013 study by the Indian scientists S. Sivani and D. Sudarsanam reports: ―Based on current available literature, it is justified to conclude that RF-EMF [electro magnetic fields] radiation exposure can change neurotransmitter functions, blood-brain barrier, morphology, electrophysiology, cellular metabolism, calcium efflux, and gene and protein expression in certain types of cells even at lower intensities.”[13]

The article goes on to detail the effects of mobile tower emissions on a wide range of living organisms: ―Tops of trees tend to dry up when they directly face the cell tower antennas. . . . A study by the Centre for Environment and Vocational Studies of Punjab University noted that embryos of 50 eggs of house sparrows were damaged after being exposed to mobile tower radiation for 5-30 minutes. . . . In a study on cows and calves on the effects of exposure from mobile phone base stations, it was noted that 32% of calves developed nuclear cataracts, 3.6% severely.”[14]

Does any of this constitute the conclusive evidence that would mandate much tighter control of the wireless infrastructure? Not in the estimation of industry and its captured agency. Citing other studies—often industry-funded—that fail to establish health effects, the wireless industry has dismissed such concerns. The FCC has typically echoed that position.

Keep in mind that light regulation has been one factor in the extraordinary growth of wireless—CTIA says exactly that in a Web post that credits the Clinton Administrations light regulatory touch.

July 25, 2013

CTIA BLOG CTIA is an international nonprofit trade association that has represented the wireless communications industry since 1984.

But our position as the world's leader was no accident. It started with the Clinton Administration that had the foresight to place a "light regulatory touch" on the wireless industry, which was in its infancy at the time. That light touch has continued through multiple Administrations.

Obviously, cellular technology is wildly popular because it offers many benefits to consumers. But even allowing for that popularity and for the incomplete state of science, don‘t some of these findings raise enough concern to warrant some backtracking on the ham-fisted federal preemption of local zoning rights?

In reality, since the passage of the 1996 law, the very opposite has occurred. Again and again both Congress and the FCC have opted to stiffen—rather than loosen—federal preemption over local zoning authority. In 2009, for example, the wireless industry convinced the FCC to impose a ―shot clock” that requires action within 90 days on many zoning applications. ―My sense is that it was an industry request,” said Robert Weller, who headed up the FCC‘s Office of Engineering and Technology when the shot clock was considered and imposed.[15]

And just last November, the FCC voted to further curb the rights of local zoning officials to control the expansion of antenna sites Again and again, Congress and the FCC have extended the wireless industry carte blanche to build out infrastructure no matter the consequences to local communities.

The question that hangs over all this: would consumers‘ embrace of cell phones and Wi-Fi be quite so ardent if the wireless industry, enabled by its Washington errand boys, hadn‘t so consistently stonewalled on evidence and substituted legal intimidation for honest inquiry? (See Appendix for online study of consumer attitudes on wireless health and safety.)

Document searches under the Freedom of Information Act reveal the central role of Tom Wheeler and the FCC in the tower siting issue. As both lobbyist and FCC chairman, Wheeler has proved himself a good friend of the wireless industry.

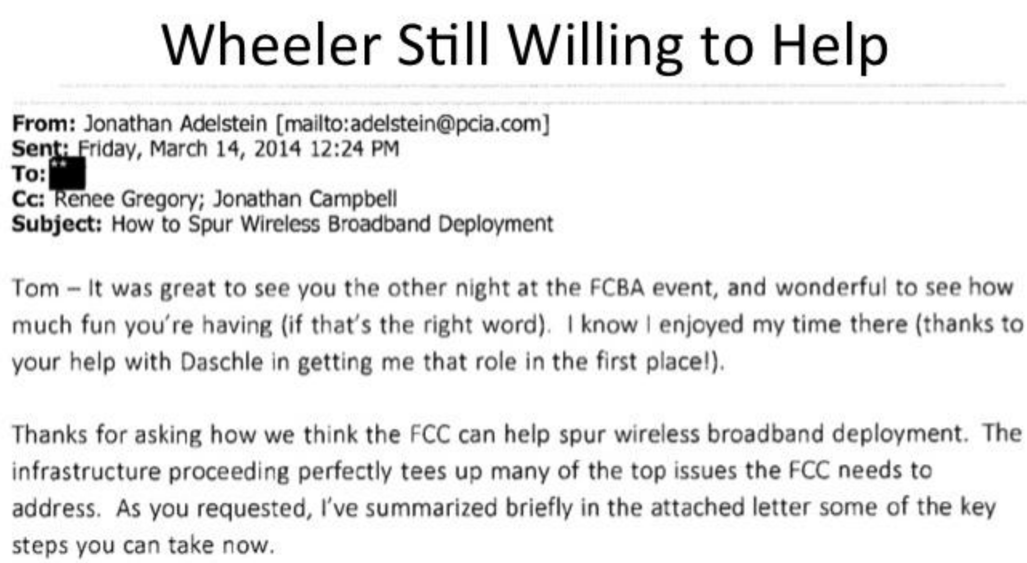
In January of 1997, CTIA chieftain Wheeler wrote FCC Wireless Telecommunications Bureau Chief Michele C. Farquhar citing several municipal efforts to assert control over siting. Wheeler, for example, asserted that one New England state had enacted a law requiring its Public Service Commissioner to issue a report on health risks posed by wireless facilities.[16] He questions whether such a study—and regulations based on its results—would infringe on FCC preemption authority.

FCC bureau chief Farquhar hastily reassured Wheeler that no such study could be consulted in zoning decisions. ―Therefore, based on the facts as you have presented them, that portion of the statute that directs the State Commissioner to recommend regulations based upon the study‘s findings would appear to be preempted,"[17] the FCC official wrote to Wheeler. She emphasized that the state had the right to do the study. It just couldn‘t deny a siting application based on anything it might learn.

The FCC in 1997 sent the message it has implicitly endorsed and conveyed ever since: study health effects all you want. It doesn‘t matter what you find. The build-out of wireless cannot be blocked or slowed by health issues.

Now let‘s fast forward to see Wheeler on the other side of the revolving door, interacting as FCC chairman with a former FCC commissioner who is now an industry lobbyist.

A March 14, 2014 letter[18] reveals the chummy relationship between Wheeler and former commissioner Jonathan Adelstein, now head of PCIA, the cellular infrastructure lobbying group. It also references FCC Chairman Wheeler seeking policy counsel from lobbyist Adelstein:



Wheeler Still Willing to Help

From: Jonathan Adelstein [mailto:adelstein@pcia.com]
Sent: Friday, March 14, 2014 12:24 PM
To: [redacted]
Cc: Renee Gregory; Jonathan Campbell
Subject: How to Spur Wireless Broadband Deployment

Tom – It was great to see you the other night at the FCBA event, and wonderful to see how much fun you're having (if that's the right word). I know I enjoyed my time there (thanks to your help with Daschle in getting me that role in the first place!).

Thanks for asking how we think the FCC can help spur wireless broadband deployment. The infrastructure proceeding perfectly tees up many of the top issues the FCC needs to address. As you requested, I've summarized briefly in the attached letter some of the key steps you can take now.

"Tom – It was great to see you the other night at the FCBA event, and wonderful to see how much fun you're having (if that's the right word). I know I enjoyed my time there (thanks to your help with Daschle in getting me that role in the first place!)."

"Thanks for asking how we think the FCC can help spur wireless broadband deployment," the wireless lobbyist writes to the ex-wireless lobbyist, now running the FCC.

Adelstein's first recommendation for FCC action: *"Amend its rules to categorically exclude DAS and small deployments* [Ed. note: these are compact tower add-ons currently being widely deployed] *from environmental and historic review."* Adelstein outlined other suggestions for further limiting local antenna zoning authority and the FCC soon did its part. Late last year, the agency proposed new rules that largely (though not entirely) complied with the antenna industry's wish list.

James R. Hobson is an attorney who has represented municipalities in zoning issues involving the FCC. He is also a former FCC official, who is now of counsel at Best, Best and Krieger, a Washington-based municipal law practice. ―The FCC has been the ally of industry," says Hobson. Lobbyist pressure at the FCC was intense even back in the 70s, when he was a bureau chief there. ―When I was at the FCC, a lot of my day was taken up with appointments with industry lobbyists." He says of the CTIA that Wheeler once headed: ―Their reason for being is promoting the wireless industry. And they've been successful at it."[19]

The FCC's deferential compliance has allowed industry to regularly bypass and if necessary steamroll local authorities. Violation of the FCC-imposed ―shot clock," for example, allows the wireless license applicant to sue.

The FCC's service to the industry it is supposed to regulate is evidently appreciated. The CTIA web site, typically overflowing with self-congratulation, spreads the praise around in acknowledging the enabling contributions of a cooperative FCC. In one brief summation of its own glorious accomplishments, CTIA twice uses the word ―thankfully" in describing favorable FCC actions.

In advancing the industry agenda, the FCC can claim that it is merely reflecting the will of Congress. But the agency may not be doing even that.

Remember the key clause in the 96 Telecom Act that disallowed denial of zoning permits based on health concerns? Well, federal preemption is granted to pretty much any wireless outfit on just one simple condition: its installations must comply with FCC radiation emission standards. In view of this generous carte blanche to move radiation equipment into neighborhoods, schoolyards and home rooftops, one would think the FCC would at the very least diligently enforce its own emission standards. But that does not appear to be the case.

Indeed, one RF engineer who has worked on more than 3,000 rooftop sites found vast evidence of non-compliance. Marvin Wessel estimates that ―10 to 20% exceed allowed radiation standards."[20] With 30,000 rooftop antenna sites across the U.S. that would mean that as many as 6,000 are emitting radiation in violation of FCC standards. Often, these emissions can be 600% or more of allowed exposure levels, according to Wessel.

Antenna standards allow for higher exposure to workers. In the case of rooftop sites, such workers could be roofers, painters, testers and installers of heating and air conditioning equipment, to cite just a few examples. But many sites, according to Wessel, emit radiation at much higher levels than those permitted in occupational standards. This is especially true of sites where service providers keep adding new antenna units to expand their coverage. ―Some of these new sites will exceed ten times the allowable occupational radiation level," said Wessel.[21] Essentially, he adds, this means that nobody should be stepping on the roof.

―The FCC is not enforcing its own standard," noted Janet Newton, who runs the EMF Policy Institute, a Vermont-based non-profit. That group several years ago filed 101 complaints on specific rooftop sites where radiation emissions exceeded allowable levels. ―We did this as an exercise to hold the FCC's feet to the fire," she said. But the 101 complaints resulted in few responsive actions, according to Newton.[22]

Former FCC official Bob Weller confirms the lax—perhaps negligible is the more appropriate word—FCC activity in enforcing antenna standards. ―To my knowledge, the enforcement bureau has never done a targeted inspection effort around RF exposure," he said.[23] Budget cuts at the agency have hurt, limiting the FCC's ability to perform field inspections, he added. But enforcement, he adds, would do wonders to insure industry compliance with its limited regulatory compliance requirements. ―If there were targeted enforcement and fines issued the industry would pay greater attention to ensuring compliance and self-regulation," he allowed.

Insurance is where the rubber hits the road on risk. So it is interesting to note that the rating agency A.M. Best, which advises insurers on risk, in 2013 topped its list of ―emerging technology-based risks" with RF Radiation:

> *"The risks associated with long-term use of cell phones, although much studied over the past 10 years, remain unclear. Dangers to the estimated 250,000 workers per year who come in close contact with cell phone antennas, however, are now more clearly established. Thermal effects of the cellular antennas, which act at close range essentially as open microwave ovens can include eye damage, sterility and cognitive impairments. While workers of cellular companies are well trained on the potential dangers, other workers exposed to the antennas are often unaware of the health risks. The continued exponential growth of cellular towers will significantly increase exposure of these workers and others coming into close contact with high-energy cell phone antenna radiation,"* A.M. Best wrote.[24]

So what has the FCC done to tighten enforcement? Apparently, not very much. Though it does follow up on many of the complaints filed against sites alleged to be in violation of standards it takes punitive actions very rarely. (The FCC did not provide answers to written questions on details of its tower enforcement policies.)

The best ally of industry and the FCC on this (and other) issues may be public ignorance.

An online poll conducted for this project asked 202 respondents to rate the likelihood of a series of statements.[25] Most of the statements were subject to dispute. Cell phones raise the risk of certain health effects and brain cancer, two said. There is no proof that cell phones are harmful, another declared. But among the six statements there was one statement of indisputable fact: ―The U.S. Congress forbids local communities from considering health effects when deciding whether to issue zoning permits for wireless antennae," the statement said.

Though this is a stone cold fact that the wireless industry, the FCC and the courts have all turned into hard and inescapable reality for local authorities, just 1.5% of all poll respondents replied that it was ―definitely true."

Public ignorance didn‘t take much cultivation by the wireless industry on the issue of local zoning. And maybe it doesn‘t matter much, considering the enormous popularity of wireless devices. But let‘s see how public ignorance has been cultivated and secured—with the FCC‘s passive support—on the potentially more disruptive issue of mobile phone health effects.

Chapter Three: Wireless Bullies and the Tobacco Analogy

Issues of cable and net neutrality have recently attracted wide public attention (more on that in Chapter Six). Still, the bet here remains that future judgment of the FCC will hinge on its handling of wireless health and safety issues.

And while the tower siting issue is an egregious example of an industry-dominated political process run amuck, the stronger health risks appear to reside in the phones themselves. This is an issue that has flared up several times in recent years. Each time, industry has managed to beat back such concerns. But it‘s worth noting that the scientific roots of concern have not disappeared. If anything, they‘ve thickened as new research substantiates older concerns.

The story of an FCC passively echoing an industry determined to play hardball with its critics is worth a further look. The CTIA‘s own website acknowledges the helpful hand of government‘s ―light regulatory touch" in allowing the industry to grow.[26]

Former congressman Dennis Kucinich ventures one explanation for the wireless industry‘s success in dodging regulation: ―The industry has grown so fast its growth has overtaken any health concerns that may have gained attention in a slow growth environment. The proliferation of technology has overwhelmed all institutions that would have attempted safety testing and standards," Kucinich said.[27]

But the core questions remain: Is there really credible evidence that cell phones emit harmful radiation that can cause human health problems and disease? Has the FCC done an adequate job in protecting consumers from health risks? Or has it simply aped industry stonewalling on health and safety issues?

Before wading into these questions, some perspective is in order.

First, there‘s simply no denying the usefulness and immense popularity of wireless technology. People depend on it for safety, information, entertainment and communication. It doesn‘t take a keen social observer to know that wireless has thoroughly insinuated itself into daily life and culture.

The unanswered question, though, is whether consumers would embrace the technology quite so fervently if health and safety information was not spun, filtered and clouded by a variety of industry tactics.

To gain some insight into this question, we conducted an online survey of 202 respondents, nearly all of whom own cell phones, on Amazon‘s Mechanical Turk Web platform (see Appendix). One striking set of findings: many respondents claim they would change behavior—reduce wireless use, restore landline service, protect their children—if claims on health dangers of wireless are true.

It is not the purpose of this reporter to establish that heavy cell phone usage is dangerous. This remains an extremely controversial scientific issue with new findings and revised scientific conclusions repeatedly popping up. Just months ago, a German scientist who had been outspoken in denouncing the view that cell phones pose health risks reversed course. In an April 2015 publication, Alexander Lerchl reported results confirming previous research on the tumor-promoting effects of electromagnetic fields well below human exposure limits for mobile phones. “Our findings may help to understand the repeatedly reported increased incidences of brain tumors in heavy users of mobile phones,” the Lerchl team concluded.[28] And in May 2015, more than 200 scientists boasting over 2,000 publications on wireless effects called on global institutions to address the health risks posed by this technology.

But the National Cancer Institute still contends that no cell phone dangers have been established. A representative of NCI was the sole known dissenter among the 30 members of the World Health Organization‘s International Agency for Research on Cancer (IARC) when it voted to declare wireless RF “possibly carcinogenic.”[29] If leading scientists still can‘t agree, I will not presume to reach a scientific conclusion on my own.

IARC RF working group: Official press release

International Agency for Research on Cancer

World Health Organization

PRESS RELEASE
N° 208

31 May 2011

IARC CLASSIFIES RADIOFREQUENCY ELECTROMAGNETIC FIELDS AS POSSIBLY CARCINOGENIC TO HUMANS

Lyon, France, May 31, 2011 -- The WHO/International Agency for Research on Cancer (IARC) has classified radiofrequency electromagnetic fields as **possibly carcinogenic to humans (Group 2B)**, based on an increased risk for **glioma**, a malignant type of brain cancer, associated with wireless phone use.

But let‘s at least look at some of the incriminating clues that health and biology research has revealed to date. And let‘s look at the responses of both industry and the FCC.

The most widely cited evidence implicating wireless phones concerns gliomas, a very serious type of brain tumor. The evidence of elevated risk for such tumors among heavy cell phone users comes from several sources.

Gliomas account for roughly half of all malignant brain tumors, which are relatively rare. The annual incidence of primary malignant brain tumors in the U.S. is only 8.2 per 100,000 people, according to the International Radio Surgery Association.

Still, when projected over the entire U.S. population, the public health impact is potentially very significant.

Assuming roughly four new glioma cases annually in the U.S. per 100,000 people, yields over 13,000 new cases per year over a total U.S. population of 330 million. Even a doubling of that rate would mean 13,000 new gliomas, often deadly, per year. A tripling, as some studies have found, could mean as many as 26,000 more new cases annually. Indeed, the respected online site Medscape in January 2015 reported results of Swedish research under the headline: *Risk for Glioma Triples With Long-Term Cell Phone Use*.[30]

And here‘s some eye-opening quantitative perspective: the wars in Iraq and Afghanistan, waged now for more than a decade each, have together resulted in roughly 7,000 U.S. deaths.

Preliminary—though still inconclusive—research has suggested other potential negative health effects. Swedish, Danish and Israeli scientists have all found elevated risk of salivary gland tumors. One Israeli studied suggested elevated thyroid cancer risk. Some research has found that men who carry their phones in their pockets may suffer sperm count damage. One small study even suggests that young women who carry wireless devices in their bras are unusually vulnerable to breast cancer.

And while industry and government have never accepted that some portion of the population is unusually sensitive to electromagnetic fields, many people continue to complain of a broad range of symptoms that include general weakness, headaches, nausea and dizziness from exposure to wireless.

Some have suggested that the health situation with wireless is analogous to that of tobacco before court decisions finally forced Big Tobacco to admit guilt and pay up. In some ways, the analogy is unfair. Wireless research is not as conclusively incriminating as tobacco research was. And the identified health risks with wireless, significant as they are, still pale compared with those of tobacco.

But let‘s not dismiss the analogy outright. There is actually a very significant sense in which the tobacco-wireless analogy is uncannily valid.

People tend to forget that the tobacco industry—like the wireless industry—also adopted a policy of tone-deaf denial. As recently as 1998, even as evidence of tobacco toxicity grew overwhelming, cigarette maker Phillip Morris was writing newspaper advertorials insisting there was no proof smoking caused cancer.

It seems significant that the responses of wireless and its captured agency—the FCC—feature the same obtuse refusal to examine the evidence. The wireless industry reaction features stonewalling public relations and hyper aggressive legal action. It can also involve undermining the credibility and cutting off the funding for researchers who do not endorse cellular safety. It is these hardball tactics that look a lot like 20th century Big Tobacco tactics. It is these hardball tactics—along with consistently supportive FCC policies—that heighten suspicion the wireless industry does indeed have something to hide.

Begin with some simple facts issuing from meta-analysis of cellular research. Dr. Henry Lai, emeritus professor of bioengineering at the University of Washington, has reviewed hundreds of published scientific papers on the subject. He wanted to see how many studies demonstrated that non-ionizing radiation produces biological effects beyond the heating of tissue. This is critical since the FCC emission standards protect only against heating. The assumption behind these standards is that there are no biological effects beyond heating.

But Dr. Lai found that just over half—actually 56%—of 326 studies identified biological effects. And the results were far more striking when Dr. Lai divided the studies between those that were industry-funded and those that were independently funded. Industry-funded research identified biological effects in just 28% of studies. But fully 67% of non-industry funded studies found biological effects (Insert Slide—Cell Phone Biological Studies).

A study conducted by Swiss and British scientists also looked at how funding sources affected scientific conclusions on the possible health effects of cell phone usage. They found that of studies privately funded, publicly funded and funded with mixed sponsorship, industry-funded studies were “least likely to report a statistically significant result.”[31] “The interpretation of results from studies of health effects of radiofrequency radiation should take sponsorship into account,” the scientists concluded.[32]

So how does the FCC handle a scientific split that seems to suggest bias in industry-sponsored research?

In a posting on its Web site that reads like it was written by wireless lobbyists, the FCC chooses strikingly patronizing language to slight and trivialize the many scientists and health and safety experts who've found cause for concern. In a two page Web post titled “Wireless Devices and Health Concerns,” the FCC four times refers to either “some health and safety interest groups,” “some parties,” or “some consumers” before in each case rebutting their presumably groundless concerns about wireless risk.[33] Additionally, the FCC site references the World Health Organization as among those organizations who've found that “the weight of scientific evidence" has not linked exposure to radiofrequency from mobile devices with ―any known health problems."

Yes, it‛s true that the World Health organization remains bitterly divided on the subject. But it‛s also true that a 30 member unit of the WHO called the International Agency for Research on Cancer (IARC) was near unanimous in pronouncing cell phones ―possibly carcinogenic" in 2011. How can the FCC omit any reference to such a pronouncement? Even if it finds reason to side with pro-industry scientists, shouldn‛t this government agency also mention that cell phones are currently in the same potential carcinogen class as lead paint?

Now let‛s look a bit more closely at the troublesome but presumably clueless crowd of ―some parties" that the FCC so cavalierly hastens to dismiss? Let‛s begin with **Lennart Hardell**, professor of Oncology and Cancer Epidemiology at the University Hospital in Oreboro, Sweden.

Until recently it was impossible to gain any real sense of brain tumor risk from wireless since brain tumors often take 20 or more years to develop. But the cohort of long-term users has been growing. In a study published in the International Journal of Oncology in 2013, Dr. Hardell and Dr. Michael Carlberg found that the risk of glioma—the most deadly type of brain cancer—rose with cell phone usage. The risk was highest among heavy cell phone users and those who began to use cell phones before the age of 20.[34]

Indeed, those who used their phones at least 1640 hours (which would be roughly 30 minutes a day for nine years) had nearly three times the glioma incidence. Drs. Hardell and Carlberg also found that gliomas tend to be more deadly among heavy wireless callers.[35]

Perhaps of greatest long-term relevance, glioma risk was found to be four times higher among those who began to use mobile phones as teenagers or earlier. These findings, along with the established fact that it generally takes decades for tumors induced by environmental agents to appear, suggest that the worst consequences of omnipresent wireless devices have yet to be seen.

In a 2013 paper published in *Reviews on Environmental Health*, Drs. Hardell and Carlberg argued that the 2011 finding of the IARC that identified cell phones as a ―possibly carcinogenic" needs to be revised. The conclusion on radiofrequency electromagnetic fields from cell phones should now be ―cell phones are not just a possible carcinogen." They can now be ―regarded as carcinogenic to humans" and the direct cause of gliomas (as well as acoustic neuromas, a less serious type of tumor).[36] Of course, these views are not universally accepted.

The usual spin among industry supporters when presented with research that produces troubling results is along the lines of: ―We might pay attention if the results are duplicated." In fact, the Hardell results were echoed in the French CERENAT study, reported in May of 2014. The CERENAT study also found higher risk among heavy users, defined as those using their phones at least 896 hours (just 30 minutes a day for five years). ―These additional data support previous findings concerning a possible association between heavy mobile phone use and brain tumors," the study concluded.[37]

Cell phones are not the only wireless suspects. Asked what he would do if he had policy-making authority, Dr. Hardell swiftly replied that he would ―ban wireless use in schools and pre-schools. You don't need Wi-Fi," he noted.[38] This is especially interesting in view of the FCC's sharply hiked spending to promote and extend Wi-Fi usage, as well as its consistent refusal to set more stringent standards for children (more on all this later). But for now let's further fill out the roster of the FCC's unnamed ―some parties."

Martin Blank is a Special Lecturer in Physiology and Cellular Biophysics at Columbia University. Unlike Dr. Hardell, who looks at broad epidemiological effects over time, Dr. Blank sees cause for concern in research showing there is biological response at the cellular level to the type of radiation emitted by wireless devices. ―The biology tells you unequivocally that the cell treats radiation as a potentially damaging influence," Dr. Blank said in a late 2014 interview.[39]

―The biology tells you it's dangerous at a low level," he added. Though some results have been difficult to replicate, researchers have identified a wide range of cellular responses including genetic damage and penetration of the blood brain barrier. Dr. Blank specifically cited the ―cellular stress response" in which cells exposed to radiation start to make proteins.

It is still not clear whether biological responses at the cellular level translate into human health effects. But the research seems to invalidate the basic premise of FCC standards that the only biological effect of the type of radiation produced by wireless devices is tissue heating at very high power levels. But the standards-setting agencies ―ignore the biology," according to Dr. Blank. He describes the FCC as being ―in industry's pocket."[40]

Sweden's Lund University is annually ranked among the top 100 universities in the world. **Leif Salford** has been chairman of the Department of Neurosurgery at Lund since 1996. He is also a former president of the European Association for Neuro-Oncology. In the spring of 2000, Professor Salford told me that wireless usage constituted ―the world's largest biological experiment ever."[41]

He has conducted numerous experiments exposing rats to cellular-type radiation. Individual experiments have shown the radiation to penetrate the blood-brain barrier, essential to protecting the brain from bloodstream toxins. Professor Salford also found that rats exposed to radiation suffered loss of brain cells. ―A rat's brain is very much the same as a human's. They have the same blood-brain barrier and neurons. We have good reason to believe that what happens in rat's brains also happens in humans," he told the BBC in 2003. Dr. Salford has also speculated that mobile radiation could trigger Alzheimer's disease in some cases but emphasized that much more research would be needed to establish any such causal relationship. Does this man deserve to be dismissed as one of a nameless and discredited group of ―some parties?"

And what about the **American Academy of Pediatrics (AAP),** which represents 60,000 American doctors who care for children? In a December 12, 2012 letter to former Ohio Congressman Dennis Kucinich, AAP President Dr. Thomas McInerny writes: ―Children are disproportionately affected by environmental exposures, including cell phone radiation. The differences in bone density and the amount of fluid in a child‘s brain compared to an adult‘s brain could allow children to absorb greater quantities of RF energy deeper into their brains than adults."[42]

In a subsequent letter to FCC officials dated August 29, 2013, Dr. McInerny points out that ―children, however, are not little adults and are disproportionately impacted by all environmental exposures, including cell phone radiation." Current FCC exposure standards, set back in 1996, ―do not account for the unique vulnerability and use patterns specific to pregnant women and children," he wrote. (Insert slide: A Plea from Pediatricians). Does an organization representing 60,000 practitioners who care for children deserve to be brushed off along with ―some health and safety interest groups?"

So what is the FCC doing in response to what at the very least is a troubling chain of clues to cellular danger? As it has done with wireless infrastructure, the FCC has to this point largely relied on industry ―self-regulation." Though it set standards for device radiation emissions back in 1996, the agency doesn‘t generally test devices itself. Despite its responsibility for the safety of cell phones, the FCC relies on manufacturers‘ good-faith efforts to test them. Critics contend that this has allowed manufacturers undue latitude in testing their devices.

Critics further contend that current standards, in place since cell phones were barely in use, are far too lax and do not reflect the heavy usage patterns that have evolved. Worse still, industry is allowed to test its own devices using an imprecise system that makes no special provision for protecting children and pregnant women. One 2012 study noted that the procedure widely used by manufacturers to test their phones ―substantially underestimates" the amount of RF energy absorbed by 97% of the population, ―especially children." A child‘s head can absorb over two times as much RF energy. Other persons with smaller heads, including women, are also more vulnerable. The authors recommend an alternative computer simulation technique that would provide greater insight into the impact of cellular radiation on children and on to the specific RF absorption rates of different tissues, which vary greatly.[43]

Acting on recommendations of the General Accounting Office, the FCC is now reconsidering its standards for wireless testing and allowed emissions. On the surface, this may seem to represent an effort to tighten standards to promote consumer health and safety. But many believe the FCC‘s eventual new standard will actually be weaker, intensifying any health risk from industry‘s self-reported emission levels. ―They‘re under great pressure from industry to loosen the criteria," notes Joel Moskowitz, director of the Center for Family and Community Health at UC Berkeley‘s School of Public Health.[44] One fear is that the FCC could measure the allowed radiation absorption level (SAR) over a wider sample of tissue, effectively loosening the standard allowable energy absorption. One FCC official, who asked that his name not be used, contended that a decision had not yet been made to loosen the standard.

But to this point, there is little evidence the FCC is listening to anyone beyond its familiar friends in the wireless industry. Carl Blackman, a scientist at the Environmental Protection agency until retiring in 2014, notes that the FCC does rely to some degree on an inter-agency governmental group for advice on health matters. The group includes, for example, representatives from the EPA and the FDA.

Blackman served on that advisory group and he says that it has been divided. Though some government advisers to the FCC find evidence of wireless health risks convincing, others remain skeptical, said Blackman. Root of the skepticism: even though numerous researchers have found biological and health effects, the mechanism for action by non-ionizing radiation on the human body has still not been identified. ―I don‗t think there‗s enough of a consensus within the Radio Frequency Inter-agency Working Group for them to come out with stricter standards," he says.[45]

But political pressures also figure mightily in all this. The EPA, notably, was once a hub of research on RF effects, employing as many as 35 scientists. However, the research program was cut off in the late 80s during the Regan presidency. Blackman says he was personally ―forbidden" to study health effects by his ―superpvisory structure."[46] He termed it ―a political decision" but recognized that if he wanted to continue to work at the EPA he would have to do research in another area.

Blackman is cautious in imputing motives to the high government officials who wanted his work at EPA stopped. But he does say that political pressure has been a factor at both the EPA and FCC: ―The FCC people were quite responsive to the biological point of view. But there are also pressures on the FCC from industry." The FCC, he suggests, may not just be looking at the scientific evidence ―The FCC‗s position—like the EPA‗s—is influenced by political considerations as well."[47]

Still, the FCC has ultimate regulatory responsibility and cannot indefinitely pass the buck on an issue of fundamental public health. Remarkably, it has not changed course despite the IARC classification of cell phones as possibly carcinogenic, despite the recent studies showing triple the glioma risk for heavy users, despite the floodtide of research showing biological effects, and despite even the recent defection of core industry booster Alex Lerchl. It is the refusal of both industry and the FCC to even acknowledge this cascade of warning signs that seems most incriminating.

Of course, industry behavior goes well beyond pushing for the FCC‗s willful ignorance and inaction. Industry behavior also includes self-serving public relations and hyper aggressive legal action. It can also involve undermining the credibility of and cutting off the funding for researchers who do not endorse cellular safety. It is these hardball tactics that recall 20th century Big Tobacco tactics. It is these tactics that heighten suspicion that the wireless industry does indeed have a dirty secret. And it is those tactics that intensify the spotlight on an FCC that so timidly follows the script of the fabulously wealthy, bullying, billion-dollar beneficiaries of wireless.

Chapter Four: You Don't Need Wires To Tie People Up

So let's look a little more deeply at some of the actions of an industry group that boasts of 500 meetings a year with the FCC. Lobbying is one thing. Intimidation is another. CTIA has shown its skill at—and willingness to use—both.

Outright legal bullying is a favored tactic. The City of San Francisco passed an ordinance in 2010 that required cell phone manufacturers to display more prominently information on the emissions from their devices. This information was already disclosed—but often buried—in operator manuals and on manufacturer websites. The idea was to ensure that consumers saw information already mandated and provided.

Seeing this as a threat to its floodtide of business, the industry sued the City of San Francisco. The City, fearing a prolonged legal fight with an industry that generates hundreds of billions of dollars in annual revenue, backed down.

On May 12, 2015, Berkeley, California's City Council unanimously passed a similar ordinance. Joel Moskowitz, director of the Center for Family and Community Health at the University of California-Berkeley's School of Public Health, has been involved in the effort. Berkeley, he says, didn't want to run into the same legal threats that paralyzed San Francisco. So it tried to draft the most inoffensive and mild language possible. The proposed Cell Phone Right to Know ordinance: ―To assure safety, the Federal Government requires that cell phones meet radio frequency (RF) exposure guidelines. If you carry or use your phone in a pants or shirt pocket or tucked into a bra when the phone is ON and connected to a wireless network, you may exceed the federal guidelines for exposure to RF radiation. This potential risk is greater for children. Refer to the instructions in your phone or user manual for information about how to use your phone safely."[48]

Sounds pretty inoffensive, no? Not to the CTIA, which indicated that it was prepared to sue, according to Berkeley City Attorney Zach Cowan.[49] (On June 8th, CTIA did indeed sue the City of Berkeley.)

Well, from the industry point of view, why not throw around your weight? Smash mouth legal tactics have been highly successful thus far as industry has managed to throttle several efforts to implicate manufacturers in cases where heavy users suffered brain tumors.

But one current case has advanced in district court in Washington to the point where the judge allowed plaintiffs to present expert witness testimony. The industry response: file a legal action seeking to invalidate long-held court methods for qualifying expert witnesses.

This is a very rich industry that does not hesitate to outspend and bully challengers into submission. Meanwhile, amidst the legal smoke and medical confusion, the industry has managed to make the entire world dependent on its products. Even tobacco never had so many hooked users.

Such sustained success in the face of medical doubt has required industry to keep a lid on critics and detractors. Many scientists who‘ve found real or potential risk from the sort of microwave radiation emanating from wireless devices have learned there is a price to be paid for standing up to the industry juggernaut. A few prominent examples:

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In 1994, University of Washington researchers Henry Lai and N.P. Singh found that rats exposed to microwave radiation suffered DNA damage to their brain cells. This was a scary finding since DNA damage can lead to mutations and possibly cancer.

The reaction from industry was swift. Motorola was at that time the U.S. market leader in cell phones. In a memorandum obtained by the journal Microwave News, Motorola PR honcho Norm Sandler outlined how the company could ―downplay the significance of the Lai study.” One step: ―We have developed a list of independent experts in this field and are in the process of recruiting individuals willing and able to reassure the public on these matters,” Sandler wrote. After outlining such measures, he concluded that Motorola had ―sufficiently war-gamed” the issue. The practices of lining up industry-friendly testimony and ―war-gaming” researchers who come up with unfavorable results have been persistent themes with this industry.

Motorola “War-Games” Bad News

Motorola, Microwaves and DNA Breaks: “War-Gaming” the Lai-Singh Experiments

“We have developed a list of independent experts in this field and are in the process of recruiting individuals willing and able to reassure the public on these matters.”

“I think we have sufficiently war-gamed the Lai-Singh issue…”

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After Lai‘s results were published, Motorola decided to sponsor further research on microwaves and DNA damage. Oftentimes, lab results cannot be reproduced by other researchers, particularly if experiments are tweaked and performed a bit differently. Non-confirming studies raise doubt, of course, on the original work.

Motorola lined up Jerry Phillips, a scientist at the Veteran‘s Administration Medical Center in Loma Linda, California, and Phillips tested the effect of radiation at different frequencies from those tested by Lai and Singh. Nevertheless, Phillips found that at some levels of exposure, DNA damage increased, while at other levels it decreased. Such findings were ―consistent" with the sorts of effects produced by chemical agents, Phillips said in an interview.[50] In some cases, the radiation may have activated DNA repair mechanisms, reducing the overall microwave effect. But what was important, Phillips explained, is that there were *any* biological effects at all. The wireless industry has long contended—and the FCC has agreed—that there is no evidence that non-ionizing radiation at the frequencies and power levels used by cell phones is biologically active.

Understanding the potential impact of ―biological effect" findings, Motorola again turned to damage control, said Phillips. He recalls receiving a phone call from a Motorola R&D executive. ―I don‘t think you‘ve done enough research,‘" Phillips recalls being told. The study wasn‘t ready for publication, according to the Motorola executive. Phillips was offered more money to do further research without publishing the results of what he‘d done.

But Phillips felt he‘d done enough. Despite warnings for his own boss to ―give Motorola what it wants," Phillips went ahead and published his findings in 1998. Since then, Phillips‘ industry funding has dried up. Meanwhile, as many other researchers report, government funding to do independent research on microwave radiation has dried up, leaving the field at least in the U.S. to industry-funded scientists. ―There is no money to do the research," Said Phillips. ―It‘s not going to come from government because government is controlled by industry."[51]

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Om P. Gandhi is Professor of Electrical and Computer Engineering at the University of Utah and a leading expert in dosimetry—measurement of non-ionizing radiation absorbed by the human body. Even before cell phones were in wide use, Professor Gandhi had concluded that children absorb more emitted microwave radiation. ―The concentration of absorbed energy is 50 to 80% greater," he explained.[52]

These conclusions were not acceptable to Professor Gandhi‘s industrial sponsors. In 1998, he recalls, an executive from a cell phone manufacturer—which he did not want to identify—told him directly that if he did not discontinue his research on children his funding would be cut off. Professor Gandhi recalled replying: ―I will not stop. I am a tenured professor at the University of Utah and I will not reject my academic freedom." Professor Gandhi also recalled some of his thought process: ―I wasn‘t going to order my students to alter their results so that I can get funding." His industry sponsors cancelled his contract and asked for a return of funds.

Professor Gandhi believes that some cell phone users require extra protection because their heads are smaller and more absorptive. ―Children, as well as women and other individuals with smaller heads absorb more concentrated energy because of the proximity of the radiating antenna to the brain tissue," he said. And yet the FCC has not acted to provide special protection for these groups. Asked why not, Professor Gandhi conceded that he doesn't know. He does note, however, that recent standards-setting has been dominated by industry representatives.[53]

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While the mobile industry refuses to admit to even the possibility that there is danger in RF radiation, giant insurance companies see things differently. Several insurers have in recent years issued reports highlighting product liability risk with cell phones. This is important because it is evidence that where money is on the line professionals outside the industry see the risk of legal liability.

Legal exposure could be one reason—perhaps the central one—the industry continues to stonewall. Should legal liability be established, one key question will be how much wireless executives knew—and at what point in time. Meanwhile, the combination of public relations denials, legal intimidation and the selective application of pressure on research follows a familiar pattern. ―The industry is basically using the tobacco industry playbook," UC Berkeley's Moskowitz said in a recent radio interview.[54]

That playbook has thus far been highly successful in warding off attention, regulation and legal incrimination.

Chapter Five: $270 Billion . . . and Looking for Handouts

The FCC‘s network of corruption doesn‘t just shield industry from needed scrutiny and regulation on matters of public health and safety. Sometimes it just puts its hand directly into the public pocket and redistributes that cash to industry supplicants.

Such is arguably the case with the Universal Service Fund. Originally established to extend telephone service to rural and urban areas that industry would find difficult or uneconomical to wire, the USF is now shifting from subsidizing landline phone service to subsidizing the extension of broadband Internet. USF monies also support the Lifeline program, which subsidizes cell phone service to low-income consumers, and the E-Rate program, which subsidizes Internet infrastructure and service to schools and libraries.

Since 1998, more than $110 billion has been allocated to Universal Service programs, notes Charles Davidson, director of the Advanced Communications Law & Policy Institute at New York Law School. The FCC has allocated over $40 billion to the E-Rate program alone.

Who pays the freight for these high-cost programs? You do.

Technically, landline and wireless phone companies are assessed for the Universal Service fund‘s expenditures. But the FCC also allows those companies to pass on such charges to their subscribers, which they do. Both landline and wireless subscribers pay a monthly Universal Service charge that is tacked on to their phone bills. That charge has been rising and recently amounted to a 16% surcharge on interstate calls.

Consumers who pay for these programs might be interested to learn that both the E-Rate and Lifeline programs have been riddled with fraud. Government watchdogs have repeatedly found the programs to be inefficient and prone to inflated and fraudulent claims. But the programs have been a windfall for tech and telecom industry beneficiaries. Wherever the FCC presides, it seems, these industries reap a windfall.

The General Accounting Office (GAO) has issued several reports citing fraud, waste and mismanagement, along with inadequate FCC oversight of the subsidy program. Bribery, kickbacks and false documentation can perhaps be expected in a handout program mandated by Congress and only indirectly supervised by the FCC.

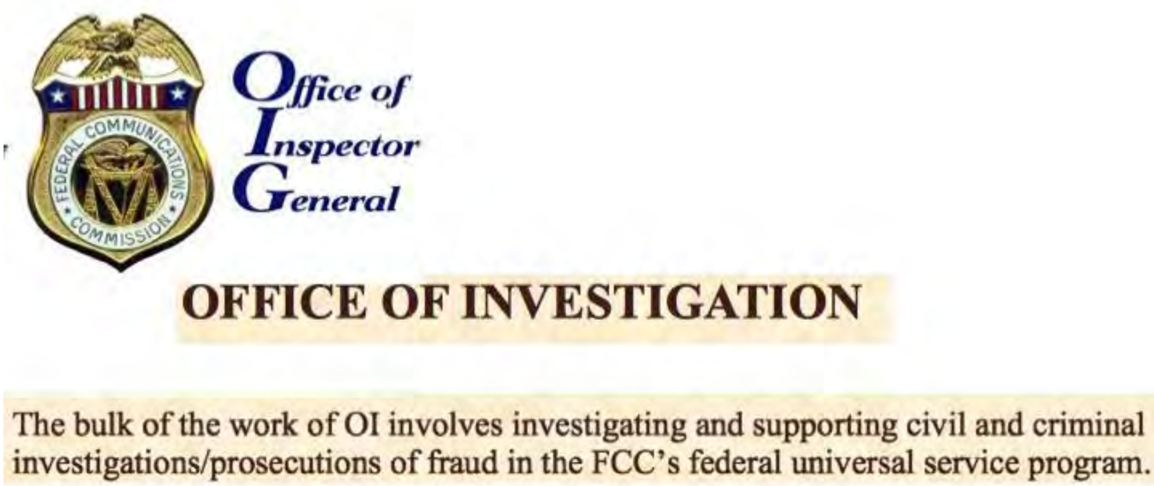
But the scope of fraud has been impressive. The most striking corruption has marred the E-Rate program, which subsidizes Internet hardware, software and service for schools and libraries, and the Lifeline cell phone subsidies.

In recent years, several school districts have paid fines to settle fraud cases involving bribery, kickbacks, non-competitive bidding of contracts and false documentation in the E-Rate program. More eye opening perhaps are the settlements of fraud claims by tech giants like IBM, Hewlett Packard and AT&T. The HP case, for example, involved some colorful bribery allegations, including gifts of yachts and Super Bowl tickets. HP settled for $16 million. An HP official and a Dallas Independent School District official both received jail sentences.

The Lifeline program has also been riddled with fraud. A Wall Street Journal investigation of the five top corporate beneficiaries of Lifeline showed that 41% of more than 6 million subsidy claimants ―couldn‘t demonstrate their eligibility or didn‘t respond to requests for certification."[55] AT&T, Verizon, and Sprint Nextel were three of the major Lifeline beneficiaries.

The FCC has initiated several efforts to clean up USF programs and seems honestly determined to bring greater accountability and efficiency to its subsidy efforts. Nevertheless, problems with fraud persist, as reported recently by the FCC‘s own top investigator.

Congress established the FCC‘s Office of Inspector General in 1989 to ―provide objective and independent investigations, audits and reviews of the FCC‘s programs and operations." Here‘s what the FCC‘s internal investigative unit said in a September 30, 2014 report to Congress about its Office of Investigation (OI): ―*The bulk of the work of OI involves investigating and supporting civil and criminal investigations/prosecutions of fraud in the FCC's federal universal service program*."[56]



OFFICE OF INVESTIGATION

The bulk of the work of OI involves investigating and supporting civil and criminal investigations/prosecutions of fraud in the FCC's federal universal service program.

Fraud—as pervasive and troubling as it has been—is just one of the problems with the programs of universal service. It may not even be the fundamental problem. More fundamental issues concern the very aim, logic and efficiency of programs to extend broadband and wireless technology at public expense. Though the aims of extending service to distant impoverished areas seem worthy on the surface, there are many reasons to think the major beneficiaries of these programs are the technology companies that win the contracts.

Lobbyists have long swarmed over the FCC looking to get an ever-growing piece of the USF honeypot. An FCC report on meetings with registered lobbyists details a 2010 meeting with representatives of the International Society for Technology in Education and other education lobbyists. Topics discussed, according to the FCC report, included ―the need to raise the E-Rate‘s annual cap."[57]

The CTIA, leaving no stone unturned in its efforts to pump up member revenues, last year responded to a House hearing on the USF by grousing that ―current USF-supported programs skew heavily toward support of wireline services. . . . The concentration of USF monies to support wireline services is inconsistent with technological neutrality principles and demonstrated consumer preferences," CTIA wrote..[58] An industry that generates hundreds of billions of dollars in equipment and service revenues annually bellies up for a bigger slice of the $8 billion a year USF.

The grousing has paid off. The FCC recently announced that it will raise spending on E-Rate from what had been a cap of $2.4 billion a year to $3.9 billion. A significant portion of new outlays will go to Wi-Fi—yet another wireless industry victory at the FCC. But the CTIA is by no means the only industry group pressing the FCC.

Leading the roster of active lobbyists on E-Rate issues is the Software and Information Industry Association. Beginning in 2006, SIAA led all lobbyists with 54 mentions of E-Rate in its filings, according to the Center for Responsive Politics. SIAA board members include executives from tech heavyweights Google, Oracle and Adobe Systems.

Tech business leaders—many of them direct beneficiaries of FCC programs—made a direct pitch to FCC Chairman Wheeler last year to hike E-Rate funding. ―The FCC must act boldly to modernize the E-Rate program to provide the capital needed to upgrade our K-12 broadband connectivity and Wi-Fi infrastructure within the next five years," the executives wrote.[59]

There were dozens of corporate executive signees to this letter, including the CEOs of many Fortune 500 giants. But let‘s just consider the participation of three: top executives of Microsoft, Google and HP all joined the call to expand E-Rate subsidies. Consider the simple fact that these three tech giants alone had revenues of $270 billion—more than a quarter of a trillion dollars—in a recent four-quarter period. Together, they produced nearly $40 billion in net income. And yet their top executives still thought it necessary to dun the FCC—and really, they were surreptitiously hitting up the public—for ramped-up spending on what was then a $2.4 billion a year program.

Is that greed? Arrogance? Or is it simply behavior conditioned by success in repeatedly getting what they want at the public trough? Almost never mentioned in these pleas for higher subsidies is the fact that ordinary American phone subscribers are the ones footing the bill for the E-Rate program—not the FCC or the telecom industry.

Much of the added spending, as noted, will go towards the installation of wireless networks. And yet Wi-Fi does not have a clean bill of health. When Lennart Hardell, professor of Oncology and Cancer Epidemiology at the University Hospital in Orebro, Sweden, was asked what he would do if given policy authority over wireless health issues, he replied swiftly that he would ―ban wireless use in schools and pre-school." Noting that there are wired alternatives, Professor Hardell flatly stated: ―You don‘t need Wi-Fi."[60] And yet the FCC, prodded by an industry ever on the lookout for incremental growth opportunities, is ignoring the health of youngsters to promote expanded Wi-Fi subsidies in schools across the U.S.

And what about the merit of the program itself? Overlooking the fraud and lobbying and Wi-Fi safety issues for a moment, shouldn‘t schools and libraries across the country be equipped with the best electronic gear, accessing the Internet at the fastest speeds? Doesn‘t the government owe that to its younger citizens, especially those disadvantaged by the long-referenced digital divide?

Well, maybe. But answers to these questions hinge on even more fundamental question: Do students actually learn more or better with access to the latest high-speed electronic gadgetry?

It would be foolish to argue that nobody benefits from access to high-speed Internet. But the benefits are nowhere near as broad or rich as corporate beneficiaries claim. Some researchers, for example, have concluded that computers don‘t seem to have positive educational impact—they may even have negative impact—when introduced into the home or freely distributed to kids from low income backgrounds.

Duke University researchers Jacob Vigdor and Helen Ladd studied the introduction of computers into North Carolina homes. They found that the academic performance of youngsters given computers actually declined. *"The introduction of home computer technology is associated with modest but statistically significant and persistent negative impacts on student math and reading test scores,"* the authors wrote in a National Bureau of Economic Research Working Paper.[61] The impact was actually most negative on the poorer students.

A study in the Journal of International Affairs examined the impact of the global One Laptop Per Child Program (OLPC), which has distributed millions of computers to children around the world. Researchers Mark Warschauer and Morgan Ames conclude: *"The analysis reveals that provision of individual laptops is a utopian vision for the children in the poorest countries, whose educational and social futures could be more effectively improved if the same investments were instead made on more proven and sustainable interventions. Middle- and high-income countries may have a stronger rationale for providing individual laptops to children, but will still want to eschew OLPC's technocratic vision. In summary, OLPC represents the latest in a long line of technologically utopian schemes that have unsuccessfully attempted to solve complex social problems with overly simplistic solutions*."[62]

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Can One Laptop Per Child Save the World's Poor?

"...In summary, One Laptop Per Child represents the latest in a long line of technologically utopian development schemes that have unsuccessfully attempted to solve complex social problems with overly simplistic solutions."

Access to computers in the home may not work educational magic. But what about computers in the classroom? Don‘t they have educational value there?

The anecdotal evidence is mixed at best. Consider how students in Los Angeles, newly equipped with flashy iPads at a mind-boggling taxpayer cost of more than $1 billion, went about using the new tools to improve their educational performance. ―Instead of solving math problems or doing English homework, as administrators envisioned, more than 300 Los Angeles Unified School District students promptly cracked the security setting and started tweeting, posting to Facebook and playing video games."[63]

But let‘s cut through the self-serving corporate claims and the troubling anecdotes to hear from someone who actually has had extensive and unique field experience. Kentaro Toyama was co-founder of Microsoft‘s research lab in India. Over more than five years he oversaw at least a dozen projects that sought to address educational problems with the introduction of computer technology. His conclusion: ―The value of technology has been over-hyped and over-sold."

The most important factor in improving schools, says Toyama, now the W.K Kellogg Associate Professor of Community Information at the University of Michigan, is good teachers. Without good, well-trained teachers, adequate budgets and solid school administration, technology does little good. ―Technology by itself never has any kind of positive impact," he said.[64]

The only schools in his experience that benefited from increased technology investment were those where ―the teachers were very good, the budgets adequate." The richer schools, in essence. But as both Vigdor and Warschauer found, the introduction of technology has by itself little if any positive effect. For a public conditioned to believe in the virtues of new technology, such testimony is a bracing dose of cold reality.

But what about cost? Doesn‘t technology in the schools more efficiently replace alternative investments? Cost reductions are often the most persuasive argument for technology, Toyama agrees. But even these have been overstated. The costs of introducing new technology run far beyond initial hardware and software investments, said Toyama. In reality, the total costs of ownership—including maintenance, training, and repair—typically run to five or ten times the initial cost, according to Toyama. He said of the investment in technology for cost benefits: ―I would say that in the long run—and even in the medium run and the short-run—that‘s probably the worst and most misguided conclusion to come to.”[65]

He adds: ―The inescapable conclusion is that significant investments in computers, mobile phones and other electronic gadgets in education are neither necessary nor warranted for most school systems. In particular, the attempt to use technology to fix underperforming class rooms . . . is futile. And for all but wealthy, well-run schools, one-to-one computer programs cannot be recommended in good conscience.”[66]

But that doesn‘t keep industry lobbyists from recommending them. And it hasn‘t kept the FCC for spending scores of billions subsidizing technology to the very groups least likely to benefit from it.

Unmoved by the arguments of researchers and educators like Vigdor, Warschauer, and Toyama, the FCC keeps moving to increase technology subsidies. Ignoring research that disputes the value of technology in closing the so-called ―digital divide,” the FCC has even pioneered a new slogan: ―the Wi-Fi gap.”

In announcing that it was lifting E-Rate‘s annual budget from $2.4 billion to $3.9 billion and stepping up investment in wireless networking, FCC chairman Wheeler exulted that ―10 million students are going to experience new and better opportunities.”[67] The impact on consumer pocketbooks (and potentially on youngsters‘ health from daily Wi-Fi exposure) were not mentioned.

The two Republican members of the FCC did at least recognize the pocketbook impact. ―It always seems easier for some people to take more money from the American people via higher taxes and fees rather than do the hard work,” said Commissioner Michael O‘Reilly.[68]

The subsidized provision of high-speed Internet service is yet another pet project of the FCC. Julius Genachowski, chairman from 2009 to 2013, championed the transition of the USF from landline phone service to broadband. Universal broadband Internet connections would begin to absorb the monies collected from consumers to extend basic phone service.

As with government subsidies for cell phone service, classroom technology, and Wi-Fi, there are basic questions about the wisdom of subsidizing broadband. Charles Davidson and Michael Santorelli of the New York Law School found that spending billions to extend broadband is a flawed approach since there are many largely ignored reasons people choose not to adopt broadband. ―Everybody is pushing broadband non-stop," noted Davidson, director of the Law School‘s Advanced Communications Law and Policy Institute. ―I think the FCC is focused on the wrong set of issues," he said.[69]

Already, he explained, over 98% of Americans have access to wired or wireless broadband. The issue is not one of supply. It‘s one of demand. Many people—for a variety of reasons—don‘t really care about broadband, he contends. Price is one issue. Also powerful factors—but given almost no attention—are privacy and security concerns. ―In our view, they should be focused on barriers to meaningful broadband utilization: privacy and security," said Davidson.[70]

But consumer privacy (more on this subject in Chapter Seven) has no well-funded lobby with limitless access to the FCC.

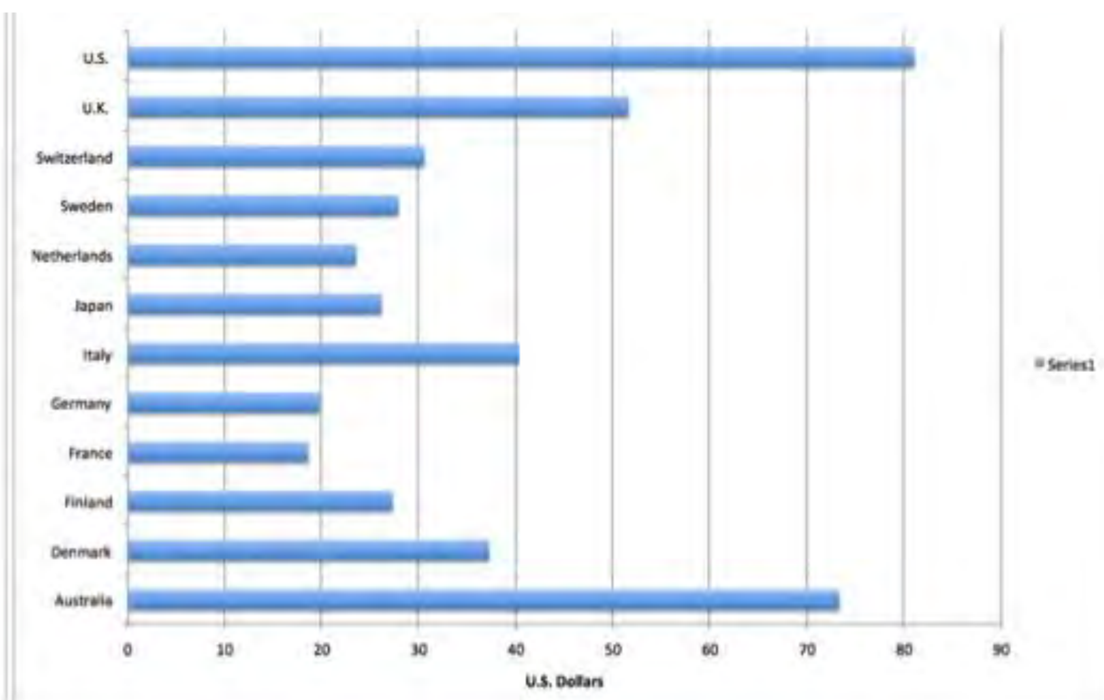
Chapter Six: The Cable Connection

The network has also been active in diluting FCC control of the cable television industry. Over the years, cable has devolved into major de facto local monopolies. Comcast and Time Warner Cable, whose merger proposal was dropped in April, are dominant forces in both cable television and broadband Internet subscriptions. Somehow, though, they have managed to steer clear of one another in specific markets, giving each pricing power where it faces little local competition.

It‘s interesting that cable companies annually rank in consumer polls among the ―most hated" or ―most disliked" American corporations. Indeed, Comcast and Time Warner Cable often top the ―most hated" list.[71] Why would these companies—providers of the TV programming that has so expanded consumer options in recent decades—be so widely scorned? After all, the U.S. has been a leader in developing both cable technology and diverse television programming.

The problem is that it hasn‘t been anything close to a leader in bringing down subscriber prices. Industry consultants typically measure pricing by the metric of average revenue per subscriber. Industry trackers at IHS compared the price of U.S. pay television (which includes satellite services) to those in more than 60 other countries. U.S. prices were the highest, with only Australia even coming close. The average revenue per subscriber in the U.S. in 2013 was $81. But in France it was just $18.55. In Germany it was $19.68. In Japan it was just over $26.

Pay TV Monthly Revenue Per Person:



And U.S. cable prices have risen in recent years at rates three or more times the rate of inflation. This has been going on for some time. From 1995 to 2013 cable rates increased at a 6.1% annual clip. The Consumer Price Index, by contrast, rose by just 2.4% annually. Former FCC commissioner Michael Copps says the FCC shares a major part of the blame. ―The FCC is as culpable for allowing that as much as the companies for imposing it," he said.[72]

One area where the FCC has contributed to the problem is in its traditional rubber-stamping of merger agreements. The proposed Comcast/Time Warner Cable deal has been shelved, largely because of Justice Department reservations. But a long run of earlier FCC-sanctioned deals allowed Comcast and Time Warner Cable to grow to the market dominance—and attendant pricing power—they currently command.

Lofty monthly cable bills pinch consumers. But it‘s more than that. Subscribers paying $80 a month are often paying for a lot of channels they don‘t watch and don‘t want. The FCC has never required cable operators to charge for what consumers actually want to watch. Kevin Martin, who chaired the FCC from 2005 to 2009, pushed to ―debundle" programming in hopes of lowering bills. But the issue was never resolved. Only recently have viable competitive alternatives to cable‘s ―bundled" packages become available. The satellite service Dish, for example, months ago introduced its Sling offering that enables consumers to opt for smaller and cheaper packages.

In fairness to cable operators, it should be pointed that programmers often require operators to take unwanted or fledgling channels along with their stars. New York cable operator Cablevision Systems filed suit against Viacom in 2013, charging that in order to get popular channels like MTV and Nickelodeon it was also forced to take low-rated channels like Nicktoons and VH1 Soul. But the simple truth is that no matter who is to blame, the cable consumer pays high prices, typically for some programming he doesn‘t want. As it often does when powerful interests pursue dubious practices, the FCC has for the most part idly stood by.

Still, the FCC isn‘t entirely to blame. Some factors in the growth of the cable giants cannot be laid at its doorstep. Local municipalities often granted monopoly or duopoly status in granting franchises to cable network builders. With the huge capital investments required to cable metropolitan areas, this once seemed to make sense.

And over the years, the cable giants have used a variety of tactics to weaken what little local competition they may have had. Active lobbyists on the local level, the cable giants have managed to convince a growing number of states to outlaw municipal systems that could threaten private corporate incumbents. The FCC for many years declined to tangle with the states in this matter, partly due to the opposition of Republican commissioners. But the Wheeler-led Commission did vote recently to override state laws that limit the build-out of municipal cable systems.

Still, many years of industry subservience will be difficult to swiftly undo. One linchpin merger shows how FCC decision-making has been thoroughly undermined by the revolving door, lobbying, and carefully targeted campaign contributions. All conspired in Comcast‘s pivotal 2011 buyout of NBC Universal, a deal which reinforced Comcast‘s domination of both cable and broadband access. This deal also set the stage for the recent headline-grabbing acrimony over the issue of net neutrality.

In 2011, mighty Comcast proposed to acquire NBC Universal. A series of mergers including the 1986 acquisition of Group W assets and the 2002 acquisition of AT&T‘s cable assets had already vaulted Comcast into cable market leadership. In bidding for NBC Universal, a huge step towards vertical integration, Comcast was once again raising the stakes. NBC Universal would give Comcast a treasure trove of programming, including valued sports content like NFL football and the Olympics.

Suddenly, the issue was not just cable subscriber base size—where Comcast had already bought its way to dominance. NBC Universal would also allow Comcast to consolidate its growing power as a broadband Internet provider. And with NBC Universal‘s programming assets, Comcast would gain new leverage when negotiating prices to carry the competing programming content of rivals. This would prompt a new round of debate over net neutrality. Couldn‘t a programming-rich Comcast slow down rival services—or charge them more to carry their programming?

To short-circuit any potential opposition to the merger, Comcast assembled a superstar cast of lobbyists. As Susan Crawford reports in her 2013 book, ―Comcast hired almost eighty former government employees to help lobby for approval of the merger, including several former chiefs of staff for key legislators on congressional antitrust committees, former FCC staffers and Antitrust Division lawyers, and at least four former members of Congress.[73] Such ―profligate hiring," Crawford observes, pretty much silenced the opposition to the deal. If Comcast had already retained one member of a lobbying firm, the firm could not under conflict of interest rules object to the deal. And Comcast had locked up key lobbying shops. Money was both weapon and silencer.

Of course, Comcast had always been a big spender on lobbying, with outlays exceeding $12 million every year since 2008. Lobbying costs peaked in 2011 at $19.6 million, according to the Center for Responsive Politics.

For its part, the FCC had a long history of approving most media mergers. So it was hardly a great surprise when the agency, after exacting some relatively minor concessions from Comcast, rubber-stamped the deal. Comcast would thus broaden its footprint as local monopoly distributor of cable. And with its new programming assets, it would enhance its leverage in negotiating deals to carry its rivals‘ programming. It would also fortify its position of growing strength as broadband Internet gatekeeper.

The most telling footnote to the deal would come just four months later. FCC Commissioner Meredith Atwell Baker, who voted to approve the merger in January 2011, left the FCC to become a top-tier Comcast lobbyist in May. It was the ultimate—and perhaps most telling—glide of the revolving door.

Baker‗s was a high-profile defection. But it was neither the first nor the last. Comcast had successfully convinced other FCC officials to take their expertise and government contacts to the cable giant. Comcast has long been a master at spinning the revolving door to its own advantage. ―Comcast has been very good at hiring everyone who is very smart," said Crawford.[74]

Approval of the NBC Universal deal was another in the long string of FCC merger approvals that made Comcast a nationwide monopolist that could dictate both pricing and viewer programming choice.

But the deal may have had another unintended consequence. It set the stage for Comcast‗s subsequent battles on net neutrality. ―Those mergers gave additional oomph to the issue of net neutrality," noted former commissioner Copps. Speaking specifically of Comcast‗s buyout of NBC Universal, IHS senior analyst Eric Brannon agreed. ―That merger laid the grounds for net neutrality."

In allowing Comcast to acquire major programming assets, the deal would sharpen questions about the power of gatekeepers like Comcast to control the flow of traffic from rival Web services. So in bowing to lobbyist pressure, the FCC would bring on itself a whole new set of pressures by focusing public attention on the issue of net neutrality.

With activists rounding up comments from the public and hip TV personalities like HBO‗s John Oliver also beating the drums, net neutrality quickly grew into a popular issue that won the support of President Obama, and by proxy, his hand-picked appointee Tom Wheeler. When the FCC ruled in February of 2015 that it would seek Title II authority to regulate the Internet and presumably block any favoritism by broadband gatekeepers, it seemed to finally cast its lot with the public against steamrolling corporate interests

The issue had simmered for years but reached full boil when movie purveyor Netflix, which had argued that its service was slowed down by Comcast, signed a side deal ensuring better download speeds for its wares. This triggered an outburst of public concern that Comcast was now in position to operate ―fast" and ―slow" lanes, depending on whether a rival programmer could afford to ensure that Comcast provide adequate download speed.

With nearly 4 million comments—many supplied or encouraged by public interest groups—filed to the FCC, net neutrality was a bankable political issue. And there‗s no question, net neutrality attracted public interest because it gave cable viewers—long furious at the treatment by the monopolists who send them monthly bills—issues of both viewing pleasure and economics.

But it also fed into the longstanding sentimental but increasingly unrealistic view of the Internet as the last bastion of intellectual freedom. Internet romanticists have long seen the Web as a place that somehow deserves special rules for breaking the stranglehold of traditional media and offering exciting new communications, information retrieval and shopping efficiencies.

Yes, the Internet is a modern marvel. This is beyond dispute. But some of the favors it has won from government over the years have had unfortunate unintended consequences.

In the 1990s, for example, net access providers were repeatedly exempted as an ―infant industry” from paying access charges to the Baby Bells even though they had to connect users through local phone networks. The long distance companies were then paying as much as $30 billion a year for the privilege. But the Internet was exempted.

As the late 90s approached, the Internet was no longer an infant industry. Still, the exemption from access charges was extended. That exemption essentially allowed AOL in the late 90s to offer unlimited unmetered online time, a key factor in boosting usage and siphoning advertisers from print media. Why buy an ad in print that might get viewed with the transitory flip of a page when you can get round-the-clock attention online?[75] FCC decisions to grant the Internet access-charge exemptions arguably accelerated the decline of print media and much of the quality journalism print advertising could once support.

Meanwhile, retailers on the Internet were making inroads into brick and mortar retail business with the help of a Supreme Court-sanctioned exemption from collecting sales tax.[76] This judicial coddling of the Internet was the death knell for many smaller mom and pop local businesses, already challenged to match online pricing. And that‘s not all. The special favors continue virtually every year, as Congress proposes and/or passes legislation to extend special tax exemptions to Internet services.

Well, maybe tax breaks aren‘t such a bad idea for such an innovative and transformational emerging technology. For all its faults, the Internet—gateway to all goods, repository of all things, wizardly guide to all knowledge, enabler of universal self-expression—is undeniably cool.

But let‘s not deny that the combination of tax advantages and deregulation was toxic. Allow an industry to emerge with advantages over useful existing industries that largely play by the rules—well, maybe that can be rationalized. But then fail to hold the upstart industry to the same rules, allowing it more leeway to trample fundamental rights because it has the technical capacity to do so. Well, then you have a cruel Faustian bargain.

With the see-no-evil deregulatory gospel loosing all constraints, the Web would devolve into a playground for corporate snoops and criminals. For all its wonders, the Internet comes at a cost: the loss of control over personal data, the surrender of personal privacy, sometimes even the confiscation of identity.

Perhaps the most favorable consequence of net neutrality—and one that has gotten surprisingly little attention—is that it could set the stage for privacy reform. (More on this in Chapter Seven). The FCC can now choose to exercise its Title II powers to enforce privacy standards over broadband Internet. Privacy is one area where the FCC has done a pretty good job in the past.

Worth remembering, though, is that the hard-fought public victory over Net Neutrality may be transitory. AT&T and others have threatened to go to court to upend the FCC rules. And there‘s a fair chance a Republican Congress will legislate against Title II.

Meanwhile, though, one supreme irony has begun to unfold in the marketplace.

Modern-day laissez fair ideologues love to invoke the wisdom of markets as represented by the ―mysterious hand” of Adam Smith. Unfortunately, in the absence of effective regulation, the putatively wise ―mysterious hand” generally seems to work its magic for those with huge financial resources and the political access it buys.

In the current cable situation, however, the mysterious hand may actually be working in consumer-friendly ways. Years of regulation that favored the cable companies have now backfired as the market reacts to monopolistic pricing and content control.

Whereas cable giants have commanded premium monthly subscriber prices to deliver packages of largely unwatched channels, the market is now beginning to burst with new ―debundled” options that are whittling away at cable‘s vast subscriber base.

Satellite service Direct TV, as noted, now offers its streaming video Sling TV package of popular networks that includes live sports and news. Amazon, Apple, CBS, HBO, Netflix, Sony, and others offer a variety of streaming video options that allow viewers to cut the cable cord. Suddenly, consumers have the cherry-picking capability that bundled—and expensive—cable packages have never allowed.

In this case, at least, the unintended consequences of the FCC‘s pro-industry policies may be producing an unexpected pro-consumer twist.

Chapter Seven: What about Privacy?

Has any issue gotten as much lip service—and as little meaningful action?

For all the various congressional bills, corporate self-regulatory schemes and presidential Privacy Bill of Rights proposals, the simple truth remains that no personal information is safe on the Internet. Data brokers have built a multi-billion dollar business exchanging information used to build profiles of Net users. Your shopping and surfing habits, your health history, your banking data, your network of social ties, perhaps even your tax filings are all potentially exposed online. Both legal and criminal enterprises amass this information. And it doesn‘t go away.

At any given moment people you don‘t know somehow know where you are. They may very well know when you made your last bank deposit, when you had your last asthma attack or menstrual period. Corporations encourage and pay for every bit of information they can use or sell. Creepy? Perhaps, but as Jeff Chester, president of the Center for Digital Democracy points out: ―The basic business model that drives online is advertising."[77]

The FCC largely escapes blame on this one. It is the Federal Trade Commission that has had primary responsibility for protecting Internet privacy. The FCC does have some limited authority, which, some critics say, could have been exercised more vigorously. But for the most part the FCC is not to blame for the rampant online abuse of personal privacy and identity.

The FCC does however have privacy authority over the phone, cable and satellite industries. Until recently, at least, the FCC has kept privacy issues at bay among the companies in these industries. ―The FCC has generally taken privacy very seriously," noted Harold Feld, a senior vice president at the non-profit Public Knowledge.[78]

But dynamics now in place suggest that privacy may be the next great testing ground for the FCC. A new chance, perhaps, to champion public interest. Even before the opportunity for privacy enforcement under Title II regulatory powers, the FCC faces new challenges from phone companies, now itching to monetize their vast consumer data stashes the way Net companies have. The commonly used term is ―Google envy."

―Until now, ISPs (Internet Service Providers) have mostly not gotten into hot water on privacy—but that‘s changing," observed Jonathan Mayer, a fellow at the Center for Internet and Society.[79] Verizon and AT&T, major providers of mobile Internet access, have each introduced ―super cookies" that track consumer behavior even if they try to delete older, less powerful, forms of cookies. AT&T is actually charging its customers an extra $30 a month *not* to be tracked.

Showdowns loom.

In adopting Title II to enforce net neutrality, the FCC has made broadband Internet access a telecom service subject to regulation as a ―common carrier.” This reclassification means that the FCC could choose to invoke privacy authority under Title II‘s Section 222. That section, previously applied to phone and cable companies, mandates the protection of consumer information. Such information—called CPNI for Customer Proprietary Network Information—has kept phone companies from selling data on whom you call, from where you call and how long you spend on the phone. Consumers may have taken such protection for granted on their phone calls. But they have no such protection on their Internet activity—which, as noted, has been a multi-billion dollar safe house hideaway for corporate and criminal abusers of personal privacy.

Now, though, the FCC could put broadband Internet communications under Section 222 protection. To Scott Cleland, a telecom industry consultant who has often been ahead of the analytic pack, this would be a momentous decision.

When the smoke clears—and it hasn‘t yet—the FCC could make consumer identifiers like IP addresses the equivalent of phone numbers. Suddenly, the Internet companies that have trafficked in all that personal data would be subject to the same controls as the phone and cable companies.

Cleland argues that the risk for privacy abuses extends beyond broadband access providers like Comcast and Verizon to Internet giants like Google and Facebook that have until now flourished with all that personal data. ―They are at risk and they are going to live under the uncertainty their business model could be ruled illegal by the FCC,” Cleland said.[80]

Much has been written about the legal challenges broadband access providers intend to mount against the FCC‘s new rules. But Cleland argues that a very different type of legal action could engulf companies that have benefited from the use and sale of private data. Trial lawyers, he argues, will see opportunity in rounding up massive class action suits of Internet users whose privacy has been violated. What sorts of privacy abusers face legal action? Anyone who has ―collected CPNI via some type of cookie,” according to Cleland.

―Right now, edge providers like Google, Facebook and Twitter are at risk of being sued by trial lawyers,” he said.[81]

Sounds great for consumers who care about privacy on the Internet and how it has been abused. But the FCC, Cleland was reminded, has never been a consumer advocate. ―Bingo,” replied Cleland. That‘s what makes the FCC‘s potential move into privacy protection so important and so surprising, he suggests.

There are other signs that the FCC under Tom Wheeler might actually become more consumer-friendly on the issue of data privacy. While Wheeler has brought some former associates from lobbying groups to the FCC, he has also peppered his staff with respected privacy advocates. Indeed, he named Gigi Sohn, longtime president of the non-profit Public Knowledge, as Counsellor to the Chairman in April.

Another appointee with a privacy background is Travis LeBlanc, head of the FCC‘s Enforcement Bureau. In previous employment in California‘s Office of the Attorney General, LeBlanc was active in enforcing online privacy. LeBlanc has stated an interest in privacy and has already taken action against two firms that exposed personal information—including social security numbers—on unprotected Internet servers.

But many aspects of LeBlanc‘s approach to regulating Internet privacy under Title II remain unclear. Unfortunately, the FCC declined repeated requests to make LeBlanc available for an interview. (It also declined to answer written questions on its enforcement intentions in both privacy and cell tower infrastructure emissions.)

It remains to be seen if LeBlanc and his superiors at the FCC are really willing to take on privacy enforcement. Such a stance would require great courage as the entire Internet infrastructure is built around privacy abuse. It is also questionable whether the FCC would have the courage to challenge Google—a rare corporate ally in the battles over Net Neutrality.

Chapter Eight: Dependencies Power the Network of Corruption

As a captured agency, the FCC is a prime example of institutional corruption. Officials in such institutions do not need to receive envelopes bulging with cash. But even their most well-intentioned efforts are often overwhelmed by a system that favors powerful private influences, typically at the expense of public interest.

Where there is institutional corruption, there are often underlying dependencies that undermine the autonomy and integrity of that institution. Such is the case with the FCC and its broader network of institutional corruption.

As noted earlier, the FCC is a single node on a corrupt network that embraces Congress, congressional oversight committees and Washington social life. The network ties the public sector to the private through a frictionless revolving door—really no door at all.

Temptation is everywhere in Washington, where moneyed lobbyists and industry representatives throw the best parties and dinners. Money also allows industry to control other important factors, like the research agenda. All of this works together to industry's advantage because—as with other instances of institutional corruption—there are compromising dependencies. Policy makers, political candidates and legislators, as well as scientific researchers are all compromised by their dependence on industry money.

Dependency #1 – So much of the trouble here comes back to the core issue of campaign finance. Cable, cellular and educational tech interests know where to target their funds for maximum policy impact. And the contributions work, seemingly buying the silence of key committee congressmen—even those with past records as progressives. Key recipients of industry dollars include Massachusetts Senator Ed Markey and, until he retired, California Democrat Henry Waxman. Though they have intermittently raised their voices on such issues as data privacy and cellular health and safety, neither has shown any great inclination to follow through and take up what would have to be a long and tough fight on these issues.

Dependency #2 – Democrats might be expected to challenge industry now and then. They traditionally have done so, after all. But this is the post-*Citizens United* era where the Supreme Court has turned government into a giant auction house.

Bid the highest price and you walk home with the prize—your personal congressman, legislative loophole, even an entire political party.

Such is the case with technology industries and the Democrats. The communications/electronics industry is the third largest industry group in both lobbying and campaign contributions, according to the Center for Responsive Politics. In just 2013 and 2014, this industry sector spent well over $750 million on lobbying.[82]

Only the finance/insurance/real estate and health industries outspend the tech sector on lobbying. But those industry groups lean Republican. Over 62% of the finance/insurance/real estate campaign contributions go to the GOP. Health contributions lean Republican 57% to 43%. But the technology group leans sharply to Democrats, who got 60% of contributions in the 2013-2014 election cycle.[83] The two next largest industry groups—energy/natural resources and agribusiness—also lean heavily Republican. So of the top five industry groups whose money fuels and often tilts elections four are strongly Republican. The Democrats need the tech industry—and they show that dependence with consistent support, rarely raising such public interest issues as wireless health and safety and Internet privacy.

Dependency #3 – Spectrum auctions give the wireless industry a money-making aura. In recent Congressional testimony, an FCC official reminded legislators that the FCC has over the years been a budget-balancing revenue-making force.[84] Indeed, the auctions of electromagnetic spectrum, used by all wireless communications companies to send their signals, have yielded nearly $100 billion in recent years. The most recent auction to wireless providers produced the unexpectedly high total of $43 billion. No matter that the sale of spectrum is contributing to a pea soup of electromagnetic ―smog" whose health consequences are largely unknown. The government needs money and Congress shows its appreciation with consistently pro-wireless policies.

Dependency #4 – Science is often the catalyst for meaningful regulation. But what happens when scientists are dependent on industry for research funding? Under pressure from budget cutters and deregulators, government funding for research on RF health effects has dried up. The EPA, which once had 35 investigators in the area, has long since abandoned its efforts.[85] Numerous scientists have told me there‘s simply no independent research funding in the U.S. They are left with a simple choice: work on industry-sponsored research or abandon the field.

Chapter Nine: A Modest Agenda for the FCC

Nobody is proposing that cell phones be banned. Nor does anyone propose the elimination of the Universal Service program or other radical reforms. But there are some steps—and most are modest—that the FCC can take now to right some of the wrongs that result from long years of inordinate industry access and influence:

1. Acknowledge that there may be health risks in wireless communications. Take down the dismissive language. Maturely and independently discuss the research and ongoing debate on the safety of this technology.

2. In recognition of this scientific uncertainty, adopt a precautionary view on use of wireless technology. Require prominent point-of-sale notices suggesting that users who want to reduce health risks can adopt a variety of measures, including headphones, more limited usage and storage away from at-risk body parts.

3. Back off the promotion of Wi-Fi. As Professor Lennart Hardell has noted, there are wired alternatives that do not expose children to wireless risk.

4. Petition Congress for the budgetary additions needed to expand testing of emissions on antenna sites. It was Congress after all that gave industry carte blanche for tower expansion so long as they comply with FCC standards. But there is evidence of vast non-compliance and Congress needs to ensure that tower infrastructure is operating within the law.

5. Acknowledge that children and pregnant women may be more vulnerable to the effects of RF emissions and require special protection.

6. Promote cable debundling as a way to lighten consumer cable bills, especially for those customers who don‘t care about high-cost sports programming.

7. Apply more rigorous analysis to properly assess the value of technology in education. Evidence continues to pile up that technology in education is not as valuable as tech companies claim. Pay less attention to tech CEOs—pay more attention to the researchers who‘ve actually studied the impact of trendy technology fixes on learning

8. Take over enforcement of personal privacy rights on the Internet. Of all the basic suggestions here, this would require the most courage as it would involve challenging many of the entrenched powers of the Internet.

Chapter Ten: Stray Thoughts

Some concluding thoughts:

Why do so many of the most dubious FCC policies involve technology?

In large part, of course, because the FCC has authority over communications and that is a sector that has been radically transformed—along with so many others—by technology.

Let‘s be clear, though. The problem is not technology, which unarguably brings countless benefits to modern life. The problem is with the over-extension of claims for technology‘s usefulness and the worshipful adulation of technology even where it has fearful consequences. Most fundamentally, the problem is the willingness in Washington—for reasons of both venality and naïveté—to give technology a free pass.

Personally, I don‘t believe that just because something can be done it should heedlessly be allowed. Murder, rape and Ponzi schemes are all doable—but subject to prohibition and regulation. Government regulators have the responsibility to examine the consequences of new technologies and act to at least contain some of the worst. Beyond legislators and regulators, public outrage and the courts can also play a role—but these can be muffled indefinitely by misinformation and bullying.

There are precedents for industries (belatedly perhaps) acting to offset the most onerous consequences of their products. In responding to a mix of litigation, public demand and regulatory requirement, the auto industry, for example, has in the last 50 years substantially improved the safety and environmental footprint of its products.

Padded instrument panels, seat belts, air bags, and crumple zones have all addressed safety issues. Environmental concerns have been addressed with tightened emissions and fuel consumption standards. The response to new safety challenges is ongoing. Before side air bags were widely deployed, sedan drivers side-swiped by much larger SUVs were at vastly disproportionate risk of death and dismemberment.[86] But the deployment of side air bags has ―substantially" reduced the risk of collision deaths.[87] Overall, auto fatality rates per 100,000 persons have dropped by nearly 60% in the U.S. since 1966.[88] Today, automakers continue to work on advanced safety features like collision avoidance.

It can be argued that most of these safety improvements came decades after autos were in wide usage and only in response to outrage at Ralph Nader‘s 1965 revelations on the auto industry.[89] No matter the catalysts. The simple truth remains that the auto industry—and its regulators—have for the last half-century been addressing safety and environmental issues.

But with the overwhelming application of money and influence, information and communications technologies have almost totally escaped political scrutiny, regulatory control, and legal discipline.

Should the Internet have been allowed to develop into an ultra-efficient tool for lifting personal information that includes financial records, health histories and social security numbers? Should wireless communications be blindly promoted even as new clues keep suggesting there may be toxic effects? Should local zoning authorities and American citizens be stripped of the right to protect their own health? Should education be digitized and imposed just because technology companies want to develop a new market and lock in a younger customer base?

All these questions can perhaps be rolled up in one: do we all just play dead for the corporate lobbyists and spinners who promote the unexamined and unregulated application of their products?

Finally, a word about the structure of the FCC. With five commissioners—no more than three from the same party—the structure seems to make some kind of sense.

But in practice, it works out poorly. The identification of commissioners by party tends to bring out the worst in both Republicans and Democrats. Instead of examining issues with clear-sighted independence, the commissioners seem to retreat into the worst caricatures of their parties. The Republicans spout free market and deregulatory ideology that is most often a transparent cover for support of business interests. The Democrats seems satisfied if they can implement their pet spending programs—extension of broadband wireless to depressed urban and rural schools, cell phone subsidies for low income clients. The result is a Commission that fulminates about ideology and spends heavily to subsidize powerful interests.

Perhaps one solution would be to expand the Commission to seven by adding two public interest Commissioners. The public interest only rarely prevails at the FCC. So it would represent vast improvement if both Republican and Democrat commissioners had to vie for support of public interest representatives in order to forge a majority. The public interest, in other words, would sometimes carry the swing votes.

It‘s very hard to believe, though, that Congress would ever approve such a plan. It simply represents too much of a threat to the entrenched political power of the two parties. Why would they ever agree to a plan that dilutes that power?

It‘s also worth noting that the public interest is not always easy to define. Sometimes there are arguably conflicting definitions. Still, an FCC with public interest commissioners is an idea worth consideration. It would at least require party apologists to defend how they so consistently champion the moneyed interests that have purchased disproportionate access and power in Washington.

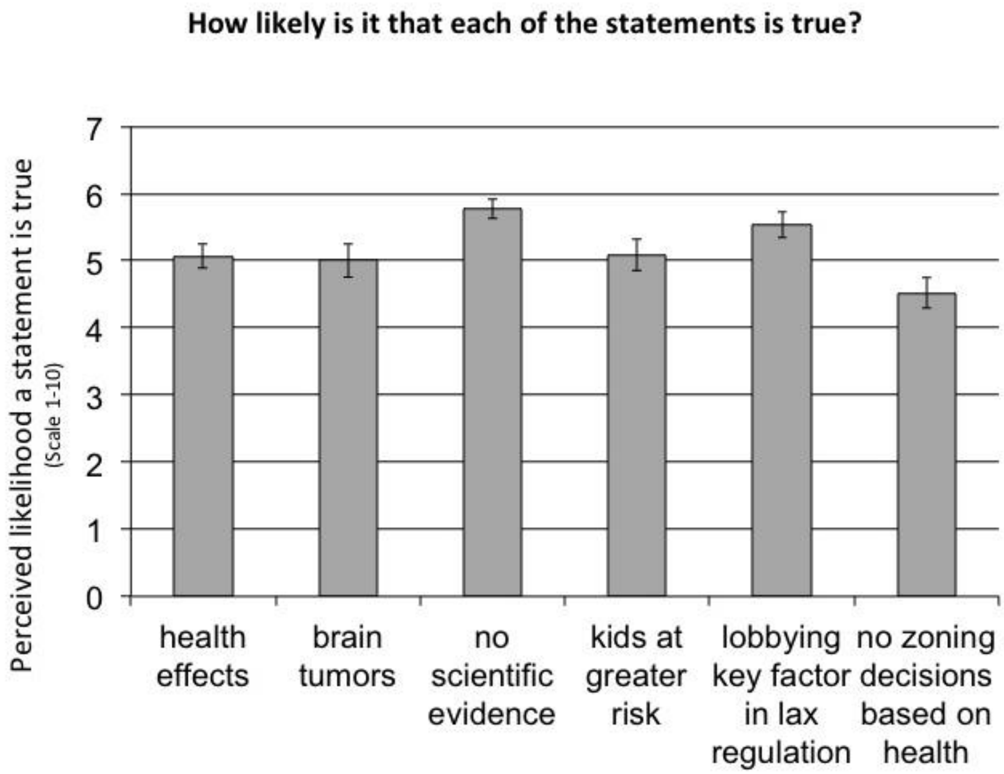
Appendix—Survey of Consumer Attitudes

What does the public believe about the science and politics of wireless health research? Under what conditions would people change wireless usage patterns? Is the FCC currently trusted to protect public health? How would confirmation of health risks affect trust in the FCC?

These are some of the questions Ann-Christin Posten[90] and Norm Alster[91] hoped to answer with an April 2015 online survey of 202 respondents. Participants were recruited through Amazon's Mechanical Turk online platform. All were U.S. residents and had achieved qualifying approval rates in prior Mechanical Turk surveys.

Participants were asked how likely they believed the following statements to be true:

> Statement 1. Prolonged and heavy cell phone use can have a variety of damaging effects on health.
>
> Statement 2. Prolonged and heavy cell phone use triples the risk of brain tumors.
>
> Statement 3. There is no scientific evidence that proves that wireless phone usage can lead to cancer or a variety of other problems.
>
> Statement 4. Children and pregnant women are especially vulnerable to radiation from wireless phones, cell towers and Wi-Fi
>
> Statement 5. Lobbying and campaign contributions have been key factors in keeping the government from acknowledging wireless hazards and adopting more stringent regulation.
>
> Statement 6. The U.S. Congress forbids local communities from considering health concerns when deciding whether to issue zoning permits for wireless antennae.

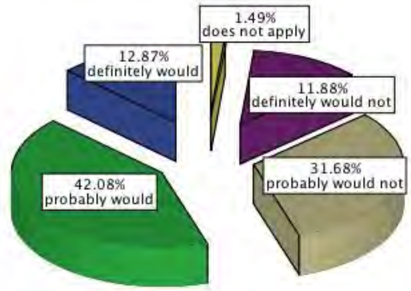


Two findings seem especially interesting:

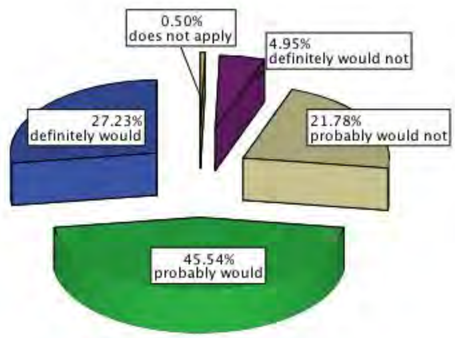
1. Statement 3 received a higher credibility rating than Statements 1 and 2. The different credibility levels are statistically significant. Respondents are more likely to trust in wireless safety than to believe there are general or specific health risks.

2. The only statement that is a matter of uncontested fact is Statement 6 on the outlawing of opposition to antenna sites on health grounds. (All other statements have been both proclaimed and denied.) And yet Statement 6 was least likely to be believed. Just 1.5% of respondents recognized this as an ―absolutely true" statement. Over 14% thought this statement was ―not true at all." Answers to this question would seem to reflect public ignorance on the political background to wireless health issues.

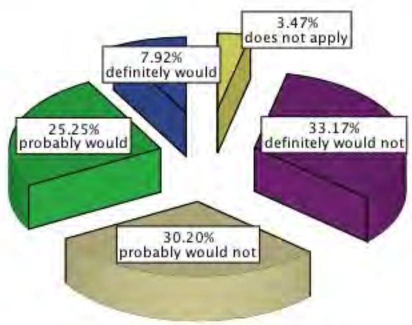
Participants were also asked how they would change behavior if claims of wireless health risks were established as true:



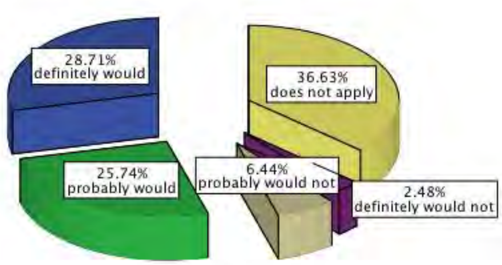
**If statement 1 was true,
I would start using headphones.**



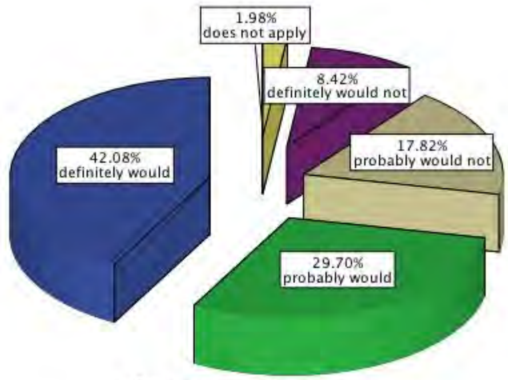
**If statement 1 was true,
I would restrict the amount of time
I spend on the phone.**



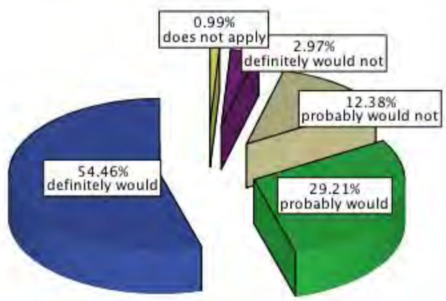
**If statement 1 was true,
I would start up a new land line
account for home use.**



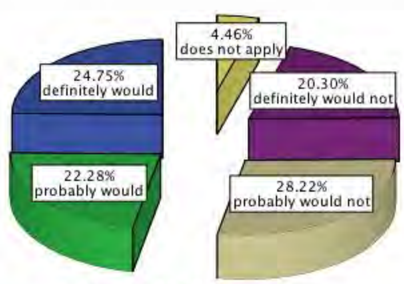
**If statement 1 was true,
I would restrict my children's cell phone use.**



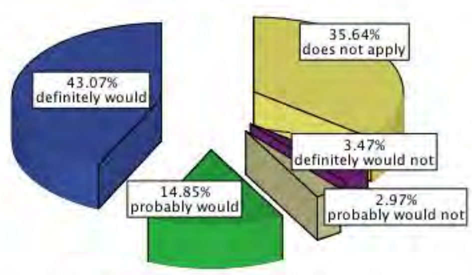
**If statement 2 was true,
I would start using headphones.**



**If statement 2 was true,
I would restrict the amount of time
I spend on the phone.**



**If statement 2 was true,
I would start up a new land line
account for home use.**



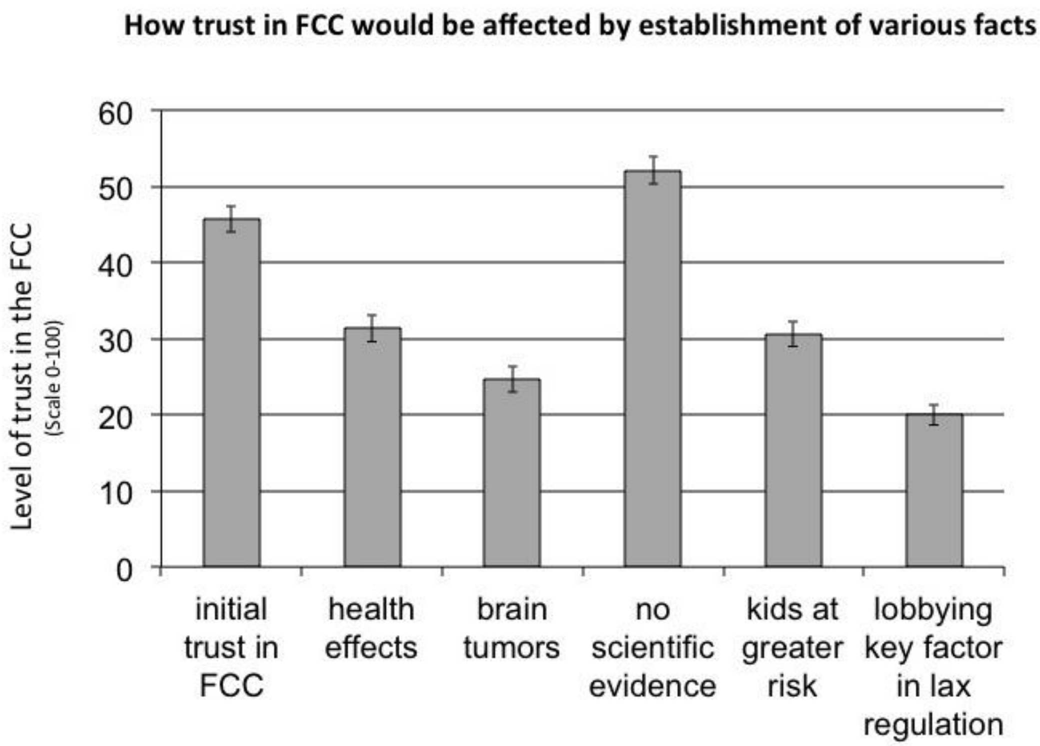
**If statement 2 was true,
I would restrict my children's cell phone use.**

The greatest impact on behavior came when respondents were asked to assume it is true that prolonged and heavy cell phone use triples the risk of brain tumors. More than half said they would –definitely” restrict the amount of time spent on the phone. Just over 43% would –definitely” restrict their children‘s phone use. Perhaps most surprisingly, close to 25% would –definitely” start up a new landline phone account. (This last response suggests it may be foolishly premature for the phone giants to exit the landline business just yet.)

The inclination of consumers to change behavior should negative health effects be confirmed suggests the stakes are enormous for all companies that derive revenue from wireless usage.

This survey points to—but cannot answer—some critical questions: Do wireless companies better protect themselves legally by continuing to deny the validity of all troublesome research? Or should they instead be positioning themselves to maintain consumer trust? Perhaps there is greater financial wisdom in listening to the lawyers right now and denying all chance of harm. If so, however, why would anyone seriously concerned about health listen to the industry—or to its captured agency? That‘s a question the FCC will eventually need to answer.

Trust could eventually become a central issue. Respondents were initially asked to describe their level of trust in the wireless industry and in the FCC as its regulator. Not surprisingly, establishment of any of the presumed health risks—or confirmation of inordinate industry pressure—resulted in statistically significant diminution of trust in both the industry and the FCC.



On a scale of 1 to 100, the FCC had a mean baseline trust level of 45.66. But if the tripling of brain tumor risk is established as definitely true, that number falls all the way to 24.68. If ―lobbying and campaign contributions" have been ―key factors" in keeping the government from acknowledging wireless hazards, the trust level in the FCC plummets to 20.02. All results were statistically significant.

It's clear that at this point confirmation of health dangers—or even of behind-the-scenes political pressures—from wireless will substantially diminish public trust in the FCC. Skeptics might argue that this gives the FCC motive to continue to downplay and dismiss further evidence of biological and human health effects. Those of a more optimistic bent might see in these findings reason to encourage an FCC concerned about public trust to shake itself loose from special interests.

Endnotes

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[14] Id., 206-208.

[15] January 2015 interview with Robert Weller.

[16] Letter from Michelle C. Farquhar, Chief of the FCC‗s Wireless Telecommunications Bureau, to Thomas Wheeler, President and CEO of the Cellular Telecommunications Industry Association, January 13, 1997.

[17] Id.

[18] Letter from FCC Chairman Thomas Wheeler to former FCC Commissioner Jonathan Adelstein, President and CEO, PCIA-The Wireless Infrastructure Association, March 14, 2014.

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[30] Medscape, ―Brain Cancer CME Learning Center," http://www.medscape.org/resource/brain-cancer/cme.

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[34] Lennart Hardell, Michael Carlberg, Fredrik Soderqvist, and Kjell Hansson Mild, ―Case-Control Study of the Association between Malignant Brain Tumours Diagnosed between 2007 and 2009 and Mobile and Cordless Phone Use," *International Journal of Oncology* 43.6 (2013): 1833-1845.

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Environmental Research 208 (2022) 112627

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Very high radiofrequency radiation at Skeppsbron in Stockholm, Sweden from mobile phone base station antennas positioned close to pedestrians' heads

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A R T I C L E I N F O

Keywords:
Radiofrequency radiation
Measurement
Base stations
Health
Cancer
Stockholm

A B S T R A C T

In urban environment there is a constant increase of public exposure to radiofrequency electromagnetic fields from mobile phone base stations. With the placement of mobile phone base station antennas radiofrequency hotspots emerge. This study investigates an area at Skeppsbron street in Stockholm, Sweden with an aggregation of base station antennas placed at low level close to pedestrians' heads. Detailed spatial distribution measurements were performed with 1) a radiofrequency broadband analyzer and 2) a portable exposimeter. The results display a greatly uneven distribution of the radiofrequency field with hotspots. The highest spatial average across all quadrat cells was 12.1 V m^{-1} (388 mW m^{-2}), whereas the maximum recorded reading from the entire area was 31.6 V m^{-1} (2648 mW m^{-2}). Exposimeter measurements show that the majority of exposure is due to mobile phone downlink bands. Most dominant are 2600 and 2100 MHz bands used by 4G and 3G mobile phone services, respectively. The average radiofrequency radiation values from the earlier studies show that the level of ambient RF radiation exposure in Stockholm is increasing. This study concluded that mobile phone base station antennas at Skeppsbron, Stockholm are examples of poor radiofrequency infrastructure design which brings upon highly elevated exposure levels to popular seaside promenade and a busy traffic street.

1. Introduction

Electromagnetic fields are known physical risk factors. When mobile phone base station antennas are installed, the immediate physical environment, including the public and the living spaces can be greatly affected by microwaves.

Measuring public exposure to radiofrequency fields is significant from public health perspective, but also for future epidemiological studies. Given the rapid development of mobile communication technologies, the radiofrequency landscape is continuously diversifying and intensifying: more frequencies are introduced to provide novel mobile phone and data services; more base station antennas are constantly installed to facilitate the increasing need for data amounts, pushed through the networks. Meanwhile, public exposure also increases.

In previous publications we have reported environmental exposure to radiofrequency (RF) electromagnetic (EMF) radiation at certain places in Stockholm in Sweden such as the Central Railway Station (Hardell et al., 2016), the Old Town (Hardell et al., 2017), with special attention to Järntorget in the Old Town (Hardell et al., 2019), and Stockholm city (Carlberg et al., 2019). Of special interest was to measure RF radiation in one Stockholm apartment with two groups of base station antennas nearby (Hardell et al., 2018). That apartment was further examined using a RF broadband analyzer and the results were compared with another Stockholm apartment with substantially much lower RF radiation but equally good wireless communication possibility (Koppel et al., 2019).

Earlier studies done in Europe show constant increase of public exposure, especially in urban environment. The increase is attributed to new mobile phone base stations installed, but also to the increased usage of corresponding mobile services. Sánchez-Montero et al. (2017) monitored urban exposure in Alcalá de Henares (Spain) for ten years and reported city mean field increase from 0.277 (203 μW m^{-2}) in 2006 to 0.395 V m^{-1} (414 μW m^{-2}) in 2015. Sánchez-Montero et al. (2017) admit that during the ten years of monitoring the number of mobile phone base

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https://doi.org/10.1016/j.envres.2021.112627
Received 3 November 2021; Received in revised form 22 December 2021; Accepted 23 December 2021
Available online 4 January 2022

station has doubled, but also conclude that the probability of being exposed to a high value of 14 V m-1 (519 mWm^{-2}) is less than 0.01% and the probability of being exposed by 28 V m-1 (2079 mWm^{-2}) is negligible (Sánchez-Montero et al., 2017).

It is expected, that wherever mobile phone base station antennas are installed, high exposure areas might be encountered. Although these highly exposed areas constitute a minor part of the urban environment, these should be carefully studied for the sake of the people who work and live there.

Urbinello et al. (2014) emphasized “A continuous monitoring is needed to identify high exposure areas and to anticipate critical development of RF-EMF exposure at public places”, while they informed a steep RF radiation growth in public places within one year. The growth of RF radiation has been substantial in many countries, also in Sweden as exemplified in this study.

Sagar et al. (2018) conducted a literature review, looking at studies in between 2000 and 2013 of radiofrequency electromagnetic exposure in microenvironments in Europe. For outdoor microenvironments they report the mean total RF exposure to be 0.54 V m-1 for spot measurements. Typical exposure levels were around 0.5 V m-1 and rarely over 1 V m-1. They report downlink contributing the most to the total RF exposure in outdoor microenvironments in all studies except one.

An updated review by Jalilian et al. (2019) on European microenvironments' studies from 2015 to 2018 found mean outdoor exposure ranging from 0.07 to 1.27 V m-1. Mobile phone base stations' downlink signals were the most relevant contributor to total exposure. The review concluded a tendency for RF levels to increase with increasing urbanity. Also, the review found that all different types of studies reported mean exposure levels of less than 1 V m-1; different types included spot measurement, fixed site monitoring, and personal measurement with volunteers.

The problem with most of the spot measurement studies is their inability to adequately represent spatial RF field distribution. This is due to two reasons: 1) the measurement sample is too small and does not account for highly exposed areas and/or 2) the spots where the measurements are collected do not coincide with the RF hotspots. RF hotspots occur usually around RF sources such as mobile phone base station antennas. Furthermore, RF hotspots depend on the radiation pattern of the antenna and the surrounding environment, hence the field distribution is uneven. It is not possible to visually identify RF hotspots around the antennas, this can only be done by detailed measurements or computer simulations.

For example, Aerts et al. conducted a detailed RF field mapping in Ghent, Belgium. They performed in total 650 broadband measurements in a city subarea of 1 km^2. The study found five hotspots, with max total electric field ranging from 1.3 to 3.1 V m-1 (Aerts et al., 2013). Their study showed, that significantly higher RF exposure levels are likely to occur than those reported by the majority of studies. In addition, they demonstrated that construction of a detailed RF heat map of the investigated area is important to characterize and outline the hotspot area.

1.1. The aim of the study

In this study we identified an area in Stockholm with an aggregation of base station antennas placed at low level, close to pedestrians' heads. The aim of this research is to point out highly exposed radiofrequency areas in the city environment and to analyze the sources and the reasons for the high exposure. We performed detailed measurements and constructed a detailed RF heat map. Such conclusions would help to better design the RF infrastructure sites with the aim of minimizing the public exposure. No ethical permission was needed since no test persons were involved.

2. Materials and methods

In this study spatial distribution of RF radiation sources was measured. The RF radiation sources were mobile phone base station antennas located at the Skeppsbron street, Stockholm, Sweden. This area is characterized by dense RF infrastructure as 15 mobile phone base station sectoral antennas from several operators are located on the same building complex, where the elevation from the street level is only few meters.

The site was selected by visually identifying radiofrequency sources, based on the dense packing of mobile phone base station antennas. Also the site is well suited for a scientific study, as it is positioned within the city center, whereas one side of the site is open to the sea where there are no RF sources nearby. The old town with old buildings is located on the other side of the street.

2.1. Study design

The measurements were conducted on a business day afternoon (January 14, 2019) with busy traffic which allows to assume higher network traffic. All measurements were done outdoor.

Field distribution was determined covering an area of 60 × 250 m, representing a street strip of old town buildings at one side and the sea (Strömmen) at the other side. The area is composed of the Skeppsbron street with busy traffic and pedestrians represented by a seaside promenade. Seaside promenade is filled with indoor and outdoor cafés, some operating throughout the year. Antennas are installed on top of those cafés. The promenade and the cafés are packed with hundreds of people on a holiday period – many of which at close range to the mobile phone base station antennas.

The area was covered by 3 × 11 quadrats, where each quadrat cell (quad) was measured with RF broadband analyzer by registering RF readings from one end of the quad to another by following North-South axis with a slow pace. For each quad, one moving measurement scan was done. Quads were drawn to both sides of the Skeppsbron street. Each quad measurement was done for about 1 min with average and maximum readings registered. The measurements were taken at the height from 1 to 1.8 m by moving the meter in circular movements along the quad. This allows covering the standing waves and detecting maximum radiation points.

RF broadband analyzer used was Narda NBM-520, with an E-field probe E0391 (Narda-Safety-Test-Solutions GmbH, Pfullingen, Germany). This meter of Narda NBM-series is capable of time and spatial averaging and determining the maximum level during the monitored period. Manufacturer's probe EF0391 is intended for base station measurements with a frequency range from 100 kHz to 3 GHz. This meter and the probe cover a large range of RF sources, including different telecommunications protocols: frequency modulation (FM) radio broadcasting; television (TV) broadcasting; TETRA emergency services (police, rescue, etc.); global system for mobile communications (GSM) second generation mobile communications; universal mobile telecommunications systems (UMTS) third generation mobile communications, 3G; long-term evolution (LTE) fourth generation mobile communications standard, 4G; digital European cordless telecommunications (DECT) cordless telephone systems standard; Wi-Fi wireless local area network protocol, 2.45 GHz; worldwide interoperability for microwave access (WIMAX) wireless communication standard for high speed voice, data and internet.

Later, the measurement readings were entered into vector mapping software 3DFIELD ver. 4.5.2.0 (by Vladimir Galouchko) and field distribution map created (in V m-1). Field distribution map was based on quadrat measurement spatial averages by using kriging, which is a geostatistical calculation method.

Additionally to analyze the frequency composition the entire quadrat was in parallel also measured with an exposimeter EME Spy 200 b y Microwave Vision Group, Paris, France. The exposimeter measures 20 predefined frequency bands covering most public RF radiation emitting devices currently used in Sweden. The exposimeter covers frequencies from 88 to 5850 MHz. For FM, TV3, TETRA, TV4&5, Wi-Fi 2.4 GHz and

Wi-Fi 5 GHz the lower detection limit is 0.01 V m^{-1} (0.27 μW m^{-2}); for all other bands the lower detection limit is 0.005 V m^{-1} (0.066 μW m^{-2}). For all bands the upper detection limit is 6 V m^{-1} (95,544 μW m^{-2}; 9.5544 μW cm^{-2}). The sampling rate used in this study was every 4th second which is the fastest possible sampling rate for the given exposimeter when all bands are active. The exposimeter was held at some distance (about 0.4 m) from the body. The unit reports the exposure in a conservative manner since each reported value is the sampling outcome, where many samples are taken and statistically processed including minimum, mean, median and maximum values. The meters had valid calibration.

Based on Cellmapper.net mobile phone operators and their corresponding services, mobile bands and frequencies were determined (Table 1). A large number of base station sector antennas emit a multitude of downlink frequency spans (N = 14) covering 2G, 3G and 4G services. Service providers have their own allocated frequency spans, but some are shared.

2.2. Statistical methods

Broadband RF readings using Narda NBM-520 were collected in Volts per meter (V m^{-1}) based on quadrat measurements covering the entire area. Each quadrat produced a spatial average and maximum reading calculated on the space covered. Based on quadrat cells measurements, two samples were formed: one of spatial averages and the second of spatial maximums. For both samples minimum, quartiles, median and maximum were calculated containing all the spatial measurement values in the area, using MS Excel 2016.

Means in microWatts per square meter (μW m^{-2}) were calculated for all measured frequency bands for measurements using the exposimeter EME Spy 200. Values below the lower detection limit were treated as no (0) exposure. Total exposure was calculated as the sum of all measured frequency bands. Stata/SE 12.1 (Stata/SE 12.1 for Windows; StataCorp., College Station, TX, USA) was used for all calculations.

3. Results

The results display a greatly uneven distribution of the RF fields with hotspots. The close proximity to the RF sources creates highly elevated field levels in the immediate vicinity to the base station. Given the antennas elevation from the ground, people walking on the street are highly exposed when passing or hanging around the area.

Fig. 1 presents a boxplot of spatial RF distribution of the entire investigated area. Both spatial average and maximum readings of RF broadband analyzer are included in the graph. The fields emanated by the base station antennas overlapped at several locations, elevating the exposure to high levels. The highest spatial average across all quadrat cells was 12.1 V m^{-1} (388 mW m^{-2}), whereas the maximum recorded reading over the entire area was 31.6 V m^{-1} (2649 mW m^{-2}). These were far-field measurement results, the meter was not used in the near-field of antennas. The lowest spatial average quadrat was 1.4 V m^{-1} (5.2 mW m^{-2}) which is still relatively high, considering the levels reported by the review studies (Jalilian et al., 2019; Sagar et al., 2018) discussed in the Introduction chapter. This emphasizes that the entire microenvironment in Skeppsbron street is covered with relatively high levels of radiofrequency radiation.

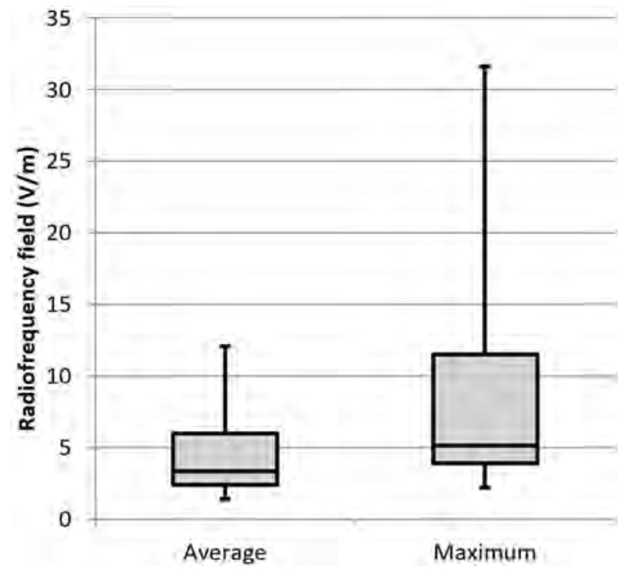

Fig. 1. Boxplot of spatial distribution of the radiofrequency field (V m^{-1}) at Skeppsbron street, based on quadrat measurements covering the entire area; sample is based on spatial averages and maximums of a quadrat cells; boxplot depicts (from bottom up) minimum, first quartile, median, third quartile and maximum of the sample containing all the spatial measurement values in the area.

Fig. 2 displays a spatial distribution of the RF field at the Skeppsbron street. Exposure readings are based on spatial average of a given quadrat cell. High field levels are encountered close to the base station antennas, whereas the highest levels were not detected below the antenna, but at 26 m distance, directly on the line of the direction of sector antenna. The field decreases with increasing distance from the base station array, but is still significantly elevated at the entire 250 m length of the studied street area.

Highest field levels as registered across the street, may also refer to confounding action of building walls, as some building materials may reflect the incident waves, hence giving rise to resultant exposure level (Koppel et al., 2017a). Also the weather can play a role in microwave propagation as wet walls may increase building material microwave reflection properties (Koppel et al., 2017b).

Exposimeter measurements (mean of sample) showed that the majority of exposure was due to mobile phone downlink bands. Most dominant were 2600 and 2100 MHz bands used by 4G and 3G mobile phone services, respectively. Also 800, 900 and 1800 MHz bands were clearly elevated in the frequency spectrum, which fits the 4G profile (Table 2). The exposimeter was unable to register the highest exposure levels as the upper detection limit was exceeded repeatedly. Therefore, FM, as well as 1800 MHz, 2100 MHz, and 2600 MHz downlinks were not properly evaluated by the exposimeter measurements. Meanwhile, broadband meter measurements were able to register also the highest levels.

Table 3 compares public exposure to radiofrequency fields in Stockholm, based on authors' studies – comparing this study at Skeppsbron street to previous measurements. Comparison is done based only on exposimeter (EME Spy 200) measurements, excluding broadband meter measurements. RF field comparison reveals that Skeppsbron street is one of the highest public exposure areas in Stockholm so far measured with the maximum field level exceeding upper detection limit of the exposimeter.

Figs. 3 and 4 are photographs of the street view with some of the mobile phone base station antennas pointed out. The antennas are placed quite low, near the street level, where microwaves irradiate

Table 1
Mobile phone operators, their corresponding services and frequencies used at Skeppsbron, information from cellmapper.net.

Operator	Bands	Downlink frequency (MHz)
Telia	4G	806, 1815, 1832, 2660
	3G	2152, 2157
	2G	950
Telenor	4G	936, 1857, 2630, 2680
	3G	2112, 2122
Tele2	4G	936, 1857, 2630, 2680
	3G	2152, 2157, 2162

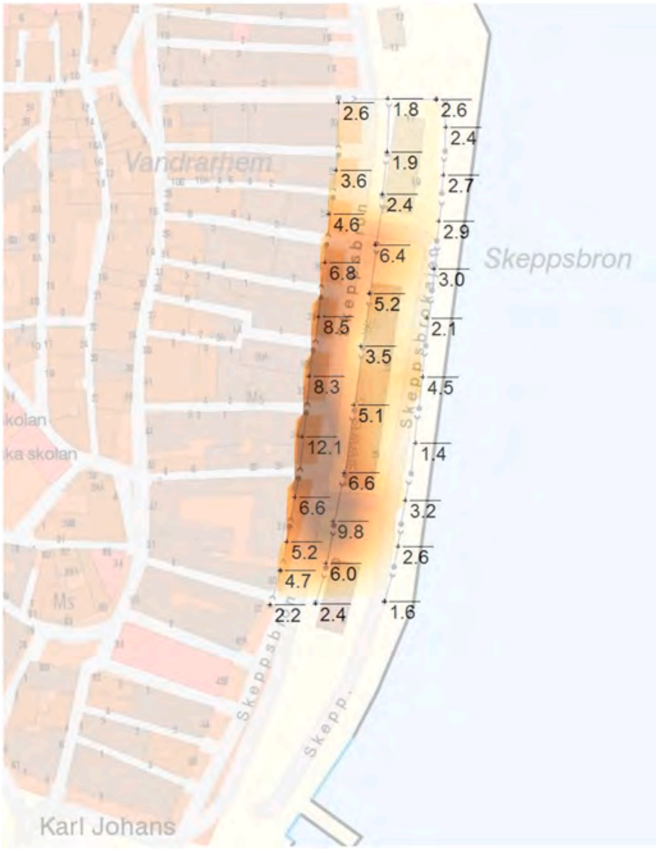

Fig. 2. Spatial distribution of the radiofrequency field (values in V m $^{-1}$) at Skeppsbron street, based on spatial average of a given quadrat cell; hotspots are displayed in darker red where pedestrians are exposed at close range or rays overlap from several mobile phone base station antennas; the investigated area measures about 250 m North to South; map by Lantmäteriet, Sweden. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Exposimeter measurements of the radiofrequency field at Skeppsbron street, analysis of all data (μW m^{-2}) treating values at detection limit as 0. (Note: Exposimeter's highest detection limit (95,522.5 μW m^{-2} was constantly exceeded, therefore Max-values are likely to be much higher, as also confirmed by broadband measurements.) Total (n = 915).

Frequency band	Mean	Median	Min	Max
FM	1304.0	19.6	0.0	95,522.5
TV3	7.2	0.0	0.0	1601.4
TETRA I	0.0	0.0	0.0	1.0
TETRA II	0.0	0.0	0.0	4.7
TETRA III	2.3	0.0	0.0	403.4
TV4&5	17.4	0.6	0.0	2434.4
800 (DL)	751.3	164.5	0.7	12,978.6
800 (UL)	0.0	0.0	0.0	6.6
900 (UL)	0.0	0.0	0.0	8.6
900 (DL)	2545.3	926.5	0.4	35,473.9
1800 (UL)	71.0	8.3	0.0	3291.8
1800 (DL)	3466.6	714.5	3.6	95,522.5
DECT	367.6	0.0	0.0	36,548.9
2100 (UL)	0.1	0.0	0.0	45.5
2100 (DL)	6558.8	1237.4	1.7	95,522.5
WIFI 2G	0.4	0.0	0.0	61.3
2600 (UL)	689.5	154.1	0.0	17,275.1
2600 (DL)	11,338.3	3483.6	1.7	95,522.5
WIMax	0.2	0.0	0.0	58.9
WIFI 5G	0.4	0.0	0.0	93.8
Total	27,120.5	10,481.5	24.4	373,381.0

Table 3
Public exposure to radiofrequency field in Stockholm – this study compared authors' previous studies; exposimeter EME Spy 200 measurements; analysis of all data (μW m^{-2}) treating values at detection limit as 0.

Study	Total (n)	Mean	Median	Min	Max
Stockholm, Central Station (Hardell et al., 2016)	1669	3860.2	920.6	5.8	9206.3
Stockholm, Old Town (Hardell et al., 2017)	10,437	4292.7	534.0	0.0	173,301.8
Stockholm, City (Carlberg et al., 2019)	11,482	5494.2	3346.0	36.6	205,154.8
Stockholm, Järntorget, Old Town (Hardell et al., 2019)	792	21,354.9	12,655.3	381.7	178,928.2
Stockholm, Skeppsbron (current study)	915	27,120.5	10,481.5	24.4	373,381.0

Fig. 3. Street view on the Skeppsbron street with some of the mobile phone base station antennas pointed out with a circle; note the low placement of the antennas, where microwaves irradiate the pedestrian at close range.

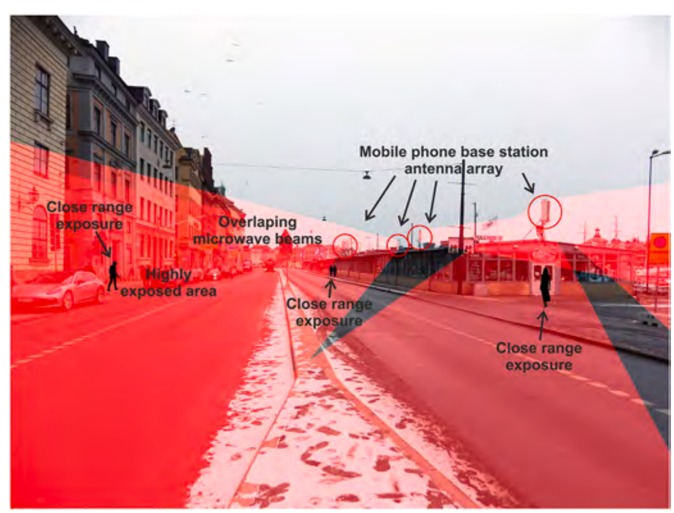

Fig. 4. Problem context of mobile phone base station antennas created high exposure at Skeppsbron street; altogether 15 antenna panels could be counted on that building, all positioned at low elevation close to the street level; the maximum RF exposure was at 31.6 V m^{-1}, registered at close range to the antennas.

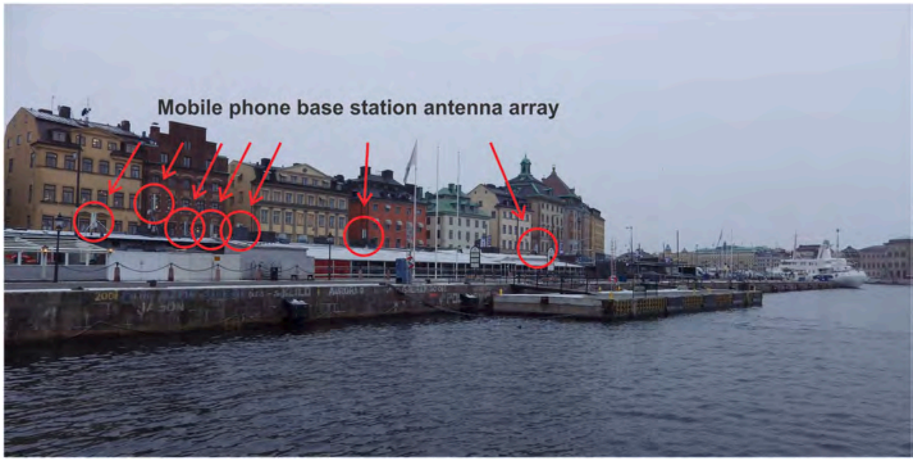

Fig. 5. The antennas are mostly facing the buildings, as the operators want to force the wave into the old town through the narrow streets. Considering the low placement of antennas and pushing all this power - creates very high exposure levels nearby.

pedestrians at close range. Fig. 5 depicts the context – very low placement of the antennas, most of which are targeting the buildings in order to push the microwave into the narrow streets and further into the old town.

4. Discussion

This study, and our previous ones, have recorded the exposure to RF radiation which will provide means for historic comparison for both public and occupational exposure. It is clear from our current study and the previous ones that the level of ambient RF radiation exposure is increasing, see Table 3. Public exposure in different places around the globe is shown in Table 4. Our average and peak RF measurement results are much higher than many of those measurements in that table, indicating a rather recent and rapid increase in radiofrequency radiation levels in city centers. To provide comparison, Bergqvist et al. (2001) measured 0,18 mW m^{-2} highest average levels in Stockholm city center in 2001 (Bergqvist et al., 2001). Swedish radiation protection authorities pointed out recently highest average levels like 720 mW m^{-2} at Järntorget (Esternberg, 2020) and 690 mW m^{-2} at Skeppsbron area (Umeå kommun 2019) in Stockholm. One possible reason for our high RF readings in 2019 was the upgrade of 4G (LTE) base stations with new antenna panels including more antenna elements for the forthcoming 5G (which started officially in Stockholm in 2020).With the development of mobile communications technologies and the widespread use of wireless services the exposure will continue to increase with substantially higher exposure levels and also ever increasing frequency bands, even though several research reports indicate health risks. These risks are relevant to those people working or living in the highly exposed places – in this study they are 1) people living in the apartments across the street from the antennas, 2) workers of the shops across the street and beneath the antennas.

This research identified an increased RF exposure risk area in the center of Stockholm city. Clearly we measured high RF radiation levels of the same magnitude at a square (Järntorget) in the old town (Hardell et al., 2019). These results may be compared with the Ramazzini Institute rat study on far field exposure to 1.8 GHz RF radiation of 0, 5, 25, 50 V m^{-1} with a whole-body exposure for 19 h/day similar to that from base stations (Falcioni et al., 2018). Increased incidence of glioma and heart tumours of the Scwannoma type were found, i.e. similar tumour types as found among people using wireless phones. A statistically significant increase in the incidence of malignant Schwannoma in the heart was found in male rats at the highest dose, 50 V m^{-1} corresponding to whole-body SAR of 0.1 W/kg. Increased non-significant incidence of heart Schwann cells hyperplasia was observed in exposed male and female rats at the highest dose. In irradiated female rats at the highest dose (50 V m^{-1}) the incidence of malignant glial tumours was increased, although not statistically significant. In the current study maximum exposure level of 31.6 V m^{-1} was measured. Thus, there is no reasonable safety limit comparing with the animal study.

Table 4
Public exposure to radiofrequency fields at different places.

Study	Investigated locations	Exposure (mean)
Joseph et al. (2010)	Europe, outdoor	372–569 μW m^{-2}
Bolte et al. (2011)	Netherlands, railway stations	304–354 μW m^{-2}
Bolte and Eikelboom (2012)	Netherlands, outdoor activities	208 μW m^{-2}
Rowley and Joyner (2012)	23 countries	730 μW m^{-2}
Urbinello et al. (2014)	Europe, Basel, Ghent, Brussels	271–892 μW m^{-2}
Verloock et al. (2014)	Belgium, public places	1020 μW m^{-2}
Estenberg and Augustsson (2014)	Stockholm city, Sweden	6700 μW m^{-2}
	Sweden, urban	1500 μW m^{-2}
	Sweden, rural	230 μW m^{-2}
Calvente et al. (2015)	Spain, Granada	799 μW m^{-2}
Gonzalez-Rubio et al. (2016)	Spain, Albecete	4,2–2102 μW m^{-2}
Choudhary and Vijay (2017)	India, Kota city residential	5452–77,840 μW m^{-2}
	industrial, commercial	2386–68,769 μW m^{-2}
	agricultural	2378–68,724 μW m^{-2}
	rural	1878–68,724 μW m^{-2}
Sánchez-Montero et al. (2017)	Spain, Alcalá de Henares	2006: 0.278 V m^{-1} (205 μW m^{-2})
		2010: 0.407 V m^{-1} (439 μW m^{-2})
		2015: 0.396 V m^{-1} (416 μW m^{-2})
Thielens et al. (2018)	Australia, Melbourne	0.05–0.89 V m^{-1} (6–2101 μW m^{-2})
Misek et al. (2018)	Ziina city, center	1.072 V m^{-1} (3048 μW m^{-2})
	residential	1.852 V m^{-1} (9097 μW m^{-2})
	rural	0.510 V m^{-1} (690 μW m^{-2})
	Visnove, rural	0.093 V m^{-1} (23 μW m^{-2})
Eeftens et al. (2018)	Europe, 5 countries	150–160 μW m^{-2}
Zeleke et al. (2018)	Australia, Melbourne	0.233 V m^{-1} (144 μW m^{-2})
Christopoulou and Karabetsos (2019)	Greece, urban	0.244 V m^{-1} (158 μW m^{-2})
	Greece, suburban	0.229 V m^{-1} (139 μW m^{-2})

Electromagnetic fields are a physical risk factor. However, current legislation does not require the mobile phone services operator to ask for approval from neighboring inhabitants, when installing RF sources. Nevertheless, when mobile phone base station antennas are installed, the immediate physical environment, including the neighborhood living environment is greatly altered by the microwaves.

Studies from recent decades have shown elevated health risk under long term exposure to such highly elevated radiofrequency fields.

A review by Khurana et al. (2010) found in 80% of the available studies neurobehavioral symptoms or cancer in populations living at distances <500 m from base stations (Khurana et al., 2010). In another review exposure from base stations and other antenna arrays showed changes in immunological and reproductive systems as well as DNA double strand breaks, influence on calcium movement in the heart and increased proliferation rates in human astrocytoma cancer cells (Levitt and Lai, 2010).

When a GSM 900 MHz base station was installed in the village Rimbach in Germany it had an influence on the neurotransmitters adrenaline, noradrenaline, dopamine and phenyletylamine (Buchner and Eger, 2011). Influence on cortisol and thyroid hormones in people living near base stations was shown in other studies (Augner et al., 2010; Eskander et al., 2012).

Dode et al. (2011 compared base station (BS) clusters and cases of deaths by neoplasia in the Belo Horizonte municipality, Minas Gerais state, Brazil, from 1996 to 2006. In their study largest electric field was 12.4 V m^{-1} and the smallest was 0.4 V m^{-1}. They found cancer-related death rates be higher close to base stations. This finding confirmed earlier findings by Eger (Eger et al., 2004).

In a study from India, genetic damage using the single cell gel electrophoresis (comet) assay was assessed in peripheral blood leukocytes of individuals residing in the vicinity of a mobile phone base station and comparing it to that in healthy controls. Genetic damage parameters of DNA migration length, damage frequency, and damage index were significantly ($p < 0.001$) elevated in the sample group compared to respective values in healthy controls (Gandhi et al., 2014).

The effect of RF radiation among 20 subjects living close to mobile phone base station compared with 20 subjects living with a distance of about 1 km was studied (Singh et al., 2016). The authors concluded that: "*It was unveiled that a majority of the subjects who were residing near the mobile base station complained of sleep disturbances, headache, dizziness, irritability, concentration difficulties, and hypertension. A majority of the study subjects had significantly lesser stimulated salivary secretion (p < 0.01) as compared to the control subjects*."

Zothansiama et al. (2017) in India inspected DNA damage and antioxidant status in cultured human peripheral blood lymphocytes (HPBLs) of individuals residing in the vicinity of mobile phone base stations and compared it with healthy controls living further away. The analyses of data from the exposed group ($n = 40$), residing within a perimeter of 80 m of mobile base stations, showed statistically significantly ($p < 0.0001$) higher frequency of micronuclei when compared to the control group, residing 300 m away from the mobile base stations.

The Ramazzini Institute findings (Falcioni et al., 2018) are supported by the results in the USNTP study on rats and mice exposed to RF radiation (National Toxicology Program, 2018a, 2018b). A clear evidence of increased incidence of heart Schwannoma and some evidence for glioma and tumours in the adreanal medulla in male rats was found according to the expert panel, for further discussion see Hardell and Carlberg (2019).

4.1. Health risks associated with mobile phone radiation

RF radiation was in 2011 classified as a possible human carcinogen, Group 2B by the International Agency for Research on Cancer (IARC) at the WHO (Baan et al., 2011; IARC Working Group, 2013), After that the evidence on cancer risk has increased so that RF radiation may now be classified as a human carcinogen, Group 1 according to the IARC classification (Carlberg and Hardell, 2017).

By now there is concordance between tumours in human epidemiology (Belpomme et al., 2018; Miller et al., 2018) and animal studies (Falcioni et al., 2018; National Toxicology Program, 2018a, 2018b), that is glioma and Schwann cell tumours. These results are supported by mechanistic studies such as oxidative stress (Yakymenko et al., 2016) and DNA damage from RF radiation (Smith-Roe et al., 2020).

So far personal use of wireless phones, mobile and cordless phones (DECT), have yielded highest RF radiation exposure especially to children and to the brain (Gandhi et al., 2012). However, ambient exposure is of increasing concern and may now be of the same magnitude as for increasing cancer incidence in animal studies. This is exemplified in this study.

The BioInititative Report (2012) defines a target level of 30–60 μW m^{-2}, and for chronic exposure and sensitive people such as children one tenth of this, 3–6 μW m^{-2}, see Chapter 24 of the BioInitiative Report (Sage, and Carpenter, 2012).

Already in 2011 Yakymenko et al. stated that: *It is now becoming increasingly evident that assessment of biological effects of non-ionizing radiation based on physical (thermal) approach used in recommendations of current regulatory bodies, including the International Commission on Non-Ionizing Radiation Protection (ICNIRP) Guidelines, requires urgent reevaluation* (Yakymenko et al., 2011).

This view is supported by 252 EMFscientists from 43 nations www.emfscientist.org:

> "Numerous recent scientific publications have shown that EMF [electromagnetic field] affects living organisms at levels well below most international and national guidelines. Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being in humans. Damage goes well beyond the human race, as there is growing evidence of harmful effects to both plant and animal life."

5. Conclusions

This study has pointed out a highly exposed radiofrequency radiation area in the Stockholm city environment and identified the sources and reasons of high exposure. By positioning RF infrastructure to the proximity of the public the risk of health effects is increased since members of the public on the street, also inhabitants in nearby buildings are highly exposed. Mobile phone base station antennas are positioned at the height of second floor levels of adjacent buildings spreading microwaves across the street. Highly elevated exposure levels would likely be encountered in the premises next to the windows facing the mobile phone base station array.

The study concluded that Skeppsbron street mobile phone base station antennas are examples of a poor radiofrequency infrastructure design with mobile phone base station antennas positioned into close range to the general public which brings upon high exposure levels. Given the low placement of the antennas (height from the street floor), the highest exposure was often registered at pedestrian head level. Given that head is one of most vulnerable parts of the body, these placements by mobile telephony service providers put pedestrians into unnecessary risk. Position of these antennas, can pose a health risk to people at close range. This is especially critical for people at particular risk, including persons with medical implants, pregnant women or chronically ill persons.

Based on the latest scientific literature regarding RF exposure and adverse health effects, this study recommends repositioning such base station antennas to areas away from the nearby inhabitants, workers and the general public. Alternatively, very low power antennas may also be considered to reduce the exposure. Occupational exposure of people working close to the antennas should also be considered – shop clerks, restaurant workers are likely to spend considerably longer time under high exposure, compared to the general public.

The following recommendations for radiofrequency infrastructure can be concluded from the current study.

1. Antennas should be positioned as far as possible from the general public, like locations at the high elevations or remote areas, where the antenna targeted area is not regularly/frequently visited by the members of the public.
2. Only low power output mobile phone base station antennas (<15W) should be used in the city environment.
3. To avoid hotspots, created by overlapping arrays, dense packing of many antennas at one site should be avoided.
4. Low power output antennas in the city environment should be positioned into locations where direct beam would not hit members of public closer than 50m.

The conclusions of this study will help to design safer mobile phone base station sites in the city environment, when the aim is to minimize public exposure.

Author contributions

T.K. and M.A. performed the measurements. Conception of the study, design and analyses of the material, writing of the article and approval of the final manuscript was made by all authors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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International Journal of Radiation Biology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/irab20

Threshold of radiofrequency electromagnetic field effect on human brain

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INTERNATIONAL JOURNAL OF RADIATION BIOLOGY
https://doi.org/10.1080/09553002.2021.1969055

REVIEW

Threshold of radiofrequency electromagnetic field effect on human brain

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ABSTRACT

Purpose: This review aims to estimate the threshold of radiofrequency electromagnetic field (RF EMF) effects on human brain based on analyses of published research results. To clarify the threshold of the RF EMF effects, two approaches have been applied: (1) the analyses of restrictions in sensitivity for different steps of the physical model of low-level RF EMF mechanism and (2) the analyses of experimental data to clarify the dependence of the RF EMF effect on exposure level based on the results of published original neurophysiological and behavioral human studies for 15 years 2007–2021.

Conclusions: The analyses of the physical model of nonthermal mechanisms of RF EMF effect leads to conclusion that no principal threshold of the effect can be determined. According to the review of experimental data, the rate of detected RF EMF effects is 76.7% in resting EEG studies, 41.7% in sleep EEG and 38.5% in behavioral studies. The changes in EEG probably appear earlier than alterations in behavior become evident. The lowest level of RF EMF at which the effect in EEG was detected is 2.45 V/m (SAR = 0.003 W/kg). There is a preliminary indication that the dependence of the effect on the level of exposure follows rather field strength than SAR alterations. However, no sufficient data are available for clarifying linearity-nonlinearity of the dependence of effect on the level of RF EMF. The finding that only part of people are sensitive to RF EMF exposure can be related to immunity to radiation or hypersensitivity. The changes in EEG caused by RF EMF appeared similar in the majority of analyzed studies and similar to these in depression. The possible causal relationship between RF EMF effect and depression among young people is highly important problem.

ARTICLE HISTORY
Received 16 June 2021
Revised 29 July 2021
Accepted 9 August 2021

KEYWORDS
Low-level RF EMF; nonthermal model; threshold; linearity; depression

Introduction

The world population has been exposed to man-made coherent electromagnetic radiation, different from the natural radiation emitted by the Sun, over a very long period of time without remarkable effects on health. The people are adapted to the level of radio and TV broadcasting radiofrequency electromagnetic field (RF EMF) about 0.1 V/m. During recent decades, the applications of mobile telecommunication technology have drastically changed the situation. The sources of RF EMF have moved closer to people and the levels of exposure are much higher. The current guidelines recommend health protection limits up to 61 V/m (ICNIRP 2020). Hundreds of studies have detected biological RF EMF effects in humans, animals and cells at the levels of exposure much less than existing health protection limits. According to the Ericsson Mobility Report, the number of mobile subscriptions by technology is over eight billion in 2020 (Ericsson Mobility Report 2020). This number is higher than the world population. The wide applications of RF EMF rise concern about possible consequences on health.

The increased oxidative stress caused by RF EMF exposure has been reported in many animal and cellular studies (Schuermann and Mevissen 2021). The relevant consequences on health (genome stability, immune system, neurodegeneration, reproduction) are likely. The radiofrequency electromagnetic field was classified as possibly carcinogenic to humans (class 2B) by the International Agency for Research on Cancer (IARC 2013).

The RF EMF effects on brain bioelectrical activity, cognition and behavior, not obligatory related to genome instability, have been a topic of interest over the past decades. The neurophysiological effects on humans have been detected in many experimental studies but the results are controversial (Valentini et al. 2007; Marino and Carruba 2009; Kwon and Hämäläinen 2011). The large variations in applied methods, different frequencies, levels of exposure and modulation parameters cause high diversity of the effects and results. The recent cohort study does not provide sufficient confirmation about the correlation between more extensive use of mobile phones and the reported symptoms nor sleep quality (Auvinen et al. 2019; Tettamanti et al. 2020). It is complicated to determine causal relationship between RF EMF biological effects and its health consequences due to diversity of exposure conditions and numerous concomitant other factors.

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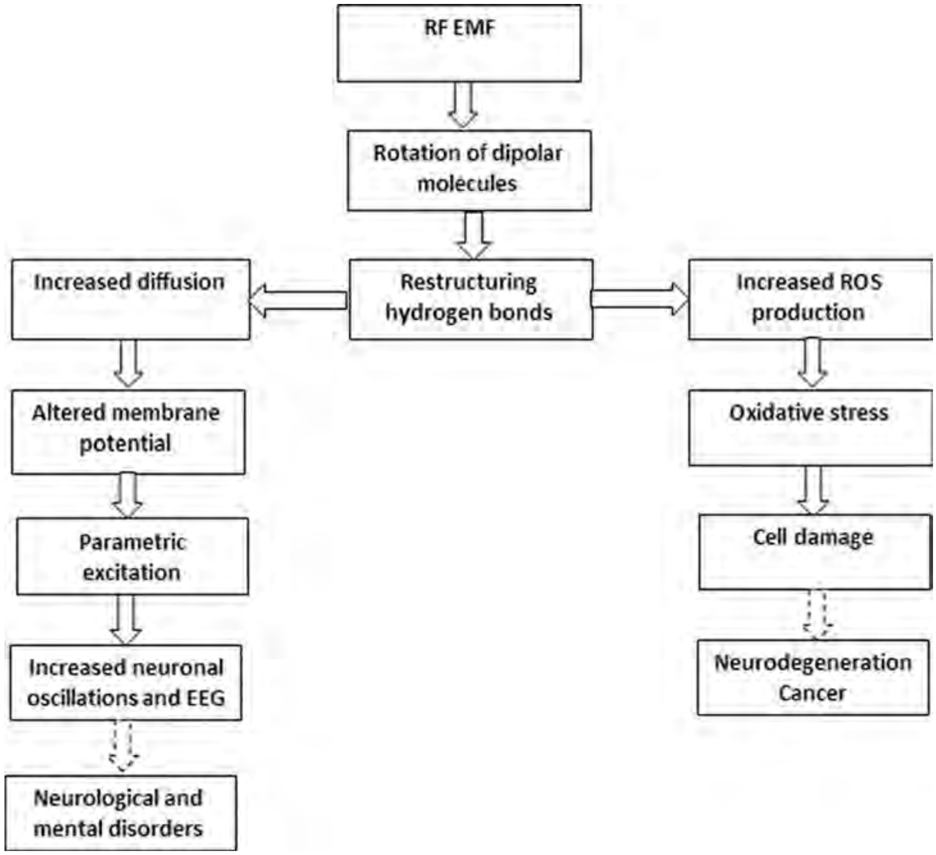

Figure 1. Model of nonthermal mechanisms of low-level RF EMF: left track neurophysiological effect, right track neurodegeneration.

Does the RF EMF has a threshold, lower of which the RF EMF does not have biological effect? This is an important question and crucial to avoid possible consequences on health.

Theoretical estimations for the sensitivity of living cells to electric field provided the threshold values about $10^{-6} - 10^{-7}$ V/m Hz$^{1/2}$ (Weaver and Astumian 1990; Hinrikus et al. 1998). In the case of wide-band telecommunication technology, the threshold rises: at 1 MHz bandwidth, the sensitivity is $10^{-3} - 10^{-4}$ V/m. However, these estimations used a simple single-cell model. Realistic model involving combinations of different cells, molecules and partly nonlinear physiological processes is highly complex. To the best of our knowledge, the calculations using complex model have been not performed.

To clarify the threshold of RF EMF effects, two approaches are applied in the current review: (1) the analyses of restrictions in sensitivity for different steps of the physical model of low-level RF EMF mechanism and (2) the analyses of experimental data to clarify the dependence of the effect on exposure level.

Analyses of different steps of the physical model of low-level RF EMF mechanism

The RF EMF is a physical stressor. Electric forces keep together atoms and molecules. The coherent RF EMF, due to regular synchronous electrical forces, causes stronger cumulative impact in a medium compared to random thermal processes (Hinrikus et al. 2018). Therefore, a nonthermal physical model based on electrical phenomena (Hinrikus et al. 2018) has been selected as a base for estimations. Figure 1 presents the logical structure of the mechanisms of the model. The low-level RF EMF approach, without heating, is appropriate in considering threshold of the effect.

Origin of the effect

The RF EMF causes displacement of free and bound charges in a dielectric medium and dielectric polarization of the medium. Displacement of electrons or ions inside a molecule leads to electronic or molecular, rotation of dipolar molecules to orientational polarization (King and Smith 1981). The intermolecular and even intramolecular electrical fields are much stronger than the applied RF EMF. Therefore, the imbalances in the spatial distribution of charges created by a RF EMF are very small. The synchronization of the displacements in a very large number of molecules leads to the measureable dielectric permittivity of materials (Zahn 2003).

Whereas the intramolecular electric forces are weaker than intermolecular forces, the orientational polarization dominates. Traditionally, the rotation of dipolar molecules caused by high-level RF EMF is considered as the origin of RF EMF thermal effect. However, the measureable electric permittivity exists also in low-level RF EMF and, consequently, the rotation of dipolar molecules takes place in low-level RF EMF at constant temperature. The synchronous cumulative impact of coherent RF electric field makes possible the low-level field-induced effect despite the energy of RF EMF is lower thermal energy causing random displacements (Hinrikus et al. 2018).

The polarization in dielectrics and water as well as dielectric parameters of tissues have been investigated in many studies (Hasted 1973; Pethig 1979; Mudgett 1985; Foster and Schwan 1995; Gabriel, Gabriel, et al. 1996; Gabriel, Lau, et al. 1996). The relaxation time of orientational polarization decreases with temperature due to increasing number of collisions disturbing the rotation. Therefore, the orientational polarization of tissues decreases with temperature (Pethig 1979).

Orientational polarization depends on the frequency and decreases with frequency due to inertia of molecules. Experimental data indicate that the dielectric constant has the frequency independent value of 1.8 at frequencies close to 100 GHz where the dielectric constant is determined only by the molecular polarization (Hasted 1973).

No theoretical nor experimental data about the threshold of polarization are available. In a linear medium, dielectric constant most probably is constant and does not depend on the level of EMF. The linearity of the response of living tissues to electromagnetic forces can be presumed at low level of EMF. Therefore, the rotation of dipolar molecules has no a determined threshold.

The synchronous rotation of dipolar molecules presumes unavoidable restructuring and weakening of hydrogen bonds between these molecules (Hinrikus et al. 2018). Hydrogen bonds are responsible for the properties of water and for holding together the DNA double helix. Hydrogen bonds are being constantly broken and reformed in liquid water because of random thermal motion of molecules despite the bonding energy is higher kT (Petrucci et al. 2007). The induced by low-level microwave radiation alterations in the properties of water demonstrate restructuring of hydrogen bonds by RF EMF (Fesenko and Gluvstein 1995). Consequently, kT does not determine the threshold of the phenomenon. There are no data about the threshold of restructuring the intramolecular bonds.

Neurophysiological effect

The left tract in Figure 1 presents the model of neurophysiological RF EMF effect that presumes no oxidative stress nor cellular damage.

Hydrogen bonds are responsible for many of the properties of water including viscosity. Weakening of hydrogen bonds decreases viscosity and increases diffusion. The caused by RF EMF increase in diffusion at constant temperature has been demonstrated by experiments in water and supported by the results of in vitro study (Hinrikus et al. 2015; Aly et al. 2008). Diffusion plays crucial role in many physiological processes including neuronal membrane potential and transfer of neurotransmitters in synapses. There are no factors nor data determining the threshold of the effect on diffusion.

Alterations in diffusion cause change in resting neuronal potential and misbalance of membrane currents (Malmivuo and Plonsey 1995; Hinrikus et al. 2017). No factors causing the threshold of membrane potential change have been reported (Malmivuo and Plonsey 1995).

The modulation of RF EMF at low frequencies close to the brain physiological frequencies is important and determines the intensity of the effect (Sanders et al. 1985; Hinrikus, Bachmann, Lass, Tomson, et al. 2008; Hinrikus, Bachmann, Lass, Karai, et al. 2008; Juutilainen et al. 2011). Low-level pulse-modulated RF EMF causes periodic alterations in neuronal electric parameters.

Periodic alterations of neuronal parameters can lead to parametric excitation of neuronal oscillations at predetermined electroencephalographic (EEG) frequencies (Hinrikus, Bachmann, Karai, et al. 2011). The process of excitation of parametric oscillation in a system has a threshold determined by the damping factor and losses in the system (Tso and Caughey 1965; Butikov 2004). However, biochemical energy compensates the losses in neuronal oscillations in brain. Therefore, the lower limit of parametric excitation is not defined. Disturbances in brain bioelectrical activity probably lead to alterations in cognition and behavior.

The brain's defense mechanisms can easily compensate the mild alterations caused by RF EMF (Bachmann, Tomson, et al. 2007). The fast compensation has been demonstrated in the experiments with RF EMF one minute ON-OFF pulse modulation: the effect has appeared statistically significant during first 30 s of ON-pulse but not significant during second 30 s (Hinrikus, Bachmann, Lass, Tomson, et al. 2008). However, in the case of continuous long-term exposure in RF EMF environment, the effect becomes permanent and consequences on health are possible.

Neurodegeneration

The right tract in Figure 1 presents the possible biological model of RF EMF effect that presumes oxidative stress and cellular damage.

The experimental results have demonstrated low-level RF EMF induced increase in the level of reactive oxygen species (ROS) (Xing et al. 2016; Marjanovic Cermak et al. 2018). The RF magnetic fields have been shown to affect the concentrations of ROS via the radical pair mechanism (Usselman et al. 2014; Castello et al. 2014; Barnes and Greenebaum 2015). The low-level RF EMF caused oxidative stress has been reported in many animal and cellular studies (Schuermann and Mevissen 2021). Oxidative stress can lead to cell damage. Further consequences in health including genome instability, neurodegeneration, immune system, male and female reproduction system are possible (Schuermann and Mevissen 2021).

Whereas body's defense mechanisms can repair the temporal changes in ROS formation process in brain cells, the health effect does not necessarily become evident. However, the probability that the defense mechanism can repair the changes caused by permanent exposure by RF EMF is much smaller.

The analyses of both models indicated no data about the factors determining the threshold of low-level RF EMF effect. The radiological protection system in low-level ionizing radiation still bases also on 'linear, no threshold' model, which assumes that there is no dose so small that it has no effect (McLean 2017).

Analyses of experimental data

Search of studies

The current review analyses the results of published original RF EMF human studies for 15 years 2007–2021. The EMF portal database was used for searching of publications. The filters: radio frequency, mobile communication, experimental studies and keywords: EEG, cognition, behavior were used for selection. Further individual evaluation excluded animal and in vitro studies. The quality of all studies was evaluated and the studies with drawbacks in used methods (insufficient data about exposure, limited numbers of subjects, incorrect statistics) were excluded. Finally, 76 relevant studies were included for the analyses.

RF EMF effects

Table 1 summarizes the RF EMF effects reported in the selected publications. The results are presented according to the formulations used by the authors. Unfortunately, the majority of studies do not report quantitative information about the effect – the numerical values of the analyzed parameters (e.g. values of changes in the powers of EEG rhythms or other parameters).

The effects are divided into four categories: changes in resting electroencephalography (EEG), in sleep EEG and sleep quality, in event-related potentials (ERP) plus cognition-behavior and others (changes in cortex oxygenation and brain glucose metabolism). Figure 2 presents the distribution of studies according to these categories. The resting EEG constitutes the largest part 47% of the total studies. The resting eyes closed EEG is most thoroughly investigated. The part of studies in sleep EEG and sleep quality constitutes 15%. The part of event-related potentials (ERP) connected to cognition and behavior effects constitutes 34% of total findings and the part of others only 4%.

Figure 3 presents the rate of studies, which revealed RF EMF effect in different categories. The relative part of

Table 1. Distribution of studies according to the reported RF EMF effects in different categories.

Resting EEG	
Increased theta	Bardasano et al. 2007
Increased alpha	Bardasano et al. 2007; Regel, Tinguely, et al. 2007; Vecchio et al. 2007; Krause et al. 2007; Hinrikus, Bachmann, Lass, Tomson, et al. 2008; Hinrikus et al. 2009; Hinrikus et al. 2011; Croft et al. 2008; Croft et al. 2010; Suhhova et al. 2013; Roggeveen, van Os, Viechtbauer, et al. 2015; Ghosn et al. 2015; Hinrikus et al. 2017; Loughran et al. 2019
Decreased alpha	Yang et al. 2017; Vecsei et al. 2018
Increased beta	Bachmann, Tomson, et al. 2007; Hinrikus, Bachmann, Lass, Karai, et al. 2008; Hinrikus et al. 2011; Suhhova et al. 2013; Roggeveen, van Os, Lousberg, et al. 2015; Hinrikus et al. 2017
Decreased beta	Yang, et al. 2017
Increased gamma	Hinrikus et al. 2009; Roggeveen, van Os, Lousberg, et al. 2015; Curcio et al. 2015
Increased complexity	Bachmann, Tomson, et al. 2007 (LDLVP); Vecchio et al. 2010 (coherence); Hinrikus, Bachmann, Karai, et al. 2011 (HFD)
No effect	Kleinlogel et al. 2008a; Loughran et al. 2013; Zentai et al. 2015; Eggert et al. 2015; Trunk et al. 2015, 2013; Nakatani-Enomoto et al. 2020
Sleep EEG and sleep quality	
Increased spindles 11-12 Hz	Schmid, Murbach et al. 2012; Lowden et al. 2019
Increased delta and theta	Lustenberger et al. 2015
Increased slow-wave activity 0.75-4.5 Hz, redused motor task	Lustenberger et al. 2013
Increased delta, theta, alpha	Schmid, Loughran et al. 2012
No effect	Regel, Gottselig et al. 2007; Fritzer et al. 2007; Leitgeb et al. 2008; Nakatani-Enomoto et al. 2013; Danker-Hopfe et al. 2011, 2010, 2020
Event related potential (ERP), cognition and behavior	
Improved memory and motor tasks	Meo et al. 2019
Visual ERP, increased P1 amplitude and N1 latency	Dalecki et al. 2018
Reduced reaction time	Verrender et al. 2016
Decrease correct answers	Sauter et al. 2015
Pain threshold increase	Vecsei 2013
Increased N100	Leung et al. 2011
Acoustic ERP, amplitude decrease, adaptation increase	de Tommaso et al. 2009
Response time change	Luria et al. 2009
Reducing psychological arousal	Augner et al. 2009
Attention increase	Wiholm et al. 2009
No effect	Regel, Tinguely et al. 2007; Haarala et al. 2007; Krause et al. 2007; Cinel et al. 2008; Stefanics et al. 2008; Kleinlogel et al. 2008b; Curcio et al. 2008; Hillert et al. 2008; Eltiti et al. 2009; Kwon et al. 2009; Riddervold et al. 2010; Kwon et al. 2010; Sauter et al. 2011; Loughran et al. 2013; Vecsei et al. 2018; Hosseini et al. 2019
Others	
Cortex oxygenation	Curcio et al. 2009
Brain glucose metabolism	Kwon et al. 2011; Volkow et al. 2011

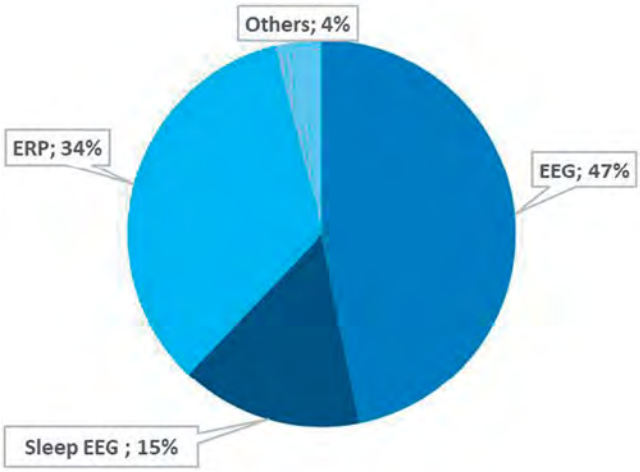

Figure 2. Relative distribution of studies according different categories of the RF EMF effects.

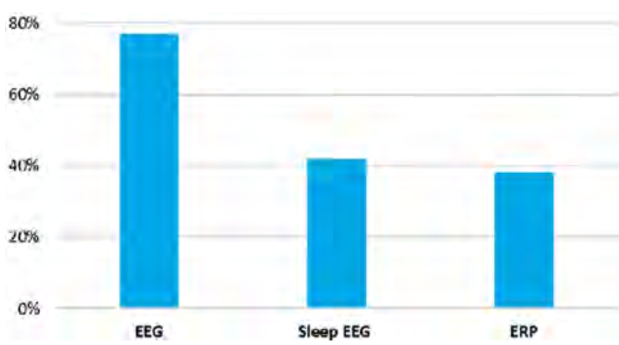

Figure 3. The rate of studies revealing RF EMF effects according different categories.

studies reporting the effect in the resting EEG category is about twofold higher than in the other sleep EEG or ERP categories. All three studies in the category others reported RF EMF effects. However, three studies are too few to make a conclusion about the rate of RF EMF effects.

Resting EEG

The rate of positive findings in resting EEG category (in total 30 studies) is 76.7%. The increased alpha power was most frequently reported (14 studies). Somewhat less studies reported increased beta power (6 studies). Decrease in alpha power was revealed only in two studies and beta power in one study. Increase in gamma power was detected in three and theta power in one study. Increased complexity was evident in three studies. Such distribution of the reported effects is obviously caused by the properties of the resting eyes closed EEG where alpha power (band 8–12 Hz) peak is much higher other bands. Therefore, the alterations in alpha power are detectable more easily.

Only few studies have applied advanced EEG analyses to detect alterations in more complicated nonlinear processes in the brain (Hinrikus, Bachmann, Karai, et al. 2011; Bachmann, Tomson, et al. 2007). The results of these studies demonstrated that RF EMF affected complexity of the brain bioelectrical activity. The RF EMF increased scores of both applied measures, Higuchi's fractal dimension (HFD) and Length distribution of low variability periods (LDLVP).

The results demonstrate that RF EMF causes excitation of brain and related increase in resting EEG alpha and beta bands powers. Exposure to radiation leads also to the higher complexity of brain bioelectrical activity.

Sleep EEG and sleep quality

The rate of positive findings in sleep EEG and sleep quality group is 41.7%. All five studies that reported the effect, declared increase in sleep EEG rhythms or spindles. The increase was evident in slow wave (delta and theta) and in alpha band. No disturbances in sleep quality were reported.

These results suggest that the radiation causes changes in neuronal activity earlier than the subjective feelings become evident.

Event-related potentials (ERP), behavior and cognition

The rate of positive findings in ERP, behavior and cognition group is 38.5%. The reported findings are diverse. Two studies reported changes in ERP. Improved behavior (memory, attention, reaction time) was demonstrated in four studies and reduced behavior (psychological arousal, correct answers, pain threshold) were shown also in four studies.

Exposure to low-level RF EMF, stimulating brain, can cause some improvement of behavior. On the other side, negative impact on behavior and arousal is evident.

Others

Positron emission tomography (PET) study reported significantly correlated with the estimated RF EMF amplitudes changes in brain glucose metabolism and its increase in the region closest to the antenna (Volkow et al. 2011). Another PET study indicated reduced cerebral metabolic rate of glucose in in the area close to the antenna (Kwon et al. 2011). The exposure did not affect task performance (reaction time, error rate). One study, using functional near-infrared spectroscopy, reported a slight influence of the RF EMF on frontal cortex oxygenation (Curcio et al. 2009).

These results support the suggestion that short-term changes in brain physiology are not obligatory related to human performance.

Dependence on exposure level

To study the dependence on exposure level, the selected for analyses studies are divided into groups according to exposure level (Table 2). While studies at SAR > 2 W/kg are considered as a single group, the numbers of studies per group are following: 7 studies in the group of SAR > 2; 22 studies in the group of SAR $= 2–1.5$ W/kg; 19 studies in the group of SAR $= 1.5–1$ W/kg; 10 studies in the group of SAR $= 1–0.5$ W/kg; 15 studies in the group of SAR $=0.5–0.1$ W/kg; and three studies in the group of SAR < 0.1 W/kg.

Table 2. Studies grouped according to the level of exposure.

SAR W/kg	Effect	No effect
10.98		Sauter et al. 2011
7.82		Sauter et al. 2011
6	Sauter et al. 2015	Eggert et al. 2015
5		Regel, Gottselig, et al. 2007
3.75		Trunk et al. 2013
2.18	Lv, Su et al. 2014; Lv, Chen et al. 2014	
2-1.5	Croft et al. 2010; Leung et al. 2011; Lowden et al. 2011; Schmid et al. 2012; Vecsei et al. 2013; Sauter et al. 2015; Lustenberger et al. 2015; Verrender et al. 2016; Yang et al. 2017; Vecsei et al. 2018; Dalecki et al. 2018; Loughran et al. 2019; Lowden et al. 2019	Stefanics et al. 2008; Croft et al. 2010; Riddervold et al. 2010; Danker-Hopfe et al. 2011; Nakatani-Enomoto et al. 2013, 2020; Trunk et al. 2015; Eggert et al. 2015
1.5-1	Regel, Tinguely et al. 2007; Hung et al. 2007; Krause et al. 2007; Luria et al. 2009; Wiholm et al. 2009; Lustenberger et al. 2015; Verrender et al. 2016; Yang et al. 2017; Dalecki et al. 2018; Loughran et al. 2019	Fritzer et al. 2007; Haarala et al. 2007; Krause et al. 2007; Kleinlogel et al. 2008a, 2008b; Hillert et al. 2008; Kwon et al. 2009, 2010, 2011; Loughran et al. 2013
1-0.5	Bardasano et al. 2007; Curcio et al. 2008; Croft et al. 2008; de Tommaso et al. 2009; Curcio et al. 2009; Croft et al. 2010; Vecchio et al. 2010; Leung et al. 2011; Ghosn et al. 2015; Curcio et al. 2015	
0.5-0.1	Bachmann, Tomson, et al. 2007; Bachmann et al. 2018: Hung et al. 2007; Hinrikus Bachmann, Lass, Tomson, et al. 2008; Hinrikus, Bachmann, Lass, Karai, et al. 2008; Hinrikus et al. 2009; Suhhova et al. 2009; Hinrikus et al. 2011; Hinrikus, Bachmann, Lass et al. 2011; Lustenberger et al. 2013; Suhhova et al. 2013; Hinrikus et al. 2017	Regel, Gottselig, et al. 2007; Eltiti et al. 2009
<0.1	Suhhova et al. 2013	Zentai et al. 2015; Bueno-Lopez et al. 2021

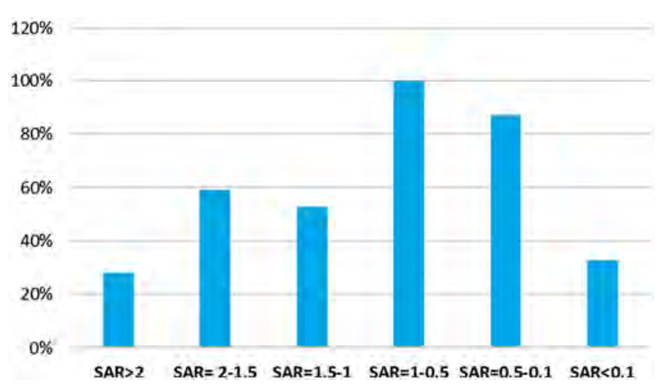

Figure 4. The rate of detected RF EMF effects in the groups of different SAR (W/kg) levels.

Figure 4 presents the rate of detected RF EMF effects in the groups. No any regular trend on the dependence of the effect on SAR level occurs. Unfortunately, only very few studies reported quantitative data about the intensity of the detected effects. The differences in the results can be caused rather by diversity of applied methods and used types of radiation. The fact that all studies at SAR = 1-0.5 W/kg indicated the effect can be considered as a chance. The group includes studies from different groups and various kind of the effects, no any reason exists for systematic advantage. The high rate of the detection 87% in the group SAR =0.5-0.1 W/kg can be explained by fact, that the majority of studies belong to one team. The team (Bachmann, Hinrikus, et al. 2007) has modified the modulation method used in Dicke radiometer (Tiuri 1964) to increase the sensitivity for the detection of changes in EEG. Therefore, small hidden in the variability of EEG changes can be detected and alteration not only in alpha but also in beta and gamma bands become evident.

The other reason for uncertainty of the results of analyses is that the majority of studies have been performed within quite narrow diapason of SAR levels between 2 and 0.1. Only few studies used higher and lower exposure levels.

According to the origin of low-level RF EMF effect mechanism (Figure 1), the effect is related to electric field strength causing rotation of dipolar molecules, not absorbed power. Therefore, electric field strength is more appropriate parameter for determining the experimental condition. Unfortunately, only very few authors have indicated field strength used in their experiments.

The dependence of the effect on exposure level can be evaluated better comparing data at two or more levels of exposure within the same study. Several studies performed experiments at two different SAR values. However, some of these studies reported no effect (Kleinlogel et al. 2008a, 2008b; Sauter et al. 2011; Danker-Hopfe et al. 2011; Eggert et al. 2015). Some others did not provide quantitative data for the results (Leung et al. 2011; Loughran et al. 2013; Sauter et al. 2015; Verrender et al. 2016; Dalecki et al. 2018).

Only one study reported quantitative data about changes at two different levels of exposure (Suhhova et al. 2013). At the higher SAR = 0.303 W/kg ($E = 24.5$ V/m) level, increases in the EEG beta2 (157%), beta1 (61%) and alpha (68%) frequency bands were detected. At the lower SAR = 0.003 W/kg ($E = 2.45$ V/m) level, increase only in the beta2 (39%) frequency band was evident. The decrease in the intensity of the effect at lower level about four times is much less than expected according to the decrease of SAR (100 times). The relative decrease of the effect is rather close to the change in field strength (10 times).

The performed analyses are not helpful in clarifying regularity of the dependence of the effect on the level of radiofrequency radiation. Obviously factors other than the level of exposure plays important role in the low-level RF EMF effects. An important factor is modulation frequency that is expected being close to the EEG frequencies (Hinrikus, Bachmann, Lass, Tomson, et al. 2008; Hinrikus et al. 2011). According to studies analyzed in the current review, the lowest electric field strength at which the effect was detected is 2.45 V/m (SAR = 0.003 W/kg) (Suhhova et al. 2013).

Possible consequences on health

The transformation of the biological effects of radiation into health consequences is a chaotic process (disrupted-line arrows in Figure 1). A very weak initial alteration on neuronal or molecular level can lead to unpredictable consequences on health – or not cause any remarkable health effect. Therefore, the threshold of RF EMF consequences on health cannot be determined.

Main attention in evaluation of the RF EMF health effects has been directed to risk of tumors (Carlberg et al. 2013; Miller et al. 2019; Choi et al. 2020). Due to long latent period, diverse exposure conditions and biological parameters, the causal relationship is difficult to reveal. The recent meta-analyses of case-control studies found that cellular phone use with cumulative call time more than 1000 h statistically significantly increased the risk of tumors (Choi et al. 2020).

Less attention in evaluation of the RF EMF health effects has been directed to neurological diseases and mental disorders. There is a possibility that the RF EMF neurophysiological effect can cause neurological and mental disorders not obligatory related to oxidative stress and genetic instability. The cohort study on cellular telephones and central nervous system diseases risks observed the excesses of migraine and vertigo and a possible association with dementia and Parkinson (Schuz et al. 2009). The recent cohort study concludes that people using mobile phones most extensively reported weekly headaches slightly more frequently than other users (Auvinen et al. 2019).

The analyses in the current review show that alteration in EEG are similar in the high majority of the studies: increase in EEG alpha, beta and gamma band levels as well as higher complexity of the signal (Table 1). Similar changes in EEG are characteristic in major depression disorder (Knott et al. 2001; Fingelkurts and Fingelkurts 2015). Based on these EEG parameters, the quantitative measures for the detection of symptoms of depression have been discussed (Ahmadlou et al. 2012; Hosseinifard et al. 2013).

The causality between the RF EMF and depression is not clear. The results of the study based on a special questionnaire indicated association between higher mobile phone use and symptoms of depression (Thomee et al. 2011). However, it is complicated to differentiate between the direct effect of RF EMF and psychological factors related to the high use of mobile phones leading sometimes even to addiction (Gutiérrez et al. 2016; Lapierre et al. 2019).

Depression has become a common mental disorder during last decades with the highest prevalence among individuals aged 18-25 (13.1%) (NIH 2021). The levels of RF EMF have increased and the use of mobile telecommunication technology has become more intense with prevalence in young people during the same period. Is this a coincidence or causality?

The results of some studies demonstrate that at the same level of RF EMF exposure and identical conditions, only a part of people are affected (Hinrikus, Bachmann, Lass, Karai, et al. 2008; Bachmann, Tomson, et al. 2007). The rate of sensitive people varies from 13% to 31% depending on modulation frequency (Hinrikus, Bachmann, Lass, Tomson, et al. 2008). It is not clear are some people 'immune' to the RF EMF permanently or occasionally. The connection between 'immunity' and hypersensitivity is important for interpretation of RF EMF health effects.

The results of some studies indicate that RF EMF-related changes in neuronal system (EEG signal) are much more frequent than in subjective behavior (Vecsei et al. 2018). The exposure-induced effects have been seen in objective indicators (EEG, glucose metabolism) but not in cognitive performance (Schmid, Murbach, et al. 2012; Kwon et al. 2011). Therefore, people would not mention existing health symptoms of the RF EMF effect. The situation that objective physiological symptoms appear earlier than the subjective feeling and symptoms is quite usual in the case of many diseases.

Conclusions

The analyses of the model of the non-thermal mechanism of RF EMF effect shows that the steps of the model contain no principal threshold for the effect. Therefore, the only way to estimate the possible threshold is analyses of experimental data. The review of experimental data of human RF EMF neurophysiological effects results in following main conclusions that indicated the directions of future research:

1. The lowest field strength that has caused the effect in EEG, according to the reviewed studies, is 2.45 V/m (SAR = 0.003 W/kg), close to the radio and TV broadcasting RF EMF field strength about 0.1 V/m. The future large-scale human, animal and in vitro studies are required to clarify the level and to increase the reliability of the experimentally determined threshold of RF EMF effect.
2. There is a preliminary indication that the intensity of the effect follows rather the field strength than SAR alteration. However, no sufficient data are available for clarifying regularity and linearity-nonlinearity of the relationship. The studies with systematic variations in exposure level (electric and magnetic field strengths, power density) would help to advance the field. The

research from cellular to humans is needed in this direction.

3. Very limited data are available about the repair and adaptive phenomena important in the interpretation of the RF EMF effects on health. Special studies are required to clarify the mechanisms and possibilities of the repair processes.
4. The finding that only part of people are sensitive to RF EMF exposure can be related to immunity to radiation or hypersensitivity. The variability of sensitivity between people and long-term stability of the status required large-scale long-term experimental studies.
5. The indication that the changes in EEG caused by RF EMF appeared similar to these in depression need a special attention. The fast increase of depression with the highest prevalence among young individuals and more intense use of mobile telecommunication technology with prevalence in young people during the same period needs attention. The possible causal relationship between RF EMF effect and depression among young people is the problem of high importance. The methodology and large-scale investigations in this direction are required.

Disclosure statement

The authors report no conflict of interest.

Funding

The research was funded partly by the Estonian Center of Excellence in IT (EXCITE) funded by the European Regional Development Fund.

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Original Article

Exposure to Cell Phone Radiations Produces Biochemical Changes in Worker Honey Bees

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ABSTRACT

The present study was carried out to find the effect of cell phone radiations on various biomolecules in the adult workers of *Apis mellifera* L. The results of the treated adults were analyzed and compared with the control. Radiation from the cell phone influences honey bees' behavior and physiology. There was reduced motor activity of the worker bees on the comb initially, followed by *en masse* migration and movement toward "talk mode" cell phone. The initial quiet period was characterized by rise in concentration of biomolecules including proteins, carbohydrates and lipids, perhaps due to stimulation of body mechanism to fight the stressful condition created by the radiations. At later stages of exposure, there was a slight decline in the concentration of biomolecules probably because the body had adapted to the stimulus.

Key words: *Apis mellifera,* biomolecules, cell phone radiations, hemolymph

INTRODUCTION

Cell phone usage is a major public health concern because of potential risk of chronic exposure to low level of radiofrequency and microwave radiation that pulse off the phone antennae in close proximity to the head.[1] These concerns have induced a large body of research, both epidemiological and experimental, in humans and animals. Honeybees are reliable indicators of environmental status and possess several important ecological, ethological, and morphological characteristics. They are the best experimental animals to study the effect of electromagnetic waves because they possess in their abdomen magnetite granules which help the bees in their orientation flight. Moreover, the integument of bees has semiconductor functions. It is in the light of these characteristics of honey bees that the present investigation was planned to study the metabolic changes with respect to proteins, carbohydrates, and lipids in hemolymph of worker honeybee of *Apis mellifera* L. exposed to cell phone radiation.

Access this article online	
Quick Response Code:	Website: www.toxicologyinternational.com
	DOI: 10.4103/0971-6580.75869

MATERIALS AND METHODS

Study area

The samples of *A. mellifera* adult worker bees were drawn from the colonies maintained by Department of Zoology, Punjab University, Chandigarh.

Experimental design

A specially designed wooden box called the observation hive was used for the experiment. Front and back of the box were made up of glass while the two sides had wire gauze to ensure proper ventilation. Two such boxes, one experimental and the other control, were taken for the present study. The phones used were of the same make and model and had the same network. Phones were kept in listen–talk mode for 40

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min using a tape recorder. Ten honeybees were collected from the exposed frame at intervals of 10, 20 and 40 min. Ten honeybees were collected from the control at the same time intervals.

Sample preparation

Hemolymph of the worker bees was extracted with the help of the micropipette inserted into the inter-segmental region of the bee's abdomen. Equal volume of hemolymph from all bees was dissolved in 1 ml of normal saline.

Biochemical estimation

Estimation of total carbohydrates

The quantitative estimation of total carbohydrates in the test and control samples of *A. mellifera* was carried out by following the method of Sawhney and Singh.[2]

Estimation of glycogen

Seifter's method[3] was followed for the estimation of glycogen in treated and non-treated hemolymph of *A. mellifera*.

Glucose estimation

For the estimation of glucose in the hemolymph of *A. mellifera*, the method of Somogyi and Nelson[4] was employed.

Estimation of total lipids

The quantitative estimation of total lipids in the treated and non-treated hemolymph extract of *A. mellifera* was carried out by following the procedure of Fringes and Dunn.[5]

Cholesterol estimation

Method of Zlatki's *et al*.[6] was employed for the estimation of cholesterol in treated and non-treated sample.

Estimation of protein

The total quantity of protein in the test and control sample of *A. mellifera* was determined by following the standard procedure of Lowry.[7]

RESULTS AND DISCUSSION

Total carbohydrates

Control

In the non-treated or control sample, the concentration of total carbohydrates in the hemolymph was found to be 1.29 ± 0.02 mg/ml.

Test

In the hemolymph of treated bees, the concentration was 1.5 ± 0.04 mg/ml in 10 min, 1.73 ± 0.01 mg/ml in 20 min and 1.61 ± 0.02 mg/ml in 40 min exposure samples.

Glycogen

In the treated sample, the glycogen content (mg/ml) was found to be 0.019 0.001 as compared to 0.047 0.001, 0.076 ± 0.001 and 0.028 ± 0.002 in 10, 20 and 40 min exposure samples, respectively.

Glucose

The glucose content (mg/ml) in control sample was 0.218 ± 0.0005, while in the various treated samples the concentration was 0.231 ± 0.002, 0.277 ± 0.001 and 0.246 ± 0.002 in 10, 20 and 40 min exposure samples, respectively.

Total lipids

The concentration of total lipids (mg/ml) in the hemolymph of control worker bee was found to be 2.06 ± 0.02. For the treated sample, the concentration of total lipids was 3.03 ± 0.02, 4.50 ± 0.035 and 3.10 ± 0.02 in 10, 20 and 40 min exposure samples, respectively.

Cholesterol

The cholesterol concentration (mg/ml) in the non-treated sample was 0.230 0.001. In the treated sample, the concentration was 1.381 ± 0.002, 2.565 ± 0.002 and 1.578 ± 0.002 in 10, 20 and 40 min exposure samples, respectively.

Total protein content

In the hemolymph of control sample, the protein concentration (mg/ml) was 0.475 ± 0.002. In the treated sample, the protein concentration was 0.525 ± 0.003, 0.825 ± 0.0001 and 0.650 ± 0.0003 in 10, 20 and 40 min exposed samples, respectively.

Very little work has been done on biochemical, metabolic and physiological influences of cell phone radiations pertaining to health risk in man.[8] Therefore, the present investigations on the influence of cell phone radiations on some biochemical and physiological aspects of honeybee biology were undertaken. That the behavior of honeybee is altered to some extent by high or low energy fields or electromagnetic radiations has been known for quite some time.[9]

During the present investigation, it was observed that there was an increase in concentration of total carbohydrates in the bees exposed to cell phone radiation for 10 min as compared to unexposed or control bees. Increasing the exposure time to 20 min resulted in further increase in the concentration, while an exposure of 40 min had a reverse effect and there was a decline in carbohydrate concentration, though it was still higher as compared to control. Hemolymph glycogen and glucose content also showed the same trend, i.e., there was increase in content up to 20 min exposure after which there was a slight decline in the concentration which remained more than the control. Sharma[10] had also reported increase in glycogen and glucose levels in the exposed pupa of *A. mellifera*.

Lipids are the major energy reserves of insects. Certain lipid classes are structure components of membranes while others are raw materials for a variety of hormones and pheromones. Estimation of total lipids and cholesterol during the present study showed that the trend was similar to that of carbohydrates. After an initial increase in concentration at the 10 and 20 min exposure period, a decline was observed in the concentration of total lipids and cholesterol at 40 min exposure.

It was interesting to note that during the present study as the exposure time increased, it appeared that the bees having assessed the source of the disturbance decided to move and a large scale movement of the workers toward the talk-mode (not toward the listening mobile) was observed. Also, the bees became slightly aggressive and started beating their wings in agitation. This mobility of the bees could be responsible for increase utilization of energy sources and consequent decrease in concentration of carbohydrates and lipids in the 40 min exposed sample.

ACKNOWLEDGMENT

Research facilities provided by Department of Zoology, Punjab University, Chandigarh, are gratefully acknowledged.

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Source of Support: Nil, None declared.

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April 21, 2021

Honorable Joseph R. Biden, President
The White House
1600 Pennsylvania Avenue N.W.
Washington, DC 20500

Dear President Biden,

We write to you as scientists deeply committed to protecting public health and the environment and as authors of several hundred publications, including some prepared for the Intergovernmental Panel on Climate Change. We are writing to urge you to take immediate actions to reduce and restrict the rapid and continuing increase in our schools, workplaces, and homes of a harmful environmental pollutant — wireless microwave radiofrequency radiation (RFR).

Children are more vulnerable to wireless radiation. They should not be doing homework on cell phones or with wireless hotspots that catch fire. Wireless networks have numerous environmental impacts meriting concerted regulatory control.

We agree that "broadband internet is the new electricity" that enables Americans to do their jobs, to participate equally in school learning and health care, and to create a fairer playing field by eliminating the digital divide. The United States must bridge the digital divide with a "future proof" broadband infrastructure that is affordable, reliable, high-speed, and sustainable.

This infrastructure should be wired, not wireless. We urge that wherever possible the broadband system envisioned in the American Jobs Plan rely on safer, more secure and efficient, wired connections, especially for schools and other institutions where wired connections will save money and eliminate exposures to wireless radiation, found by the National Toxicology Program to cause clear evidence of cancer.

BIOLOGICAL AND ECOLOGICAL IMPACTS OF WIRELESS AND NON-IONIZING RADIATION

A substantial body of peer-reviewed scientific reports document multiple serious negative impacts on human health from wireless microwave radiation, including increased brain, breast and thyroid cancer risk, cellular stress, genetic damage, harm to the reproductive system, learning and memory deficits, behavioral problems, neurological effects, damage to brain development, headaches, and various impacts to wellbeing.

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This letter takes the liberty of providing a detailed appendix with some of the growing and robust independent scientific literature linking wireless radiofrequency radiation to numerous health effects. The literature makes clear the need for a major change in our approach to wireless technology, especially as millions of families increasingly use video conferences for school and work.

Most notable among the science on RFR is the United States' own years-long National Toxicology Program (NTP) study into the effects of cellphone radiation exposure. The $30 million, interagency-supported study originally requested and commissioned by the Food and Drug Administration (FDA) exposed animals in their lifetimes to the same levels of cell phone radiation that humans get today. Using standard protocols for testing, the NTP study showed conclusively that low-intensity, modulated radio signals of the form of GSM and CDMA cause cancer and heart damage in animals as well as DNA damage in multiple organs.

Non-ionizing radiation at lower frequencies also can cause biological harm to humans, studies show. As an example, Kaiser Permanente research on prenatal exposures to magnetic field non-ionizing electromagnetic field (EMF) radiation has found increased miscarriage as well as higher incidences of ADHD, obesity, and asthma. While several countries have strict limits on residential exposures, the United States has no regulatory limits whatsoever on allowable exposures to magnetic field non-ionizing EMF.

Recent reports from the Swiss government's EMF expert advisory group, the National Research Foundation of Korea, and Yale Medicine, confirm the view that *legal levels* of wireless radiation can damage the health of children, pregnant women, and the medically vulnerable.

Christopher Portier PhD, a longtime U.S. government scientist now retired, recently submitted a comprehensive review of the scientific research in a major cell phone/brain cancer lawsuit where he concludes that "the evidence on an association between cellular phone use and the risk of glioma in adults is quite strong."

"In my opinion, RF exposure probably causes gliomas and neuromas and, given the human, animal and experimental evidence, I assert that, to a reasonable degree of scientific certainty, the probability that RF exposure causes gliomas and neuromas is high," he wrote.

The 176-page expert report with 443 references was prepared for the plaintiffs in a major product liability lawsuit, Murray et al. v Motorola, Inc. et al., filed in the Superior Court for the District of Columbia against the telecommunications industry. Dr. Portier was the Director of the United States National Center for Environmental Health at the Centers for Disease Control and Prevention in Atlanta, and the Director of the Agency for Toxic Substances and Disease Registry. He is one of many US governments scientists and advisors to the World Health Organization highlighting the ever-growing body of scientific evidence showing harm.

THE ENVIRONMENTAL IMPERATIVE

The unfettered proliferation of new wireless networks including 5G and 4G antenna densification constitutes a major global contributor to greenhouse gases and hazardous e-waste. Rather than advance climate objectives, 5G instead constitutes an unmitigated disaster for our climate because of the vast surge in energy demand that will take place. Further, 5G deployment will increase environmental levels of RFR, which science documents to be harmful not only to human health, but also to wildlife and the environment.

5G requires hundreds of thousands of new so-called "small" cell towers and billions of new wireless devices, which will use massive amounts of energy in their production, operation, and disposal. 5G antennas are referred to as "hungry, hungry hippos" and "a battery vampire." Numerous reports have documented the exponentially increased use of energy by 5G and 4G densification and the Internet of Things. Streaming with wireless results in higher greenhouse gas emissions compared to safer, faster, and more secure corded/wired fiber-optic connections.

While there may be improvements in energy efficiency for new devices individually, these gains are completely lost in the increases in total demand that will take place with the proliferation of games, videos, other streaming services, and the continued generation of highly addictive apps.

Additionally, telecommunications firms contend that 5G network antennas must be sited about every 100 yards, and they have haphazardly started nationwide construction on hundreds of thousands of new "small cell" antennas near our homes and schools.

5G densification to accommodate this wireless infrastructure will inevitably require the removal of countless numbers of trees from urban and rural locales. Not only will this destroy valuable tree canopies, increase greenhouse gases, and damage root systems, but it will cause a dramatic increase in environmental levels of radiofrequency radiation (RFR) known to damage trees. Wireless technology can also impact insects, bees, plants, animals, and bacteria, all of which are vital to the ecosystem, even in the densest urban environment.

U.S. FEDERAL POLICY ON 5G DISREGARDS HEALTH AND ENVIRONMENTAL IMPACTS

The implication of the NTP study, and a parallel study carried out by the Ramazzini Institute of Bologna, Italy, along with recent reviews on oxidative stress, reproduction and genetic effects, is that current Federal Communications Commission (FCC) human exposure limits for non-ionizing RFR originating from the wireless infrastructure allow for hazardous levels of exposure. In reality, the push for 5G constitutes an unethical experiment with all of us as unwitting subjects.

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The FCC has proposed new rules for a large range of EMF frequencies (lower than are currently used for wireless networks) without adequate safety testing. As scientific comments in FCC Docket 19-226 document, these lower frequencies cannot be considered safe.

It is not widely appreciated that the FCC already ushered in unprecedented and untested commercial expansion of 5G and 4G cellular technology without serious deliberation on the effects of this new technology on humans and the environment. Its lack of serious, systematic deliberation on the science is demonstrated by its unchecked rejection of the need to comply with the National Environmental Policy Act (NEPA), the Administrative Procedures Act (APA, and the Americans With Disabilities Act (ADA).

Our historic legal appeal, EHT et al. v. FCC, documents numerous violations of these federal laws and demonstrates how the FCC did not provide evidence of having undergone a “hard-look” or systematic assessment of the scientific evidence on the FCC’s own record when deciding in 2019 to keep its outdated 1996 wireless radiation limits.

Under NEPA, all major federal regulations must undergo review for their potential impact on the environment. FCC limits are not designed to protect wildlife or the natural environment, yet the FCC refused to conduct an environmental assessment of the 5G network. Although the records were withheld, FOIA investigations by the Environmental Health Trust have found that the FCC internally discussed the issue of environmental review related to 5G, yet never moved forward to complete one. Studies attached in our appendix show the folly of this unscientific decision.

Unlike other countries that provide robust resources to their people on how to decrease exposure, United States agencies downplay the issue of health effects and provide minimal information on how families can reduce exposures. The Centers for Disease Control (CDC) hired an industry consultant to draft numerous website pages on the health effects of non-ionizing radiation. The EPA scrubbed their website of content on potential health risks of wireless radiation.

Further, the FCC and FDA now state that they rely on a self-appointed, self-monitored, private club, to which no American belongs, termed the International Commission of Non-ionizing Radiation Protection (ICNIRP). This small group of around one dozen scientists is closely allied with industry and does not represent the larger expert scientific community. It repeatedly puts forward unfounded criticisms of U.S. government research yet remains unchecked by oversight or independent external review. Numerous investigations, published research, and a 2020 report released by European Members of Parliament details the ways in which ICNIRP has serious conflicts of interests and remains under the influence of the telecommunications industry. Yet both the FCC and the FDA substantiate their rejection of the US NTP $30 million animal study with ICNIRP’s criticism despite the fact that several retired scientists of the National Institutes of Health have documented that ICNIRP’s criticisms are erroneous.

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As a result of the FCC's omissions, the 5G rollout and 4G densification must be halted until environmental evaluations are completed and federally developed safety limits that protect public health and the environment are created.

POLICY RECOMMENDATIONS

As scientists dedicated to public health, we ask that the broadband infrastructure cited in the American Jobs Plan prioritize a wired telecommunication infrastructure, and that the climate, public health, and environmental impacts of future networks be integrated into any assessment of policy options and proposed regulations promulgated by your administration.

We recommend the following:

1. **A sustainable wired (not wireless) infrastructure: The administration should focus on infrastructure that includes wired networks *up to* and *inside* of buildings and evaluate economic opportunities to ensure environmentally sustainable infrastructure.** In anticipating thousands of miles of new transmission lines to be laid to renew the electrical grid, we stress that much-needed expanded access to broadband need not and should not depend on wireless networks but instead on economical wired fiber-optic cable that goes to and through the premises.
2. **An immediate halt to the 5G rollout and associated 4G densification**. Consistent with concerns expressed by a number of environmental organizations in this nation and expert advice from experts in other nations, we call for a full halt to the more than 1 million new 5G network antennas and associated cell towers — some slated for neighborhoods and areas of pristine wilderness in our National Parks — and the concomitant destruction of hundreds of thousands of trees and wildlife habitats.
3. **An assessment of the energy consumption and climate impact of 5G and 4G densification.** We urge you to include a full life-cycle assessment of the potential impact of wireless antenna densification on climate policy that takes into account growing evidence of substantially increased greenhouse gas emissions if 5G were to be implemented, as well as emissions and pollution analysis related to the extraction, production, transportation, and disposal of materials in the full life cycle of wireless technologies.
4. **An assessment of the environmental impact of the 5G network.** The U.S. must first do a comprehensive assessment on the environmental impacts of the hundreds of thousands of new 5G/4G wireless facilities which includes impacts to tree canopy, wildlife habitat, and how millimeter waves will impact insects and pollinators and more.
5. **A genuine review of the entire body of scientific research on non-ionizing electromagnetic radiation on human and environmental health**. Independent experts and relevant government authorities must conduct a review of the full body of scientific research so that they may develop biologically based federal safety limits for human and wildlife exposures to radiofrequency and magnetic field non-ionizing electromagnetic

radiation. The review must engage all relevant U.S. health, science, and environmental agencies (such as the Environmental Protection Agency (EPA), National Cancer Institute (NCI), Occupational Safety and Health Administration (OSHA), the National Institutes of Health (NIH) and National Toxicology Program (NTP)) and take into account the ever-growing scientific evidence of immediate and long-term biological impacts as well as the rapidly expanding impacts on climate, wildlife, and our natural world.

6. **The development of science-based safety limits for human and wildlife exposures to RFR and non ionizing EMF.** The allowable exposure limits for RFR were adopted in 1996 and have not changed since then. The EPA should develop safety limits based on scientific research. The United States must also develop exposure limits on magnetic field EMF and other frequencies in the non-ionizing range used in electricity distribution, wireless power transfer and other applications.
7. **Appointment of FCC commissioners who are absent of ties to the wireless Industry.** We call on you to end the revolving door through which FCC commissioners come from and return to the telecom industry. The FCC is termed a "Captured Agency" in a Safra Center for Ethics, Harvard Law School report. We ask you to ban all telecom industry executives, lobbyists, and representatives from any advisory or official position in your transition team, cabinet, and administration.
8. **Appointment of an interdisciplinary committee at the National Academies of Sciences (NAS) to review the science underlying 5G and wireless networks, to identify major data gaps and uncertainties, and to set priorities for research on health and safety.** This review must systematically consider the full lifetime costs and benefits of 5G and other telecom technologies now on the drawing board and evaluate immediate and long-term climate impacts. The National Academy of Sciences (NAS) Report "An Assessment of Illness in U.S. Government Employees and Their Families at Overseas Embassies" commissioned by the U.S. State Department cites "directed, pulsed radiofrequency energy" as "the most plausible mechanism" to explain the mystery illness suffered by U.S. Embassy personnel. The NAS must also develop a major interdisciplinary training program for medical and engineering professionals to better understand the impacts of bioelectromagnetics.
9. **A multimedia national public awareness education campaign so that people know why and how to reduce exposure to wireless and other non-ionizing electromagnetic radiation**. We also ask that your administration develop and validate a nationwide educational campaign for parents, teachers, and the public so they understand why and how to reduce daily exposures to wireless radiofrequency and other non-ionizing radiation from laptops, cell phones, and the numerous digital devices in our lives today. This includes an update to the public information posted on the websites of the CDC, EPA, National Cancer Institute, and FCC to include straightforward, unambiguous recommendations to reduce exposure to non-ionizing radiation as well as refer to the full results of the National Toxicology Program study and other independent research on wireless and non-ionizing radiation.

10. **Promotion of policies that reduce wireless exposures in schools.** Strategies are urgently needed to eliminate sources of radiofrequency radiation in the indoor environment, especially in schools and public buildings. Wi-Fi infrastructure should be replaced with wired networks in the classroom where children spent most of their waking hours.
11. **Labor policy that addresses growing occupational exposures.** An investigation by the National Department of Labor and Occupational Safety and Health Administration into current and projected occupational exposures and practical measures to reduce occupational exposures is urgently needed addressing the range of workplace exposure from hospitals, to schools, to delivery drivers, to electricians working on rooftops, to cell tower climbers.
12. **The launch of a task force convened by the Surgeon General on how to minimize health effects of technology on children.** The harmful physical, social, and emotional effects of screens is well documented yet our children's use of screens is ever increasing.

INTERNATIONAL ACTIONS ON WIRELESS INFRASTRUCTURE

While the U.S. should be leading efforts to create and validate safer technology, especially for our schools and workforce, we have fallen far behind other countries in this regard. It is time for change.

Several high-tech nations have surpassed the United States in recognizing not only environmental but also human impacts from wireless radiation exposure. France, Israel, Korea, French Polynesia, and Switzerland, among others, have policies and educational programs to reduce public exposure to wireless and non-ionizing radiation. Numerous countries have far more stringent cell tower radiation exposure limits compared to the United States.

Deeply concerned about growing evidence linking brain cancer to cell phone use, the Korean National Cancer Institute has issued clear recommendations to reduce cell phone radiation to children. Other nations issue notices at points of sale, ban or restrict the use of Wi-Fi and cell phones in schools, and ban the advertising and sale of cell phones to young children.

In economic terms, the American Jobs Plan notes that the United States "has some of the highest broadband prices among OECD countries." Current proposals for wireless 5G are far more costly and wasteful than wired communications. Wired cables create a safer, more secure, faster, and longer-lasting connection. In sum, they are more cost-effective.

Our experts stand ready to provide more detailed information to you on this important issue, including elaborating on materials in the attached appendix and assistance with evaluating the science and impacts on humans, climate, animals, and wilderness.

Yours sincerely,

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cc: The Honorable Xavier Becerra, Secretary of Health and Human Services
The Honorable John Kerry, Special Presidential Envoy for Climate
Mr. Shawn Benge, Acting Director of the U.S. National Park Service
The Honorable Nancy Pelosi, CA-12
The Honorable Conor Lamb, PA-17
The Honorable Susie Lee, NV-03
The Honorable Chrissy Houlahan, PA-06
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The Honorable Edward Markey, MA
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The Honorable Benjamin Cardin, MD

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APPENDIX

Reports and White Papers: 5G, Energy Consumption, and Climate

Data Center Forum White Paper, (2020) Environmentally Sustainable 5G Deployment https://www.datacenter-forum.com/datacenter-forum/5g-will-prompt-energy-consumption-to-grow-by-staggering-160-in-10-years

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Letter from the EPA to Environmental Health Trust

--------- Forwarded message ---------
From: **Veal, Lee**<Veal.Lee@epa.gov>
Date: Wed, Jul 8, 2020 at 11:32 AM
Subject: RE: Letter with specific Questions Related to the FDA review and to the EPA, CDC, NIOSH and FDA Jurisdiction on EMFs
To: Theodora Scarato <Theodora.Scarato@ehtrust.org>

Dear Director Scarato;

Thank you for sending us your questions and references regarding radiofrequency (RF) radiation. Up through the mid-1990s, EPA did study non-ionizing radiation. The Telecommunications Act of 1996 directs the Federal Communications Commission (FCC) to establish rules regarding RF exposure, while the U.S. Food and Drug Administration (FDA) sets standards for electronic devices that emit non-ionizing or ionizing radiation. EPA does not have a funded mandate for radiofrequency matters, nor do we have a dedicated subject matter expert in radiofrequency exposure. The EPA defers to other agencies possessing a defined role regarding RF. Although your questions are outside our current area of responsibilities, we have provided a response to each one as you requested.

1. *What is your response to these scientists’ statements regarding the FDA report and the call to retract it?*

   EPA Response: The EPA does not have a funded mandate for radiofrequency matters, has not conducted a review of the FDA report you cited or the scientists' statements, and therefore has no response to it.

2. *To the FDA- What consultants were hired for the FDA review and report on cell phone radiation?*

   EPA Response: This is not an EPA matter. Please refer this question to the FDA.

3. *What U.S. agency has reviewed the research on cell phone radiation and brain damage? I ask this because the FDA only has looked at selected studies on cancer. If your agency has not, please simply state you have not.*

   EPA Response: EPA's last review was in the 1984 document Biological Effects of Radiofrequency Radiation (EPA 600/8-83-026F). The EPA does not currently have a funded mandate for radiofrequency matters.

4. What U.S. agency has reviewed the research on damage to memory by cell phone radiation? If so, when and send a link to the review.

   EPA Response: EPA's last review was in the 1984 document Biological Effects of Radiofrequency Radiation (EPA 600/8-83-026F). The EPA does not currently have a funded mandate for radiofrequency matters.

5. *What U.S. agency has reviewed the research on damage to trees from cell phone radiation? If so, when was it issued and send a link to the review.Note this study showing damage from long term exposure to cell antennas.*

   EPA Response: The EPA does not have a funded mandate for radiofrequency matters, and we are not aware of any EPA reviews that have been conducted on this topic. We do not know if any other U.S. agencies have reviewed it.

6. *What U.S. agency has reviewed the research on impacts to birds and bees? If so, when and send a link to the review. I will note the latest research showing possible impacts to bees from higher frequencies to be used in 5G.*

   EPA Response: The EPA does not have a funded mandate for radiofrequency matters, and we are not aware of any EPA reviews that have been conducted on this topic. We do not know if any other US agencies have reviewed it.

Int. J. Environ. Res. Public Health **2015**, *12*, 14519-14528; doi:10.3390/ijerph121114519

OPEN ACCESS

International Journal of
Environmental Research and Public Health
ISSN 1660-4601
www.mdpi.com/journal/ijerph

Article

Association of Exposure to Radio-Frequency Electromagnetic Field Radiation (RF-EMFR) Generated by Mobile Phone Base Stations with Glycated Hemoglobin (HbA1c) and Risk of Type 2 Diabetes Mellitus

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Academic Editor: Omorogieva Ojo

Received: 15 September 2015 / Accepted: 11 November 2015 / Published: 13 November 2015

Abstract: Installation of mobile phone base stations in residential areas has initiated public debate about possible adverse effects on human health. This study aimed to determine the association of exposure to radio frequency electromagnetic field radiation (RF-EMFR) generated by mobile phone base stations with glycated hemoglobin (HbA1c) and occurrence of type 2 diabetes mellitus. For this study, two different elementary schools (school-1 and school-2) were selected. We recruited 159 students in total; 96 male students from school-1, with age range 12–16 years, and 63 male students with age range 12–17 years from school-2. Mobile phone base stations with towers existed about 200 m away from the school buildings. RF-EMFR was measured inside both schools. In school-1, RF-EMFR was 9.601 nW/cm^2 at frequency of 925 MHz, and students had been exposed to RF-EMFR for a duration of 6 h daily, five days in a week. In school-2, RF-EMFR was 1.909 nW/cm^2 at frequency of 925 MHz and students had been exposed for 6 h daily, five days in a week. 5–6 mL blood was collected from all the students and HbA1c was measured by using a Dimension Xpand Plus Integrated Chemistry System, Siemens. The mean HbA1c for the students who were exposed to high RF-EMFR was significantly higher (5.44 ± 0.22) than the mean HbA1c for the students who were exposed to low RF-EMFR (5.32 ± 0.34) (p = 0.007). Moreover, students who were exposed to high RF-EMFR generated by MPBS had a significantly higher risk of type 2 diabetes mellitus (p = 0.016) relative to their counterparts who were exposed to low RF-EMFR. It is concluded that exposure to high RF-EMFR generated by MPBS is associated with elevated levels of HbA1c and risk of type 2 diabetes mellitus.

Keywords: mobile phone radiation; mobile phone base station; RF-EMFR; HbA1c; hyperglycemia

1. Introduction

During the last two decades, the use of mobile phones has increased spectacularly among individuals of all age groups in both developing and developed countries. Mobile phones have become a prevalent means of communication and a part of everyday life [1]. There are about 7.3 billion mobile phone subscribers worldwide, almost equal to the world population [2]. Mobile phones are low power radio devices, transmit and receive radio frequency radiation, and are considered the strongest source of human exposure to radio frequency electromagnetic field radiation RF-EMFR. The RF-EMFR generated by mobile phone base stations ranges between 400 MHz and 3 GHz [3–5].

The extensive increase and development of new mobile phone technologies resulted in a major change of radiofrequency electromagnetic field radiation (RF-EMFR) exposure patterns in everyday settings [6,7]. To provide better services to the customers, mobile phone companies install base stations in the residential and commercial areas, including the school buildings, which stirred up widespread public concern about the hazards of RF-EMF radiation generated by mobile phone base stations (MPBS). The environment is exposed to RF-EMFR and health effects of RF-EMFR have been controversially discussed in the literature [8]. RF-EMFR can cause fatigue, headache, dizziness, tension, sleep disturbance [1], hearing and vision complaints [9]. The WHO International Agency for Research on Cancer has classified RF-EMFR as possibly carcinogen [10]. RF-EMFR promotes cancer development via stimulation of cell proliferation and apoptosis inhibition [11].

Presently about 382 million people are suffering from diabetes mellitus, this number is expected to upsurge to 592 million by 2035 and 183 million people are unaware of their diabetes mellitus [12]. Hemoglobin A1c (HbA1c) reflect the mean glucose concentration over the previous period of about 8–12 weeks. HbA1c is commonly used as a marker of hyperglycemia and an increased HbA1c has been regarded as an independent and reliable marker for diabetes mellitus [13]. World Health Organization, the International Diabetes Federation, and the American Diabetes Association have recently endorsed HbA1c as a diagnostic test for diabetes mellitus [13,14]. To our knowledge, this is the first study aimed to determine the association of exposure to RF-EMFR generated by MPBS with HbA1c and incidence of type 2 diabetes mellitus.

2. Subjects and Methods

2.1. Subjects

This cross-sectional study was conducted in the Department of Physiology, College of Medicine, King Saud University, Riyadh, Saudi Arabia. All the subjects and or their parents signed the written informed consent. The study protocol was approved by the Ethical Review Committee of College of Medicine Research Centre, King Saud University, Riyadh, Saudi Arabia (IRB-14/412).

Students were recruited based on their voluntary participation, apparently healthy status, same age, gender, nationality, regional, cultural and socio-economic status. We invited 250 participants (125 from school-1, and 125 from school-2). A detailed interview was conducted followed by clinical history taking and examination to assess whether to include in the study or not. All the students were questioned with regard to anthropometric parameters, age, height, weight, ethnicity, socioeconomic status, and family history of diabetes mellitus, blood diseases, and cigarette smoking. After clinical history and examination, finally, we selected 159 apparently healthy, male, volunteer students (96 from school-1, and 63 from School-2). The age of the students who belonged to the school-1 group was 12–16 years (mean age 13.98 ± 0.92). The age of the students who belonged to the school-2 group was 12–17 years (mean age 14.21 ± 1.99).

2.2. Exclusion Criteria

Subjects with known cases of gross anemia, blood diseases, history of blood transfusion, personal or family history of known diabetes mellitus, students who suffered from marked obesity, asthma, and students who smoked tobacco were excluded from the study. Moreover, students who were living (residence) close to the any high transmission lines or MPBS and students who frequently consumed fast food and excess sweet diet were also excluded from the study. We also excluded the students who were athletes or performed regular vigorous exercise.

2.3. Methods

2.3.1. Selection of the Schools and Measurement of RF-EMFR

In this study, two different elementary schools (labeled as school-1 and school-2) were selected from the Riyadh region. Both schools were located close to MPBS. It was ensured that there were no significant sources of generation and transmission of EMFR in or near the school building. In school-1 MPBS had been installed on the residential building about 200 m away from the school building. Inside the schools RF-EMF was measured by using the Narda Safety Test Solution SRM-3006. SRM-3006 is a frequency-selective field strength measurement system, which measures the RF-EMFR [15]. In this school, the RF-EMF was 9.601 nW/cm^2 at frequency of 925 MHz, and students had been exposed to RF-EMFR for a duration of 6 h daily, five days in a week.

The second school (school-2) was also located close to MPBS. The MPBS was installed on the residential building about 200 m away from the school building. RF-EMF was 1.909 nW/cm^2 at frequency of 925 MHz and students had been exposed to RF-EMFR for a duration of 6 h daily, five days in a week. RF-EMFR was measured in both schools in various class rooms. We selected the points to measure RF-EMFR based on the location of class rooms. RF-EMFR was measured at three different points including the center, as well as the corners, of the class room from which we selected the students. We recorded the RF-EMFR two times per day at each point. The number of measurement was the same in the different places in the school.

2.3.2. Blood Sample Collection

All the participants of both schools were allocated a serial number; an expert technician took 5–6 mL of blood with a vein puncture method and blood was collected in 10 mL container containing ethylenediamine tetra-acetic acid (EDTA). Blood was transferred into a container with specific code number of the student on the container. The blood was immediately kept in the refrigerator under the temperature of 4–5 °C. All blood samples were immediately transferred to the hematology laboratory, to analyze the HbA1c.

2.3.3. Measurements of HbA1c

HbA1c measurements were performed on ethylenediamine tetra-acetic acid (EDTA) blood samples, and HbA1c was measured by Dimension Xpand Plus Integrated Chemistry System, USA. The HBA1c assay on the Dimension Xpand Plus Integrated Chemistry System is an *in vitro* diagnostic assay for the quantitative determination of HBA1c in human anticoagulant whole blood. The measurement was based on the principle of turbidimetric inhibition immunoassay (TINIA). Each kit contains matched sets of HBA1c reagent cartridge and calibrators. These components were not interchangeable between the kits and other lot numbers. HBA1c required lot specific scalers which were entered before the calibration. The scaler values were provided on the reagent cartridge. The system was calibrated daily and a few samples were tested twice to check the accuracy of HbA1c with the Dimension Xpand Plus Integrated Chemistry System.

2.4. Statistical Analysis

The data were computed into the computer and analyzed by using the Statistical Package for Social Sciences (SPSS for Windows, version 20.0). Unpaired Student’s t-test (parametric test with the assumption of equal variances) was applied to check the difference of the means values between the two quantitative variables. All the variables were entered into a logistic regression model and results were presented as an odds ratio and 98% confidence interval. The level of significance was assumed at $p < 0.05$.

3. Results

Table 1 summarizes the comparison of the anthropometric variables and HbA1c parameters between the students of two different schools where students had been exposed to RF-EMFR generated by MPBS at 9.601 nW/cm^2 at frequency of 925 MHz for the duration of 6 h daily, five days per week, over the last two years (school-1). While in the second school, students were exposed to RF-EMFR of 1.909 nW/cm^2 at a frequency of 925 MHz for the duration of 6 h daily, five days per week, over the last two years (school- 2).The age of the students at school-1 (group 1) was 12–16 years (mean age 13.98 ± 0.92), while the age of the students at second school-2 (group-2) was 12–17 years (14.21 ± 1.993).

The mean HbA1c for the students who were exposed to high RF-EMFR (9.601 nW/cm^2 at frequency of 925 MHz) was significantly higher (5.4%) than the mean HbA1c for the students who had been exposed to low RF-EMFR (1.909 nW/cm^2 at frequency of 925 MHz) generated by MPBS was (5.3%) (p = 0.007). The results show students who were exposed to high RF-EMFR have significantly impaired HbA1c (30, 31.25%) than the students who exposed to low RF-EMFR (17, 27.0%) (Table 2). It shows an association of RF-EMFR and higher risk of type 2 diabetes among the students who were exposed to high RF-EMF relative to their counterparts who were exposed to low radiation (Table 2). Logistic regression analysis showed a significant association with high RF-EMFR, HbA1c, and risk of type 2 diabetes mellitus (Table 3).

Table 1. Comparison of anthropometric parameters and HBA1c percentage of the students who were exposed to RF-EMFR generated by mobile phone base stations at (9.601 nW/cm^2 at frequency of 925 MHz) *versus* the students exposed to RF-EMFR at (1.909 nW/cm^2 at frequency of 925 MHz).

Parameters	School Group #1 (*n* = 96) RF-EMFR: 9.601 nW/cm^2	School Group # 2 (*n* = 63) RF-EMFR: 1.909 nW/cm^2	*p* Values
Age (years)	13.98 ± 0.92	14.21 ± 1.003	0.138
BMI (m/kg)^2	22.91 ± 5.12	21.47 ± 5.47	0.093
HbA1c (%)	5.445 ± 0.22	5.325 ± 0.34	0.007

Note: Values are presented in mean ± SD.

Table 2. Comparison of prevalence of pre-diabetes mellitus based on HBA1c percentage of the students exposed to RF-EMFR generated by mobile phone base stations at (9.601 nW/cm^2 at frequency of 925 MHz) *versus* the students exposed to RF-EMFR at (1.909 nW/cm^{2}at frequency of 925 MHz).

Parameters	School Group #1 (*n* = 96) RF-EMFR:9.601 nW/cm^2	School Group # 2 (*n* = 63) RF-EMFR: 1.909 nW/cm^2	*p* Values
Prevalence of Impaired HbA1c ≥5.6 (Prediabetes)	30 (31.25%)	17 (27%)	0.016

Values are presented in %. HbA1c ≥ 5.6 was considered impaired HbA1c (pre diabetes) [16].

Table 3. Logistic regression analysis for variables predicting an association of RF-EMFR with HbA1c and prevalence of risk of type 2 diabetes mellitus.

Parameters	Odds Ratio	95% Confidence Interval	*p* Values
Age (years)	0.67	0.23–1.92	0.454
Obesity	1.87	0.539–6.493	0.324
Underweight	2.79	0.649–11.166	0.148
RF-EMFR	342	46–2530	0.0001

Note: The model predicts 89%.

4. Discussion

The findings of this study show that the students who were exposed to high RF-EMF had significantly higher HbA1c than the students who were exposed to low RF-EMF. Moreover, students who were exposed to high RF-EMFR generated by MPBS had a significantly higher proportion of diabetes mellitus relative to the students who were exposed to low RF-EMFR.

HbA1c is well recognized among clinicians as a marker of chronic hyperglycemia, increased HbA1c has also been regarded as an independent marker for diabetes mellitus [17]. HBA1c has numerous advantages compared to the Fasting Plasma Glucose (FPG), including greater expediency, fasting is not mandatory, better pre-analytical stability and less day-to-day worries during a period of stress and illness. HbA1c has recently been endorsed as a diagnostic test for diabetes by the World Health Organization, the International Diabetes Federation, as well as the American Diabetes Association [12,14,17,18].

FPG of 100 mg/dL or 5.6 mmol/L equals to an HbA1c of 5.4% and FPG of 110 mg/dL or 6.1 mmol/L is parallel to HbA1C of 5.6% [13]. The normal cut-off point of HbA1c is equal to or less than 5.4%. Compared to the fasting glucose cut point of 100 mg/dL (5.6 mmol/L), the HbA1c cut point of 5.7% is more specific and has a higher positive predictive value to identify people at risk for development of diabetes. HbA1c levels below 5.7% may still be at risk to develop diabetes mellitus [13]. Literature also indicates that subjects within the HbA1C range of 5.5%–6.0% have a five-year cumulative incidence of diabetes mellitus that ranges from 12% to 25% [19]. In the present study, we found that the mean HbA1c for the students who were exposed to high RF-EMFR was 5.44% compared to the mean HbA1c for the students who were exposed to low RF-EMFR 5.32% (Table 1).

4.1. RF-EMFR and HbA1c

The possibility of induction of biological and health effects by low-energy radiation emitted by MPBS remains a debatable issue. In spite of decades of research, there is still ongoing discussion about RF-EMFR and physiologically-relevant effects. Literature is available on the association of RF-EMF with headache, tension, and sleep disorder-like symptoms [1]. In addition, studies have also shown that RF-EMFR has extensive damaging effects on the nervous system, cardiovascular, and male reproductive system [20]. RF-EMFR also causes oxidative damage [21] and cancer [22].

Bieńkowski *et al.* [23] conducted a study and measured the changes in the electromagnetic field intensity in a school building and its surrounding after the MPBS installation on the roof of the school. They found that the EMF intensity increased in the building and its surroundings after the MPBS installation. Shahbazi-Gahrouei [24] conducted a cross-sectional study on people living near the mobile phone base transceiver stations (BTS). The authors reported that discomfort, irritability, nausea, headache, dizziness, nervousness, depression, sleep disturbance, memory loss, and decreased libido were statistically significant among the people living near the BTS antenna (less than 300 m distant) compared to those living far from the BTS antenna (more than 300 m). They suggested that cellular phone BTS towers should not be installed at less than a distance of 300 m to human population to minimize exposure.

Meo *et al.* [25] determined the effects of exposure to RF-EMFR generated by mobile phones on fasting blood glucose in albino rats. The authors found that, Wister albino rats exposed to RF-EMF generated by mobile phone for more than 15 min a day for a maximum period of three months had significantly higher fasting blood glucose and serum insulin compared to the control group. Meo *et al.* [25] also reported that increase in fasting blood glucose was due to insulin resistance. In the present study, we found that students who were exposed to high RF-EMFR generated by MPBS had significantly higher HbA1c (Table 1) and a higher prevalence of type 2 diabetes mellitus (Table 2) than the students who were exposed to low RF-EMFR.

Altpeter *et al.* [26] reported that the incidence for diabetes mellitus was higher among the subjects living within a close radius of a shortwave transmitter in Schwarzenburg, Switzerland compared with a population living away from the a shortwave transmitter. There was a significant linear relationship between RF radiation exposure and prevalence of diabetes mellitus.

Jolley *et al.* [27] exposed the islets of Langerhans from rabbits to low-frequency pulsed magnetic fields and noted a significant decrease in insulin release during glucose stimulation compared to controls. Similarly, Sakurai *et al.* [28] measured the insulin secretion from an islet cell, exposed to low-frequency magnetic fields compared with sham exposure group. Insulin secretion was decreased by about 30% when exposed to low-frequency magnetic fields compared to sham exposure.

Li *et al.* [29] exposed hepatocytes *in vitro* to 50 Hz pulsed EMF noted a conformation change in the insulin molecule. The authors found a decrease in the binding capacity of insulin to its receptors compared with controls.

Congruently, Havas [30] reported that exposure to electromagnetic pollution cause higher plasma glucose levels and may contribute to diabetes mellitus. Havas [30] also concludes that decreased insulin secretion and reduced binding capacity of insulin to its receptors may explain the elevated levels of plasma glucose in subjects exposed to electromagnetic fields. Similarly, in the present study, we found that students who were exposed to high RF-EMFR generated by MPBS had significantly higher HbA1c and risk of type 2 diabetes mellitus than the students who were exposed to low RF-EMFR. Choi *et al.*, 2011 [31] reported that individuals with HbA1c ≤ 5.5 is a normal; 5.6 to 6.9 is impaired HbA1c or pre-diabetes, and HbA1c 7.0 considered as a diabetes. They also reported that HbA1c ≥5.6% have an increased risk for future diabetes. In our study, we found that students who were exposed to high RF-EMFR have significantly higher HbA1c than the mean HbA1c for the students who had been exposed to low RF-EMFR. Moreover, students exposed to high RF-EMFR have significantly impaired HbA1c (31.25%) than the students who exposed to low RF-EMFR (27.0%).

4.2. What This Study Adds

The present study is one of the first studies to investigate the association of EMFR generated by MPBS with HbA1c and prevalence of type 2 diabetes mellitus. Students who were exposed to high EMFR generated by MPBS had significantly higher HbA1c and prevalence of pre diabetes mellitus compared to their students who exposed to low EMFR. We believe that EMFR appears to be another risk factor contributing to high levels of HbA1c and risk of type 2 diabetes mellitus. This notion may present a possible paradigm shift in the development of diabetes mellitus. This research provides awareness to the community and to the health officials regarding the effects of EMFR generated by MPBS on HbA1c and incidence of diabetes mellitus.

4.3. Study Strengths and Limitations

To our knowledge, no study exists yet to establish an association between the RF-EMFR generated by MPBS and HbA1c and risk of type 2 diabetes mellitus. We measured the levels of RF-EMFR inside the schools to determine the impact of RF generated by MPBS on HbA1c. In this study for subject selection criteria, we follow the American Diabetic Association guidelines, and considered age, race, ethnicity, anemia, and hemoglobinopathies into consideration while using the A1C to diagnose diabetes [32]. Moreover, our study exclusion criteria and assays are highly standardized. The limitation of the present study is the involvement of male gender only because in Saudi Arabia there is no co-education system at schools, colleges, and university levels. This study is a relatively small sample size, and because of the cross-sectional design of the study we could not establish the causation.

5. Conclusions

Exposure to high RF-EMFR generated by MPBS is associated with elevated level of HbA1c and prevalence of pre diabetes mellitus among school aged adolescents. RF-EMFR appears to be another risk factor contributing to high levels of HbA1c and incidence of type 2 diabetes mellitus. This study provides awareness to the community and to the health officials regarding the effects of RF-EMFR generated by MPBS on HbA1c and its association with type 2 diabetes mellitus. We cannot deny the services provided by the mobile phone industry but we also strongly believe that health is more important and it cannot be compromised over anything. Thus, it must be kept in mind the mobile MPBS should not be installed in the thickly populated areas, especially in or near the school buildings.

Acknowledgements

The authors are thankful to the Deanship of Scientific Research, King Saud University, Riyadh, Saudi Arabia for supporting the work through research group project (RGP-VPP 181).

Authors Contributions

Sultan Ayoub Meo, designed the study, supervised the overall research project and contributed to writing the manuscript. Zaid Almubarak, Hisham Almutawa, Yazeed Alsubaie, Yazeed AlQasem were involved in IRB writing, data collection, data entry and analysis and literature review. Rana Muhammed Hasanato contributed to measurements of HbA1c and literature review and manuscript writing. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare that there are no conflict of interests.

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American Journal of Men's Health
1–6
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DOI: 10.1177/1557988318816914
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Mobile Phone Base Station Tower Settings Adjacent to School Buildings: Impact on Students' Cognitive Health

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Abstract

The use of mobile phones has remarkably increased and become a basic need of daily life. Increasing subscriptions of mobile phones boost the installation of mobile phone base station towers (MPBSTs) in crowded commercial and residential areas including near school buildings. This study investigated the impact of exposure to radiofrequency electromagnetic field (RF-EMF) radiation generated by MPBSTs on cognitive functions. Two hundred and seventeen volunteer male students aged between 13 and 16 registered from two different intermediate schools: 124 students were from School 1 and 93 students were from School 2. The MPBSTs were located within 200 m from the school buildings. In School 1, RF-EMF was 2.010 μW/cm^2 with a frequency of 925 MHz and in School 2, RF-EMF was 10.021 μW/cm^2 with a frequency of 925 MHz. Students were exposed to EMFR for 6 hr a day, 5 days a week for a total period of 2 years. The Narda Safety Test Solution device SRM-3006 was used to measure RF-EMF in both schools, and cognitive functions tasks were measured by the Cambridge Neuropsychological Test Automated Battery (CANTAB). Significant impairment in Motor Screening Task (MOT; $p = .03$) and Spatial Working Memory (SWM) task ($p = .04$) was identified among the group of students who were exposed to high RF-EMF produced by MPBSTs. High exposure to RF-EMF produced by MPBSTs was associated with delayed fine and gross motor skills, spatial working memory, and attention in school adolescents compared to students who were exposed to low RF-EMF.

Keywords

Electromagnetic Field Radiation, Mobile Phones Base Station Tower, Cognitive function

Received August 10, 2018; revised October 20, 2018; accepted November 8, 2018

In recent years, tremendous developments in mobile phones have revolutionized the telecom industry by making telecommunication faster, economical, and more convenient (D'Silva, Swer, Anbalagan, & Bhargavan, 2014). With the introduction of new applications and multifunctional technology in mobile phones, the telecom industry is appealing to both youth and adults. The usage of mobile phones has dramatically increased, which is considered as a basic tool in daily life (Al-Khlaiwi & Meo, 2004). Worldwide, the number of subscriptions of mobile phones is about 7.52 billion. This number is more than the worldwide population, as many users own more than one mobile phone (World Bank, 2018). The extensive usage of cellular phones has led to the growing installation of mobile phone base station towers (MPBSTs) in crowded commercial and residential areas, which raises community concerns (Buckus et al., 2017; Meo et al., 2015; Wiedemann, Freudenstein, F., Böhmert, Wiart, & Croft, 2017; Zhang et al., 2017; Figure 1).

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Figure 1. Mobile phone base station tower located in a residential area.

Source: Photo taken by a coauthor.

MPBSTs are mainly installed on tall trees, water tanks, or tall commercial and residential buildings to provide the best possible network services (Meo et al., 2015). Mobile phones communicate with nearby MPBSTs mainly through EMF radiofrequency waves operating at the frequencies of 1.8–2.2 GHz for digital systems and 400–900 MHz for analogue systems (Buckus et al., 2017). The EMFs absorbed by MPBSTs are based on the properties of the absorbing tissue, antenna position, magnetic field frequency, the power emitted, and distance of their placement (Wiedemann et al., 2017). Exposure to RF-EMF has several effects on human health including fatigue, tension, headache, sleep disturbance (Al-Khlaiwi & Meo, 2004), physiological and psychological problems (Deniz et al., 2017), hearing and vision complaints (Meo & Al-Drees, 2005), risk of type 2 diabetes mellitus (Meo et al., 2015), and cancer (Moulder, Foster, Erdreich, & McNamee, 2005).

Extensive fixing of MPBSTs in densely populated commercial, residential areas, and school buildings has started community concerns about adverse effects on human health (Meo et al., 2015), mainly brain function (Saikhedkar et al., 2014). Therefore, this study explored the association of exposure to radio frequency electromagnetic field radiation (RF-EMFR) generated by MPBSTs on cognitive function amongst school-going adolescents.

Methods

Study Design and Participants

Students were recruited based on their apparently healthy status, voluntary participation, same gender, age, height, weight, ethnicity, and from homogenous educational, socioeconomic, and residential backgrounds. Initially, 300 students (150 from School 1 and 150 from School 2) were registered. A detailed clinical history was obtained to consider whether the students should be included or not. After clinical history, finally 217 were selected:124 students from School 1 and 93 from School 2. The age of School 1 group was 13–16 years (mean age 14.25 ± 0.98) and that of School 2 group was 13–16 years (mean age 14.10 ± 1.01). The study was piloted as permitted by the Institutional Review Board, College of Medicine King Saud University, Riyadh, Saudi Arabia (Ref # E-16-2124). Written consent was obtained from the students and or their parents.

Exclusion Criteria

Students with clinical histories of blood disease, anemia, diabetes mellitus, obesity, asthma, seizures, malignancy, and those who smoked tobacco were excluded from the study. Known cases of anxiety, vision problems, attention deficit, skeletal muscle disorders, physical disability, those on sedatives, and those with sleep disturbance history were also excluded from the study (Meo, Bashir, Almubarak, Alsubaie, & Almutawa, 2017; Timothy, Durazzo, Meyerhoff, & Nixon, 2010). Students whose residence was near the high transmission lines or MPBST were also excluded (Meo et al., 2015). Students who frequently used and kept cordless phones and Wi-Fi routers in their bedrooms were also excluded from the study (Meo et al., 2015).

Radiofrequency Field Exposure

Two different intermediate schools were selected; both had MPBSTs situated nearby and were operational for

Table 1. Anthropometric Variables of Students in Both Schools.

Parameters	School 1 (n = 124) RF-EMF: 2.010 μW/cm^2	School 2 (n = 93) RF-EMF: 10.021 μW/cm^2	p value
Age (years)	14.25 ± 0.98	14.10 ± 1.01	.29
Height (m)	1.61 ± 0.08	1.61 ± 0.09	.95
Weight (kg)	56.13 ± 16.55	59.11 ± 16.91	.19
BMI (kg/m^2)	21.25 ± 5.03	22.40 ± 5.16	.09

Note. Values are expressed in mean ± *SD*. RF-EMF = radio frequency electromagnetic field; *SD* = standard deviation.

about 3 years. The source of RF-EMF around the schools was visually checked by two coauthors to exclude the presence of any other source of RF-EMF, overhead power lines, or high transmission electricity lines in the surrounding area. RF-EMFR measurements were done in three different sites of the classrooms (center and two corners), twice a day before and after recording the test parameters during the study period in a similar research methodology approach used by (Meo et al., 2015).

The Narda Safety Test Solution SRM-3006 was used to measure the RF-EMF. In School 1, the RF-EMF was 2.010 μW/cm^2 and in School 2 it was 10.021 μW/cm^2 at a frequency of 925 MHz; students were exposed to RF-EMFR for 6 hr daily, 5 days a week (Meo et al., 2015) for a total period of 2 years.

Neuropsychological Tests Procedure

Cognitive function was tested using the Cambridge Neuropsychological Test Automated Battery (CANTAB) research suite 6.0.37. Measurements were recorded at a fixed time of the day (9:00–11:00 am) to minimize the physiological diurnal variations. Each subject was tested in two tasks; the total time required to complete the tasks was about 15–20 min. Sitting well on a chair, with a flat touch screen in front, students were asked to complete the tasks by stirring the screen with the index finger of the dominant hand. There was a distance of 25 cm between the participant and the screen.

Motor Screening Task

The Motor Screening Task (MOT) is a simple reaction time test; it measures the psychomotor functions, speed, and accuracy. The MOT is an essential test of fine and gross motor skills appraised in a visuomotor accuracy-tracking task (Geertsen et al., 2016). It is vital for global understanding abilities, mainly the attention and information on the sensorimotor function or comprehension (Cercel et al., 2014). It provides a general assessment of sensorimotor deficits or lack of comprehension and measures the person's response time to a visual stimulus. Fine and gross motor skills are highly essential in managing the routine activities in everyday life; these skills are linked to objective performance with higher cognitive functions (Geertsen et al., 2016).

Spatial Working Memory Task

The Spatial Working Memory (SWM) task is a test of memory retention and visuospatial information (Deniz et al., 2017). This test is essential to measure the working memory for spatial stimuli and requires the subject to use prompt reminding information to work toward the objective. A number of boxes appear each time, the task requires the participant to press the boxes until he finds the token inside each one; the token moves from one box to another and never appears in any box twice. Elimination by the subject is required until the token is found in each box.

Statistical Analysis

Statistical analysis was conducted using the Statistical Package for Social Sciences (SPSS for Windows, version 21.0). Independent t-test was used to compare the differences in the mean values of the two quantitative variables. The effect size was measured using Cohen's d formula, and statistical significance was set at $p < .05$.

Results

In School 1, students were exposed to RF-EMF produced by MPBSTs at 2.010 μW/cm^2 at a frequency of 925 MHz for 6 hr a day, 5 days a week. Although in School 2, students were exposed to RF-EMF of 10.021 μW/cm^2 at a frequency of 925 MHz for 6 hr a day, 5 days a week for a total period of 2 years (Table 2). In School 1 group, students' age range was 13–16 years (mean age 14.25 ± 0.98), while in School 2, it was 13–16 years (14.10 ± 1.01; Table 1) .

MOT and SWM tasks were recorded; the MOT results are expressed as the standard score of mean latency (MOT ML). There was a statistically significant impairment in the MOT ML (806.99 ± 136.28 vs. 849.53 ± 160.14; p = .036) and SWM task (37.29 ± 3.14 vs. 36.40 ± 3.22; p = .043) among students who were exposed to

Table 2. Comparison of the Cognitive Function Between Students Who Were Exposed to RF-EMF at 2.010 μW/cm^2 Versus Students Who Were Exposed to RF-EMF Generated by MPBSTs at 10.021 μW/cm^2.

Parameters	School 1 (n = 124) RF-EMF: 2.010 μW/cm^2	School 2 (n = 93) RF-EMF: 10.021 μW/cm^2	p value
MOT mean latency	806.99 ± 136.28	849.53 ± 160.14	.03
SWM strategy	37.29 ± 3.14	36.40 ± 3.22	.04

Note. Values are expressed in mean ± *SD*. Cohen's *d* for MOT mean latency is 0.28 and for SWM strategy is 0.27. MOT = Motor Screening Task; SWM = Spatial Working Memory; RF-EMF = radio frequency electromagnetic field; *SD* = standard deviation.

high RF-EMFR generated by MPBSTs (School 2) compared to students who were exposed to low levels of RF-EMFR (School 1; Table 2). Cohen's *d* for MOT ML was 0.28 and for SWM strategy was .27; it shows small effect of RF-EMF produced by MPBSTs on cognitive function impairment.

Discussion

The RF-EMF radiations are the waves emitted from MPBSTs. The occurrence of RF-EMFR changes rapidly with distance and they scattered in different directions toward the ground (Buckus et al., 2017). The RF-EMFR carry non-ionizing radiations, known to have biological effects on human health (Hardell, Carlberg, & Hedendahl, 2018). The present study identified a decrease in fine and gross motor skills, spatial working memory, and attention among school children who had been exposed to high RF-EMF compared to students who had been exposed to low RF-EMF.

Singh et al. (2016) investigated the RF-EMFR generated by MPBSTs and its impact on the public health of people who lived close to the MPBSTs. The authors reported that majority of the subjects who were living adjacent to the MPBSTs complained about cardiovascular and nervous system associated clinical symptoms including headache, sleep disturbances, dizziness, difficulties in concentration, and high blood pressure, when compared to the control subjects.

In agreement with present study findings, researchers established a link between high exposure to RF-EMF and cognitive function (Calvente et al., 2016). The study outcome demonstrates a positive link between exposure to RF-EMF and decline in cognitive function. Children who were exposed to high levels of RF-EMF had lower cognitive scores for verbal expression and comprehension in comparison to those living in areas with lower exposure. They also identified that exposure to RF-EMFR has a negative impact on cognitive and behavioral development in children. Similarly, Thomas et al. (2010) reported a significant decrease in response time in adolescents who were involved in using mobile phones for long durations.

Contradictory to present study findings, Malek, Rani, Rahim, and Omar (2015), Haarala, Björnberg, Ek, Laine, Revonsuo, and Koivisto (2003), and Riddervold et al. (2008) reported no impact of RF-EMF exposure generated from MPBSTs on human cognitive function. The most probable reason for this contradiction is the determination of acute effect in a very limited time period. However, in the current study, the students were exposed to 6 hr a day, 5 days a week for a total period of 2 years.

Abdel-Rassoul et al. (2007) performed a study on inhabitants living near the MPBSTs. The exposed people experienced a considerable increase in neuropsychiatric symptoms including headache, dizziness, sleep disturbance, depressive feelings, and memory changes compared to those in the control group. The exposed inhabitants exhibited a decreased performance in attention and short-term memory tests. Silva, Barros, Almeida, and Rêgo (2015) demonstrated an association between anxiety and depression in individuals who live 100–200 m closer to MPBSTs compared to subjects living 300 m away from MPBSTs. Augner and Hacker (2009) reported that closer the distance to the MPBSTs, greater the radiation and higher the percentage of somatization, anxiety, and phobic nervousness in individuals living near MPBSTs. Kalafatakis, Bekiaridis-Moschou, Gkioka, and Tsolaki (2017) identified that mobile phone use has a significant negative impact on the working memory performance of people. The current study findings are in agreement with the results found by Abdel-Rassoul et al. (2007) and Kalafatakis et al. (2017).

Saikhedkar et al. (2014) determined the effects of mobile phone radiation on cognitive performances mainly on learning and memory. Their study findings indicate significant changes in behavior and poor learning in the exposed group as compared to the control group. These study findings agree with the present study findings that high exposure to RF-EMF produced by MPBSTs is associated with a decline in the fine and gross motor skills and spatial working memory and attention in the school adolescents who had been exposed to high RF-EMF compared to the students who had been exposed to low RF-EMF.

The potential reasons behind cognitive functions impairment in subjects exposed to RF-EMF radiation from MPBSTs are sleep disturbances, behavioral problems (Hardell et al., 2018), reduced regional cerebral blood flow (Hossman & Herman, 2003; Huber et al., 2002), myelin sheath damage (Kim, Yu, et al., 2017), and neuronal function impairment (Kim, Kim, et al., 2017). RF-EMF radiation may result in these mechanisms associated with neurological functioning resulting in cognitive impairment.

Strengths and Limitations

We took considerable efforts to adjust the relevant confounding factors; still there might be some residual confounding. This study has a relatively reasonable sample size, well-established research methodology, exclusion criteria, reliable tools used to measure the RF-EMFR, and minimized confounding factors (Meo et al., 2015). The recruitment of the male gender only is the limitation of this study due to the rules and regulations in Saudi Arabia that do not allow co-education systems in schools or universities. Students whose residences were adjacent to high power lines or MPBSTs and students who commonly used and kept cordless phones and Wi-Fi devices in their bedrooms were excluded from the study. There may be chances of exposure to RF-EMF generated from other sources such as television, remote devices, and wireless networks.

Conclusions

Despite the limitation of this cross-sectional study, it is identified that high exposure to RF-EMF produced by MPBSTs is associated with a decrease in fine and gross motor skills and spatial working memory and attention in school adolescents compared to students who had been exposed to low RF-EMF. This study provides cognizance to society and stakeholders in health care about the health hazards of RF-EMF produced from MPBSTs. No one can deny the facilities that are being provided by the telecommunication industry, but it is believed that nothing should be compromised over health. MPBSTs must be installed away from thickly populated residential zones particularly in or near the school buildings or there must be some system to shield human beings from RF-EMFR.

Acknowledgments

The authors are thankful to the Deanship of Scientific Research, King Saud University, Riyadh, Saudi Arabia for supporting the work through research group project (RGP-VPP 181). We also thankful to Dr. Shahid Bashir, Department of Physiology, College of Medicine, KSU for providing cognitive function lab facilities for data collection.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the Deanship of Scientific Research, King Saud University, Riyadh, Saudi Arabia (RGP-VPP 181).

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Myth Fact on Statements Made to New Hampshire Legislature
Working Draft March 8, 2022

The State of New Hampshire is considering a proposed bill that would set a 1640-foot setback between cell towers and homes, schools and nurseries.

The CTIA Wireless Industry sent New Hampshire lawmakers testimony for the bill which we believe to be riddled with inaccurate and misleading information. In addition Josiah Bartlett also included numerous myths in a blog post about New Hampshire cell tower legislation.

This document compiles the inaccurate statements put forth by the CTIA wireless industry and documents the facts in a comprehensive detailed list with links to sources. The New Hampshire Commission 5G Report also covers a significant amount of these facts. Please see New Hampshire State Commission 5G Report. In the interest of time everything is sourced with hyperlinks. Please view this online to see references.

MYTHS

Click on the underlined myth to go to the section.

List of Myths

5. Myth: The Food And Drug Administration (FDA) has reviewed the science on 5G and cell towers and determined the radiation is safe and FCC limits protect public health.
6. Myth: The World Health Organization webpages confirm there are no health effects for cell towers or cell phones

RADIATION EXPOSURES

Myth: 5G will not increase RF radiation levels in your neighborhood because the power levels of 5G antennas are much much lower than large tall cell towers.

SCIENTIFIC EVIDENCE

Myth: There is no scientific evidence that 5G, cell towers or cell phones are harmful to health.
Myth: The majority of studies on RF show no harm. The WHO found only 5% of 25,000 studies showed harmful effects but that is the false positive rate.
Myth: Wireless radiation is not a carcinogen. The classification by the WHO International Agency for Research in Cancer of wireless radio frequency as a Class 2B "Possible Carcinogen" simply means wireless radiation like talcum powder or picked vegetables.
Myth: There is no cumulative health or biological effect from cell tower or radiofrequency radiation.
Myth: An Australian study found "no confirmed evidence that low-level RF fields above 6 GHz such as those used by the 5 G network are hazardous to human health," so 5G is safe.

FCC LIMITS

Myth: FCC limits have a large safety margin- a 50 times safety factor.
Myth: Professor Swanson's brain, the sun and his hot water bottle violate FCC limits.
Myth: FCC limits for cell tower radiation emissions are very strict and as Professor Swanson states, "protect us very well."

Myth: The FCC "has commanded" local and state governments to streamline 5G small cells in front of homes and there is nothing we can do.

Myth: There is a scientific consensus for 5G, cell tower and wireless safety.

Myth: There is a scientific consensus that there are no known adverse health risks from 5G and wireless networks. The scientific consensus is that wireless networks are safe.

Example of the Myth Asserted by the CTIA Wireless Industry to New Hampshire lawmakers:

> *"The consensus of the US and international scientific community is that there are no known adverse health risks from the levels of RF energy emitted at the frequencies used by wireless devices (including cell phones) and facilities (including small cells)."* LINK

Fact: There is not a scientific consensus for safety. There are thousands of scientists, doctors and medical professionals cautioning that wireless technology can cause harm. Numerous expert reports recommend more accountability by governments to protect the public. Hundreds of researchers who have published research in the field of bioelectromagnetics are calling for urgent policy action due to the mounting scientific evidence confirming adverse effects.

- **255 scientists who have published in the field** signed the EMF Scientists Appeal which states "numerous recent scientific publications have shown that EMF affects living organisms at levels well below most international and national guidelines. Effects include increased cancer risk, cellular stress, increase in harmful free radicals, genetic damages, structural and functional changes of the reproductive system, learning and memory deficits, neurological disorders, and negative impacts on general well-being in humans. Damage goes well beyond the human race, as there is growing evidence of harmful effects to both plant and animal life."
- **419 scientists and doctors** have signed the European Union 5G Appeal which states, "5G will substantially increase exposure to radiofrequency electromagnetic fields (RF-EMF) on top of the 2G, 3G, 4G, Wi-Fi, etc. for telecommunications already in place. RF-EMF has been proven to be harmful for humans and the environment."
- **Over 3,500 medical doctors** signed onto a 2020 Consensus statement that wireless RF has been proven to damage biological systems at intensities below government limits (See signatures here, PDF of Consensus Statement).
- **Examples of Numerous Appeals by Medical Professionals:** International Society of Doctors for Environment, Cyprus Medical Association, the Vienna Austrian Medical Chamber and the Cyprus National Committee on Environment and Children's Health, Belgium Doctors Appeal, Canadian Doctors, Cyprus Medical Association, Physicians of Turin, Italy, the German Doctors Appeal, International Appeal to Stop 5G on Earth and Space, Letter to President Trump, Letter to President Biden and Chilean Doctors. There have been appeals and position statements for decades. Read a full list here.
- Numerous expert reports conclude that safety is not assured.
    - The New Hampshire State Commission 5G Report has 15 recommendations to protect the public
    - The Pittsburgh Law Review: The FCC Keeps Letting Me Be: Why Radiofrequency Radiation Standards Have Failed to Keep Up With Technology explains how the FCC and FDA have failed to develop adequate safety limits.
    - The Harvard Press Book "Captured Agency: How the Federal Communications Commission is Dominated by the Industries it Presumably Regulates" details

how wireless companies are using the Big Tobacco playbook and how the FCC is a captured agency.

Fact: Groups often referenced as "authorities" that downplay health risks or say that health risks are "not established" are often small with documented conflicts of interest.

- **The International Commission on Non-Ionizing Radiation Protection (ICNIRP) for example, is an under 13 member private group** with documented conflicts of interest. Many ICNIRP members have a long history in wireless industry ties. The Journal of Cancer Science and Clinical Therapeutics published Aspects on the International Commission on Non-Ionizing Radiation Protection (ICNIRP) 2020 Guidelines on Radiofrequency Radiation" and a report commissioned by two European Parliament Members published in June 2020 entitled "The International Commission on Non-Ionizing Radiation Protection: Conflicts of Interest, Corporate Capture and the Push for 5G" which documents these conflicts.
- The IEEE's International Committee on Electromagnetic Safety ICES TC95, which develops safety limits and is referred to as supporting and being used in the FCC's human exposure "safety" limits has long been led by industry tied engineer. For example, the Chair has long been CK Chou- longtime Motorola Chief EME Scientist, the Director of Corporate EME Research Laboratory, responsible for RF product safety, now retired. (See ICES leadership here). Meetings are sometimes held at Motorola headquarters.
  - In 2016 ICES TC95 Chairman CK Chou gave a presentation at the Mobile Manufacturers Forum sponsored IEEE ICES Exposure Limits Above 6 GHz. "No adverse effects have been established from low-level exposures despite 50 years of research…The committee is unaware of any more recent studies that would change the conclusions reached in the 2005 version of the standard (June 2011)." (despite the NTP results.) "The development of this standard is based on protection against...established adverse health effects:"
  - You also can watch a 2017 presentation by CK Chou here to see what Chou presents.

- **WHO EMF Project Director confirms there is no consensus**: According to Dr. Emilie van Deventer, Head of the World Health Organization's EMF Project as quoted in The Daily Princetonian in 2015, "The data is gray. It's not black and white...There is no consensus, it's true." (Note, the WHO EMF project is different from the WHO International Agency for Research on Cancer and the EMF Project is also documented to have transparency issues and numerous conflicts of interest.)

Additional Documentation

- "Appeals that matter or not on a moratorium on the deployment of the fifth generation, 5G, for microwave radiation" published in Clinical and Molecular Oncology documents the numerous appeals by independent scientists and states, *"It is striking that 5G is deployed without previous scientific evaluation of health risks. Not only cancer risks, but also other health effects such as fertility, cognitive and neurobehavioral effects, oxidative stress and electromagnetic hypersensitivity (EHS) have been associated with RF exposure."*

Fact: Numerous countries have taken steps to reduce cell phone, wireless and cell tower radiation exposure to the public. If there were a scientific consensus for safety why would these countries have such policies?

1. Countries that have set RF exposure limits and regulatory schemes for cell tower networks far more stringent than the FCC and ICNIRP include China, Russia, Canada, Israel, Turkey, Bulgaria, Brussels Belgium, Chile, Belarus, Serbia, Slovenia, Croatia, Montenegro, Italy, Switzerland, Greece, India, Liechtenstein, Tajikistan, Kazakhstan, Kyrgyzstan, Ukraine, Kuwait, Grand Duchy of Luxembourg, Bosnia Herzegovina, Georgia, Uzbekistan, Republic of Moldova, Iraq, (ITU-D Study Group 2, 2017; Madjar, 2016; Redmayne, 2016; Repacholi et al., 2012, GSMA Website).
2. Over a dozen public health bodies of various governments have issued recommendations on their websites or educational materials and brochures that the public and/or children should reduce exposure to their brain by keeping the phone away from their head. The recommendations *do not say* "if you are worried" but instead they clearly recommend reducing exposure. (A full list with direct links to sources can be found at Environmental Health Trust (EHT, 2021). Examples include:
    - Belgium: "Experts – including those on the Superior Health Council – advise everyone to limit their exposure to mobile phone radiation states the Health Food Environment Agency of Belgium (Belgian Federal Government, 2016)
    - Ireland: "Advice from the Chief Medical Officer on mobile phone use: We may not truly understand the health effects of mobile phones for many years. However, research does show that using mobile phones affects brain activity. There is general consensus that children are more vulnerable to radiation from mobile phones than adults. Therefore the sensible thing to do is to adopt a precautionary approach rather than wait to have the risks confirmed.In the light of these findings, the Chief Medical Officer of the Department of Health and Children strongly advises that children and young people who do use mobile phones, should be

encouraged to use mobile phones for “essential purposes only (Government of Ireland Department of Health, 2019).

- U.S. Public health authorities have issued recommendations.
    - The California Department of Health released an advisory on how to reduce cell phone radiation stating, "Parents should consider reducing the time their children use cell phones and encourage them to turn the devices off at night” (California Department of Public Health, 2021) and (California Department of Public Health, 2017).
    - The Connecticut Department of Public Health states it is “wise” to reduce RFR to one’s brain (Connecticut Department of Public Health, 2015). The North Carolina Public Health Department’s Occupational health Department lists the full cancer findings of the NTP study, the FDA stance and also the American Academy of Pediatrics recommendations to reduce cell phone radiation stating “there is some concern that exposure to non-ionizing radiation, also called radio frequency radiation, that is emitted by cell phones may result in an increased risk of cancer or other health effects” (North Carolina Department of Health and Human Services, 2020).
    - The Maryland State Children’s Environmental Health And Protection Advisory Council, whose 19 member Commission includes experts in public health issued a report recommending reducing RFR to children in schools (Environmental Health Trust Posted Friday, 2017).
- Several countries have laws in place to reduce exposure, in addition to their public health campaigns. For example, France, Belgium, and French Polynesia have bans on mobile phone ads targeted to children and bans on the sale of phones designed for children. Several countries limit Wi-Fi RFR in classrooms including France, Israel, French Polynesia and Cyprus (Environmental Health Trust, n.d.).
- A 2019 French government Order of the Minister for Solidarity and Health and the Minister for the Economy and Finance, stated consumers should be informed that they should use speakerphone to keep the phone away from their head, limit frequency and duration of cell phone calls for children and phones have instructions that state “keep away from the belly of pregnant women, Keep away from the lower abdomen of adolescents” (Order of 15 November 2019 Relating to the Display of the Specific Absorption Rate of Radio Equipment and to Consumer Information, 2019). Several other countries have laws and orders in place to inform consumers about the RFR from the device and educate the public to reduce exposure.

Myth: 5G will not increase RF radiation levels in your neighborhood because the power levels of 5G antennas are much much lower than large tall cell towers.

Myth in CTIA Statement to New Hampshire Legislatures
"Furthermore, a recent study demonstrated that 5G antenna densification does not increase the level of exposure" in contrast to a very popular belief. On the contrary, antenna densification does not change the exposure levels for the majority of the population, while, at base station proximity, a huge radiation decrease is experienced when more base stations are deployed in the same territory." (Footnote goes to Chiaraviglio 2021)

Professor Swanson asserted that 5G would result in lower exposure, "There is less immediate exposure when you make it low power…" and "they are very low power to all of our benefit Typically a block apart, again typically they are very low power, to our benefit, higher more reliable communication and less exposure." (Listen to Professor Swanson state 5G will lower exposure.)

Fact: It is a fact that ambient environmental RF levels will increase from the densification of small cell wireless facilities. 5G deployment goes hand in hand with the proliferation of small cell antennas and, in addition, more macro (tall) cell towers. 5G relies on 4G as its backbone so the current built companies are engaged in includes 5G *and* 4G. The antennas emit low, mid and high band frequencies.

Fact: Studies have shown an increase in RF in neighborhoods where dense small cell networks are deployed. The fact is that the closer you are to an antenna, the higher the RF. For people in close vicinity to a cell antenna, the RF levels will go up. The wireless industry statements that a small cell emits less than a large cell tower is technically correct but a misleading half truth. A person living in a neighborhood where small cell networks are deployed will likely have an increased ambient exposure, compared to their exposure before the small cell deployment. The person living with the cell antenna in front of their home will have a mich higher exposure.

Even though each individual "small" cell has less power than a macro tower, remember that there will be thousands of new 5G and 4G antennas, each increasing RF, in the vicinity of the new towers. Some communities will have several carriers and wireless facilities *on each block*.

A 2021 report by the French government on 5G analyzing more than 3,000 measurements found that RF levels had not significantly increased yet but this was due to the lack of 5G traffic. So they did additional measurements specific to 5G in the 3500 MHz band with artificially generated traffic and concluded, "initial results suggest an eventual increase of about 20% in overall exposure."

Additional research clearly documents the increase in environmental RF to people in close proximity to antennas.

- A 2018 study published in Annals of Telecommunications found small cell LTE networks in two European urban cities increased the radio emissions from base stations - ambient exposures- by a factor of 7–46.
- A 2020 paper "Radiation Analysis in a Gradual 5G Network Deployment Strategy," presented at the IEEE 3rd 5G World Forum documents how engineers found significant increases in RF levels if a mmWave-based 5G network was fully deployed in Austin Texas.
- A study published in Environmental Research created heat maps of RF from the proliferation of cell antennas mounted close to the ground on buildings and poles and the researchers found increasing RF levels.
- Countries that monitor RF (unlike the US) have found increases from 5G. For example, in Australia the telecom companies report RF levels with the proposals of new networks. Examples include 6.44% to 14.22%, 1.67% to 3.39% and 11% to .42% of the limit. A Russell Street Melbourne 5G network increased the level from .09% to .75% of the limit.

The CTIA letter references research that does demonstrate how people closer to 5G antennas *will have higher RFR, compared to those further away of the the 5G antenna. The reference does not consider 5G networks in the context of real world exposure.*

CTIA cites as a reference for the conclusion that 5G antenna densification "does not increase the level of exposure" the study Chiaraviglio 2021 which states, "Finally, specific groups of people may still receive a higher amount of exposure from a dense 5G deployment with respect to a sparse one. For example, cell phone providers may install small cells on utility poles close to buildings, and therefore, people working/living in close proximity to the small cells may receive exposure levels that exceed those from macrocells." Although the researchers state that "beyond the compliance distance (e.g., around a meter from a small cell) will be far below accepted safety limits," the reality is that safety limits have not been set to protect against cancer, DNA damage or oxidative stress. Government safety limits are not scientifically substantiated with an up to date science review. Importantly, what protections are in place for people close to the cell antennas.

Importantly, 5G networks will not exist on their own. As the paper describes, 5G networks will exist in addition to 4G networks, with an untold ever increasing amount of of new wireless devices and networks. The paper states, “In addition, any commercial 5G dense deployment has to coexist with base stations implementing other technologies (e.g., 4G)—which may be colocated or not over the same sites hosting 5G base stations—and base stations owned by other operators simultaneously covering the same area. In this case, the composite exposure resulting from all the base stations in the territory has to be always ensured below the maximum limits enforced by laws.” Macro towers with networks using lower frequencies will co-exist with new 5G networks for the time being. Thus there will be an exposure to a person that is a combination of all these networks- a composite exposure- not just exposure from the new 5G network. Because 5G mm-Wave band networks have not been widely deployed, more measurement studies and trials are needed to quantify the actual exposures from deployment. The critical question is - to what degree does the densification of 5G and *wireless networks in a neighborhood impact real world exposure? Only measuring 5G without looking at real world scenarios is not adequate.* These 5G networks will be situated among the real world with trees and other obstructions which can impact the signal for higher frequencies. In turn the power of the device will increase.

The reference provided by the CTIA does not ensure that a persons composite RF exposure will decrease with 5G. There are numerous real world variables that can only be evaluated in the actual world with proper **before and after** measurements. The reality is that current research shows that exposures are increasing. As described earlier in this document, when small cell networks are densified, the real world exposure measurements show an increase in ambient environmental exposures in the community.

This is why there is a need for companies to prioritize and promote safer wired technologies whenever possible in order to decrease the need to add more and more wireless networks.

Fact: Companies themselves state that new 4G and 5G network antennas will increase the wireless radiation levels in the area so much that they are working to loosen several governments’ radiation limits in order to roll it out. They claim they can't build out new networks unless the government changes the law to allow more RF.

If 5G and 4G did not increase RF levels in neighborhoods, then why would industry pressure governments to change their laws to allow more RF in order to deploy 4G and 5G?

Why does industry state that it is harder to rollout 4G and 5G in countries with strict RF limits?

- The ITU Report “The impact of RF-EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and 5G mobile network deployment” reviews how 5G deployment is “constrained” by these countries’ limits.

- The GSMA report discusses how strict exposure limits are problematic for 4G LTE.
- A powerpoint presentation by Ericsson "Impact of EMF limits on 5G network roll-out" that states the 5G rollout is "a major problem or impossible" due to some countries' precautionary RF limits.
- Industry lobbied Poland, Lithuania, Italy, Switzerland and Brussels Belgium to weaken their regulations in order to allow more radiation for 5G. In 2020, industry succeeded in Lithuania and Poland. Italy and Switzerland voted no. Brussels Belgium loosened their limits but they are still more stringent than ICNIRP. The maximum limit in Brussels Belgium will increase to 14.5 volts per meter, from the 6 V/m. Now industry has its eyes on Russia, which along with several countries such as China and India has RF limits much stricter lower than the USA.

Myth: The scientific consensus of U.S. federal health and safety agencies is that wireless networks and base stations compliant with the FCC's exposure levels are safe.

Example of the Myth Asserted by the CTIA Wireless Industry to New Hampshire Lawmakers in CTIA Testimony

"The scientific consensus as evaluated by expert international standard setting bodies, and federal health and safety agencies is that wireless devices and base stations at the FCC's exposure levels are safe."

Fact: Federal health and safety agencies have NOT evaluated the totality of up to date science to make any such determination. If anyone believes our federal agencies have performed an evaluation of FCC limits and the scientific evidence, please ask them to locate the research review or report that supports this conclusion. Such a report simply does not exist.

Fact: The Centers for Disease Control, National Cancer Institute, American Cancer Society, Food And Drug Administration and Environmental Protection Agency have not evaluated the latest science on 5G or cell tower exposures to issue a safety determination. Their website pages provide no substantiated proof of safety and some were drafted with industry consultants. No US regulatory agency with health or environmental expertise has completed a risk analysis or systematic review based on the latest evidence.

Click on the agency/org name for full documentation of the lack of scientific review.

- Centers for Disease Control
- National Cancer Institute
- American Cancer Society
- The Food And Drug Administration
- The Environmental Protection Agency

Myth: The National Cancer Institute (NCI) has determined that cell towers, 5G and cell phone radiation is safe.

Fact: The NCI has confirmed that they never systematically reviewed the science on wireless radiation to make a determination on cell tower safety or evaluate FCC limits.

Myth Included in Statement by CTIA Wireless Industry to New Hampshire Lawmakers: *'The National Cancer Institute agrees that "studies [on the possible association between cell phone using cancer] are mixed but overall they do not show an association between cell phone use and cancer.*" (CTIA Footnote goes to NCI cell phones and Cancer factsheet.)

Josiah Bartlett also misleadingly references the NCI in his blog post about New Hampshire cell tower legislation: *"The NCI says that cell phone radiofrequency "energy is too low to damage DNA" and "there are no other clearly established dangerous health effects on the human body from radiofrequency radiation."* Most people will read such statements and assume this means that cell phone and cell tower radiation is proven safe. This is false.

Fact: There are no scientific reports by the NCI that exist regarding 5G, cell tower or cell phone safety. Even if NCI scientists had an official determination (which they do not), the agency is only focused on cancer, and does not investigate other effects such as brain or reproductive damage. Thus, even if the NCI did have an opinion, it would not be proof of safety- as research has shown damage to the brain and fertility. .

Documentation on the National Cancer Institute's lack of safety evaluation.

1. The fact that the NCI has not reviewed the science nor concluded any official position on safety was confirmed by a letter from New Hampshire 5g Commissioner Denise Ricciardi to the NCI asking, "What is the NCI opinion on the safety of cell phones?" On July 30, 2020, the National Cancer Institute wrote Ricciari back that, "As a Federal research agency, the NCI is not involved in the regulation of radiofrequency telecommunications infrastructure and devices, nor do we make recommendations for policies related to this

technology…Our sister agencies, the FDA as well as the FCC, retain responsibility for reviewing guidance on safety concerns and informing the public if those circumstances change." Read the Exchange From New Hampshire 5G Commission Report.

2. The NCI did not provide any opinion on the safety of wireless radiation to the FCC during the 7 year inquiry opened re FCC's safety limits for wireless radiation. Instead the NCI sent a two paragraph letter to the FCC without mention of any opinion on the state of science. Read the NCI Letter to FCC

3. The NCI wrote to EHT's Executive Director Theodora Scarato, stating of the NCI that, "Neither the literature reviews, nor the fact sheets, make safety determinations." (Letter from NCI to Scarato)

Myth: The American Cancer Society (ACS) has determined that cell towers and cell phones are safe.

The CTIA Wireless Industry used the ACS in it's letter to New Hampshire Lawmakers: "Likewise the American Cancer Society explained that "the RF waves given off by cell phone towers don't have enough energy to damage DNA directly or to heat body tissues. Because of this it's not clear how cell towers might be able to cause cancer." (CTIA then Footnotes to ACS Cell Phone Towers Page

Josiah Bartlett also references the NCI in his blog post about New Hampshire cell tower legislation stating, "At this time, there's no strong evidence that exposure to RF waves from cell phone towers causes any noticeable health effects," the American Cancer Society has concluded."

Fact: The ACS has not reviewed the science on cell towers or cell phones and their webpages do not provide science backed safety assurances.

- In fact, the ACS website states very clearly that ACS does "not have any official position or statement on whether or not radiofrequency radiation from cell phones, cell phones towers, or other sources is a cause of cancer."
- Furthermore the ACS says they "look to other expert organizations to determine if something causes cancer " and the ACS then lists the International Agency for Research on Cancer (IARC) and the US National Toxicology Program (NTP) both of which document *science showing links to cancer.* See IARC and NTP.

- When the NTP found “clear evidence” of cancer from wireless RFr radiation, the ACS referred to the study in their press release as paradigm shifting “good science.”

Furthermore the ACS press release on the NTP study: “The NTP report linking radiofrequency radiation (RFR) to two types of cancer marks a paradigm shift in our understanding of radiation and cancer risk. The findings are unexpected; we wouldn’t reasonably expect non-ionizing radiation to cause these tumors.”

Myth: The Food And Drug Administration (FDA) has reviewed the science on 5G and cell towers and determined the radiation is safe and FCC limits protect public health.

Myth: The FDA’s website clearly shows that the FDA has reviewed the totality of scientific evidence and found cell phones, 5G and cell towers are safe. After all, the FDA concluded in February of 2020 that “there is no consistent or credible scientific evidence of health problems caused by the exposure to radio frequency energy emitted by cell phones.

Myth in CTIA Testimony to New Hampshire Lawmakers:
“And the FCC sister agency, the FDA stands in full support of the adequacy of the FCC standards. The director of the FDA center for Devices and Radiological Health wrote, "based on our ongoing evaluation of this issue and taking into account all available scientific evidence we have received, we have not found sufficient evidence that there are adverse health effects in humans caused by exposures at or under the current radiofrequency energy exposure limits."

Fact: The FDA has never evaluated the totality of the science to conclude any opinion on the safety of human exposure to 5G technology or cell tower radiation. All the FDA has done is to release a now outdated literature review (ending in 2018) focused solely only on cell phones and cancer. This literature review omits studies on damage to DNA, the brain and reproduction. The FDA literature review is not a systematic review nor is it a risk analysis nor is it an evaluation of FCC cell tower radiation limits, despite being presented in this way.

Fact: The FDA has no authority in regards to cell tower radiation and 5G infrastructure. This was confirmed in a January 11, 2022 letter by Ellen Flannery of the Director of the FDA Office of Policy Center for Devices and Radiological Health who wrote that the FDA doesn't regulate cell towers. When asked about the safety of a cell tower outside a California mother’s window, she responded, “The FDA does not regulate cell towers or cell tower radiation. Therefore, the FDA has no studies or information on cell towers to provide in response to your questions.” Link to FDA Letter.

While the public might assume the FDA is always monitoring the science and monitoring exposures, this is inaccurate. For example, the 2021 FDA's Annual report was released on January 31, 2022 and there is no mention of the issue of cell phones or cell towers or wireless electromagnetic radiation. The FDA has not shown any evidence of monitoring research with new agency reports, meetings or budget on the issue.

As the Pittsburgh Law Review article concludes, "The FCC and FDA have failed in their obligation to prescribe safe RFR guidelines produced from wireless communication devices to protect the public health and safety."

Additional Documentation

- The Government Accountability Report on 5G (GAO 2020) clarified that the FDA and other organizations "only reviewed a subset of the relevant research" and stated in regards to the FDA Literature Review that "The assessment focused on cancer-related animal and human studies of frequencies below 6 GHz."
- Not only did the FDA do a limited literature review looking *only at cancer,* but it omitted impacts to the brain, oxidative stress, and reproduction. It omitted evaluation of children's unique vulnerability. Most importantly it discounted the results of the National Toxicology Program which is why numerous scientists - including several now retired US government scientists - are calling for the FDA to retract the review as it offers unsubstantiated assurance of safety (EHT 2020).
- EHT's 150 page report "FDA's Misleading Information on Cell Phone Radiation on the FDA documents the lack of adequate research review and misleading information put forward by the FDA.
- In 2020, the FDA refused to testify to the New Hampshire State Commission on 5G and refused to answer specific questions regarding it's purported review of health effects of 5G and wireless networks. Although the FDA responded with a few general sentences about how "FDA's doctors, scientists and engineers continually monitor the scientific studies and public health data for evidence that radio frequency energy from cell phones could cause adverse health effects, "the FDA refused to answer specifics such as providing reports or answering questions about the safety margin, and the FDA's research activities. Read FDA Communications with the New Hampshire 5G Commission

Environmental Health Trust
P.O. Box 58, Teton Village WY 83025
ehtrust.org

The Centers for Disease Control and Prevention (CDC) has concluded 5G, cell towers and cell phones are safe.

Myth: The CDC website statements that "we do not have the science to link health problems to cell phone use" confirm that cell phones and towers are safe.

Fact: CDC experts have not reviewed the latest research on wireless radiation and the website pages do not reflect an opinion or determination on safety.

1. First,and most importantly, there are no scientific reports by the CDC on wireless safety, nor does the agency have staff with expertise monitoring the science and evaluating risk. As far as we know they have never undertaken any research review as the CDC has no authority on the issue.
2. In fact, due to the lack of CDC scientists with subject matter expertise in wireless, the agency hired an outside consultant to help draft several CDC webpages. This individual has longstanding financial ties to industry and consults for cell tower companies. The pages he helped draft at the CDC omit scientific research that has found health effects and the text downplays any health risk. Read the EHT expose on the CDC industry tied consultant here.
3. In 2014, the CDC actually posted cautionary statements that recommended people reduce cell phone radiation exposure. However, these statements were removed just a few weeks after they were posted. Read the New York Times article which tells part of the story as well as the Microwave News article on influence to CDC webpage from wireless industry consultants.
4. Of note- a now retired top CDC expert now states that the research shows cell phone radiation likely causes cancer. Chris Portier PhD, retired CDC Director of the National Center for Environmental Health and former Director of the Agency for Toxic Substances and Disease Registry submitted scientific research review in a major cell phone/brain cancer lawsuit where he concludes that "the evidence on an association between cellular phone use and the risk of glioma in adults is quite strong."

Myth: The Environmental Protection Agency has evaluated the science and deemed 5G and wireless networks as safe.

Fact: The Environmental Protection Agency (EPA) has not performed a research review for over thirty years and is not monitoring or researching the issue.

As the EPA stated to Theodora Scarato in a 2020 letter, “EPA’s last review was in the 1984 document Biological Effects of Radiofrequency Radiation. The EPA does not currently have a funded mandate for radiofrequency matters.”

Fact: The EPA was defunded from researching the issue just as it was poised to develop RF safety standards for human exposure in 1996. Thus, the US does not have federally developed safety standards based on U.S. agency expert research to determine a safe level. Instead the US has RF exposure guidelines promulgated by the FCC which set limits in 1996 based on limits created by industry dominated/tied groups.

Fact: The EPA used to measure RF and non-ionizing EMF levels. The last Report was a 1986 Report on Environmental Exposure Levels. The FCC also had programs taking RF measurements from cell antennas but the field offices were shuttered. In sharp contrast to the USA, many other countries have RF measuring projects with RF radiation levels posted on public websites including: France , Spain, Austria, Greece, Turkey, India, Israel, Gibraltar, Brussels Belgium, Switzerland, Bulgaria, Tunisia, Malta, Brazil, Bahrain, Monaco, French Polynesia, Bhuton, Senegal. France even has 5G monitoring stations.

Some communities are starting to address this lack of accountability. For example, see the Copake NY code: Pretesting and post testing by RF engineer and annual monitoring of RF emissions by the independent RF engineer using actual field measurements like in Copake New York. Davis, Burbank and Berkeley also have testing requirements in their ordinances. An RF engineer performs measurements and the OWNER of the wireless facility pays for this.

Fact: EPA scientists have long tried to address the inadequacies of FCC’s limits. EPA expert staff signed onto letters in 1999 and 2003 to the RF limit setting group leadership requesting answers to identified shortcomings in their recommended human exposure limits.

Fact: In 2019, the EPA website pages on cell phones, cell tower and EMFs were rewritten (scrubbed) and now parrot FCC verbiage and link to the FCC as the authority, despite the fact that the EPA has done no recent research, nor developed any opinion on safety. When the FCC asked the EPA to comment on the need to update or change FCC’s 1996 limits in their 2013 Inquiry, the EPA responded with a one paragraph letter offering no opinion.

Fact: EPA has confirmed that FCC RF exposure limits were not created to address health effects from long term exposure. A 2002 EPA letter stated, “I believe that it is correct to say that there is uncertainty about whether or not current guidelines adequately treat nonthermal, prolonged exposures (exposures that may continue on an intermittent basis for many years)…Federal health and safety agencies have not yet developed policies concerning possible risk from long-term, nonthermal exposures. When developing exposure standards for other physical agents such as toxic substances, health risk uncertainties, with emphasis given to sensitive populations, are often considered. Incorporating information on exposure scenarios involving repeated short duration/nonthermal exposures that may continue over very long periods of time (years), with an exposed population that includes children, the elderly, and people with various debilitating physical and medical conditions, could be beneficial in delineating appropriate protective exposure guidelines."

Brief History

- Previous to 1996, the EPA conducted robust research on electromagnetic radiation (EPA Letter) and was in development of safety limits for wireless radiation. See EPA Briefing, and a 1995 EPA Letter to the FCC on their near completion of non ionizing EMF guidelines clearly detailing how they were in development of safety limits which considered thermal and thermal impacts. However, heavy industry lobbying abruptly halted the EPA from standards development. The same year it passed the Telecommunications Act of 1996, Congress eliminated EPA's funding for activities related to RF radiation in an appropriations bill. Congress specified that "EPA shall not engage in EMF activities." Thus the EPA shuttered its research on standards development.
- 1993 EPA Comments to the Federal Communication Commission's (FCC's) proposed RF/MW radiation limits 93-142 Guidelines For Evaluating the Non Thermal Effects of Radiofrequency Radiation includes information asserting that certain subgroups are more at risk (pregnant women, children and the elderly) and calls for an updated, comprehensive review that considers the biological effects of RF, specifically pointing to the need to update the (1986) NCRP Report 86 (Note: NCRP 86 is still the basis for US regulations according to the FCC and this report has not been updated to include biological effects). The EPA stated:

  > "The FCC should not adopt the 1992 ANSI IEEE standard; there are serious flaws in the standard that call into question whether the proposed use of the 1992 ANSI IEEE is sufficiently protective."
  >
  > "It is clear that the adverse effects threshold of 4W /kg is based on acute exposures (measured in minutes of a few hours) that elevate temperature in laboratory animals including non-human primates and not on long term, low level (non thermal) exposure."

Documentation

- 2020 EPA letter to EHT Executive Director Theodora Scarato.
- US Exposures Limits: A History of Their Creation documents how ANSI and IEEE limits were developed, despite awareness of biological effects.
- FCC's Legal Duties to Inform and Protect the Public by Sharon Buccino Natural Resources Defense Council Washington, DC

- 1984 letter by the U.S. Science Advisory Board that recommends that the EPA develop radiation protection guidance to protect the public.
- 1993 EPA Letter states that "it is clear" that the U.S. human exposure limits are based on short term exposures and not on research considering chronic long term exposures.
- 1996: EPA Letter that US Limits are only protective for thermal impacts
- 1996: EPA comments to FCC Docket 93-62 includes recommendations that the FCC request the NCRP revise its 1986 report to include an updated, comprehensive review of the biological effects of RF.
- 1999: Scientists from US federal agencies of the radiofrequency interagency workgroup (RFIWG) write IEEE Work Group Chair on critical issues about RF exposure limits
- 2002: EPA Letter stating FCC's 1996 RF limits do not protect against all effects
- 2003: Scientists from US federal agencies write IEEE again on additional issues re IEEE's RF exposure limits. Both 1999 and 2003 letters remain unanswered.

Myth: The World Health Organization webpages confirm there are no health effects for cell towers or cell phones.

Example of the Myth Asserted by the CTIA Wireless Industry to New Hampshire Lawmakers:

> *"The legislative findings and purpose section of HB 1644 erroneously suggests that the World Health Organization views RF emission from telecommunications equipment as a "carcinogen". To the contrary, the WHO position has been and continues to be that there is no convincing scientific evidence that the weak signals from base stations and wireless networks can cause adverse health effects."* (Note- the CTIAs footnote 7 goes to a 2006 WHO webpage)

The CTIA also states

> "The WHO also concluded that research has not been able to provide support for a causal relationship between exposure two electromagnetic fields and self-reported symptoms or electromagnetic hypersensitivity." (CTIA then footnotes to the WHO mobile phone web page with one unsubstantiated sentence).

Fact 1. The CTIA inaccurately conflates two separate entities of the WHO and the position the CTIA references was drafted over a decade ago by one person who used wireless company money to start the "WHO EMF Project."

The CTIA was inaccurate in stating the WHO "position was that of "no evidence." In fact, the WHO has two distinct and separate entities addressing the issue; 1. the WHO EMF Project who wrote the webpages referred to and 2. the WHO International Agency for Research on Cancer.

1.The WHO International Agency for Research on Cancer (WHO/IARC) in fact designated wireless radiation as a class 2 B "possible" carcinogen in 2011 largely based on human studies that found long term cell phone users had increased risk for tumors- glioblastomas and acoustic neuromas (Read the WHO/ IARC 2011 press release). The scientific documentation for the determination was compiled in a 2013 monograph (IARC 2013). Furthermore, because that determination was a decade ago, the WHO/IARC advisory group now has recommended wireless be re-evaluated as a "high priority" within 5 years due - largely in part- to the recent animal research (Falconi, 2018; NTP, 2018) would found evidence for cancer (IARC, 2019).

2.The World Health Organization (WHO) EMF Project webpages are not official determinations because this group has not reviewed the science *since 1993.*

There are two WHO EMF Project web pages that are often referenced by the wireless industry. 1. The mobile phone webpage that says "no adverse health effects have been established as being caused by mobile phone use" and 2. The base station (cell tower) webpage which states "from all evidence accumulated so far, no adverse short- or long-term health effects have been shown to occur from the RF signals produced by base stations."

Fact: The outdated WHO website statements are not based on a scientific review of the totality of the evidence.

- The WHO EMF Project website pages are outdated (cell towers in 2006, cell phones in 2014) and are not official conclusions from a review.
- The WHO EMF Project, the entity that drafted these webpages, has not reviewed the science *since 1993.* WHO webpages list the recent monographs (scientific research evaluations on health risks) and clearly state that the last one on radiofrequency wireless was completed in 1993. Read WHO Webpage stating 1993 as the last date of research review.
- The WHO EMF Project is trying to launch a systematic review of the research but it has not been completed. The process was stalled for years due to serious transparency issues.
- Further, these online WHO webpages are authored by a scientist who started the WHO EMF Project with wireless industry funding and with staff documented to have long standing conflicts of interest. Read a published article about the conflicts published in the International Journal of Oncology by Dr. Lennart Hardell.
- Listen to industry funded Scientist Michael Repacholi in a community meeting in India (brought in by the Cellular Operators of India) stating he wrote the online webpage

factsheets at the WHO in this video and how “they have been accurate for 10 years.” (Yet he shares no scientific reports.)

Conflicts of Interest at the WHO EMF Project

- The WHO EMF Project was started by a scientist, Michael Repacholi, who funneled money from wireless companies through a hospital to start the EMF Project at the WHO. Hardel and Carlberg 2017 states “Michael Repacholi immediately set up a close collaboration between WHO and ICNIRP (being head of both organizations) inviting the electric, telecom and military industries to meetings. He also arranged for a large part of the WHO EMF project to be financed by the telecommunication industry's lobbying organizations; GSM Association and Mobile Manufacturers Forum, now called Mobile & Wireless Forum (MWF).”
- The WHO EMF Project founder Repacholi is now on several wireless company advertisements speaking about cell phone and electromagnetic safety.
    - Watch him talk about children are safe with cell phones here
    - Watch him talk about how EMFs are safe here.

- **Transparency:** The engineer who now directs the EMF Project refuses to answer questions about how the online factsheets were written or where the scientific reports are that back up the cell tower and cell phone statements. Read letter sent to engineer Emile Van Deventer WHO EMF Project Director that remains unanswered. Dr. Lennart Hardell also describes transparency issues here. The current WHO Project Director is an engineer and not a medical doctor or public health expert.

Myth: FCC limits have a wide safety margin- a 50 times safety factor.

Fact: There is not a 50 times safety factor as confirmed by the latest science. It simply does not exist.

The CTIA misleadingly asserted this myth to New Hampshire lawmakers in the CTIA testimony stating that, *“Indeed, when setting limits for the RF emissions of wireless devices, the FCC intentionally provided a significant safety margin- 50 times below the threshold at which adverse effects have been observed in laboratory animals.”*

This statement is misleading because while it is true that FCC limits were set in 1996 based on animal studies, that was 25 years ago. New studies have found harmful effects in animals and humans at much lower RF levels yet they are all dismissed for various reasons by the industry tied groups considered “authorities” (Lerchl et al., 2015, Smith-Roe et al., 2020, Tan et al., 2017, Yakymenko et al., 2015, Schuermann & Mevissen, 2021, Bas et al., 2009; Deshmukh et al., 2015, Shahin et al., 2017, Megha et al., 2015, Aldad et al., 2012; Zhang et al., 2015, Sonmez, et al., 2010, Dasdag et al., 2015, Shahin et al., 2018, Obajuluwa et al., 2017, Tan et al., 2021, Hasan et al., 2021, U.S. National Toxicology Program, 2018, Uche & Naidenko ., 2021). Yet, the FCC/ICNIRP/IEEE limits continue to be based on a handful of small animal studies from the 70s (as detailed below).

The CTIA footnotes their statement that a safety margin exists by citing the FCC’s 2013 Notice of Inquiry. However this was not a determination, *but an Inquiry.* The outcome of that Inquiry was an FCC action which was deemed arbitrary and capricious by a judgment of the U.S. Court of Appeals for the District Of Columbia in August 2021. Thus, the CTIA footnoted statement is irrelevant. The last defensible FCC determination was in 1996.

The CTIA also has a second footnote reference to the IEEE C95.1 2019 standard as if it provided up to date proof of a 50 times safety factor. Once again, the CTIA points to a document based on decades old science. Further, the IEEE C95 is not a peer reviewed systematic review and it’s leadership/membership is largely industry financed. As just one example, the Chairman of the IEEE group that developed the 2019 IEEE Standard - ICES TC95 is Dr. C-K Chou, retired Chief Scientist at Motorola for RF safety, now industry consultant. The Co-Chair Kevin Graf is an Engineer at FCC formerly with Exponent- called a “science for hire” firm.

Importantly, the IEEE standard determines the “established critical temperature levels leading to adverse biological effects- the “effect threshold” which they determined to be 4 W/kg- citing only a few ancient small animal studies. The sixth row of Table B.10 on page 125 of the IEEE standard lists the studies specifically; De Lorge 1984- a study of five food-deprived rhesus monkeys; De Lorge 1983 (See full 1982 study report for naval research)- a study of five rhesus monkeys, one squirrel monkeys and one rat; and D‘Andrea et al., 1977- a study of eleven rats. The fifty times safety factor is considered established based on these studies.

While numerous studies showing low level non thermal effects are referenced in the IEEE document, the bottom line is that the IEEE C-95 Committee concluded that none were reproducible or they had various flaws and thus they retain their effect threshold at 4W kg. Environmental Health Trust has detailed the inaccuracy of the often referenced “fifty-fold safety factor” in our Submission to the FCC.

Fact: Even when it comes to protecting against heating effects only, organizations that industry reference as the authority confirm that *there is not a 50 times safety factor, especially when it comes to local limits for cell phones*

ICNIRP 2020 Limits State Safety Factor is 2 and 10:

- The self appointed small invite only group named the International Commission on NonIonizing Radiation Protection (ICNIRP) which industry promotes as an authority states in their latest 2020 guidelines that for Type 2 tissues **such as the head** the local adverse health effect threshold is a SAR of 20 W/kg averaged over 10 g. Therefore, the reduction factors in the 2020 ICNIRP guidelines are 2 for the occupational local exposures and 10 for the general public local exposures- ***not 50***.

Fact: The August 2021 U.S. Court of Appeals of the District of Columbia Circuit ruling in favor of EHT et al highlighted the FCC's lack of justification for the "large safety margin" on page 19 of the federal court ruling. The judges stated the FCC had failed "to provide a reasoned explanation for its determination that exposure to RF radiation at levels below its current limits does not cause negative health effects." Further, cell phones emit RF levels that can exceed FCC limits by up to ten times. Studies show that if cell phones and wireless devices are in body contact positions (without a separation distance), the RF exposure can violate U.S. government human exposure limits up to 11 times the radiofrequency limit when the cell phone is pressed to the body. The FDA and FCC have been fully informed of this and knowingly allow the American public to be exposed to RFR levels that exceed the U.S. regulatory limit.

Fact: Even if the safety factor were 50 (which it is not), 50 is NOT a "wide margin" of safety. The Environmental Protection Agency typically uses safety factors in the 100's or 1000's range. A study in Environmental Health analyzing the findings of tumor and heart damage from the National Toxicology Program study concluded that FCC limits should be strengthened by 200 to 400 times to protect children according to current risk assessment guidelines (Uche 2021).

Not only does the CTIA repeat the myth of the 50 fold safety factor and footnote their statements with invalid references, but in addition, the CTIA then uses these invalid references to further assert that the safety margin protects people who are more sensitive to the exposure. The CTIA states of the FCC's 2019 Order (found to be arbitrary and capricious by the Court on August 2021) that "The agency explained the this 50 fold factor can well "accommodate a variety of variables such as different physical characteristics and individual sensitivities and even the potential for exposures to occur in excess of FCC limits without posing a health hazard to humans." As detailed earlier, the 2019 FCC Order Refusing to Change 1996 RF limits was found to be in violation of the law- specifically the Administrative Procedures Act.

Myth: An Australian study found "no confirmed evidence that low-level RF fields above 6 GHz such as those used by the 5 G network are hazardous to human health," *so 5G is safe.*

Statement in Josiah Bartlett Blog post: "An Australian study published in March of 2021 reviewed 138 studies of radio frequency fields consistent with 5G networks. It found "no confirmed evidence that low-level RF fields above 6 GHz such as those used by the 5 G network are hazardous to human health."

Fact: This study does not show proof of safety. In fact, it proves that no long term research even exists to assess health risks from years of 5G millimeter wave networks stating "there are no epidemiological studies investigating 5 G directly as yet." Most importantly, this review was only on high band frequencies and not on the low and mid band frequencies- frequencies that 5G networks **will use** in addition to high band frequencies. In other words, 5G will use a wide range of frequencies, many of which have already been extensively studied.

The Nature review did not look at low and mid band frequencies of which there is copious research indicating biological effects. 5G uses 4G networks as its backbone so one cannot claim safety with one review that only focuses on 5G millimeter wave networks.

Notably, this study (not a systematic review) was authored by individuals associated with a group called ICNIRP- a small private group known to have conflicts of interest and to reject research showing harm.

Interestingly, in the Nature paper the authors declare no conflicts of interest. However, in several other papers, author Andrew Wood disclosed that he has three telecom company employees in his lab. A 2022 paper Wood co-authored states, "*Declaration of Competing Interest: The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: AWW directs a research group, which includes three technical associates who are telecommunications company employees."*

*Another paper Wood co-authored states, "*AWW directs a research group, which includes three technical associates who are telecommunications company employees. The group is also providing advice for a local government authority and a utility on electric and magnetic field exposure issues on a fee-for-service basis."

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Further, the laboratory contains equipment from Telstra Research Lab. The laboratory webpage states, "the Radiofrequency Dosimetry Laboratory was funded by Telstra Corporation and Swinburne and is part of the NHMRC-funded Australian Centre for Electromagnetic Bioeffects Research." Note NHMRC is in fact *also funded by Telstra* ***as documented in public information requests which show how*** *industry money is moved through the NHMC but comes from AMTA- the Australian Mobile Telecommunications Association.*

Thus author Andrew Wood has long had Telecom staff working with him in the Telecom equipment funded lab- with salaries paid for by Telstra, the telecommunications company of Australia.

- The *Journal of Cancer Science and Clinical Therapeutics* published an article on ICNIRP's conflicts here.
- Read an European Parliament Members Report on ICNIRP conflicts here.

Hardell and Carlberg published "Health risks from radiofrequency radiation, including 5G, should be assessed by experts with no conflicts of interest" (Hardell & Carlberg, 2020) detailing how the independent evaluations of RF radiation health risks are ignored by ICNIRP and other closely connected groups. They conclude that, " there seems to be a cartel of individuals monopolizing evaluation committees, thus reinforcing the no-risk paradigm. We believe that this activity should qualify as scientific misconduct."

Myth: There is no evidence that 5G, cell towers or cell phones are harmful to health.

Professor Eric Swanson testified at the February 7, 2022 New Hampshire House Committee hearing on the behalf of the CTIA wireless industry that there are "No verified effects on the human body except for heating… "

Fact: There are hundreds of credible research studies showing harmful effects from wireless radiation and non ionizing radiation.

The respected journal Lancet Planetary Health published Bandara and Carpenter 2018 that states:

> "A recent evaluation of 2,266 studies (including in-vitro and in-vivo studies in human, animal, and plant experimental systems and population studies) found that most studies (n=1546, 68·2%) have demonstrated significant biological or

health effects associated with exposure to anthropogenic electromagnetic fields. We have published our preliminary data on radiofrequency electromagnetic radiation, which shows that 89% (216 of 242) of experimental studies that investigated oxidative stress endpoints showed significant effects. This weight of scientific evidence refutes the prominent claim that the deployment of wireless technologies poses no health risks at the currently permitted non-thermal radiofrequency exposure levels."

Examples of research on radio frequency- including frequencies emitted from low/mid band 5G networks, small cells, cell towers, cell phones and wireless electronics.

- European Parliament requested a research report "Health Impact of 5G" released in July 2021 concluding that commonly used RFR frequencies (450 to 6000 MHz) are probably carcinogenic for humans *and* clearly affect male fertility with possible adverse effects on the development of embryos, fetuses and newborns.
- A review on real world exposure to 5G published in *Toxicology Letters* found that 5 G will have systemic effects as well as adverse effects to the skin and eyes (Kostoff et al., 2020).
- A landmark three part **2021 research review** on effects of non ionizing radiation to wildlife published in *Reviews on Environmental Health* by U.S experts, including former U.S. Fish and Wildlife senior biologist Albert Manville, states current science should trigger urgent regulatory action citing more than 1,200 scientific references which found adverse biological effects to wildlife from even very low intensities of non ionizing radiation with findings of impacts to orientation and migration, reproduction, mating, nest, den building and survivorship (Levitt et al., 2021a, Levitt et al., 2021b, Levitt et al., 2021c).
- 2021 systematic reviews that find RFR can harm sperm (Kim et al., 2021, Sungjoon et al, 2021, Yu et al., 2021).
- A 2021 systematic review on the effects of RFR to male reproductive hormones found that wireless can decrease testosterone (Maluin et al, 2021).
- A review on the genetic effects of non-ionizing electromagnetic fields found DNA strand breaks, micronucleus formation, and chromosomal structural changes (Lai 2021).
- A systematic review published in the Annals of the New York Academy of Sciences found that neuronal ion channels are particularly affected (Bertagna et al 2021).
- A review in the International Journal of Oncology describes how EMFs lead to dysfunction of ion channels which lead to reactive oxygen species/free radical overproduction providing " a complete picture" of how exposure may indeed lead to DNA damage and related pathologies, including cancer," (Panagopoulos et al. 2021).
- A systematic review and meta-analysis of case-control studies found evidence that linked cellular phone use to increased tumor risk (Choi et al., 2020).
- The Switzerland Institute of the Environment expert published review found increased oxidative stress in the majority of animal studies and cell studies with exposures within regulatory limits (Schuermann et al., 2021) corroborating an earlier review (Yakymenko et al 2016) on oxidative stress that concluded 93 of 100 studies found oxidative effects.

A sampling of research on cell tower radiation specifically:

- A 2017 study entitled the "Impact of radiofrequency radiation on DNA damage and antioxidants in peripheral blood lymphocytes of humans residing in the vicinity of mobile phone base stations" published in Electromagnetic Biology and Medicine found higher RFR exposures in people living near mobile phone base stations was linked to changes in the blood that are considered biomarkers predictive of cancer.
- A 2018 study Mobile Phone Base Station Tower Settings Adjacent to School Buildings: Impact on Students' Cognitive Health published in the American Journal of Men's Health found school-aged adolescents exposed to higher levels of RFR exposure had delayed fine and gross motor skills, spatial working memory, and attention in comparison to those exposed to lower RFR levels.
- A 2015 study Association of Exposure to Radio-Frequency Electromagnetic Field Radiation (RF-EMFR) Generated by Mobile Phone Base Stations with Glycated Hemoglobin (HbA1c) and Risk of Type 2 Diabetes Mellitus published in the International Journal of Environmental Research and Public Health on elementary students found higher Type 2 Diabetes Mellitus in students exposed to higher levels of RFR.
- A 2011 review found a year of operation of a powerful cell base station resulted in a dramatic increase in cancer incidence among the population living nearby.
- A large-scale animal study published in Environmental Research which exposed rats to cell tower levels of RF found increased cancers, the same tumor types as found by the National Toxicology program animal studies (Falcioni 2018).
- A 2020 study considering liability issues for wireless companies recommends that "although direct causation of negative human health effects from RFR from cellular phone base stations has not been finalized, there is already enough medical and scientific evidence to warrant long-term liability concerns for companies deploying cellular phone towers. In order to protect cell phone tower firms from the ramifications of the failed paths of other industries that have caused unintended human harm (e.g. tobacco)" the author recommends, "voluntarily restrictions can be made on the placement of cellular phone base stations within 500 m of schools and hospitals."
- An analysis of studies found ~80% showed biological effects near towers. "Many biological effects have been documented at very low intensities comparable to what the population experiences within 200 to 500 ft (*60–150 m) of a cell tower, including effects that occurred in studies of cell cultures and animals after exposures to low-intensity RFR. Effects re- ported include: genetic, growth, and reproductive; increases in permeability of the blood–brain barrier; behavioral; mo- lecular, cellular, and metabolic; and increases in cancer risk." (PDF).
- A 2021 study published in the International Journal of Environmental Research and Public Health Found higher cell tower RFR radiation exposures linked to increased mortality for all cancers including breast, cervix, lung, and esophagus cancers.

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- A study from Germany found that stress hormones adrenaline and noradrenaline significantly increased over the first 6 months after cell tower antenna activation and after 18 month dopamine and PEA levels decreased.
- A study by a Municipal Health Department and several universities in Brazil found a clearly elevated relative risk of cancer mortality at residential distances of 500 meters or less from cell phone towers.
- A review published in the International Journal of Occupational and Environmental Health of epidemiological studies found in 80% of the studies, people living <500 m from base stations had an increased adverse neuro-behavioral symptoms and cancer.
- An analysis by human rights experts published in Environmental Science & Policy argues that cell tower placement near schools is a human rights issue for children because "protection of children is a high threshold norm in Human Right law" and "any widespread or systematic form of environmental pollution that poses a long-term threat to a child's rights to life, development or health may constitute an international human rights violation." The authors document numerous studies indicating a myriad of effects and conclude that, "because scientific knowledge is incomplete, a precautionary approach is better suited to State obligations under international human rights law." (PDF)
- A 2014 study entitled "RF radiation from mobile phone towers and their effects on human body" published in the Indian Journal of Radio & Space Physics surveyed residents 6 years after the cell tower was erected. They measured the RF and notably found very high levels when the antennas were closest to homes and also very high levels when the antennas were directly facing the antennas without any obstructions. Residents living within 50 meters had more health complaints (fatigue, nausea, sleep, headache etc.) than those living over 50 meters from the antennas.
- A 2021 research study with a total of 268 surveys completed by residents of a Madrid neighborhood surrounded by nine telephone antennas, and 105 measurements of electromagnetic radiation both outside and inside the houses found people who are exposed to higher radiation values present more severe headaches, dizziness and nightmares. Moreover, they sleep fewer hours."

Myth: 5G and wireless networks are safe because they are non-ionizing radiation.

Fact: Claims that 5G networks are safe because "the radiation is non ionizing" are simply false. More than enough research exists to confirm that non-ionizing radiation has biological effects.

Our scientific understanding of electromagnetic radiation is in a paradigm shift. The ionizing versus non-ionizing model is no longer relevant to understanding the health effects of RFR. Just because RFR is non-ionizing does not mean that it cannot initiate, promote, or play a role in the development of cancer. Research has found adverse health effects from RFR including increased cancer risk, cellular stress, increase in harmful free radicals, genetic damage, structural and functional changes in the reproductive system, learning and memory deficits, and damage to the nervous system (Belpomme et al., 2018; Miller et., 2019, Schuermann et al., 2021).

Fact: Scientists have published papers on the mechanisms by which non ionizing radiation can impact human health and the environment.

Several pathways have been suggested to explain how non-ionizing RFR could lead to DNA damage -without causing direct DNA damage in the same way as ionizing radiation, (Barnes and Greenebaum, 2018; Belpomme et. al., 2018; Blank and Goodman, 2009,: Markov et al., 2010).

RFR can interfere with oxidative repair mechanisms, induce oxidative stress, and impact cellular processes leading to cancer (Havas, 2017; Melnick, 2019; Yakymenko et al., 2016). A 2021 review reported the majority of the animal studies and more than half of the cell studies found increased oxidative stress caused by non-ionizing electromagnetic fields and concluded that “a trend is emerging” that non ionizing EMF exposure, even in the low dose range, may well lead to changes in cellular oxidative balance (Schuermann et al., 2021). Induction of oxidative stress is a key characteristic of many human carcinogens (Smith et al., 2016).

Several publications document biophysically plausible mechanisms for biological effects (Belyaev, 2015; Dasdag and Akdag, 2016; Georgiou CD, 2010; Pall 2013, 2015). For example, although they are low power, wireless RFR communication signals have complex waveforms, and include components of lower frequency non-ionizing electromagnetic fields, which can induce perturbations of Voltage Controlled Calcium Gates (VCCG) in cellular membranes. This leads to imbalances in cytoplasmic ionic concentrations, leading to excessive reactive oxygen species (ROS) and DNA damage (Panagopoulos, 2019; Panagopoulos et al., 2021).

Myth: Wireless radiation is not a carcinogen. The classification by the WHO International Agency for Research in Cancer of wireless radio frequency as a Class 2B "Possible Carcinogen" simply means wireless radiation like talcum powder or picked vegetables.

Fact: The WHO International Agency for Research on Cancer (IARC) concluded that RFR was a Group 2B "possible" carcinogen was largely based on human studies that found long term cell phone users had increased risk for tumors- glioblastomas and acoustic neuromas (WHO/ IARC 2011). The scientific documentation for the determination was compiled in a 2013 monograph (IARC 2013).

In 2011, there was limited animal evidence demonstrating carcinogenicity and this is one of the reasons the WHO/IARC designation was not stronger. However, since that date, two large scale animal studies have found increased tumors demonstrating carcinogenicity in laboratory animals exposed to both near field (cell phone) and far field (cell tower) exposures (Falconi, 2018; NTP, 2018). The tumor types found in the recent animal studies, glioma and schwannoma, are similar to those associated with the use of wireless phones, glioma and acoustic neuroma (vestibular schwannoma), in human epidemiological studies (Hardell, 2018). Thus, the WHO/IARC advisory group recommended RFR be re-evaluated as a "high priority" within 5 years due - largely in part- to the recent animal research findings positive for cancer (IARC, 2019). IARC has not reviewed the research since 2011.

Fact: The WHO/IARC Director recommended people reduce exposure after the 2011 classification.

"Given the potential consequences for public health of this classification and findings it is important that additional research be conducted into the long-term, heavy use of mobile phones. Pending the availability of such information, it is important to take pragmatic measures to reduce exposure such as hands-free devices or texting," stated WHO/IARC Director Christopher Wild Press Release from WHO/IARC classification

Fact: The research linking RFR to cancer has increased since 2011.

Several scientists, several of whom notably *served* ***on*** *the WHO/IARC EMF working group in 2011*, reviewed the findings of the NTP as well as other recent studies and now conclude the evidence is adequate for the International Agency for Research to conclude that cell phone radiation is a probable carcinogen and even a proven Group 1 human carcinogen (Miller et al., 2018; Peleg et al., 2018; Carlberg and Hardell 2017; Belpomme et al., 2018; Melnick, 2019; Portier, 2021; Lin, 2019; Directorate-General for Parliamentary Research Services (European Parliament) & Belpoggi, 2021).

There are publications which conclude that Bradford Hill criteria for carcinogenicity is met (Carlberg and Hardell 2017, Peleg et al 2018) meaning that yes, radiofrequency radiation can cause cancer.

Hardell and Carlberg 2018 comments that the NTP findings allow the following conclusion “there is clear evidence that RF radiation is a human carcinogen, causing glioma and vestibular schwannoma (acoustic neuroma). There is some evidence of an increased risk of developing thyroid cancer, and clear evidence that RF radiation is a multi-site carcinogen. Based on the Preamble to the IARC Monographs, RF radiation should be classified as carcinogenic to humans, Group 1.”

Professor Lennart Hardell, who notably worked on DDT decades ago, presented his conclusion that RFR met Bradford criteria in a lecture entitled “Using the Bradford Hill viewpoints to evaluate the evidence on RF radiations from mobile phones to head tumors lecture”(Royal Society of Medicine, 2019) at Brunel University, London in October 2016.

Fact: In addition to brain cancer, research also associates RFR with thyroid cancer and breast cancer (Luo et al., 2020, Di Ciaula et al., 2021, Carlberg et al., 2020, Shih et al., 2020, West et al., 2013).

Fact: Research has found that wireless radiation could act as a tumor promoter. It also could combine with other toxic exposures synergistically, amplifying the effects.

Research has found that non ionizing EMF exposure can act synergistically with other environmental pollutants potentiating harmful effects (Kostoff and Lau, 2017). Animal studies have found tumor promoting effects when RFR is combined with a known carcinogen (Lerchl et al., 2015; Tillmann et al., 2010). Animal studies have also found combining lower frequencies of non ionizing electromagnetic fields (ELF-EMF) with known carcinogens can increase tumors (Soffritti et al., 2016, Soffritti et al., 2016).

Additionally, RFR can impact the integrity of the blood-brain barrier that protects the brain from toxic molecules circulating in the blood (Leszczynski et al., 2002; Salford et al., 2003; Sirav & Seyhan, 2011; Sırav & Seyhan, 2016; Tang et al., 2015). It is notable that prenatal and postnatal mobile phone exposure has been linked to greater neurobehavioral effects in children with elevated lead levels (Choi et al., 2017, Byun et al., 2017).

Fact: Cell phone and wireless radiofrequency cannot be compared with talcum powder or pickled vegetables.

First, all agents classified as a Class 2 B carcinogen like wireless radiation, talc and various chemicals are not the same. Other hazards that made it to the list of 2B carcinogens remain the subject of major regulatory attention, including pesticides like DDT and Kepone, industrial materials such as PBBs, carbon black and carbon tetrachloride, jet and diesel fuel, and mercury. The IARC classification is based on weight of evidence, not amount of risk. With any toxic exposure, it takes decades to accumulate enough weight of evidence, meaning enough scientific research and statistics (in human epidemiology this refers to sick people) to show the exposure is toxic.

Regardless, we are now exposed to cell phones and wireless radiation day and night, totally different from talcum powder.

As an example of how long it takes to show an exposure causes cancer, take the case of talcum powder. The talc in talcum powder for years was heavily contaminated with asbestos, which increases the risk of ovarian cancer. In fact, in 2016 Johnson & Johnson was fined to pay $72 million in damages to the family of a woman whose death from ovarian cancer was linked to her use of the company's body powders. According to the Washington Post, more than 1,200 women from across the country are suing Johnson & Johnson for failing to warn consumers of the dangers associated with talc—the mineral used in baby powder.

On June 23, 2020, the Missouri Court of Appeals upheld a jury verdict that Johnson & Johnson's talcum powder caused ovarian cancer in 22 women, and ordered the company to pay $2.1 billion.

On May 19, 2020, Johnson & Johnson announced it was stopping sales of its talc-based baby powder in the U.S. and Canada.

How do they know it is the talcum powder causing ovarian cancer? Answer: the talc was found within the tumors themselves—many of those tumors took 40 years to develop.

Myth: Professor Swanson's brain, the sun and his hot water bottle violate FCC limits.

At the February 7, 2022 New Hampshire House Committee hearing Professor Eric Swanson testified on the behalf of the CTIA Wireless Industry stating (at minute 1:33:00) that, “My brain is a radio transmitter…It violates FCC regulations by about a factor of 10. …The sun violates FCC regulations by about a factor of 16. My hot water bottle violates FCC regulations by about a factor of 50. As you might gather from what I am saying, these regulations are very strict and protect us very well.”

Fact : FCC limits apply to specific frequencies- 300 kHz to 100 GHz.The brain, sun and hot water bottle do not emit telecommunications frequencies in this frequency range. The statement is incorrect and scientifically unsound.

When a radiofrequency engineer measures the RF from a cell tower they do not measure the sun's rays. Even if they were measuring the sun's rays, these types of electromagnetic fields (EMFs) are not the same as artificial EMFs.

Panagopoulos et al 2015 published in the journal Nature explains how man-made EMFs (in comparison to natural EMFs like the sun) are polarized and thus more biologically active.

> “Polarized EMFs/EMR can have increased biological activity, due to: 1) Ability to produce constructive interference effects and amplify their intensities at many locations. 2) Ability to force all charged/polar molecules and especially free ions within and around all living cells to oscillate on parallel planes and in phase with the applied polarized field. Such ionic forced- oscillations exert additive electrostatic forces on the sensors of cell membrane electro-sensitive ion channels, resulting in their irregular gating and consequent disruption of the cell’s electrochemical balance. These features render man-made EMFs/EMR more bioactive than natural non-ionizing EMFs/EMR. This explains the increasing number of biological effects discovered during the past few decades to be induced by man-made EMFs, in contrast to natural EMFs in the terrestrial environment which have always been present throughout evolution, although human exposure to the latter ones is normally of significantly higher intensities/energy and longer durations. Thus, polarization seems to be a trigger that significantly increases the probability for the initiation of biological/health effects.”

The conclusions of Panagopoulos et al 2015 directly address Swanson’s inaccurate claims:

> “The present theoretical analysis shows that polarized man-made EMFs/EMR can trigger biological effects while much stronger and of higher energy (frequency) unpolarized EMFs/Non-Ionizing EMR (e.g. heat, or natural light) cannot. This is the reason why polarized microwave radiation of maximum power 1W emitted by a mobile phone can damage DNA and cause adverse health effects while non-polarized infrared, visible, and ultraviolet radiation from a 100 W light bulb, or ~400 W infrared and visible EMR from a human body cannot.”

Professor Swanson's analogy is solely focused on the heat from the sun and his hot water bottle. Heating is not the only harm. Adverse effects have been found at levels that do not increase heat (Belpomme et al., 2018, Miller et al., 2019, Yakymenko et al., 2015, Schuermann & Mevissen, 2021).

Myth: FCC limits for cell tower radiation emissions are very strict and as Professor Swanson states, "protect us very well."

At the February 7, 2022 New Hampshire House Committee hearing Professor Eric Swanson testified on the behalf of the CTIA Wireless Industry stating of FCC regulations that, "The regulations are extremely strict. I won't give you the numbers…As you might gather from what I am saying these regulations are very strict and protect us very well."

Fact: U.S. limits for radiofrequency radiation from cell tower networks are not strict. They are among the most permissible in the world, meaning the U.S allows RF emissions at levels that are so high – *they would be illegal in many countries.*

Note: When cell tower network RFR limits are discussed, ICNIRP limits are often referenced. For example, India dropped its limits to 1/10th of ICNIRP limits. FCC and ICNIRP cell tower emission limits are very similar so if a country has RF limits "more restrictive than ICNIRP," they are also more restrictive than FCC limits.

Countries which have limits far more stringent than the US include China, Russia, Italy, Switzerland, India and Israel, Turkey, Bulgaria, Brussels Belgium, Chile, Belarus, Serbia, Slovenia, Croatia, Montenegro, Greece, Liechtenstein, Tajikistan, Kazakhstan, Kyrgyzstan, Ukraine, Kuwait, Grand Duchy of Luxembourg, Bosnia Herzegovina, Georgia, Uzbekistan, and the Republic of Moldova.

- Note: Industry lobbied Poland, Lithuania, Italy, Switzerland and Brussels Belgium to weaken their regulations in order to allow more radiation for 5G. In 2020, industry succeeded in Lithuania and Poland. Italy and Switzerland voted no. Now industry has its eyes on Russia, which along with several countries such as China and India has RF limits much stricter lower than the USA.

Fact: When the Italian government considered weakening their RF limits in 2020, U.S. scientists who served in leadership positions in the CDC and at NIH wrote a letter to the lawmakers urging them to maintain their more stringent limits.

Linda Birnbaum PhD, retired Director of the National Institute of Environmental Health Sciences and Chris Portier PhD, former Director of the National Center for Environmental Health, US Centers for Disease Control and Prevention joined Lennart Hardell MD, Professor Department of Oncology, Faculty of Medicine and Health, Örebro University, Devra Davis PhD and several other experts as signatories to a letter to the government of Italy stating, "As senior scientists with relevant experience of EMF/RFR we are writing to you to caution against raising, by 100 times in terms of power density, the 20 year- old, and path- breaking, Exposure Limits for protecting the Italian public from EMF/RFR, and to replace them with the higher exposure limits recommended 20 years ago (and reiterated in 2020) by the private sector body, ICNIRP."

Documentation

- Scientists letter to the Italian government, April 6, 2021
- "Human radio frequency exposure limits: An update of reference levels in Europe, USA, Canada, China, Japan and Korea"
- TU-D Study Group 2, "Strategies and policies concerning human exposure to electromagnetic field, 6th Study Period, 2014-2017"
- GSMA Website on 5G Deployment Policy and EMF RF Limits , GSMA website with Map of SAR and RF limits
- Mary Redmayne (2016) International policy and advisory response regarding children's exposure to radio frequency electromagnetic fields (RF-EMF), Electromagnetic Biology and Medicine, 35:2,

Fact: China and Russia have strict limits because of research indicating non-thermal effects.

In a 2003 International Seminar of the World Health Organization, Dr. Huai Chiang of Zhejiang University School of Medicine, China explained the basis for China's continued strict RF limit rested on science that found a variety of behavioral, neurological, reproductive abnormalities, as well as DNA damage.

"In summary, there are many reports of non-thermal potential health effects from microwave radiation using both in vivo and in vitro, and some of them are cited above. The SAR threshold for the adverse effects in the frequency range from 100 kHz to 10 GHz may be at 0.5 to 1.0 W/kg, rather than 4.0 W/kg. Thus, a whole body average SAR of 0.1 W/kg is chosen as the restriction for occupational exposure, and 0.02 W/kg for general public exposures in the draft of amending China exposure standard"

"The main differences (with ICNIRP) and its own rationale are as follows: (1) ICNIRP guidelines are based on short-term, immediate health effects such as stimulation of peripheral nerves and muscles, and elevated tissue temperature resulting from absorption of energy during exposure to EMF (thermal effects). However, there is a body of literature, which reports that health effects can be shown at such a level of radiation that does not produce heating or stimulation."

- Read Proceedings from Dr. Chiang's presentation *on page 69* of the International EMF Seminar in China: Electromagnetic Fields and Biological Effects Guilin, 2003
- Read Dr. Chiang's Short Summary here.

A 2012 paper documents the scientific evidence such as impacts to the nervous system used to develop the original USSR RF exposure limits and subsequent Russian public health standards- which are more strict than FCC or ICNIRP limits.

According to the The Russian National Committee on Non-Ionizing Radiation Protection, "the following health hazards are likely to be faced in the near future by children who use mobile phones: disruption of memory, decline in attention, diminished learning and cognitive abilities, increased irritability, sleep problems, increase in sensitivity to stress, and increased epileptic readiness. For these reasons, special recommendations on child safety from mobile phones have been incorporated into the current Russian mobile phone standard."

- Read Scientific Basis for the Soviet and Russian Radiofrequency Standards for the General Public

Fact: Wireless companies warn their shareholders of a financial risk should they lose lawsuits or should regulations change regarding radiofrequency radiation. Wireless companies warn their shareholders but they do not warn the users of these products, nor do they warn the people exposed to emissions from their products and infrastructure. These corporate investor warnings by companies such as AT&T, Verizon, Vodaphone and Crown Castle are contained in their Annual Reports filed on Form 10-K (or Form 20-F or 40-F for foreign companies) with the Securities and Exchange Commission (SEC) and they clearly inform shareholders that companies may incur significant financial losses related to electromagnetic fields. Safety is not assured.

- Verizon Wireless warns their shareholders in their 10-K form to the US Securities and Exchange Commission that: "Our wireless business also faces personal injury and wrongful death lawsuits relating to alleged health effects of wireless phones or radio frequency transmitters. We may incur significant expenses in defending these lawsuits. In addition, we may be required to pay significant awards or settlements."
- As another example, Crown Castle states in their 2020 Annual Report, "If radio frequency emissions from wireless handsets or equipment on our communications infrastructure are demonstrated to cause negative health effects, potential future claims could adversely affect our operations, costs or revenues. The potential connection

between radio frequency emissions and certain negative health effects, including some forms of cancer, has been the subject of substantial study by the scientific community in recent years. We cannot guarantee that claims relating to radio frequency emissions will not arise in the future or that the results of such studies will not be adverse to us…If a connection between radio frequency emissions and possible negative health effects were established, our operations, costs, or revenues may be materially and adversely affected. We currently do not maintain any significant insurance with respect to these matters."

- Wireless companies themselves define non-ionizing radiation as a "pollutant". Both AT&T Mobile Insurance (pg. 4) and Verizon Total Mobile Protection(page 10) state that coverage is excluded for pollutants, which are defined as "Any solid, liquid, gaseous, or thermal irritant or contaminant including smoke, vapor, soot, fumes, acid, alkalis, chemicals, artificially produced electric fields, magnetic field, electromagnetic field, sound waves, microwaves, and all artificially produced ionizing or non-ionizing radiation and waste."
- Insurers rank 5G and electromagnetic radiation as a "high" risk, comparing the issue to lead and asbestos. A 2019 Report by Swiss Re Institute, a world leading provider of insurance, classifies 5G mobile networks as a "high", "off-the-leash" risk stating, "Existing concerns regarding potential negative health effects from electromagnetic fields (EMF) are only likely to increase. An uptick in liability claims could be a potential long-term consequence" and "[a]s the biological effects of EMF in general and 5G in particular are still being debated, potential claims for health impairments may come with a long latency."
- US Mobile operators have been unable to get insurance to cover liabilities related to damages from long term exposure to radiofrequency emissions for over a decade.
- Due to the high risk that electromagnetic (EMF) field exposure poses, many insurance companies do not cover electromagnetic fields as standard practice and have very clear "electromagnetic field exclusions." EMFs are classified as a "pollutant" alongside smoke, chemicals and asbestos. A&M Insurance for Medical Professionals – No Coverage for Electromagnetic Fields states "GENERAL INSURANCE EXCLUSIONS: Electromagnetic fields directly or indirectly arising out of, resulting from or contributed to by electromagnetic fields, electromagnetic radiation, electromagnetism, radio waves or noise."

- If you want insurance that will cover EMFs you often have to purchase additional "Pollution Liability" or "Policy Enhancement" coverage.
    - The Electromagnetic Fields Exclusion (Exclusion 32) is a General Insurance Exclusion and is applied across the market as standard. The purpose of the exclusion is to exclude cover for illnesses caused by continuous long-term non-ionising radiation exposure i.e. through mobile phone usage." - CFC Underwriting LTD in London, the UK agent for Lloyd's

- Complete Markets "Electromagnetic Fields (Utilities) Liability Insurance" states: "Classified alongside chemicals, smoke, and asbestos as "pollutants" electromagnetic fields (EMF) poses a high risk to various persons such as users of electrical power, electrical power generating companies, power transmission companies, and large generators. Sources of possible EMF health risks include radio frequencies, extremely low frequencies, and static magnetic fields. In homes, EMF exposures come from electrical appliances. The public has targeted cell phone manufacturers and electric power lines as likely EMF targets. Electromagnetic Fields (Utilities) Liability Insurance is a way for prudent companies to minimize exposure to vexatious litigation and adverse publicity.

- Some insurance companies not only exclude coverage for harm, but also exclude coverage for defense related to recommendations that should or should not have been given. For example, the City of Ann Arbor Michigan Insurance Policy: Electromagnetic Radiation Exclusion not only excludes mitigation and harm from electromagnetic radiation but also excludes paying for the defense of "any supervision, instruction, recommendation, warning or advice given or which should have been given in connection with bodily injury, property damage, abatement and/or mitigation etc. (page 14)

If FCC limits "protect us very well" then why does the New Hampshire Commission Report on 5G conclude to reduce wireless radiation exposure?

- The New Hampshire State Commission 5G Report has 15 recommendations including reducing public exposure to cell phones, wireless devices and ensuring cell network infrastructure antenna setbacks from schools and homes as well as the establishment of establish wireless radiation-free zones.

If FCC limits "protect us very well, then why do scientists conclude with the recommendations to reduce wireless radiation exposure?

- The American Academy of Pediatrics recommends families redice cell phone radiation and states of cell towers that, "An Egyptian study confirmed concerns that living nearby mobile phone base stations increased the risk for developing: headaches, memory problems, dizziness, depression, sleep problems. Short-term exposure to these fields in experimental studies have not always shown negative effects, but this does not rule out cumulative damage from these fields, so larger studies over longer periods are needed to help understand who is at risk. In large studies, an association has been observed between symptoms and exposure to these fields in the everyday environment."

- Roda & Perry, 2014 states, "dearth of legislation to regulate the installation of base stations (cell towers) in close proximity to children's facilities and schools clearly constitutes a human rights concern…"
- Singh and Kappor 2014 conclude, "For the time being, the public should follow the precautionary principle and limit their exposure as much as possible."
- Bandara and Carpenter 2018 recommend a "coordinated international effort" to reduce public exposure.
- Sangun et al., 2015 reviewed effects to the endocrine system (an issue OHA omitted) and concluded that "Although the results are conflicting and cannot be totally matched with humans; there is growing evidence to distress us about the threats of EMF on children."
- Redmayne 2016 concludes "minimum exposure of children to RF-EMF is recommended."
- Miller et al., 2019 concludes, "current knowledge provides justification for governments, public health authorities, and physicians/allied health professionals to warn the population that having a cell phone next to the body is harmful, and to support measures to reduce all exposures to RFR."
- Moon 2020 a review on impacts to children states, "Precautionary approaches are recommended for children…"
- Frank 202 on 5G deployment and children's health concludes, "after reviewing the evidence cited above, the writer, an experienced physician-epidemiologist, is convinced that RF-EMFs may well have serious human health effects...Based on the precautionary principle, the author echoes the calls of others for a moratorium on the further roll-out of 5G systems globally, pending more conclusive research on their safety."

Myth: There is no cumulative effect from cell tower or radiofrequency radiation.

Myth presented at the February 7, 2022 New Hampshire House Hearing after a Representative asks, "What is the cumulative effect of me constantly walking by or living near a cell tower and having it outside by door." Professor Swanson then states, "There actually is no cumulative effect…[he gives an analogy of trying to throw a rock across the river]…There is not enough energy on these 5G waves to disrupt anything and it doesn't matter how long you stand there. It's still not going to disrupt anything for basically the same reason as I said… the rock throwing."

Fact: Research has shown a cumulative effect from exposure. Chronic, low-intensity cumulative exposures have been ignored by standard setting groups. They claim as Professor Swansn does, without independent systematic scientific documentation, that cumulative effects do not exist. Numerous studies show that a longer duration of exposure (i.e more hours or years) increases effects. A one time exposure is different than years and years of exposure.

A comprehensive meta-analysis of case-control studies found significant evidence linking cellular phone use to increased tumor risk, especially among cell phone users with cumulative cell phone use of 1000 or more hours in their lifetime (which corresponds to about 17 min per day over 10 years), and especially among studies that employed high quality methods. (Choi et al., 2020).

The Switzerland Institute of the Environment review which found increased oxidative stress in the majority of animal studies and cell studies (with exposures within regulatory limits) documents how several studies showed "effects can be cumulative with duration of exposure" (Schuermann et al., 2021).

- "After 24 h of exposure with a 1.8 GHz RF-EMF (GSM signal, continuous, or intermittent), an increase in oxidative DNA damage, ROS production, and autophagy activity was observed in GC-2 cells at the highest SAR dose of 4 W/kg [164,169,170,171]. Hence, there is evidence that the increase in ROS production does not occur immediately but with increasing exposure time (>12 h) or cumulative dose [170]."

Studies on people living near cell towers and base station antennas (antennas mounted on buildings) are important in considering cumulative impacts as people are exposed continuously.

A 2018 study "Radiofrequency radiation from nearby base stations gives high levels in an apartment in Stockholm, Sweden: A case report" which documents high RF levels in apartments close to mobile phone base stations on the roof summarized several cell tower studies showing the longer the exposure, the higher the impacts.

- Buchner and Eger studied residents in the village of Rimbach in Germany after a GSM mobile base station was built and found for the participants with RF radiation exposure over 100 μW/m2 at home, 3 neurotransmitters showed a clear dose-response relationship. Phenylethylamine (PEA) levels decreased at first for the highest exposed group, but after 18 months the 3 groups were all statistically significantly decreased. After 18 months, even the lowest exposed group had decreased dopamine and PEA levels. PEA is often low in patients with depression and attention deficit hyperactivity disorder (ADHD). Chronic dysregulation of the catecholamine system and PEA may contribute to chronic illnesses and health problems in the long term.

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The study “How does long term exposure to base stations and mobile phones affect human hormone profiles?” followed participants for 6 years. Blood samples were collected regularly every 3 years for time intervals of 1 year, 3 years and 6 years. They found a reduction in volunteers' plasma ACTH, serum cortisol levels as well as a decrease in the release thyroid hormones. “In addition, each of their serum prolactin in young females (14–22 years), and testosterone levels significantly dropped due to long-term exposure to radio frequency radiation. Conversely, serum prolactin levels for adult females (25–60 years) significantly rose with increasing exposure time.” The researchers concluded that, “The intensity and frequency of RFR and exposure duration are important determinants of the cumulative effect that could occur and lead to an eventual breakdown of homeostasis and adverse health consequences. Therefore, greater commitment from policy makers, health care officials and providers is needed to raise public awareness about the hazardous outcomes of long term exposure to RFR.”

Additional documentation

- A large-scale animal study from the Ramazzini Institute used RF exposure levels similar to those from a mobile phone base station. They exposed rats to levels (lower than FCC limits) every day until their death. The study found increases in tumors (Falcioni et al., 2018).
- A study carried out by the Municipal Government of Belo Horizonte along with 3 Universities located in Brazil looked at death records, telecommunications records and city population data. The results found higher mortality rates were exhibited for the residents inside a radius of 500 meters from cellular telephone base stations. In fact, there were 14 times more deaths within a 500 meter radius than outside 500 meters.
- A 2018 review Effect of radiofrequency radiation on reproductive health concludes that “available data indicate that exposure to EMF can cause adverse health effects. It is also reported that biological effects may occur at very low levels of exposure. The RFR effect can be more intensified based on the range and duration of the exposure.”
- A study on 4G found kidney inflammation in mice was higher in the mice exposed for 60 minutes compared to 40 minutes (Hasan et al., 2021.) “It is concluded that fourth-generation cell phone radiation exposure may affect blood hemostasis and inflammation of mice's kidney and testis tissue. Based on these studies, it is important to increase public consciousness of potential adverse effects of mobile phone radiofrequency electromagnetic radiation exposure.”

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Myth: The majority of studies on RF show no harm. The WHO found only 5% of 25,000 studies showed harmful effects but that is the false positive rate.

Myth in Professor Swanson's testimony to New Hampshire Lawmakers in February 7, 2022 Hearing:

- A Representative asked, "We just heard some testimony about bio effects…Voltage gated channels being disrupted… I wonder if you have any impressions…"
- Professor Swanson responded, "I hear about this all the time, it's all wrong, all of it. And I want to explain why this even exists. The medical industry standard for conducting a study is to work at 5 percent false positive level, it's called alpha."
- Swanson continued, "All medical studies desire to have a 5% false positive level. Meaning that if you run a hundred studies, five of them are going to find something. That's the definition of a false positive level. Twenty five thousand studies have been done estimated by the World Health Organization. 5 percent of that is about a thousand. About a thousand studies are going to find something."
- Swanson summarized that, "Now what do they find? It's random, remember. It's a false positive rate. So they find random stuff and it's all over the map. And the reason it's all over the map and the reason you get such a long laundry list of disastrous things is because it's random. When people focus on these thousand studies -the five percent- they are ignoring the 95% of studies that don't find any effect whatsoever. Its natural instinct of course to just - oh that agrees with my viewpoint, i'm going to pay attention to that. And ignore the 95% that disagrees with you. That's what underpins all of this stuff."

Fact #1: Numerous reviews and analysis have found the majority of studies for various endpoints do show effects. Professor Swansons reference to 25,000 is based on an unknown statement (?) and is not based on any up to date analysis. We hope that Professor Swanson will be asked for scientific substantiation for his statement.

Numerous analyses of studies have found the majority of studies evaluated show effects.

1.The respected journal Lancet Planetary Health published Bandara and Carpenter 2018 that states: "A recent evaluation of 2,266 studies (including in-vitro and in-vivo studies in human, animal, and plant experimental systems and population studies) found that most studies (n=1546, 68·2%) have demonstrated significant biological or health effects associated with exposure to anthropogenic electromagnetic fields. We have published our preliminary data on radiofrequency electromagnetic radiation, which shows that 89% (216 of 242) of experimental studies that investigated oxidative stress endpoints showed significant effects. This weight of scientific evidence refutes the prominent claim that the deployment of wireless technologies poses no health risks at the currently permitted non-thermal radiofrequency exposure levels."

2. A November 18, 2021 letter from Cindy Sage, M.A., David O. Carpenter, MD., Lennart Hardell, M.D., Ph.D., Prof. Henry Lai, Ph.D. documents the majority of recent studies show effects concluding that the "research published over the last two years has added significant additional weight to the body of evidence which indicates that FCC public safety exposure limits are grossly inadequate to protect public health given the proliferation of RFR-emitting devices now in common usage."

- "When the cumulative body of evidence is assessed over the last decades of research, the overall picture for studies on radiofrequency radiation effects shows clear and consistent patterns of effects on living tissues. Chronic RFR exposures at environmental levels common today can reasonably be presumed to produce health harm at and below current FCC safety limits for humans and should be substantially lowered."
    - Neurological effects: Effect= 74% (271 studies); No Effect= 26% (97 studies) (literature up to November 12, 2021)
    - Oxidative effects: Effect= 92% (258 studies); No Effect= 8% (23) studies) (literature up to November 12, 2021)"
    - Genetic effects: Effect= 67% (259 studies); No Effect= 33% (129 studies) (literature up to November 12, 2021)

3. Earlier in 2020, Henry Lai PhD updated his reports on published studies finding effects from RFR and non ionizing radiation. He posted this analysis as well as all the abstracts for the studies.

- Neurological RFR studies report effects in 73 % of studies on RF radiation -- or 244 of 336 studies. (Bioinitiative 2020).
- Genetic effect studies report effects in 65 % of studies on RF radiation -- or 224 of 346 studies (Bioinitiative 2020).
- Free Radical (Oxidative Damage) effect studies report effects in 91 % of studies on RF radiation -- or 240 of 261 studies (Bioinitiative 2020).
- RFR Comet Assay effect studies report effects in 65 % of studies on RF radiation -- or 78 of 125 studies (Bioinitiative 2020).

4. Numerous published reviews confirm and corroborate such evaluations.

- For example, the Switzerland Institute of the Environment expert published review found increased oxidative stress in the majority of animal studies and cell studies with exposures within regulatory limits (Schuermann et al., 2021).
- An earlier review (Yakymenko et al 2016) on oxidative stress concluded 93 of 100 studies found oxidative effects.
- Recent systematic reviews find harm to sperm (Sungjoon et al, 2021, Yu et al., 2021, Kim et al., 2021) corroborating earlier reviews that concluded harm to sperm (Adams et al 2014, Houston et al 2016, Liu et al 2014).

Additional Comments on the CTIA Testimony

The CTIA has created a false impression of safety with true statements and industry tied conclusions. Here are some examples.

1.The CTIA presents conclusions of so-called authorities neglecting to mention the reports are well outdated, authored by scientists known to have conflicts of interest and some of the organizations are even defunct.

The CTIA states, "Likewise both the United Kingdom Health Protection Agency Independent Advisory Group on Non ionizing Radiation and the Swedish Council for Working Life and Social Research agree that RF exposure below guideline levels consistent with FCC limits do not cause health effects."

- The CTIA Footnote goes to two reports *from 2012.*
- The United Kingdom Health Protection Agency Independent Advisory Group on Non ionizing Radiation *no lon*ger exists. The CTIA has it as a link to the wayback machine. The incorrect and misleading statements as serious conflicts of interest of the group is documented in a published paper entitled, "Inaccurate official assessment of radiofrequency safety by the Advisory Group on Non-ionising Radiation" (Starkey 2016). (Watch a video of Dr. Starkey presenting her research/Download Dr. Starkey's PPT).
- The Swedish Swedish Council for Working Life 2012 Report that the CTIA references (found here) was was authored by 4 scientists: Professor Ahlbom was officially removed from WHO/IARC's Expert Working Group on RF the day before the meeting began, due to conflicts-of-interests as he found to be a member of the Board of Directors of Gunnar Ahlbom AB, a lobby group headed by his brother Gunnar Ahlbom that represented the interest of the leading Swedish mobile phone operator TeliaSonera, among others; Maria Feychting also has a long history of industry ties.

Additional Resources

Policy

- New Hampshire State Commission 5G Report
- Pittsburgh Law Review: The FCC Keeps Letting Me Be: Why Radiofrequency Radiation Standards Have Failed to Keep Up With Technology, 2021
- The Harvard Press Book "Captured Agency: How the Federal Communications Commission is Dominated by the Industries it Presumably Regulates"
- FCC's Legal Duties to Inform and Protect the Public by Sharon Buccino Natural Resources Defense Council Washington- an overview of some of the key legal principles that affect the authorization of wireless services and the construction of the networks needed to provide these services.

Santa Clara Medical Association Magazine Articles

- "Wireless Silent Spring"
- "A 5G Wireless Future: Will it give us a Smart Future"
- "Wi-Fi in Schools Are We Playing It Safe With Our Kids?" **PDF**
- **"**Shallow Minds: How the Internet and Wi-F in Schools Can Affect Learning"

Investigative Reports

- Santa Fe New Mexican, Report says wireless radiation may harm wildlife, Scott Wyland
- The Journal of Scientific Practice and Integrity, Experts Blast David Robert Grimes for His Failure to Understand Science and Love of Self-Citation, January 18, 2022
    - Also published in Disinformation Chronicle "Experts Blast David Robert Grimes for His Failure to Understand Science and Love of Self-Citation"
- Wireless Hazards by Barbara Koepell in the Washington Spectator
- "Is Wireless Technology an Environmental Health Risk?" Society of Environmental Journalists Journal
- The Harvard Press Book "Captured Agency: How the Federal Communications Commission is Dominated by the Industries it Presumably Regulates"
- Investigate Europe's Three Part Investigation on 5G
    - "The ICNIRP Cartel: Who's Who in the EMF Research World
    - 5G The Mass Experiment (Part 1)
    - How Much is Safe? Finances Effect Research (Part 2)
    - Real 5G issues overshadowed by Covid-19 conspiracy theories (Part 3)

- A report released by European Members of Parliament "The International Commission on Non-Ionizing Radiation Protection: Conflicts of Interest, Corporate Capture and the Push for G." (PDF)

- "How Big Wireless Made Us Think That Cell Phones Are Safe: A Special Investigation: The Disinformation Campaign—And Massive Radiation Increase—Behind The 5G Rollout" by Mark Hertsgaard And Mark Dowie in The Nation April 23, 2018
- NPR, On Point "The Connection Between Cellphones And Cancer" April 5, 2018
- KALW News "The Nation investigates how big wireless made us think that cell phones are safe"
- Is 5G Going to Kill Us. The New Republic by Christopher Ketcham
- Seattle Magazine, "UW Scientist Henry Lai Makes Waves in the Cell Phone Industry." Seattle Magazine on Motorola working to create doubt and attack Dr. Lai's research finding DNA damage.
- We Have No Reason to Believe 5G is Safe. Scientific American, by Joel Moskowitz PhD
- There's a clear cell phone-cancer link, but FDA is downplaying it. The Hill, Ronald Melnick, Ph.D.
- Alternet: What the Cellphone Industry Doesn't Want You to Know About Radiation Concerns: A leading expert goes to battle against a multi-trillion-dollar industry.
- Today Show: Pediatricians' New Warning: Limit Children's Exposure to Cellphones

Nerve Cell Damage in Mammalian Brain after Exposure to Microwaves from GSM Mobile Phones

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The possible risks of radio-frequency electromagnetic fields for the human body is a growing concern for our society. We have previously shown that weak pulsed microwaves give rise to a significant leakage of albumin through the blood–brain barrier. In this study we investigated whether a pathologic leakage across the blood–brain barrier might be combined with damage to the neurons. Three groups each of eight rats were exposed for 2 hr to Global System for Mobile Communications (GSM) mobile phone electromagnetic fields of different strengths. We found highly significant ($p < 0.002$) evidence for neuronal damage in the cortex, hippocampus, and basal ganglia in the brains of exposed rats. *Key words:* blood–brain barrier, central nervous system, microwaves, mobile phones, neuronal damage, rats. *Environ Health Perspect* 111:881–883 (2003). doi:10.1289/ehp.6039 available via *http://dx.doi.org/* [Online 29 January 2003]

The voluntary exposure of the brain to microwaves from hand-held mobile phones by one-fourth of the world's population has been called the largest human biologic experiment ever (Salford et al. 2001). In the near future, microwaves will also be emitted by an abundance of other appliances in the cordless office and also in the home. The possible risks of radio-frequency electromagnetic fields (RF EMFs) for the human body is a growing concern for our society (for a review, see Hyland 2000). Most researchers in the field have dwelled on the question of whether RF EMFs may induce or promote cancer growth. Although some have indicated increased risk (Hardell et al. 2002; Repacholi et al. 1997), most studies, including our own, have shown no effects (Salford et al. 1997a) or even a decreased risk (Adey et al. 1999).

The possible risks of microwaves for the human body has attracted interest since the 1960s (i.e., before the advent of mobile phones), when radar and microwave ovens posed a possible health problem. Oscar and Hawkins (1977) performed early studies on effects of RF EMFs on the blood–brain barrier. They demonstrated that at very low energy levels (< 10 W/m^2), the fields in a restricted exposure window caused a significant leakage of ^{14}C-mannitol, inulin, and also dextran (same molecular weight as albumin) from the capillaries into the surrounding cerebellar brain tissue. These findings, however, were not repeated in a study using ^{14}C-sucrose (Gruenau et al. 1982). A recent *in vitro* study has shown that EMF at 1.8 GHz increase the permeability of the blood–brain barrier to sucrose (Schirmacher et al. 2000). Shivers and colleagues (Shivers et al. 1987; Prato et al. 1990) examined the effect of magnetic resonance imaging upon the rat brain. They showed that the combined exposure to RF EMFs and pulsed and static magnetic fields gave rise to a significant pinocytotic transport of albumin from the capillaries into the brain.

Inspired by this work, since 1988 our group has studied the effects of different intensities and modulations of 915 MHz RF EMFs in a rat model where the exposure takes place in a transverse electromagnetic transmission line chamber (TEM-cell) during various time periods. In series of more than 1,600 animals, we have proven that subthermal power densities from both pulse-modulated and continuous RF EMFs—including those from GSM (Global System for Mobile Communications) mobile phones—have the potency to significantly open the blood–brain barrier such that the animals' own albumin (but not fibrinogen) passes out of the bloodstream into the brain tissue and accumulates in the neurons and glial cells surrounding the capillaries (Malmgren 1998; Persson et al. 1997; Persson and Salford 1996; Salford et al. 1992, 1993, 1994, 1997b, 2001) (Figure 1). These results have been duplicated recently in another laboratory (Töre et al. 2001). Similar results have been reported by others (Fritze et al. 1997).

We and others (Oscar and Hawkins 1977; Persson et al. 1997) have pointed out that when such a relatively large molecule as albumin can pass the blood–brain barrier, so too can many other smaller molecules, including toxic ones, which may escape into the brain because of exposure to RF EMFs. We have hitherto not concluded that such leakage is harmful for the brain. However, Hassel et al. (1994) have shown that autologous albumin injected into the brain tissue of rats leads to damage to neurons at the injection site when the concentration of albumin in the injected solution is at least 25% of that in blood. In the present study, we investigated whether leakage across the blood–brain barrier might cause damage to the neurons.

Materials and Methods

TEM-cells used for the RF EMF exposure of rats were designed by dimensional scaling from previously constructed cells at the National Bureau of Standards (Crawford 1974). TEM-cells are known to generate uniform electromagnetic fields for standard measurements. A genuine GSM mobile phone with a programmable power output was connected via a coaxial cable to the TEM-cell; no voice modulation was applied.

The TEM-cell is enclosed in a wooden box (15 × 15 × 15 cm) that supports the outer conductor and central plate. The outer conductor is made of brass net and is attached to the inner walls of the box. The center plate, or septum, is constructed of aluminum.

The TEM-cells were placed in a temperature-controlled room, and the temperature in the TEM-cells was kept constant by circulating room air through holes in the wooden box.

The specific absorption rate (SAR) distribution in the rat brain has been simulated with the finite-difference time-domain method (Martens et al. 1993) and found to vary < 6 dB in the rat brain.

The rats were placed in plastic trays (12 × 12 × 7 cm) to avoid contact with the central plate and outer conductor. The bottom of the tray was covered with absorbing paper to collect urine and feces.

Thirty-two male and female Fischer 344 rats 12–26 weeks of age and weighing 282 ± 91 g were divided into four groups of eight rats each. The peak output power of 10 mW, 100 mW, and 1,000 mW per cell from the GSM mobile telephone was fed into two TEM-cells simultaneously for 2 hr. This exposed the rats to peak power densities of 0.24. 2.4, and 24 W/m^2, respectively. This exposure resulted in average whole-body SARs of 2 mW/kg, 20 mW/kg, and 200 mW/kg, respectively. For further details about exposure conditions and SAR calculations, see Martens et al. (1993) and Malmgren (1998). The fourth group of rats was simultaneously

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We thank S. Strömblad and C. Blennow at the Rausing Laboratory for excellent technical assistance.

The work was supported by a grant from the Swedish Council for Work Life Research.

The authors declare they have no conflict of interest.

Received 4 October 2002; accepted 28 January 2003.

kept for 2 hr in nonactivated TEM-cells. The animals were awake during the exposure and could move and turn within the exposure chamber.

The animals in each exposure group were allowed to survive for about 50 days after exposure. They were carefully observed daily for neurologic and behavioral abnormalities during this period, at the end of which they were anesthetized and sacrificed by perfusion fixation with 4% formaldehyde.

The brains were removed from the skull by nontraumatic technique (resection of bone structures at the skull base, followed by a midline incision from the foramen magnum to the nose) after an extended *in situ* postmortem fixation time of 30 min. Each brain was sectioned coronally in 1–2-mm-thick slices, which all were embedded in paraffin, cut in 5-µm sections, and stained for RNA/DNA with cresyl violet to show dark neurons. Applying albumin antibodies (Dakocytomation Norden AB, Älvsjö, Sweden) reveals albumin as brownish spotty or more diffuse discolorations (Salford et al. 1994).

The occurrence of "dark neurons" was judged semiquantitatively by the neuropathologist as 0 (no or occasional dark neurons), 1 (moderate occurrence of dark neurons), or 2 (abundant occurrence). The microscopic analysis was performed blind to the test situation. The Kruskal-Wallis one-way analysis of variance by ranks was used for a simultaneous statistical test of the score distributions for the four exposure conditions. When the null hypothesis could be rejected, comparisons between controls and each of the exposure conditions was made with the Mann-Whitney nonparametric test for independent samples.

Results and Discussion

Controls and test animals alike showed the normal diffuse positive immunostaining for albumin in hypothalamus, a kind of built-in method control.

Control animals showed either no positivity or an occasional and often questionable positivity for albumin outside the hypothalamus (Figure 1A). In one control animal we observed a moderate number of dark neurons, but no such change was observed in all the other controls.

Exposed animals usually showed several albumin-positive foci around the finer blood vessels in white and gray matter (Figure 1B). Here the albumin had spread in the tissue between the cell bodies and surrounded neurons, which either contained no albumin or contained albumin in some foci. Scattered neurons, not associated with albumin leakage between the neurons, were also positive.

The cresyl violet staining revealed scattered and grouped dark neurons, which were often shrunken and darkly stained, homogenized with loss of discernible internal cell structures. Some of these dark neurons were also albumin positive or showed cytoplasmic microvacuoles indicating an active pathologic process. There were no hemorrhages and no discernible glial reaction, astrocytic or microglial, adjacent to changed neurons. Changed neurons were seen in all locations, but especially the cortex, hippocampus, and basal ganglia, mixed in among normal neurons (Figure 2). The percentage abnormal neurons is roughly appreciated to be maximally around 2%, but in some restricted areas they dominated the picture.

The occurrence of dark neurons under the different exposure conditions is presented in Figure 3, which shows a significant positive relation between EMF dosage (SAR) and number of dark neurons.

A combined nonparametric test for the four exposure situations simultaneously revealed that the distributions of scores differed significantly between the groups ($p < 0.002$).

We present here for the first time evidence for neuronal damage caused by nonthermal microwave exposure. The cortex as well as the hippocampus and the basal ganglia in the brains of exposed rats contained damaged neurons. We realize that our study comprises few animals, but the combined results are highly significant and exhibit a clear dose–response relation.

We considered the observed dark neurons not to be artifacts for the following reasons: first, the brains were removed atraumatically and perfusion fixed *in situ*; second, the dark

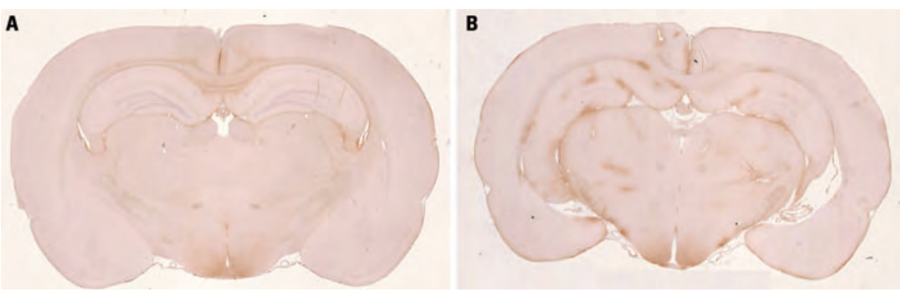

Figure 1. Cross-section of central parts of the brain of (*A*) an unexposed control rat and (*B*) an RF EMF-exposed rat, both stained for albumin, which appears brown. In (*A*), albumin is visible in the central inferior parts of the brain (the hypothalamus), which is a normal feature. In (*B*), albumin is visible in multiple small foci representing leakage from many vessels. Magnification, about ×3.

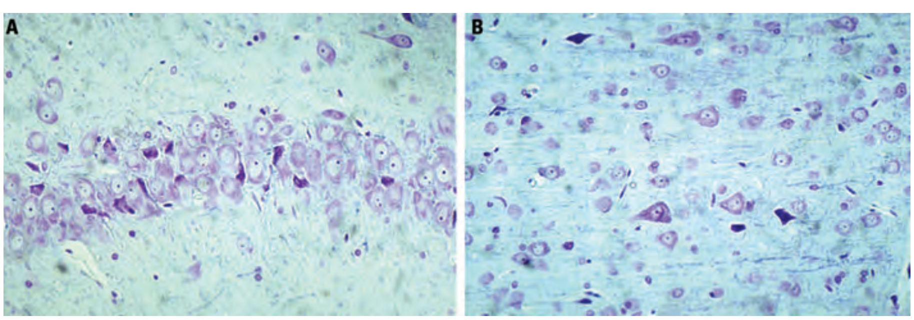

Figure 2. Photomicrograph of sections of brain from an RF EMF-exposed rat stained with cresyl violet. (*A*) Row of nerve cells in a section of the pyramidal cell band of the hippocampus; among the normal nerve cells (large cells) are interspersed black and shrunken nerve cells, so-called dark neurons. (*B*) The cortex, top left, of an RF EMF-exposed rat showing normal nerve cells (pale blue) intermingled with abnormal, black and shrunken "dark neurons" at all depths of the cortex, but least in the superficial upper layers. Magnification, ×160.

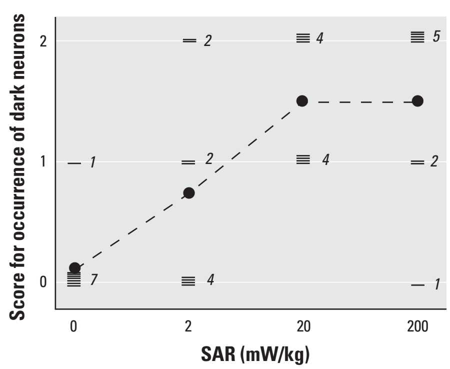

Figure 3. Distribution of scores for the occurrence of "dark neurons" as a function of exposure condition. The dashed line connects mean values for each condition. Numbers in the figure indicate the number of animals in the treatment group with that score. A simultaneous nonparametric comparison of all four conditions revealed significant differences ($p < 0.002$). As compared to control, $p < 0.2$ for 2 mW/kg; $p = 0.01$ for 20 mW/kg; and $p = 0.03$ for 200 mW/kg.

neurons were intermingled with normal-appearing neurons (see Figure 2). Also, the presence of vacuoles in several of the dark neurons is a clear sign that damage occurred in the living animal. We cannot exclude that the neuronal change described may represent apoptotic cell death.

The neuronal albumin uptake and other changes described would seem to indicate serious neuronal damage, which may be mediated through organelle damage with release of not only hydrolytic lysosomal enzymes but also, for example, sequestered harmful material, such as heavy metals, stored away in cytoplasmic organelles (lysosomes).

The time between last exposure and sacrifice is of great importance for the detection of foci of leakage because extravasated albumin rapidly diffuses down to, and beyond, concentrations possible to demonstrate accurately immunohistologically. However, the initial albumin leakage into the brain tissue (seen within hours in ~40% of exposed animals in our previous studies) may start a secondary blood–brain barrier opening, leading to a vicious circle—because we demonstrate albumin leakage even 8 weeks after the exposure.

We chose 12–26-week-old rats because they are comparable with human teenagers—notably frequent users of mobile phones—with respect to age. The situation of the growing brain might deserve special concern from society because biologic and maturational processes are particularly vulnerable during the growth process. The intense use of mobile phones by youngsters is a serious consideration. A neuronal damage of the kind described here may not have immediately demonstrable consequences, even if repeated. In the long run, however, it may result in reduced brain reserve capacity that might be unveiled by other later neuronal disease or even the wear and tear of aging. We cannot exclude that after some decades of (often) daily use, a whole generation of users may suffer negative effects, perhaps as early as in middle age.

Correction

Figure 1 in the original manuscript was cited in "Materials and Methods" and illustrated albumin leakage that we had reported earlier. The figure showed examples of cross-sections of the brains of rats sacrificed immediately after exposure to microwaves. Because this could be misunderstood, in the interest of clarity and with the permission of the editor, we have replaced that figure.

The new Figure 1 is now cited in "Results" and shows animals from the present study. Figure 1A illustrates the brain of a sham-exposed control animal, and Figure 1B illustrates an animal exposed to 2 mW/kg for 2 hr.

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Scientific and Policy Developments in Radiofrequency Radiation

December 2019 through November 29, 2021

Selected Research Publications Showing Adverse Effects Since the FCC Issued its Determination December 2019 Not to Update its 1996 Standards for Evaluating Wireless Radiation from Cell Phones, Electronic Devices and Networks

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New Scientific and Policy Developments in Radiofrequency Radiation

A Sampling of Research Publications Showing Adverse Effects Since the FCC Issued its Determination Not to Update its 1996 Standards for Evaluating Wireless Radiation from Cell Phones, Electronic Devices and Networks

More than 75 new important scientific developments, expert reports and recommendations have been published since the FCC issued its determination to not initiate a rulemaking proceeding to update its regulatory limits for human exposure to wireless radiofrequency radiation (RFR) in December 2019.

This report showcases a small sampling of the last two years of scientific publications that have documented adverse effects of RFR exposure. Studies include impacts to wildlife and the environment, the unique vulnerability of children and the fetus, DNA damage, oxidative stress, nervous and reproductive system impacts and brain development. New experimental and epidemiological evidence for cancer tied to RFR has been published as well as papers detailing how cancers can arise from non-ionizing radiation.

Further, recent publications have documented significant health and environmental implications arising from 5G network related millimeter wave frequencies and all current and new wireless air interfaces' use of modulation, pulsation and other waveform manipulation. Wireless telecommunications signals are complex and FCC regulations do not address the biological impact of different modulations nor consider the numerous unique characteristics of real world telecommunication signals. We highlight how new landmark papers document the science indicating the urgent need to consider modulation and pulsation, rather than simply power density.

The evidence is now clear that RF emissions within the Commission's guidelines have significant negative adverse biological effects.

WILDLIFE/ENVIRONMENT

The FCC's current FCC radiofrequency radiation (RFR) emissions limits apply to human exposures.They do not address wildlife, plants or trees. Birds perch and nest on cell towers. Bats and bees and other airborne species occupy air space in close proximity to transmitting cell antennas. Wireless network densification increases RFR levels (El-Hajj & Naous, 2020) and with over 800,000 new cell sites projected[1] for the 5G buildout, environmental effects need to be properly examined because ambient RFR is increasing in wildlife habitat.

A landmark three-part research review on effects to wildlife was published in R*eviews on Environmental Health in 2021* by U.S experts, including former U.S. Fish and Wildlife senior biologist Albert Manville. The authors reviewed and cited more than 1,200 scientific references. These experts concluded that the evidence was adequate to trigger urgent regulatory action. The review found adverse biological effects to wildlife from even very low intensity non-ionizing

[1] Remarks of FCC Chairman Ajit Pai White House 5G Summit Washington DC, September 28, 2018

radiation emissions at multiple orders of magnitude below current FCC-allowed levels (Levitt et al., 2021a, Levitt et al., 2021b, Levitt et al., 2021c).

Comprehensive documentation of the biological effects of non-ionizing electromagnetic radiation to flora and fauna has never before been undertaken to this degree in any previous publication. These three experts divide their science and findings with urgent warnings into three parts: **Part 1** identifies ambient EMF adverse effects on wildlife, and notes a particular urgency regarding millimeter wave emissions and the pulsation/modulation used in 5G technologies. **Part 2** explores natural and man-made fields, animal magnetoreception mechanisms, and pertinent studies to all wildlife kingdoms. **Part 3** examines current exposure standards, applicable laws, and future directions. Their conclusions after this expansive review of the science are neither equivocal nor speculative. This environmental research review is a clarion call to develop regulations that ensure wildlife and its habitat are protected. The abstract summarizes the findings:

> "Numerous studies across all frequencies and *taxa* indicate that low-level EMF exposures have numerous adverse effects, including on orientation, migration, food finding, reproduction, mating, nest and den building, territorial maintenance, defense, vitality, longevity, and survivorship. Cyto-toxic and geno-toxic effects have long been observed. It is time to recognize ambient EMF as a novel form of pollution and develop rules at regulatory agencies that designate air as 'habitat' so EMF can be regulated like other pollutants. Wildlife loss is often unseen and undocumented until tipping points are reached. A robust dialog regarding technology's high-impact role in the nascent field of electroecology needs to commence. Long-term chronic low-level EMF exposure standards should be set accordingly for wildlife, including, but not limited to, the redesign of wireless devices, as well as infrastructure, in order to reduce the rising ambient levels."

Numerous individual studies on impacts to flora and fauna have been published over the last two years, notably several on pollinators and insects.

Two studies used scientific simulations to quantify the amount of power absorbed into the bodies of various insects for different RFR frequencies. In January 2020 researchers published "Radio-frequency electromagnetic field exposure of Western Honey Bees" in *Scientific Reports* on the absorption of RFR into honey bees at different developmental stages with phantoms simulating worker bees, a drone, a larva, and a queen (Thielens et al., 2020). The simulations were combined with measurements of environmental RF-EMF exposure near beehives in Belgium in order to estimate realistic exposures. They found absorbed RF-EMF power increases by factors of up to 16 to 121 when the frequency is increased from 0.6 GHz to 6 GHz for a fixed incident electric field strength. The implications of the impacts to such an ecologically and economically important insect species bees would be widespread and consequential.

In October 2021 a second simulation study with far-reaching implications "Radio-frequency exposure of the yellow fever mosquito (*A. aegypti*) from 2 to 240 GHz" published in *PLOS Computational Biology* simulated the far field exposure of a mosquito between 2 and 240 GHz and found power absorption is 16 times higher at 60 GHz than at 6 GHz at the same incident field strength. This increase is even larger (by a factor of 21.8) for 120 GHz when compared to 6 GHz. The authors conclude "higher absorption of EMF by yellow fever mosquitoes, which can cause dielectric heating and have an impact on behaviour, development and possibly spread of the insect."

In 2020, a report by Alain Hill of the biological effects of non-ionizing radiation on insects found that mobile communications were a critical factor in weakening the insect world along with pesticides and habitat loss. (Khan et al., 2021) found the Apis Cerana bee becomes very passive at a certain level of frequencies and power.

In May 2021, biologistb Alfonso Balmori published "Electromagnetic radiation as an emerging driver factor for the decline of insects" in *Science of The Total Environment. concluding* that electromagnetic radiation threatens insect biodiversity worldwide. He documents sufficient evidence of non-thermal, effects of non-ionizing radiation on insects at levels well below the limits allowed by FCC guidelines, and warns that action must be taken now before significant deployment of new technologies (like with 5G) is undertaken. He cautions that the loss of insect diversity and abundance will likely provoke cascading effects on food webs and ecosystem services.

A November 2021 review of the effects of millimeter waves, ultraviolet, and gamma rays on plants found many non-thermal effects specifically from millimeter waves (Zhong et al. 2021). (The paper examined the millimeter range 30 to 300 GHz which overlaps with FCC's limits 300 kHz to 100 GHz.) Millimeter-wave irradiation stimulated cell division, enzyme synthesis, growth rate, and biomass. The review highlights how different doses and durations provoked dynamic morphophysiological effects in plants. Seed pretreatment with weak microwaves or millimeter wave irradiation altered root physiology. Different effects were observed in different plants and the authors state that, "the discordance of proteomic changes in different plants is reasonable, since different plants have a distinct tolerance to stress. Moreover, the cell tissues from soybeans and chickpeas used for proteomic analysis were different, which implies that tissue-specific or organ-specific responses of plants under millimeter-wave irradiation might exist and require further investigation." This review adds to the published analysis confirming non thermal effects from RFR. While these frequencies may have beneficial uses in agriculture, the adverse impact to trees and plants in close vicinity to transmitting antennas must be addressed.

CHILDREN

Children are proportionally more exposed to RF-EMF than adults because their brain tissue is more conductive, their skulls are thinner, and their bodies are smaller. Children are known to be at greater risk than adults when exposed to any carcinogen because of their rapidly dividing cells. Because the average latency time between first exposure and diagnosis of a tumor can be decades, tumors induced in children from RFR may not be diagnosed until adulthood. Even more importantly, children and the developing fetus are more vulnerable to RFR because their brains and organs are still developing and more sensitive. Research over the last two years has added critical new science on children's vulnerability to health impacts from RFR and supports the acute need to reduce exposures..

To start, the Environmental Working Group published a landmark study in *Environmental Health* analyzing the findings of increased tumors and heart damage from the National Toxicology Program study and concluded that FCC limits should be strengthened by 200 to 400 times to protect children according to current risk assessment guidelines (Uche, 2021). "The analysis presented here supports a whole-body SAR limit of 2 to 4 mW/kg for adults, an exposure level that is 20- to 40-fold lower than the legally permissible limit of 0.08 W/kg for whole-body SAR under the current U.S. regulations. A ten-fold lower level of 0.2–0.4 mW/kg whole-body SAR may be appropriate for young children. Both technology changes and behavior changes may be necessary to achieve these lower exposure levels. Simple actions, such as keeping the wireless devices farther away from the body, offer an immediate way to decrease RFR exposure for the user."

(Cabré-Riera et al., 2020) investigated RFR doses in preadolescents at 9 – 12 years old. In "Estimated whole-brain and lobe-specific radiofrequency electromagnetic fields doses and brain volumes in preadolescents" published in *Environment International* the authors reveal their findings that although whole-brain and lobe-specific RF-EMF doses from all RF-EMF sources together, from mobile and DECT phone calls and far-field sources were not associated with global, cortical, or subcortical brain volumes, a higher whole-brain RF-EMF dose from mobile phone use for internet browsing, e-mailing, text messaging, tablet use, and laptop use while wirelessly connected to the internet was indeed associated with a smaller caudate volume. The caudate nucleus plays an important role in procedural learning, associative learning and inhibitory control of action and it is also one of the brain structures comprising the reward system. Analysis of cognitive impacts in another analysis (Cabré-Riera et al., 2020) found higher overall whole-brain RF-EMF doses from all RF-EMF sources together and from phone calls were associated with lower non-verbal intelligence score in Dutch and Spanish preadolescents.

Yet another publication by the same group (Cabré-Riera et al., 2021) investigated the association of estimated all-day and evening whole-brain radiofrequency electromagnetic field (RF-EMF) doses with sleep disturbances and objective sleep measures in preadolescents. The researchers, publishing their findings in *Environmental Research*, found preadolescents with high evening whole-brain RF-EMF dose from phone calls had a shorter total sleep time compared to preadolescents with zero evening whole-brain RF-EMF dose from phone calls.

A 2020 research review from the Department of Pediatrics, Hanyang University School of Medicine, Seoul, Korea (Moon, 2020) recommends precaution and minimizing EMF exposure to children, cautioning that the nervous systems of children are more vulnerable to the effects of electromagnetic waves than those of adults.

PREGNANCY

Using a mobile phone for calls for more than 30 minutes per day during pregnancy was associated with a negative impact on fetal growth (Boileau et al., 2020). Mobile phone use during pregnancy was associated with night-wake of infants (Weng et al., 2020). (Bektas et al., 2020) concluded that mobile phone exposure during pregnancy could cause oxidative stress and DNA damage in cord blood and placenta. Finally, the combined effects of Wi-Fi plus mobile phone exposure could have a higher potential to cause synergistic effects.

Recent animal research includes a study that found Wi-Fi signals increase lipid peroxidation, SOD activity (oxidative stress), apoptosis and CDKN1A and GADD45a overexpression in mice placenta tissue (Vafaei et al., 2020). A study on pregnant rats found damage to cells in the cerebellum. The authors conclude that prenatal mobile phone radiation might lead to the damage of axon, the nerve fiber, and myelin, the sheath that forms around nerves, with activity of astrocytes in cerebellum of male rat offspring (Yang et al., 2020).

CHARACTERIZING RFR EXPOSURES DURING CHILDHOOD AND PREGNANCY

Current FCC exposure levels were set in 1996 without a complete understanding of how RFR is absorbed into the fetus, pregnant women or children. Research published in 2020 and 2021 adds critical new data regarding these exposures. For example, (Foroutan et al., 2020) studied the absorption of WiFi and LTE frequencies into a 43-year-old pregnant woman model carrying a 24-week baby to allow scientists to better understand health impacts due to the interaction between electromagnetic fields and human tissue. (Psenakova et al., 2020) states “numerical results have shown that the obtained maximal SAR values in AustiWoman model is higher than are maximum values determined according to maximum SAR in European standards limit.”

In “Electromagnetic Field in Vicinity of Electronic Baby Monitor” published by IEEE, (Gombarska et al., 2020) found exposures from a baby monitor to be regulation-compliant but the authors warn, “Some caution should be exercised when using such devices, in particular regarding keeping a safe distance from the little children.” These and other new studies confirm the urgent need to reduce exposures, especially for children and pregnant women.

FERTILITY

Environmental Research published “A meta-analysis of in vitro exposures to weak radiofrequency radiation exposure from mobile phones (1990–2015)” describing 1127 experimental observations in cell-based in vitro models on RFR. It found less differentiated cells such as epithelium and spermatozoa are more sensitive to RF (Halgamuge et al., 2020). This study also confirms observations from the REFLEX project, Belyaev and others that cellular response varies with signal properties.

Several reviews on RFR impacts to sperm and reproduction were published over the last two years analyzing the body of evidence. A systematic review and meta-analysis (Sungjoon et al., 2021) evaluated 18 studies and found exposure to mobile phones is associated with reduced sperm motility, viability and concentration. (Yu et al., 2021) found mobile phone RFR exposure could decrease the motility and viability of mature human sperm *in vitro* and the pooled results of animal studies showed that mobile phone RF-EMR exposure could suppress sperm motility and viability. A systematic review on the effects of RFR to male reproductive hormones (Maluin et al., 2021) found that wireless can impact testosterone. The authors detail how testes are one of the most vulnerable organs to RF-EMR. Testicular tissues are more susceptible to oxidative stress due to a high rate of cell division and mitochondrial oxygen consumption.

(Okechukwu, 2020) reviewed human and animal studies published from 2003 to 2020 investigating RFR from cell phones and male fertility, publishing their findings "Does the Use of Mobile Phone Affect Male Fertility? A Mini-Review" in *Journal of Human Reproductive Sciences*. They found evidence in both animal and human spermatozoa of reduced motility, structural anomalies, and increased oxidative stress due to overproduction of reactive oxygen species after RFR exposure. The authors assert that scrotal hyperthermia and increased oxidative stress might be the key mechanisms through which EMR affects male fertility.

As an example of the experimental studies published over the last two years, an animal study on 4G found kidney inflammation and damage to the testes in mice (Hasan et al., 2021). The researchers concluded that fourth-generation cell phone radiation exposure may affect blood hemostasis and inflammation of mice's kidney and testis tissue and they warn that "based on these studies, it is important to increase public consciousness of potential adverse effects of mobile phone radiofrequency electromagnetic radiation exposure."

(Hassanzadeh-Taheri et al., 2021) assessed the effects of cell phone RFR on sperm parameters, DNA fragmentation, and apoptosis in normozoospermic and found higher apoptotic sperms and DNA fragmentation in the RFR exposed. The authors conclude: "it is recommended to keep the cell phone away from the pelvis as much as possible."

ELECTROSENSITIVITY

The International Journal of Molecular Sciences published "Electrohypersensitivity (EHS) as a Newly Identified and Characterized Neurologic Pathological Disorder: How to Diagnose, Treat, and Prevent It" (Belpomme & Irigaray, 2020). This paper documents the data and shows EHS is a neurologic pathological disorder which can be diagnosed, treated, and prevented. Utilizing a database of over 2000 electrohypersensitivity (EHS) and/or multiple chemical sensitivity (MCS) self-reported cases, they found EHS can be clinically characterized by a similar symptomatic picture to multiple chemical sensitivity by low-grade inflammation and an autoimmune response involving autoantibodies against O-myelin. According to the authors: "80% of the patients with EHS present with one, two, or three detectable oxidative stress biomarkers in their peripheral blood, meaning that overall these patients present with a true objective somatic disorder."

"The Critical Importance of Molecular Biomarkers and Imaging in the Study of Electrohypersensitivity. A Scientific Consensus International Report" in the *International Journal of Molecular Sciences* is a scientific consensus international report authored by 32 scientists. They call for the acknowledgement of electrohypersensitivity as a distinct neuropathological disorder and for inclusion in the WHO International Classification of Diseases (*e.g.*, distinct from the current grouping within other ICD codes addressing exposure to non-ionizing radiation) (Belpomme et al., 2021). The paper presents the French teams' EHS/MCS physiopathological model based on low-grade neuroinflammation and oxidative/nitrosative stress-induced blood–brain barrier disruption, which attempts to account for the mechanisms through which pathophysiological effects could take place in the brain of EHS and/or MCS patients and how EHS and/or MCS pathogenesis may consequently occur. The paper also documents the methodological defects that make provocation tests unsuitable for sham versus EMF exposure analysis in EHS-bearing patients. The paper documents how EHS patients' RFR exposure has been found to increase plasma glucose levels, affect heart rate variability and in multiple sclerosis-bearing patients RFR exposure can worsen symptoms, meaning that RFR can induce objective, bioclinical alterations in humans.

BRAIN/NEUROLOGY

(Hasan et al., 2021) found long-term exposure to 2400 MHz 4G impacted the structural integrity of the hippocampus and increased anxiety-like behavior in mice. (Hu et al., 2021) published "Effects of Radiofrequency Electromagnetic Radiation on Neurotransmitters in the Brain" in *Frontiers in Public Health,* offering a review that summarizes the effects of EMR on the neurotransmitters in the brain. The nervous system is an important target organ system and is sensitive to EMF. They document research that suggests that long-term exposure to EMR may lead to abnormal norepinephrine and epinephrine contents in the brain, metabolic disorders of monoamine neurotransmitters in the brain and excitatory amino acid neurotransmitters in the hippocampus, "which may affect the excitatory-inhibitory balance of neurons, thus causing a decline in learning and memory ability." The authors also considered the underlying mechanism as "EMR exposure does increase the intracellular calcium and the formation of ROS, which would alter the cellular function eventually and lead to numerous biological effects including neurotransmitter imbalance." The authors call for more research to clarify effects.

A systematic review (Bertagna et al., 2021) published in *Annals of the New York Academy of Sciences* found that neuronal ion channels are particularly affected by EMF exposure. Changes in calcium homeostasis, attributable to the voltage-gated calcium channels, were the most commonly reported result of EMF exposure. EMF effects on the neuronal landscape appear to be diverse and greatly dependent on parameters like the field's frequency, exposure time, and intrinsic properties of the irradiated tissue, such as the expression of VGCs. The researchers systematically clarify how neuronal ion channels are particularly affected and differentially modulated by EMFs at multiple levels, such as gating dynamics, ion conductance, concentration in the membrane, and gene and protein expression. Ion channels represent a major transducer for EMF-related effects on the CNS.

(Tan et al., 2021) evaluated the acute effects of 2.856 GHz and 1.5 GHz microwaves to male rats and found exposures induced a decline in spatial memory.

“Exposure of Radiofrequency Electromagnetic Radiation on Biochemical and Pathological Alterations” in *Neurology India* (Sharma et al., 2020) found 800 MHz frequency at a SAR of 0.433 W/kg in male Wistar rats led to neurochemical and pathophysiological damage by initiating the inflammatory process in various brain regions, especially in hippocampus and cerebral cortex. The authors conclude that since the hippocampus involves storing and retaining information during the learning process, RFR exposure negatively affects the memory and learning process and “could be a huge risk of induction of brain damage.”

(Hinrikus et al., 2021) review “Threshold of radiofrequency electromagnetic field effect on human brain” in the *International Journal of Radiation Biology* found the threshold for EEG effects is far lower than the level deemed safe by the U.S. FCC. The lowest level of RF EMF at which the effect in EEG was detected is 2.45 V/m (SAR = 0.003 W/kg). The authors state the changes in EEG caused by RF EMF appeared similar in the majority of analyzed studies and similar to those found in depression. They conclude that the “possible causal relationship between RF EMF effect and depression among young people is [a] highly important problem.”

(Luo et al., 2021) in their paper “Electromagnetic field exposure-induced depression features could be alleviated by heat acclimation based on remodeling the gut microbiota” published in *Ecotoxicology and Environmental Safety* share their findings that pulsed electromagnetic fields (2450 MHz) caused gut microbiota and metabolites disturbance similar to depression model. “In our study, EMF induced disturbance in the metabolite profiles of serum samples. Significantly different metabolites included cholesterol, D-fructose and fumaric acid and these were associated with depression (Xiong et al., 2020). Based on KEGG classification, the metabolites involved in neurotransmitters and steroids were altered significantly.”

They concluded that “our study demonstrated that EMF exposure could not only lead to neurobehavioral disorders such as depression, but also cause gut microbiota imbalance.” The researchers also referenced how “growing evidence indicates that the gut microbiota affects not only gastrointestinal function but also central nervous system (CNS) physiology and behavior by regulating the microbiota-gut-brain axis.”

OXIDATIVE STRESS

More recently published studies demonstrate consistency for the induction of oxidative stress. Oxidative DNA damage can lead to mutations, chromosomal translocations, and genomic instability, which are cellular events that can result in cancer development. Induction of oxidative stress, which is a key characteristic of many human carcinogens including ionizing radiation and asbestos, may also lead to the genotoxicity and carcinogenicity of non-ionizing

RFR. Oxidative stress caused by EMFs is thought to be due to the altering of recombination rates of short-lived radical pairs leading to increases in free radical concentrations. Thus, even without causing direct DNA damage, RFR may induce oxidative DNA damage and thereby initiate or promote tumor development.

(Schuermann & Mevissen, 2021) published a major review on oxidative stress, “Manmade Electromagnetic Fields and Oxidative Stress – Biological Effects and Consequences for Health” in *International Journal of Molecular Sciences*. The authors found increased oxidative stress in the majority of animal studies and cell studies, many with exposures compliant with FCC and ICNIRP regulatory limits. Increased oxidative stress caused by RF-EMF and ELF-EMF were reported in the majority of the animal studies and in more than half of the cell studies. Investigations in Wistar and Sprague-Dawley rats provided consistent evidence for oxidative stress occurring after RF-EMF exposure in the brain and testes and some indication of oxidative stress in the heart. Observations in Sprague-Dawley rats also seem to provide consistent evidence for oxidative stress in the liver and kidneys. “A trend is emerging, which becomes clear even when taking these methodological weaknesses into account, i.e., that EMF exposure, even in the low dose range, may well lead to changes in cellular oxidative balance.” The authors explain that pre-existing conditions like diabetes and neurodegenerative diseases compromise the body’s defense mechanisms, including antioxidant protection processes, and individuals with pre-existing conditions are more likely to experience health effects. Further, very young or old individuals can react less efficiently to oxidative stress. This puts them at greater risk of health impacts.

“Effects of different mobile phone UMTS signals on DNA, apoptosis and oxidative stress in human lymphocytes” (Gulati et al., 2020) published in *Environmental Pollution* comparatively analyzed genotoxic effects of UMTS signals at different frequency channels used by 3G mobile phones (1923, 1947.47, and 1977 MHz) and found a relatively small but statistically significant induction of DNA damage in dependence on UMTS frequency channel with maximal effect at 1977.0 MHz, supporting the notion that each specific signal used in mobile communication should be tested.

“Effects of pulse-modulated radiofrequency magnetic field (RF-EMF) exposure on apoptosis, autophagy, oxidative stress and electron chain transport function in human neuroblastoma and murine microglial cells” published by (Zielinski et al., 2020) in *Toxicology in Vitro* investigated the effects of ELF-modulated 935 MHz RF-EMF on apoptosis, autophagy, oxidative stress and electron exchange in human neuroblastoma and murine microglial cells. The authors found effects indicating that “short-time RF-EMF at SAR levels accepted by today's safety guidelines might cause autophagy and oxidative stress with the effect being dependent on cell type and exposure duration. Further studies are needed to evaluate possible underlying mechanisms involved in pulse-modulated RF-EMF exposure.”

(Singh et al., 2020) exposed male Wistar rats to RFR for 16 weeks (2 h/day) and observed oxidative stress, an inflammatory response, and HPA axis deregulation. “Effect of mobile phone radiation on oxidative stress, inflammatory response, and contextual fear memory in Wistar rat" was published in *Environmental Science and Pollution Research International.* The study shows that chronic exposure to MP-RF-EMF radiation emitted from mobile phones may induce oxidative stress, inflammatory response, and HPA axis deregulation.

(Hussien et al., 2020) found a significant decrease in plasma nesfatin-1 level and thyroid functions with an increase in oxidative stress and apoptosis. Further, there was a correlation between nesfatin-1 level and markers of thyroid function, oxidative stress and apoptosis. The researchers conclude that Nesfatin-1 plays a role in thyroid dysfunctions of rats exposed to mobile phone radiation. The authors' "Decreased level of plasma nesfatin-1 in rats exposed to cell phone radiation is correlated with thyroid dysfunction, oxidative stress, and apoptosis" published in *Archives of Physiology and Biochemistry* details these findings.

GENOTOXICITY/ DNA DAMAGE

Major studies using validated experimental protocols published in 2020 and 2021 associate non-ionizing RFR exposure with DNA damage.

In February 2020, U.S. government scientists published landmark findings of "significant increases in DNA damage" in groups of male mice, female mice and male rats after just 14 to 19 weeks of non-thermal cell phone RFR exposure as part of the large scale National Toxicology Program cell phone animal studies (Smith-Roe et al., 2020). "Evaluation of the genotoxicity of cell phone radiofrequency radiation in male and female rats and mice following subchronic exposure" published in *Environmental and Molecular Mutagenesis* details the much-anticipated results of the comet assay showing significant increases in DNA damage in the frontal cortex of male mice (both modulations), leukocytes of female mice (CDMA only), and hippocampus of male rats (CDMA only). Increases in DNA damage judged to be equivocal were observed in several other tissues of rats and mice. "In conclusion, these results suggest that exposure to RFR is associated with an increase in DNA damage." In short, DNA damage was found at non-thermal RFR levels, levels the FCC regulatory limits presume are harmless.

The authors explain that the NTP studies were designed to evaluate non-thermal effects of cell phone RFR exposure, which meant that body temperature could not change more than 1° C and therefore the NTP scientists considered it unlikely that thermal effects were a confounding factor for these genetic toxicity tests. Thus, this data again adds to the large body of evidence confirming that the assumption that non-ionizing radiation does not cause any adverse health effects other than by heating is wrong. The study is a game changer because the NTP exposures were carefully controlled and NTP studies are considered the gold standard in animal testing.

In "Genetic effects of non-ionizing electromagnetic fields" published in *Electromagnetic Biology and Medicine,* (Lai, 2021) reviewed the research on the genetic effects of non-ionizing electromagnetic fields and found many studies reported effects in cells and animals after exposure to EMF at intensities similar to those in the public and occupational environments. Approximately 70% of reviewed studies showed effects including DNA strand breaks, micronucleus formation, and chromosomal structural changes. Lai highlights how the effects are waveform and cell-type specific.

Dr. Lai's findings underscore the complexity of interactions between EMF and biological tissues, and may partially explain why effects were observed in some studies but not others. Lai states it is essential to understand why and how certain wave-characteristics of an EMF are more effective than other characteristics in causing biological effects, and why certain types of cells are more susceptible to EMF effects. Very significantly, Dr. Lai asserts that "there are different biological effects elicited by different EMF wave-characteristics" and this is a critical proof for the existence of non-thermal effects.

The review explains how genetic effects depend on various factors, including field parameters and characteristics (frequency, intensity, wave-shape), cell type, and exposure duration. Lai also found non-ionizing EMFs interact synergistically with different entities on genetic functions. These interactions, particularly with chemotherapeutic compounds, raise the possibility of using EMF as an adjuvant for cancer treatment to increase the efficacy and decrease side effects of traditional chemotherapeutic drugs.

Lai explains that since the energy level is not sufficient to cause direct breakage of chemical bonds within molecules, the effects are probably indirect and secondary to other induced chemical changes in the cell. He suspects that biological effects are caused by multiple inter-dependent biological mechanisms. He states that the mechanism remains to be uncovered, "but, knowing the mechanism is not necessary to accept that the data are valid. It is also a general criticism that most EMF studies cannot be replicated. I think it is a conceptual and factual misstatement. Replication is also not a necessary and sufficient condition to believe that certain data are true." Lai then states that, "to prove an effect, one should look for consistency in data. Genetic damage studies have shown similar effects with different set-up and in various biological systems. And, the gene expression results (Supplement 3) also support the studies on genetic damages. Expression of genes related to cell differentiation and growth, apoptosis, free radical activity, DNA repair, and heat-shock proteins have been reported. These changes could be consequences of EMF-induced genetic damages."

An October 2021 review "Human-made electromagnetic fields: Ion forced-oscillation and voltage-gated ion channel dysfunction, oxidative stress and DNA damage (Review)" in the *International Journal of Oncology* describes the cascade of effects from non-ionizing EMFs that lead to DNA damage. (Panagopoulos et al., 2021) documents the scientific research base indicating EMF exposures lead to ion channel dysfunction. According to the ion forced-oscillation mechanism for dysfunction of VGICs, human-made (polarized and coherent) ELF/ULF EMFs or the ELF/ULF modulation/pulsing/variability components of modern RF/WC EMFs can alter intracellular ionic concentrations by irregular gating of VGICs on cell membranes. This leads to immediate oxidative stress by ROS [oxidative stress that cause damage to lipids, proteins and DNA] (over)production in the cytosol and/or the mitochondria, which can damage DNA when cells are unable to reinstate electrochemical balance (normal intracellular ionic concentrations). Consequently, DNA damage can lead to reproductive disabilities, neurodegenerative diseases, aging, genetic alterations and cancer.

Moreover, the review addresses how, in addition to polarization and coherence, ELFs are a common feature of almost all human-made EMFs. The authors suggest that the non-thermal biological effects attributed to RF EMFs are actually due to their ELF components. The researchers conclude that, “The long-existing experimental and epidemiological findings connecting exposure to human-made EMFs and DNA damage, infertility and cancer, are now explained by the presented complete mechanism. The present study should provide a basis for further research and encourage health authorities to take measures for the protection of life on Earth against unrestricted use of human-made EMFs.”

NEW GOVERNMENT REPORTS AND RECOMMENDATIONS

The European Union

In July 2021, the European Parliament Panel for the Future of Science and Technology European Parliamentary Research Service Report “Health Impact of 5G” offered a review of the epidemiological and experimental evidence which has significantly increased since 2011 when the International Agency for Research on Cancer (IARC) classified radiofrequency (RF) EMF as “possibly carcinogenic to humans” (Group 2B). Due to the post-2011 published research, the IARC advisory group has now recommended RF exposure for re-evaluation “with high priority” (IARC, 2019). The report concludes that the body of evidence now indicates that the frequencies of 450 to 6,000 MHz are “probably carcinogenic for humans, in particular related to gliomas and acoustic neuromas.”

For non-cancer effects the EU Report concludes that there was sufficient evidence of reproductive/developmental adverse effects in experimental animals and “these frequencies clearly affect male fertility and possibly female fertility too. They may have possible adverse effects on the development of embryos, foetuses and newborns.” In regards to 5G’s higher frequencies (24.25-27.5 GHz), and frequencies 24 to 100 GHz the systematic review found there was an inadequate base of studies either in humans or in experimental animals with which to even substantiate a conclusion one way or the other regarding a carcinogenic effect or any other non-thermal effect.

The report makes several policy recommendations, including:

- Adopting stricter RFR limits for mobile phone devices and reducing RFR exposure with devices that emit lower energy and “if possible only working when at a certain distance from the body”.
- Revisiting RFR exposure limits for the public and the environment in order to reduce RF-EMF exposure from cell towers through more stringent limits such as those used in Italy, Switzerland, China, and Russia - all of which are significantly lower than those recommended by ICNIRP and the FCC.

- Adopting measures to incentivise the reduction of RF-EMF exposure which include using optic-fibre cables to connect schools, libraries, workplaces, houses, public buildings, and all new buildings etc. “Public gathering places could be 'no RF-EMF' areas (along the lines of no-smoking areas) so as to avoid the passive exposure of people not using a mobile phone or long-range transmission technology, thus protecting many vulnerable elderly or immune-compromised people, children, and those who are electro-sensitive.”
- Promoting a multidisciplinary scientific research effort to assess the long-term health effects of 5G millimeter waves (MMW) in order to rule out the risk that tumours and adverse effects on reproduction and development may occur upon exposure to 5G MMW, and to exclude the possibility of synergistic interactions between 5G MMW networks and other frequencies and networks that are already being used. Research is needed on the biological effects of 5G MMW at frequencies between 6 and 300 GHz not only for humans but also for the flora and fauna of the environment, e.g. non-human vertebrates, plants, fungi, and invertebrates.
- Promoting research to identify an adequate method of monitoring exposure to 5G because there is currently inadequate monitoring of the actual exposure of the population.
- Promoting a public educational awareness campaign on the potential harms of RFR at all levels, beginning with schools. This campaign should include the potential health risks, opportunities for digital development, safer infrastructure alternatives, and strategies to reduce exposure to wireless phones.

The report concludes that the gaps in knowledge in regards to 5G’s higher frequencies justify the call for a moratorium on 5G millimeter wave networks, pending completion of adequate research, “before exposing the whole world population and environment.” The report’s conclusion carries a very clear warning: “Implementing MMW 5G technology without further preventive studies would mean conducting an 'experiment' on the human population in complete uncertainty as to the consequences.”

In 2020, the European Parliament briefing Effects of 5G wireless communication on human health reviewed the various policies and reports in Europe including: 1) the 2011 Council of Europe Parliamentary Assembly Resolution 1815 that recommended reducing RFR exposure; the fact that the European Environment Agency (EEA) has long advocated precaution concerning EMF exposure; 2) the European Commission Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) 2015 opinion and the organizations that suggest many members of SCENIHR could have conflict of interests, as they had professional relationships with or received funding from various telecom companies; 3) the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER), replacing the former Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) evaluated the scale, urgency and interactions (with ecosystems and species) of possible hazard from 5G *as high as* “there could be biological consequences from a 5G environment.”

The briefing also highlighted the biological impacts from pulsations and modulations stating, “Studies show that pulsed EMF are in most cases more biologically active and therefore more dangerous than non-pulsed EMF. Every single wireless communication device communicates at least partially via pulsations, and the smarter the device, the more pulsations. Consequently, even though 5G can be weak in terms of power, its constant abnormal pulse radiation can have an effect. Along with the mode and duration of exposures, characteristics of the 5G signal such as pulsing seem to increase the biologic and health impacts of exposure, including DNA damage, which is considered to be a cause of cancer. DNA damage is also linked to reproductive decline and neurodegenerative diseases."

A review of occupational EMF exposures (Stam, 2021) of the National Institute for Public Health and the Environment of the Netherlands pointed to the need for exposure guidelines and regulation to incorporate new technology developments, especially in regards to 5G applications. Although ICNIRP's thermally-based RFR limits were used as the action level in this article (and adverse biological effects have been found at non-thermal levels as documented in this report), this paper highlights the critical need to characterize occupational exposures and better assess health effects because of the new wireless networks found in the modern workplace.

In April 2020, the Swiss Parliament refused to weaken their RFR radiation limits. In September 2020, the Netherlands issued a 5G and Health Advisory Report that recommended measuring environmental levels of RFR (an action the FCC does not take) and importantly, the Report also recommended *against* using the 26 GHz frequency band for 5G "for as long as the potential health risks have not been investigated."

Starting in July 2020, new French government policy ensures that wireless companies label tablets, laptops, Wi-Fi routers, DECT phones and other wireless connected electronics with RFR SAR exposure levels at point of sale and in all advertising. Legislation in the country has long ensured labeling cell phones for SAR levels, but this did not apply to other wireless devices. Now all wireless devices used close to the head and body are potentially covered.The ANFR (The National Frequency Agency) SAR Regulation Guide lists the equipment qualified as radio equipment that required SAR testing. One category includes mobile phones, tablets equipped with a 3G or 4G/5G SIM card, connected watches that contain a mobile phone SIM card, 3G or 4G/5G pocket format routers, Maritime Portable VHF, laptops (3G or 4G/5G); and the second category includes DECT cordless phones, walkie-talkies or equivalent devices (PMR), tablets operating using Wi-Fi or bluetooth, wireless microphones, radio controls used for drones or model making, connected motorcycle helmets and Wi-Fi laptops. ANFR states that technological evolutions in connected objects may lead to the extension of this labeling to include radio frequency belts, connected glasses ("smart glasses"), wireless headphones or headsets, portable safety sensors (distance sensors) and virtual reality headsets.

Expert Recommendations to Minimize Exposure to Children

Since the COVID pandemic, there have been several new expert recommendations to reduce RFR exposure for children in virtual education on computers for 7 hours or more a day. For example, in April 2020 the Cyprus National Committee on Environment and Children's Health released recommendations for parents on how to set up wired internet. In March 2020, the Scientific Research Institute of Hygiene and Children's Health of the Russian Ministry of Health and the Russian National Committee on Non-Ionizing Radiation Protection also released recommendations for distance learning including restricting cell phones, using wired connections rather than Wi-Fi, reading real books and writing in real notebooks to support learning objectives. In November 2020, the Switzerland Doctors for Environmental Protection (AefU) released "Consistently apply the precautionary principle in mobile communications" demanding a reduction in exposure for children and youth.

Expert Appeals

Expert recommendations to reduce public and environmental exposures have escalated over the last two years. The 2020 Consensus Statement of UK and International Medical and Scientific Experts and Practitioners on Health Effects of Non-Ionising Radiation (NIR) was signed by over 3500 medical doctors cautioning: "Hundreds of peer-reviewed scientific studies have demonstrated adverse biological effects occurring in response to a range of NIR [non-ionizing radiation] exposures below current safety guidelines; however emissions continue to escalate. Medical evidence of harm has now reached the critical mass necessary to inspire the medical community to step out of their usual roles, stand up and speak out regarding their concern."

Expert groups have continued to organize and call for urgent action in various countries. For example, in October 2020 a letter signed by 135 health professionals in Chile requested a moratorium on the deployment of 5G technology, and a 5G Appeal was launched in support of a new 5G petition: "Apoya con tu firma la carta de solicitud de moratoria al 5G en Chile enviada al Ministro Paris"; English Translation: "With your signature, support the letter requesting a moratorium on 5G in Chile sent to Minister Paris".

In France, a September 2020 petition addressed to the Prime Minister was signed by over 60 elected officials urging the government to assess environmental effects before deploying 5G. In Canada, the Urgent Appeal to the Government of Canada to Suspend the 5G Rollout and to Choose Safe and Reliable Fiber Connections was launched by Canadians for Safe Technology (C4ST) in May 2020. The Appeal calls for a systematic review of the scientific evidence of health effects of RFR as well as binding guidelines to protect wildlife and the environment from RFR. The CEO of C4ST calling for this review is Frank Clegg, the former Chairman of Microsoft Canada.

Medical Conference on EMF

In 2021, the EMF Medical Conference 2021 presented evidence based information on the prevention, diagnosis and treatment of EMF associated illness featuring leading EMF experts in science, medicine, health and assessment. These proceedings are available as online courses for continuing medical education credits for medical doctors and health professionals. See www.emfconference2021.com

Expert Recommendations in the USA

The New Hampshire State Commission released its 2020 Report on 5G Health and Environment with 15 recommendations that included reducing public exposure to RFR via wired (not Wi-FI) internet connections in schools and libraries; software changes to phones and wireless devices to minimize exposure; informing the public about RFR exposures via educational campaigns and public posting of RFR levels; government measuring of RFR exposures; developing updated safety standards to protect the public and environment; and ensuring independent scientific review of the research.

On June 17th, 2020, over U.S. 400 medical professionals wrote the FCC a letter calling for consideration of non-thermal biological impacts. The Alliance of Nurses for Healthy Environments (ANHE), a national organization of nurses, also sent a 2020 letter calling for the FCC to address the science on children's vulnerability.

Over the last two years, several U.S. cities have passed resolutions and policies to halt increased RFR exposure and to ensure adequate scientific review of the health effects of RFR radiation. For example, Hawai'i County (July 2020), Easton Connecticut (May 2020), Keene New Hampshire (March 2020) and Farragut Tennessee (May 2020) have passed resolutions to halt 5G. The Coconut Creek Florida Commission adopted a Resolution on 5G and radiofrequency radiation (November 2020) "imploring the US Congress to allocate funding and direct a cross discipline federal agency study of the effects caused by exposure to current and proposed electromagnetic spectrum and radiofrequency commissions on human health and the environment in light of the recent implementation of fifth generation technology and to use those findings to create science based laws or rules regarding limiting human and environmental exposure."

On April 2, 2021 Montgomery County Maryland Council President Hucker and County Executive Elrich sent a letter to U.S. Senator Chris Van Hollen that included two specific requests regarding RFR:

> *"Request responsibility for setting RF standards be transferred from the Federal Communications Commission (FCC) - a regulatory agency - to the National Institute of Standards and Technology (NIST) - a standards setting body. Direct NIST to complete a review of credible published papers on the health effects of RF emissions on humans, including women and children, and tests to measure biological impact on humans, and thermal and biological tests of RF at different frequencies within 6 months. Further direct NIST to create and update thermal and biological standards for smartphones, small cells, and household Internet-of-Things (IoT) devices, Wi-Fi, and Bluetooth devices within 2 years and review and update standards every 5 years thereafter.*

Environmental Groups

Internationally and in the USA, environmental groups have issued statements and positions calling for protections for the environment before allowing wireless network proliferation. For example, in 2021, a major environmental group in Spain, Ecologistas en Accion or Ecologists in Action issued a position on 5G calling for precaution. They propose information campaigns, reducing exposure, monitoring compliance and requiring transparency, impartiality and plurality in health risk assessments. They also recommend wireless networks are replaced with wired connections and the recognition of electrohypersensitivity syndrome as an environmental disease with protections that include the creation of EMF-free zones.

In February 2021, the Green Party of California issued a Statement on 5G Wireless Technology advocating for “robust and independent scientific environmental review of 4G/5G wireless exposure” and to reduce exposures per the As Low As Reasonably Achievable (ALARA) principle. It is notable that environmental organizations are also issuing statements regarding the increased energy consumption of 5G. For example, Greenpeace France’s “What is Digital Pollution” addresses how 5G will increase “digital pollution.” Several investigative articles have been published on the environmental impacts including “How Green is 5G?” published November 2021 in Envirotech Magazine; “What Will 5G Mean for the Environment?” published January 2020 by Clair Curran of the Henry M. Jackson School of International Studies; and “Is Wireless Technology an Environmental Health Risk?” published January 2021 by Katie Alvord in the journal of the Society of Environmental Journalists.

5G NETWORKS AND MILLIMETER WAVE FREQUENCIES

The review paper “Adverse health effects of 5G mobile networking technology under real-life conditions” (Kostoff et al., 2020) published in *Toxicology Letters* identified a wide range of adverse systemic effects from 5G network deployment when real life conditions are considered such as the information content of signals along with the carrier frequencies and other toxic stimuli that can act in combination with the exposure. Many experiments do not include the real-life pulsing and modulation of the carrier signal. The vast majority of experiments do not account for synergistic adverse effects of other toxic stimuli with wireless radiation. 5G mobile networking technology will affect the skin and eyes and has adverse systemic effects. “In aggregate, for the high frequency (radiofrequency-RF) part of the spectrum, these reviews show that RF radiation below the FCC guidelines can result in: carcinogenicity (brain tumors/glioma, breast cancer, acoustic neuromas, leukemia, parotid gland tumors), genotoxicity (DNA damage, DNA repair inhibition, chromatin structure), mutagenicity, teratogenicity, neurodegenerative diseases (Alzheimer’s Disease, Amyotrophic Lateral Sclerosis), neurobehavioral problems, autism, reproductive problems, pregnancy outcomes, excessive reactive oxygen species/oxidative stress, in ammation, apoptosis, blood-brain barrier disruption, pineal gland/melatonin production, sleep disturbance, headache, irritability, fatigue, concentration difficulties, depression, dizziness, tinnitus, burning and flushed skin, digestive disturbance, tremor, cardiac irregularities, adverse impacts on the neural, circulatory, immune, endocrine, and skeletal systems.” The authors conclude that “Superimposing 5G radiation on an already imbedded toxic wireless radiation environment will exacerbate the adverse health effects shown to exist. Far more research and testing of potential 5G health effects under real-life conditions is required before further rollout can be justified."

In "Absorption of 5G Radiation in Brain Tissue as a Function of Frequency, Power and Time" published in *IEEE Access* (Gultekin & Siegal, 2020) examines the beam penetration, absorption and thermal diffusion at representative 4G and 5G frequencies and shows that RF heating increases rapidly with frequency due to decreasing RF source wavelength and increasing power density with the same incident power and exposure time.

(Trillo et al., 2021) in their paper "Effects of the signal modulation on the response of human fibroblasts to in vitro stimulation with subthermal RF currents" published in *Electromagnetic Biology and Medicine* found the modulated signal was more efficient in inducing Hsp27 and decorin overexpression and promoting cell proliferation. "These data indicate that the cellular response is dependent on the RF signal modulation…"

5G human exposure studies include (Kim & Nasim, 2020). In their paper "Human Electromagnetic Field Exposure in 5G at 28 GHz" published in *IEEE Consumer Electronics Magazine* the authors compared the human EMF exposure in a 5G system to previous-generations of cellular systems. They suggest a minimum separation distance between a transmitter and a human user in order to keep exposure compliant with regulatory limits.

In their paper "Human RF-EMF Exposure Assessment Due to Access Point in Incoming 5G Indoor Scenario" published in *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology* (Bonato et al., 2021) simulated the exposure to an adult and child from an indoor 5G access points (3.7 GHz and at 14 GHz) to evaluate how beamforming and the higher frequency use could impact exposure levels and found the reciprocal position between the antenna and the model head and the frequency range and the distance are factors that could greatly influence the exposure levels.

"Physiological effects of millimeter-waves on skin and skin cells: an overview of the to-date published studies" published in *Reviews on Environmental Health* is an overview of the physiological effects of millimeter waves on skin and skin cells (Leszczynski, 2020) by Dr. Leszczynski, one of the IARC working group members who voted 29 to 1 in May 2011 to classify RF-EMF as a 2B or "possible human" carcinogen. The author explains how the skin and eyes are directly exposed to the millimeter-waves from 5G and yet the current body of research on millimeter-waves is insufficient to devise science-based exposure limits and policies. He recommends precautionary measures such as postponing or limiting 5G deployment in residential areas until adequate research studies scientifically establish safety thresholds.

In "Limiting liability with positioning to minimize negative health effects of cellular phone towers" published in *Environmental Research* (Pearce, 2020) summarizes the peer-reviewed literature on the effects of RFR from cellular phone base stations and concludes that, "to protect cell phone tower firms, companies should seek to minimize human RFR exposure" because there is "already enough medical-scientific evidence to warrant long-term liability concerns."

In "Millimeter (MM) wave and microwave frequency radiation produce deeply penetrating effects: the biology and the physics" published in *Reviews on Environmental Health*, (Pall, 2021) highlights three very important findings “rarely recognized in the EMF scientific literature: coherence of electronically generated EMFs; the key role of time-varying magnetic fields in generating highly penetrating effects; the key role of both modulating and pure EMF pulses in greatly increasing very short term high level time-variation of magnetic and electric fields. It is probable that genuine safety guidelines must keep nanosecond timescale-variation of coherent electric and magnetic fields below some maximum level in order to produce genuine safety. These findings have important implications with regard to 5G radiation.”

STANDARDS

The Environmental Working Group modeled the health effects incidence data from the National Toxicology Program (NTP) cell phone radiation studies to estimate departure points for exposure guidelines in a landmark analysis published in *Environmental Health*. The NTP study reported an increased incidence of cardiomyopathy in female and male rats and increased incidences of various neoplasms in male rats. They concluded that FCC limits should be strengthened by 200 to 400 times to protect children according to current risk assessment guidelines concluding that ”the analysis presented here supports a whole-body SAR limit of 2 to 4 mW/kg for adults, an exposure level that is 20- to 40-fold lower than the legally permissible limit of 0.08 W/kg for whole-body SAR under the current U.S. regulations. A ten-fold lower level of 0.2–0.4 mW/kg whole-body SAR may be appropriate for young children.

Both technology changes and behavior changes may be necessary to achieve these lower exposure levels. In “Development of health-based exposure limits for radiofrequency radiation from wireless devices using a benchmark dose approach” published in *Environmental Health*, the authors suggest: “Simple actions such as keeping the wireless devices farther away from the body offer an immediate way to decrease RFR exposure for the user.” (Uche, 2021)

In April 2020, Barnes and Greenebaum published “Setting Guidelines Electromagnetic Exposures Research Needs”, in *Bio Electro Magnetics* about the fact that current limits for exposures to non-ionizing electromagnetic fields do not address long-term exposures but are instead based on relatively short-term exposures. “What is missing in the current guidelines or regulations are guidelines for long-term exposure to weak EMF.” The authors document the science substantiating their recommendations for next steps regarding research and approaches for more protective exposure guidelines. They conclude that the science is sufficient indicating biological impacts at low levels:

> *“However, over the last 20 years the evidence has become extremely strong that weaker EMF over the whole range for frequencies from static through millimeter waves can modify biological processes. There is now solid experimental evidence and supporting theory showing that weak fields, especially but not exclusively at low frequencies, can modify reactive free radical concentrations and that changes in radical concentration and that of other signaling molecules, such as hydrogen peroxide and calcium, can modify biological processes…”*

The authors posit with copious scientific documentation how non-ionizing EMFs can impact cancer cell growth rates, membrane potentials, concentrations of calcium, reactive oxygen species (ROS), superoxide ($O2-$), nitric oxide (NO), hydrogen peroxide ($H2O2$), and intercellular pH, specifically highlighting the issue of oxidative stress as long-term elevations ``are associated with cancer, aging, and Alzheimer's." They highlight how funding for research into the effects of EMF in the United States "is close to nonexistent" and make numerous recommendations for research studies. They also recommend, for example, that guidelines be set at three levels: the individual user, local company, and national or international level and posit that recommended limits could well be a function of frequency, amplitude, and modulation systems as well as be dependent on the condition of the person being exposed. Barnes and Greenebaum acknowledge, "There seem to be a smaller number of 'hypersensitive people' who have very real and serious problems" from exposure to weak RF fields.

The co-authors conclude: "We believe a carefully targeted program of federal research funds is called for, supplemented by communications system operators and corporations that manufacture equipment, under independent scientific management. Both governmental and private entities that emit RF signals would be well advised to fund research to elucidate and define threshold signal levels for the generation of long-term biological effects."

CANCER

The evidence that RFR is a human carcinogen has continued to increase with the publication of several new research studies and papers. Furthermore, cancer incidence is rising among children and young adults. The latest U.S. Annual Report to the Nation on the Status of Cancer (a collaborative effort among the American Cancer Society, the Centers for Disease Control and Prevention, the National Cancer Institute, part of the National Institutes of Health; and the North American Association of Central Cancer Registries) published in *Journal of the National Cancer Institute* found higher overall cancer incidence rates in children and young adults in almost all racial/ethnic groups, with increasing trends for the most common cancer types among children including leukemia, brain and other nervous system cancers, and lymphoma.

In November 2020 a systematic review and meta-analysis of case-control studies by (Choi et al., 2020), "Cellular Phone Use and Risk of Tumors: Systematic Review and Meta-Analysis", was published in *Environmental Research and Public Health.* The authors found evidence that linked cellular phone use to increased tumor risk. The meta-analysis established that 1,000 or more hours of cell phone use, or about 17 minutes per day over 10 years, was associated with a statistically significant 60% increase in brain tumor risk.

In their paper "Genetic susceptibility may modify the association between cell phone use and thyroid cancer: A population-based case-control study in Connecticut" published in *Environmental Research* (Luo et al., 2020), the Yale researchers with support from the American Cancer Society found cell phone use was significantly associated with thyroid cancer in people with a type of common genetic variation. The association increased as cell phone use duration and frequency increased. The authors conclude that their findings “provide more evidence for RFR carcinogenic group classification.”

Regarding the impact of EMFs to the thyroid, a 2021 review by California Institute of Behavioral Neurosciences & Psychology researchers (Alkayyali et al., 2021) focused on thyroid hormones and thyroid gland histopathology documented studies indicating that RFR could be associated with alterations in hormone levels and impacts such as the hyperstimulation of thyroid gland follicles, causing oxidative stress and apoptosis of follicular cells. In “An Exploration of the Effects of Radiofrequency Radiation Emitted by Mobile Phones and Extremely Low Frequency Radiation on Thyroid Hormones and Thyroid Gland Histopathology” published in *Cureus*, the researchers found studies correlated thyroid impacts to the exposure duration, intensity, and SAR value of the RFR exposure. The authors state that “non-ionizing EMF radiation might be responsible for the recent increase in the incidence of thyroid insufficiency and cancer in the general population.”

In “The Effect of Continuous Low-Intensity Exposure to Electromagnetic Fields from Radio Base Stations to Cancer Mortality in Brazil” (Rodrigues et al. 2020) published their findings in the *International Journal of Environmental Research and Public Health* linking higher exposure to radio frequency radiation from cell antenna installations in Brazil to increased deaths from cancers. For all cancers and for the specific types investigated (breast, cervix, lung, and esophagus cancers), the higher the exposure, the higher the median of mortality rate.

The last two years of research has significantly increased the scientific evidence that RFR can increase oxidative stress, a hallmark of cancer, addressed earlier in this document. However, in addition, there are other endpoints associated with cancer that have been published in the last two years increasing the evidence related to the carcinogenicity of RFR. For example, (Ghandehari et al. 2021) found increased cell phone usage significantly correlated with a higher frequency of the micronucleus containing buccal mucosa cells and a higher frequency of micronucleus in each cell in the buccal mucosa. In “Micronucleus Assay in Cell Phone Users: Importance of Oral Mucosa Screening” published in *International Journal of Preventive Medicine*, the authors surmise, “Based on these results, it can be concluded that human buccal cells are likely to show increased micronucleus cells as a result of the genotoxic effects of cell phone waves which have been chronically exposed.”

Micronuclei are biomarkers of disease and they play an active role in tumor biology (Kwon et al. 2020). (Yao et al. 2021), in “The biological effects of electromagnetic exposure on immune cells and potential mechanisms” published in *Electromagnetic Biology and Medicine*, undertake a review of the biological effects of electromagnetic exposure on immune cells. The researchers found: “Accumulated data suggested that electromagnetic exposure could affect the number and function of immune cells to some extent, including cell proportion, cell cycle, apoptosis, killing activity, cytokines contents…”; and the authors conclude that, “knowledge of the biological effects on immune cells associated with electromagnetic fields is critical for proper health hazard evaluation, development of safety standards, and safe exploitation of new electromagnetic devices and applications.”

(Hardell & Carlberg, 2021) published “Lost opportunities for cancer prevention: historical evidence on early warnings with emphasis on radiofrequency radiation” in *Reviews in Environmental Health*. This eloquent review gives insight into missed opportunities for cancer prevention exemplified by asbestos, tobacco, certain pesticides and now RF radiation. The authors highlight how economic considerations were favored instead of cancer prevention. “A strategy to sow doubt on cancer risks was established decades ago and is now adopted and implemented in a more sophisticated way by the telecom industry regarding RF-EMF risks to human beings and the environment. Industry has the economic power, access to politicians and media whereas concerned people are unheard.” The examples clearly show that if the scientific evidence on cancer risks had been taken seriously, many lives could have been saved.

The 2020 study “Increased Generational Risk of Colon and Rectal Cancer in Recent Birth Cohorts under Age 40 - the Hypothetical Role of Radiofrequency Radiation from Cell Phones” published in *Annals of Gastroenterology and Digestive Disorders* by Davis et al. presented data from the U.S. Centers for Disease Control and Prevention, the U.S. Surveillance Epidemiology and End-Results Program and Iranian cancer registries on the staggering increases in colon and rectal cancer in those under age 50. Those born in the U.S. in the 1990s have a doubled risk of colon cancer and a fourfold increase in rectal cancer by the time they reach age 24 compared to those born six decades ago. The researchers document experimental studies indicating that cells from the colon and rectum of Sprague-Dawley rats are exquisitely sensitive to RFR and assert that these cancer increases could be due to the way people carry cell phones close to their bodies in front and back pockets. They reference how the French government frequency testing agency (ANFR) found that 9 out of 10 phones exceeded the safety guidelines when held against the body by factors of 1.6-3.7 times for the European standard or by factors as high as 11 if 1-g SAR values were to be measured as required by the U.S. FCC. “It appears prudent to promote policies to reduce exposures to radiofrequency radiation and encourage ALARA during pediatric CT procedures, while continuing to promote advances in software and hardware of phones and scanners that can lower exposures to non-ionizing radiation during normal operations. In addition, major public educational programs should be developed to promote awareness of the need to practice safer technology, especially for the young, who may well be at greater risk of developing cancer due to their immunological immaturity.”

In March 2021, Christopher Portier, Ph.D., formerly the Director of the United States National Center for Environmental Health at the Centers for Disease Control and Prevention (CDC) in Atlanta and the Director of the Agency for Toxic Substances and Disease Registry submitted a comprehensive review of the scientific research in a major cell phone/brain cancer lawsuit where he concludes: “The evidence on an association between cellular phone use and the risk of glioma in adults is quite strong.” Portier further states in his Expert Report: “In my opinion, RF exposure probably causes gliomas and neuromas and, given the human, animal and experimental evidence, I assert that, to a reasonable degree of scientific certainty, the probability that RF exposure causes gliomas and neuromas is high.”

A important paper was published in *Health Physics* in 2020 by longtime NIH scientist Dr. Ronald Melnick entitled “ICNIRP’S Evaluation of the National Toxicology Program’s Carcinogenicity Studies on Radiofrequency Electromagnetic Fields” addressing numerous criticisms of the NTP findings. Melnick documents one by one how these criticisms include false claims and “several incorrect statements that appear to be written to justify retaining exposure standards that were established more than 20 years ago.” He presents the scientific documentation that each of these criticisms are unfounded stating “ICNIRP’s misrepresentation of the methodology and interpretation of the NTP studies on cell phone RF radiation does not support their conclusion that “limitations preclude drawing conclusions about carcinogenicity in relation to RF EMFs.”

Melnick explains that the utility of the NTP studies for assessing human health risks is undermined by the incorrect statements and misinformation in the ICNIRP critique. Melnick describes how the ICNIRP note failed to recognize that focal hyperplasias (proliferative lesions) of glial cells in the brain and of Schwann cells in the heart are putative preneoplastic lesions that may progress to malignant glioma or to cardiac schwannoma tumors, respectively.

Further, Melnick documents how the ICNIRP note focused on the carcinogenicity but ignored other adverse biological effects observed in the NTP studies, including reduced birth weights, DNA strand breaks in brain cells (which is supportive of the cancer findings), increased incidences of proliferative lesions (tumors and hyperplasia) in the prostate gland, and exposure-related increases in the incidence of cardiomyopathy (a type of tissue damage) of the right ventricle of the heart in male and female rats.

“After all, it was the US Food and Drug Administration that requested the NTP studies of cell phone radiation in experimental animals to provide the basis to assess the risk to human health. The NTP studies show that the assumption that RF radiation is incapable of causing cancer or other adverse health effects other than by tissue heating is wrong. If ICNIRP’s goal is truly aimed at protecting the public from potential harm, then it would be appropriate for this group to quantify the health risks associated with exposure to RF-EMFs and then develop health-protective guidelines for chronic exposures, especially for children, who are likely to be more susceptible than adults to adverse effects of RF radiation.”

These studies are a small sampling of the numerous studies that have documented adverse effects from RFR.

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Review Article

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Millimeter (MM) wave and microwave frequency radiation produce deeply penetrating effects: the biology and the physics

https://doi.org/10.1515/reveh-2020-0165
Received December 11, 2020; accepted April 28, 2021;
published online May 26, 2021

Abstract: Millimeter wave (MM-wave) electromagnetic fields (EMFs) are predicted to not produce penetrating effects in the body. The electric but not magnetic part of MM-EMFs are almost completely absorbed within the outer 1 mm of the body. Rodents are reported to have penetrating MM-wave impacts on the brain, the myocardium, liver, kidney and bone marrow. MM-waves produce electromagnetic sensitivity-like changes in rodent, frog and skate tissues. In humans, MM-waves have penetrating effects including impacts on the brain, producing EEG changes and other neurological/neuropsychiatric changes, increases in apparent electromagnetic hypersensitivity and produce changes on ulcers and cardiac activity. This review focuses on several issues required to understand penetrating effects of MM-waves and microwaves: 1. Electronically generated EMFs are coherent, producing much higher electrical and magnetic forces then do natural incoherent EMFs. 2. The fixed relationship between electrical and magnetic fields found in EMFs in a vacuum or highly permeable medium such as air, predicted by Maxwell's equations, breaks down in other materials. Specifically, MM-wave electrical fields are almost completely absorbed in the outer 1 mm of the body due to the high dielectric constant of biological aqueous phases. However, the magnetic fields are very highly penetrating. 3. Time-varying magnetic fields have central roles in producing highly penetrating effects. The primary mechanism of EMF action is voltage-gated calcium channel (VGCC) activation with the EMFs acting via their forces on the voltage sensor, rather than by depolarization of the plasma membrane. Two distinct mechanisms, an indirect and a direct mechanism, are consistent with and predicted by the physics, to explain penetrating MM-wave VGCC activation via the voltage sensor. Time-varying coherent magnetic fields, as predicted by the Maxwell–Faraday version of Faraday's law of induction, can put forces on ions dissolved in aqueous phases deep within the body, regenerating coherent electric fields which activate the VGCC voltage sensor. In addition, time-varying magnetic fields can directly put forces on the 20 charges in the VGCC voltage sensor. There are three very important findings here which are rarely recognized in the EMF scientific literature: coherence of electronically generated EMFs; the key role of time-varying magnetic fields in generating highly penetrating effects; the key role of both modulating and pure EMF pulses in greatly increasing very short term high level time-variation of magnetic and electric fields. It is probable that genuine safety guidelines must keep nanosecond timescale-variation of coherent electric and magnetic fields below some maximum level in order to produce genuine safety. These findings have important implications with regard to 5G radiation.

Keywords: 5G modulating pulses; coherent electronically generated EMFs; EMF pathophysiological and therapeutic effects; increased [Ca2+]i and calcium signaling; modulating pulses and biological EMF effects; penetrating effects via time-varying magnetic field penetration.

Introduction

Electronically generated electromagnetic fields (EMFs) are highly coherent, being generated at specific frequencies, with specific vector direction, with a specific phase and specific polarity. The special physics properties of such coherent EMFs have been discussed [1–5]. Similarly, biological impacts of coherent EMFs have also been discussed [6–10]. Such coherent EMFs generate much stronger electrical forces and magnetic forces than do natural incoherent EMFs. Most but not all natural EMFs are incoherent. The much stronger forces produced by electronically generated EMFs are of great importance with regard to EMF

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causation of biological effects and also with respect to our ability to use such EMFs for wireless communication. A study where coherence is central to wireless communication is the article of Geffrin et al. [5] which discusses many examples where coherence is essential for wireless communications and also discusses how antenna design is greatly influenced by the need to maintain such coherence. The biological importance of coherence was discussed in two contexts by Panagopoulos et al. [9]. The coherence of the polarity is required for maximum force generation. In addition, the coherence of phase is also important because identical phase produces constructive interference and supra-additive effects, whereas phase shifts lead to high amounts of destructive interference and much lower effects [9]. Golant [7] discusses how coherent MM-wave EMFs may produce resonance interactions with specific biological targets. Strong electrical forces produced by coherent electronically generated EMFs are an important feature of the Fröhlich [6] theoretical model of biological activity of EMFs. While it is clear from this, that there is a substantial literature that electronically generated EMFs are coherent and that such coherence is important for their acting in wireless communication and in producing non-thermal biological effects, this literature is not widely known nor is its importance appreciated among the vast majority of scientists studying EMF effects.

EMF propagation in a vacuum or in very low dielectric constant media, such as air, is characterized by a fixed relationship between the electric field and the magnetic field, as described by Maxwell's equations [11]. However electric fields are much more susceptible to absorption than are magnetic fields by many media, producing a breakdown of that fixed relationship (Keller and Karal [2]). Because the dielectric constant of intracellular and extracellular biological aqueous phases is estimated to be about 120 [12], such differential absorption is relevant to the issue of biological effects. However, as also discussed in ref. [2], the magnetic field penetration is determined by the magnetic field permeability which in essentially all biological tissues is very high, producing very high magnetic field penetration. Strong absorption of electric fields but not magnetic fields are found with MM-wave or microwave radiation traversing biological tissues and also many other media including building materials [13–15]. Electric field absorption is a function of both the dielectric properties of materials and also of the EMF frequency, such that the electric fields of MM-wave EMFs are almost completely absorbed in the outer 1 mm of the body, as shown in ref. [13–15]. The impedance of biological tissues is also likely to have roles in limiting electric field penetration. The rapid electric field absorption in biological tissues has lead telecommunications industry-associated and other scientists to predict that MM-wave biological effects will be limited to the outer 1 mm of the body and that lower microwave frequency effects, in the 400 MHz to 5 GHz range, are suggested to be limited to the outer 1–3 cm of the body. Various definitions are used to define microwave frequency radiation. In this paper, that term refers to 400 MHz to 5 GHz radiation, the range most commonly used for wireless communication.

Other scientists such as in many articles cited in Betskii and Lebedeva [16] have found deeply penetrating effects of MM-waves in human and animal bodies, but have interpreted these as possibly caused by effects near the surface of the body indirectly producing penetrating effects. Similar views are expressed in the Pakhomov et al. [17] review as follows: On p. 393, Pakhomov et al. [17] state that "The term millimeter waves (MMW) refers to extremely high frequency (30–300 GHz) electromagnetic oscillations. Coherent oscillations of this range are virtually absent from the natural electromagnetic environment." Further down [17] continues "Indeed, MMW have been reported to produce a variety of bioeffects, *many of which are quite unexpected from radiation penetrating less than 1 mm into biological tissues*" (italics added). It can be seen from this that although Pakhomov et al. [17] are aware that these MM-waves are coherent, they fail to consider that the MM-wave magnetic fields are highly penetrating and may, therefore, produce highly penetrating effects. On p. 400 of ref. [17], states that "It is clearly understood that MMW penetration into biological tissues is rather shallow, and any primary response must occur in skin or subcutaneous structures, or at the surface of the eye." This review will discuss towards its end, two distinct probable mechanisms by which highly penetrating time-varying MM-wave magnetic fields can produce highly penetrating effects reported in ref. [16, 17] and elsewhere.

Gaiduk [18] showed that when most of the water molecules are hydrogen bonded to solutes or when such solutes otherwise greatly determine water hydrogen bonding structures, as is often the case within living cells, the electric field absorption is lowered. This may be minor part of the mechanism leading to greater penetration of effects, shown below but time varying penetrating magnetic field effects are argued here to be much more important.

Penetrating effects of MM-wave and microwave radiation

Penetrating effects of non-thermal, non-pulsed, continuous wave MM-wave exposures have been reported in a large number of studies. Zalyobokskaya [19] reported that such exposures in rodents produced pathophysiological structural, functional and biochemical changes in each of the following internal organs: the brain, the myocardium, liver, kidney and bone marrow. These are each deeper in the body that 1 mm and therefore provide evidence for deeper MM-wave effects than the industry claims is possible.

Betskii and Lebedeva [16] reviewed large numbers of studies, both human and animal studies of highly penetrating nonthermal MM-wave effects. I will concentrate here on some of the human studies cited in that paper, although animal studies such as discussed in Zalyobokskaya [19] were also reviewed. When that review [16] was published, the voltage-gated calcium channel mechanism, discussed below, was not known so that their interpretation of the various findings discussed was very different from the interpretation discussed below.

We will be discussing here MM-wave effects impacting human brain function as well as a number of other penetrating effects of MM-wave radiation. References [20–24] each show that low intensity, non-thermal non-pulsed MM-wave EMFs produce changes in the EEGs in the human brain which are a measure of the electrical activity of the brain. The citations [21–24] each also find other neurological effects in addition to EEG effects are produced such MM-wave EMFs. The shortest path from outside the body into the human brain is through the skin, skull and meninges surrounding the brain, usually circa 6–7 mm in adults.

Such findings should not be surprising for two different reasons discussed in this paragraph and the following two paragraphs. Pikov et al. [25] and also Siegel and Pikov [26] at Caltech each find that stunningly low intensities of non-pulsed MM-wave EMFs produce strong impacts on brain derived neurons. Pikov et al. [25] in their abstract state that: “The applied levels of MMW power are three orders of magnitude below the existing safe limit for human exposure of 1 mW/cm^2. Surprisingly, even at these low power levels, MMWs were able to produce considerable changes in neuronal firing rate and plasma membrane properties. At the power density approaching 1 $\mu W/cm^2$, 1 min of MMW exposure reduced the firing rate to one third of the pre-exposure level in four out of eight examined neurons. The width of the action potentials was narrowed by MMW exposure to 17% of the baseline value and the membrane input resistance decreased to 54% of the baseline value across all neurons.”

Consequently, Pikov et al. [25] are seeing large, repeated impacts on neuronal cell activity at exposure levels of 1 $\mu W/cm^2$, one one-thousandth of the normal safety guideline allowable levels. They are seeing large effects at exposure levels of 1/1,000th of allowable levels. Normally, safety guideline allowable levels are set at no more than 1% of the lowest level found to produce any effects. By that standard, safety guidelines for MM-wave radiation should be *more than* 100,000 times lower than the current safety guidelines. Siegel and Pikov [26] found effects at still lower level exposures, 300 mW/cm^2, which argues that safety levels should be *more than* 330,000 times lower than current safety guidelines. It should be noted that these are cells in culture, with no shielding from tissues above the cells, other than that produced by the culture medium. Each of the findings, discussed above, are effects produced by non-pulsed, continuous wave MM-wave EMFs, not the extraordinarily highly pulsed 5G radiation, which is predicted to have vastly stronger effects than do these non-pulsed MM-wave, continuous wave EMFs, as discussed below. The US FCC and other regulatory agencies are pushing to change safety guidelines to allow much higher exposures than currently allowed by the current safety guidelines!

There is a second reason why these MM-wave, brain-related findings are not surprising. Reference [27] cited multiple primary literature studies and also review articles which show that EEGs are influenced by low intensity, non-thermal microwave frequency EMFs and also cited many primary literature studies showing that such microwave frequency EMFs also produce widespread human neurological and neuropsychiatric effects. Reference [28] cited 15 review articles showing that such microwave frequency EMFs produce neurological/neuropsychiatric effects.

The remaining human highly penetrating MM-wave effects discussed here, from Betskii and Lebedeva review [16], are apparent therapeutic effects. There are genuine therapeutic effects produced by microwave and other frequency EMFs, so it should not be surprising to find that MM-waves can produce therapeutic effects. There are multiple studies reporting that non-thermal, non-pulsed MM-waves produce improved bone marrow function in humans [29–32]. Other therapeutic effects of MM-waves include increased healing of gastric and duodenal ulcers [33] and improved cardiac function [34, 35]. Two other types of penetrating effects documented by the Pakhomov et al. [17] review, will be discussed later in this paper.

The studies outlined in the previous paragraphs of this section, are all highly penetrating effects produced by non-thermal, non-pulsed MM-wave EMFs. 5G radiation, however, uses extraordinarily high levels of modulating pulses in order to carry extraordinarily high amounts of information per second [36]. Reference [28] cited 10 different reviews each showing that EMFs with modulating pulses produce, in most cases, much higher levels of biological effects than do non-pulsed (continuous wave) EMFs of the same average intensity. If follows that 5G may be predicted to produce very damaging highly penetrating effects because of its extraordinary level of modulating pulsation. The relationship between therapeutic effects and pathophysiological effects produced by EMFs is discussed below.

The recent publication of Kostoff et al. [37] came to similar conclusions to those stated in the previous paragraphs, that MM-waves produce highly penetrating effects: "These results reinforce the conclusion of Russell (quoted above) that *systemic results may occur from millimeter wave radiation*" (italics added). Continuing from ref. [37] "To re-emphasize, for Zalyubovskaya's experiments, the incoming signal was unmodulated carrier frequency only, and the experiment was single stressor only. Thus, the expected real-world results (when human beings are impacted, the signals are pulsed and modulated, and there is exposure to many toxic stimuli) would be far more serious and would be initiated at lower (perhaps far lower) wireless radiation power fluxes."

Much deeper effects than predicted by the industry are not limited to millimeter waves but also occur with microwave radiation. Microwave radiation, as discussed above, has been argued to produce effects limited to the outer 1–3 cm in the body. However, Hässig et al. [38, 39], in Switzerland, find that pregnant cattle grazing near a cell phone tower (also known as a mobile phone base station) produce large numbers of newborn calves with cataracts. The fetus's deep location in the mother's body should protect it from cell phone tower radiation but does not. Switzerland has safety guidelines for cell phone tower radiation that are 100 times more stringent than the U.S. or EU guidelines so that these are quite low intensity EMFs by most standards, but they produce effects very deeply in the mother's body.

The rest of this paper focuses on how such highly penetrating effects can be produced. Both the biology and the physics are essential to this discussion.

The primary mechanism of action of low intensity EMFs in producing biological effects is activation of voltage-gated calcium channels (VGCCs) via its voltage sensor

The most important type of evidence for the EMF-voltage gated calcium channel (VGCC) activation mechanism, is that effects produced by EMF exposures can be blocked or greatly lowered by calcium channel blockers, drugs that are specific for blocking voltage-gated calcium channels [VGCCs) [12, 27, 28, 40]. Five different types of calcium channel blockers have been used in these studies, each of which is thought to be highly specific for blocking VGCCs [40]. Diverse EMFs produce effects which are blocked or greatly lowered by the calcium channel blockers, ranging from millimeter wave frequencies, microwave, radiofrequencies, intermediate frequencies, extremely low frequencies (including 50 and 60 Hz), all the way down to static electric fields and even static magnetic fields [12, 28, 40]. Following EMF exposure, the exposed cells and tissues have large, rapid increases in calcium signaling [12, 27, 28, 40], produced by increases in intracellular calcium [Ca2+]i levels. This overall interpretation has been confirmed by patch-clamp studies, studies using calcium-free medium, and studies measuring [Ca2+]i levels [28]. This mechanism has been widely recognized in the scientific literature with the first publication on this [40] being cited 305 times according to the Google Scholar database, at this writing. New scientific paradigms are usually only very slowly recognized in the scientific literature such that the widespread interest in and acceptance of this mechanism is very unusual. That does not, of course, mean that everyone accepts it.

The direct target of the EMFs is the voltage-sensor, which, in the normal physiology, controls the opening of the VGCCs in response to partial depolarization across the plasma membrane. Four distinct classes of VGCCs are activated in response to low level EMF exposures, L-type, T-type, N-type and P/Q-type VGCCs [40]. Voltage-gated sodium, potassium, and chloride channels, each controlled by a similar voltage sensor are also activated by low intensity EMF exposures, although these have relatively minor roles in producing effects compared with those of VGCC-produced [Ca2+]i elevation [28]. Plant TPC channel activation via a similar voltage sensor also produce plant calcium-dependent EMF effects [41]. Each of these channels is controlled by a similar voltage-sensor, suggesting that the voltage-sensor is the direct EMF target.

The electrical forces produced by even weak electronically generated EMFs on each of the 20 positive charges in the VGCC voltage sensor are thought to be very strong due each of three distinct mechanisms, which act multiplicatively: 1. Electronically generated EMFs are highly coherent, as discussed above, being emitted with a specific frequency, in a specific vector direction, with a specific phase and specific polarity. This high-level coherence causes the electrical and magnetic forces produced by these to be vastly higher than are forces produced by incoherent natural EMFs. 2. The electrical forces on these charges in the voltage sensor are thought to be approximately 120 times higher than forces on charges in the aqueous phases of our cells and bodies, as predicted be Coulomb's law, due to the difference of the dielectric constant in the two locations [12, 28]. 3. The forces on the charges in the voltage sensor are also thought, to be approximately 3,000 times higher because of the high electrical resistance of the plasma membrane and therefore the high level of amplification of the electric field across the plasma membrane [12, 28]. This helps us to understand how VGCCs and other voltage-gated ion channels can be activated by what are considered to be very weak EMFs. The important finding here is that EMFs activate the VGCCs and other voltage-gated ion channels not via depolarization of the plasma membrane but rather via the direct forces they produce on the circa 20 charges in the voltage sensor. One puzzle discussed in ref. [40] and also below in this paper is how can static magnetic fields activate the VGCCs when physics shows that static magnetic fields cannot put forces on static electrical charges. These magnetic field effects are discussed in the next section.

How then does EMF-produced VGCC activation produce biological effects? Our best understanding of this is outlined in Figure 1 [12, 28, 40]. The main pathophysiological effects seen going to the bottom of Figure 1, are produced through excessive calcium signaling produced by [Ca2+]i elevation and by the peroxynitrite pathway, with the latter involving increases in reactive free radicals, oxidative stress, NF-kappaB activity and inflammatory cytokine levels and also mitochondrial dysfunction. There is also a pathway by which VGCC activation, acting via increased nitric oxide (NO), NO signaling and Nrf2 stimulation can produce therapeutic effects that also helps explain EMF effects. The therapeutic pathway is thought to be produced by modest [Ca2+]i elevation whereas the pathophysiological pathways are produced by higher level [Ca2+]i elevation.

MM-waves have been shown to act via activation of the VGCCs and also voltage-gated potassium channels [42–44]. Therefore it seems likely that MM-waves act via such channel activation as do lower frequency EMFs. This interpretation is confirmed by findings that MM-waves raise [Ca2+]i levels, calcium signaling and also nitric oxide (NO) [42] (compare with Figure 1). It is also confirmed by findings that MM-waves raise peroxynitrite [45] and by findings, discussed above, that MM-waves can produce similar pathophysiological effects and therapeutic effects to those produced by lower frequency EMFs. There is an additional channel that is probably activated by MM-waves acting on voltage sensors, the Ca2+-activated potassium channel as shown by Geletyuk et al. [46]. It was shown in ref. [46] using patch-clamp studies, that closed Ca2+-activated potassium channels are opened by exposures to low intensity non-pulsed MM-waves. This same channel has also been shown to be activated by both 50 Hz and microwave frequency EMFs [47]. Ca2+-activated potassium channels have been shown to be activated by a voltage sensor similar in structure to the voltage sensors discussed above acting synergistically with increases in [Ca2+]i. It follows that EMFs may act to activate Ca^{2+}-activated potassium channels via the voltage sensor in that channel and also via the VGCC voltage sensors.

Can Nrf2 activation (see Figure 1) produce the therapeutic responses reported to occur following MM-wave exposures [16], as discussed in a previous section? Garkavi et al. [48] showed that MM-waves produced antistress responses and such antistress responses have been shown to be produced by therapeutic Nrf2 elevations (see, for example [49, 50]). Consequently, it is plausible that the therapeutic mechanism outlined in Figure 1 can produce the penetrating therapeutic effects, discussed above to be found following non-pulsed MM-wave exposures.

What mechanisms produce highly penetrating effects of MM-waves?

With the electrical parts of MM-wave radiation largely absorbed in the outer 1 mm of the body, how, can we get these highly penetrating effects through impacts on the voltage sensor of the VGCCs produced by these highly coherent electronically generated EMFs?

Two explanatory mechanisms are proposed here, each as a consequence of the very highly penetrating, time-varying magnetic forces produced by the highly coherent electronically generated EMFs including MM-wave EMFs. Let's consider each these two explanatory mechanisms, one at a time.

The discussion on Maxwell's equations in Wikipedia [11] states that "The Maxwell–Faraday version of Faraday's law of induction describes *how a time varying magnetic field* creates ('induces') an electric field" (italics added). Coherent highly penetrating time-varying magnetic fields will produce strong forces on ions dissolved in the aqueous phases in our bodies, moving those ions in both the extracellular medium and also in intracellular aqueous phases and therefore regenerating a highly coherent electric field similar to but of lower intensity to the original electric field of the EMF before entering the body. The regenerated EMF can, then act to put forces on the charges of the voltage sensor thus activating the VGCCs. The

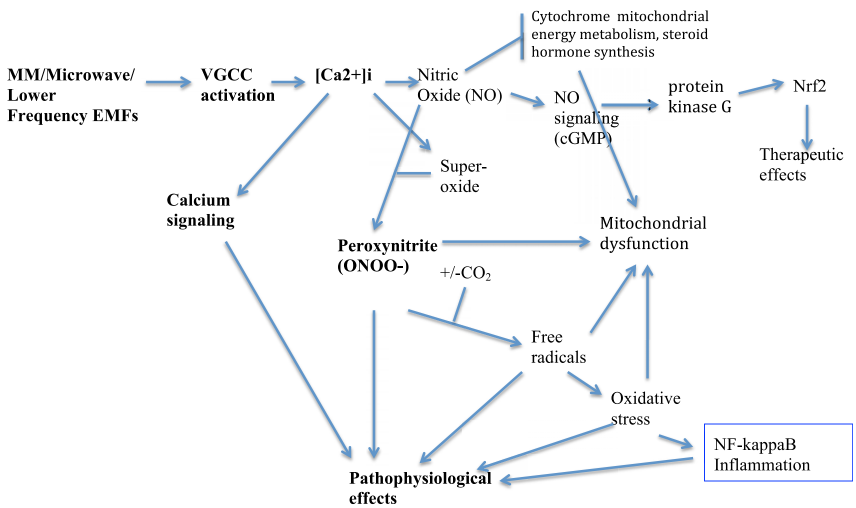

Figure 1: Diverse frequency EMFs act via activation of voltage-gated calcium channels (VGCCs) producing increased intracellular calcium [Ca2+]i. [Ca2+]i is defined as the calcium ion concentration in the cytoplasm which is distinct from the calcium concentration in the endoplasmic reticulum or the mitochondria, which are regulated separately. This leads to production of pathophysiological effects mainly via excessive calcium signaling and activation of the peroxynitrite/free radical/oxidative stress, NF-kappaB and inflammation pathway. Therapeutic effects are produced primarily via nitric oxide (NO) signaling leading to increased Nrf2 activity. Because the therapeutic pathway produces effects that are almost exactly opposite the effects produced by the peroxynitrite pathway, different EMF exposures may produce almost opposite effects. Copied from ref. [28] with permission.

physics here is essentially identical to the physics of electrical generation. In electrical generators, time-varying magnetic fields put forces on mobile electrons in copper wires, moving those mobile electrons and generating, in turn, an electrical current. In our bodies, the highly penetrating time varying magnetic fields put time-varying forces on dissolved mobile ions in aqueous phases in our bodies, generating a coherent electric field which can act on the voltage sensors to activate the VGCCs, as discussed above. A study providing support for this mechanism is the study of Deghoyan et al. [51] which found that non-thermal effects on cells in culture were produced through MM-wave irradiation of the medium surrounding these cells. This may or may not be the primary mechanism by which MM-waves produce highly penetrating effects.

There is second highly plausible mechanism by which highly penetrating magnetic fields can put forces on the charges in the voltage sensor activate voltage-gated ion channels. In ref. [40] it was shown that static magnetic fields also act, as do EMFs, via VGCC activation to produce biological effects that can be blocked with calcium channel blockers, so that the biological effects must have been produced via VGCC activation. Specifically, in Table 1 of ref. [40] and refs. [10], [12] and [24] in that paper each showed that effects produced by static magnetic fields can be blocked by calcium channel blockers, drugs specific for blocking VGCCs. Consequently, static magnetic fields produce effects via VGCC activation. That conclusion has been confirmed by the findings from patch-clamp studies, showing that static magnetic fields produced VGCC activation and also activation of voltage-gated sodium channels [52]. Those findings that static magnetic fields can act via the voltage sensor to activate VGCCs and apparently other voltage-gated ion channels created a puzzle that was discussed in ref. [40]. That puzzle is that static magnetic fields do not produce forces on static electrically charged objects. The answer to that puzzle, as discussed in ref. [40], is that the plasma membranes of cells are constantly moving and therefore the voltage sensors of the VGCCs located in the plasma membrane are also moving, so that static magnetic fields can produce time-varying forces on the charges of the VGCC voltage-sensor. These findings clearly raise the possibility that the highly penetrating time-varying magnetic fields derived from MM-wave or other frequency EMFs, including the extraordinarily high densities of modulating pulses of 5G, can have very high activity when acting directly on the 20 positive charges in the voltage sensor of the VGCCs to activate the VGCCs.

Both modulating EMF pulses and pure EMF pulses can act via each of the two mechanisms discussed here to produce large, very short term, penetrating changes in the forces on electrical charges including the voltage gated ion channel voltage sensor charges. Modulating and pure pulses inevitably produce vastly greater maximum time-variation and are, therefore, predicted to produce vastly greater maximum forces on the voltage sensor charges.

Because each of the two mechanisms proposed in this section for the generation of penetrating effects are dependent upon time-varying magnetic fields, together they provide a new understanding of the great importance of both modulating and pure pulsation in producing high level EMF effects.

Pakhomov et al. [17] reviewed findings with regard to non-pulsed MM-Waves: cardiac effects and electromagnetic hypersensitivity (EHS)

There are important findings on both animal cardiac effects and on animal tissue and human EHS-like effects produced by non-pulsed MM-wave exposures that were reviewed in Pakhomov et al. [17]. These are discussed here, in contrast, other MM-wave studies including those reviewed by Zalyobokskaya [19] and by Betskii and Lebedeva [16] which were discussed much earlier.

There are two important reasons for the author choosing to discuss the Pakhomov et al. [17] review on cardiac effects and also EHS-like effects here, as opposed to much earlier. Each of these require comparing animal studies with human studies. When highly penetrating MM-wave magnetic fields produce highly penetrating effects in animals and in humans, the difference in body size between humans and rodents is of little importance in predicting effects. A second reason for discussing these parts of ref. [17] here, is that the VGCC activation mechanism discussed above is predicted to be central to our understanding of both cardiac effects and EHS.

Chernyakov et al. [53], as discussed on p. 399 of ref. [17], reported on 990 experiments where very low intensity MM-wave EMFs changed the membrane function of the pacemaker cells of the sinoatrial node of the frog heart. In most cases, there was an almost instantaneous (less than 2 s) decrease in the interspike interval of these cells which in an intact heart would produce tachycardia. These occurred with intensity ranges of 20–500 $\mu W/cm^2$ and were, therefore, clearly non-thermal effects. Furthermore, as discussed on p.400 of ref. [17], Chernyakov et al. [53] showed that very low intensity MM-wave EMFs could produce changes in heart rate in anesthetized frogs, including both tachycardia (increase heartbeat) and bradycardia (slow heartbeat) and also arrhythmias. These also occurred when the hearts had been completely denervated although the severity of these changes decreased with denervation. The studies in this paragraph show that low intensity MM-wave EMFs produce direct effects on the membrane activity of the pacemaker cells in the sinoatrial node of the frog heart, influencing the heartbeat, but that the responsiveness of these cells can be influenced by neurological activity.

Other important cardiac studies of low intensity MM-waves were reported by Potekhina et al. [54] in the rat. They [54] showed that MM-waves produced changes in heartbeat including arrhythmias, tachycardia and bradycardia. Longer term (circa 3 h) exposures produced large numbers of animals who died of apparent sudden cardiac death. It is the author's opinion that most if not all of these EMF cardiac effects are produced by the direct impacts of diverse EMFs impacting the pacemaker cells in the sinoatrial node of the heart. One additional set of observations supporting that view are the findings of Liu et al. [55] showing that pulsed microwave EMFs produce heart failure-like changes in the sinoatrial node of the heart. The reason the pacemaker cells of the sinoatrial node of the heart may be particularly sensitive to EMFs is because they contain particularly high densities of T-type VGCCs, with both T-type and L-type VGCCs having essential roles in producing the pace making activity [56, 57]. These findings suggest that penetrating EMF effects can produce commonly observed cardiac effects via direct impacts on the pacemaker cells in the sinoatrial node of the heart.

Pakhomov et al. [17] also reviewed findings showing that non-pulsed MM-wave EMF exposures produce EHS-like effects in animal nerve tissue, and in humans. EHS is characterized by long term sensitivity responses to electromagnetic or electric fields [17] describes three studies where non-pulsed MM-wave exposures produced fairly long-term sensitivities in animal tissues and three additional studies of long term neurological/neuropsychiatric sensitivity in humans.

Burachas and Mascoliunas [58] described changes in the compound action potential (CAP) in the frog sciatic nerve following MM-wave exposures. They found that "CAP decreased exponentially and fell 10-fold within 50–110 min of exposure at 77.7 GHz, 10 mW/cm^2. CAP restored entirely soon after exposure, but the nerve became far more sensitive to MMW. CAP suppression due to the next exposures became increasingly steep and finally took only 10–15 min. This sensitized state persisted for at least 16 h" CAP is a measure of the overall electrical activity of the nerve. These findings may be interpreted in terms of MM-wave EMF exposures producing long-term EHS-like sensitivities in the frog sciatic nerve.

A second study by Chernyakov et al. [53] also reported sensitivity changes using a different frog nerve and also different MM-wave exposure protocols. “The exposures lasted 2–3 h, either with a regular frequency change of 1 GHz every 8–9 min or with a random frequency change every 1–4 min (53–78 GHz band, 0.1–0.2 mW/cm^2). The latter regimen induced an abrupt CAP ‘rearrangement’ in 11 of 12 exposed preparations: the position, magnitude and polarity of the CAP peaks (the initial CAP was polyphasic) drastically changed in an unforeseeable manner. The other exposure regimen altered the CAP peaks components in 30–40 min”

Akoev et al. [59] found EHS-like effects following low intensity MM-wave exposures on the activity of electroreceptors of skates (the article cited here is an English language study, published in an international journal that appears to be similar or identical to the Russian language article cited in ref. [17]). “When a power intensity of 1–5 mW/cm^2 was used at a distance of 1–20 mm from the duct opening only excitatory responses were observed in receptors with electrical thresholds of 4–20 nA”, p. 15 in ref. [59]. Reference [59] states further (p. 17) “It is of interest that at low EMR intensity, the electroreceptors (have) prolonged excitatory responses which differ from responses to the d.c. electrical stimuli (where) the ampullae of Lorenzini completely adapt within a few minutes. Thus it is the long-lasting slow adapting excitatory response that may reflect the peculiarity of the low-intensity millimeter-wave EMR effect on biological tissues.” These results show that low intensity MM-wave EMFs produce long-term hypersensitivity of the electroreceptors. There are similar electroreceptors in sharks, skates and rays and given that the target producing hypersensitivity here is that receptor, it is important to identify the identity of electroreceptor. Bellono et al. [60] showed that the electroreceptor is the VGCC Ca(V)1.3. Other studies implicate excessive [Ca2+]i in electroreception and VGCC activation was also implicated in the Zhang et al. [61] study of the skate electrosensor. We have, therefore, VGCCs implicated as the direct EMF target involved in producing EHS-like responses.

Is there other evidence implicated excessive VGCC sensitivity in producing EHS? One such study was published by Dr. Cornelia Waldmann-Selsam [62]. She studied an EHS patient who showed high sensitivity to extremely low intensity EMFs and who also had a profound parathyroid deficiency. This patient showed very large rapid drops in extracellular Ca^{2+} concentration, including in the blood plasma, following extremely low intensity EMF exposure. Because the only possible mechanism that can produce such a large rapid drop in extracellular Ca^{2+} concentration is a large influx of Ca^{2+} ions into cells of our bodies, this argues strongly for EHS producing large increases in activity of one or more calcium channels in the plasma membranes of cells. Because VGCC activation is known to be the major mechanism of EMFs, all of these findings argue that the VGCCs in EHS become hypersensitive to EMF activation.

The parathyroid deficiency of this patient [62] is of great importance because in people with normal parathyroid function, large drops in extracellular calcium levels produce a rapid increase in parathyroid hormone secretion, which mobilizes calcium from the bones to help restore normal extracellular calcium levels, thus making drops of extracellular Ca^{2+} concentrations in exposed EHS patients with normal parathyroid function more difficult to document. However, these considerations suggest a simple clinical test for EHS patients. Such patients should have large increases in parathyroid hormone following low intensity EMF exposures to which they report sensitivity, whereas normal people should not show such large increases to the same exposures. Because parathyroid hormone can be measured by clinical testing laboratories, this prediction can be easily tested and possibly used as a simple, inexpensive test of EHS.

A fourth MM-wave animal study, discussed above in this section, also suggests possible EHS-like effects in animals. This is the Potekhina et al. [54] study in the rat which found that non-pulsed MM-wave exposures for 3 h or more started to produce apparent sudden cardiac death in these exposed rats. These findings suggest cumulative effects of EMF exposure. However, their relevance to EHS must be viewed as more questionable than are the three studies discussed more immediately above, because there were no measurements which demonstrated that exposures produced increased sensitivity following MM-wave exposures in Potekhina et al. [54].

Three human studies, cited in ref. [17] each showed apparent EHS effects following low intensity non-pulsed MM-wave exposures, including neurological/neuropsychiatric sensitivities [21, 63, 64]. The sensitivities shown in each are brain-related neurological/neuropsychiatric sensitivities that are commonly reported in EHS.

EHS causation by EMF exposures is not only documented by the studies cited above. They are also documented by the largest occupational exposures ever performed, as shown in the Hecht review of such exposures [65]. Reference [65] also documents EMF causation of neurological/neuropsychiatric effects and cardiac effects.

In addition the much earlier US Government (NASA) document [66] also documents EMF occupational exposure causation of neurological/neuropsychiatric effect and cardiac effects [28] lists 15 different published reviews each of which provide substantial bodies of evidence that neurological/neuropsychiatric effects are caused by low-intensity, non-thermal EMF exposures. Lamech [67] showed that smart meter radiation exposure was associated with large increases in EHS, neurological/neuropsychiatric effects and cardiac effects and similar findings were reported in the Conrad study of smart meter radiation.

Four reviews on EHS each report that among the most common sensitivities in EHS patients are neurological/neuropsychiatric sensitivity and cardiac sensitivity [65, 68–70].

It follows from the findings discussed in this section, that EMFs with substantial impacts on our bodies will produce many cases of EHS with the consequent sensitivity responses often including neurological/neuropsychiatric effects and cardiac effects. The next question to be considered here is whether 5G radiation is likely to be among the EMFs that may produce substantial impacts.

Earlier in this paper we discussed two important findings that are important for assessing the probable impacts of 5G radiation. 5G radiation, however, uses extraordinarily high levels of modulating pulses in order to carry extraordinarily high amounts of information per second [36]. Reference [28] cited 10 different reviews each showing that EMFs with modulating pulses produce, in most cases, much higher levels of biological effects than do non-pulsed (continuous wave) EMFs of the same average intensity. If follows that 5G may be predicted to produce very damaging highly penetrating effects because of its extraordinary level of modulating pulsations.

Is there any evidence that 5G radiation produces high human impacts including EHS, neurological/neuropsychiatric effects and cardiac effects?

There has been no biological safety testing of highly pulsed 5G radiation despite calls from many scientists for such testing before any 5G rollout should occur. There have also been no scientific studies of 5G radiation effects after any 5G rollouts, to my knowledge. Consequently, the only evidence we have is from reports of 5G effects in the media. These reports are not, of course, scientific studies but rather are derived from what may be viewed as questionable observations. Nevertheless, due to the lack of any other 5G information, it is important to look at what little information we do have.

Reference [71] is a German news article about protests of German physicians in Stuttgart Germany following a 5G rollout. The physicians report seeing substantial apparent effects on their patients including neurological/neuropsychiatric effects, cardiac effects and EHS. These observations can be seen to be similar to the predicted 5G effects in the previous section. German physicians may be more aware of EHS than are physicians in other countries because the European environmental medicine organization, EUROPAEM, has been headquartered in Germany for many years – [69] is a EUROPAEM-related paper.

There are also reports of neurological/neuropsychiatric effects, cardiac effects and possibly also EHS in Switzerland following 5G rollout in parts of that country [72–74]. These reports may be somewhat less reliable than those from Stuttgart because they come from lay people.

There was much concern about three suicides over an 11 day period of emergency medical technicians working in the first 5G ambulance [75]. This occurred in Coventry, UK. The idea was that 5G could be used to transmit much medical information from the hospital to the ambulance and could also be used to transmit much electronic patient information from the ambulance to the hospital. The first EMT suicide occurred approximately two weeks after the EMTs started working in the 5G ambulance. Among the more common neuropsychiatric effects produced in humans by EMF exposures are depression and anxiety [27], both of which when severe can cause suicide. It is possible that EHS may play a role in the approximate two week time period between the beginning of service of the 5G ambulance and the first suicide. Development of progressively more severe EHS over that two week period may be predicted to produce progressively more severe depression and anxiety.

Again, these are not scientific studies but given the lack of any contrary information, they need to be taken seriously and should be the subject of serious scientific study rather than massive rollout of untested and possibly very dangerous 5G systems. One thing that should be pointed out is that any initial effects on rollout of 5G, are likely to be dwarfed by effects of any full-fledged 5G system communicating with billions of devices on the 'internet of things." Of course, the effects of such massive amounts of pulsed EMF communication may be further amplified through the action of EHS in the victims.

Search strategies

Articles on important physical or biological properties of coherent electronically generated EMFs were found using two search strategies: The EMF Portal database was searched using coherent or coherence. The Web of Science database and Google Scholar were each searched using electromagnetic fields and coherent.

Reviews on biological including human effects of millimeter waves were searched for in the EMF Portal database searching with the words millimeter waves and limiting responses to review articles. Similarly, reviews were searched in the EMF Portal database using EHS to identify EHS reviews.

The work on EMFs acting primarily via the voltage sensor to activate VGCCs is limited to my own work where only highly cited peer-reviewed articles were cited.

Two specific questions were answered as follows

When it was shown that millimeter wave exposures produced increased sensitivity of the skate electroreceptor, it was important to determine whether the electroreceptor is a VGCC, the most important direct target of EMFs. A Web of Science search using electroreceptor and voltage calcium channel found two studies each showing that the electroreceptor is a VGCC.

It was shown that millimeter waves act directly on the pacemaker cells of the sinoatrial node of the heart to change the beat frequency. It was important to determine whether microwave frequency radiation also target such cells in the sinoatrial node. A search of the EMF Portal database limited to radiation over 1 MHz for studies on sinoatrial node found a study showing that repeated or prolonged exposures produced heart failure-like changes in the sinoatrial node of the rat heart.

Two of the Russian language articles are available as CIA English translations, as shown in the citation list. All other foreign language documents cited where suitable PDFs of the original documents were available were translated into English using Google Translate.

Research funding: The author states that there was no funding involved.

Author contributions: The author has accepted responsibility for the entire content of this manuscript.

Competing interests: The author states that there is no conflict of interest.

Informed consent: Informed consent is not applicable.

Ethical approval: There are no new human or animal studies requiring ethical approval. All reviewed research involving human or animal studies complied with relevant national ethical standards and the Helsinki declaration.

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Human-made electromagnetic fields: Ion forced-oscillation and voltage-gated ion channel dysfunction, oxidative stress and DNA damage (Review)

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Received July 9, 2021; Accepted August 23, 2021

DOI: 10.3892/ijo.2021.5272

Abstract. Exposure of animals/biological samples to human-made electromagnetic fields (EMFs), especially in the extremely low frequency (ELF) band, and the microwave/radio frequency (RF) band which is always combined with ELF, may lead to DNA damage. DNA damage is connected with cell death, infertility and other pathologies, including cancer. ELF exposure from high-voltage power lines and complex RF exposure from wireless communication antennas/devices are linked to increased cancer risk. Almost all human-made RF EMFs include ELF components in the form of modulation, pulsing and random variability. Thus, in addition to polarization and coherence, the existence of ELFs is a common feature of almost all human-made EMFs. The present study reviews the DNA damage and related effects induced by human-made EMFs. The ion forced-oscillation mechanism for irregular gating of voltage-gated ion channels on cell membranes by polarized/coherent EMFs is extensively described. Dysfunction of ion channels disrupts intracellular ionic concentrations, which determine the cell's electrochemical balance and homeostasis. The present study shows how this can result in DNA damage through reactive oxygen species/free radical overproduction. Thus, a complete picture is provided of how human-made EMF exposure may indeed lead to DNA damage and related pathologies, including cancer. Moreover, it is suggested that the non-thermal biological effects attributed to RF EMFs are actually due to their ELF components.

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Abbreviations: DECT, digitally enhanced cordless telecommunications; ELF, extremely low frequency; EMF, electromagnetic field; MT, mobile telephony; OS, oxidative stress; RF, radio frequency; ROS, reactive oxygen species; ULF, ultra low frequency; VGICs, voltage-gated ion channels; VGCCs, voltage-gated calcium channels; WC, wireless communications; Wi-Fi, wireless fidelity; 2G/3G/4G/5G, second/third/fourth/fifth-generation of mobile telephony

Key words: EMF, ion forced-oscillation, VGICs, free radicals, OS, ROS, DNA damage, cancer

Contents

1. Introduction

Experimental and epidemiological findings connecting exposure of living organisms to ELF and complex RF human-made EMFs with genetic damage, infertility and cancer. There is a plethora of experimental findings connecting the *in vivo* or *in vitro* exposure of experimental animals or cells to extremely low frequency (ELF) (3-3000 Hz) or radio-frequency (RF)/microwave (300 kHz-300 GHz) electromagnetic fields (EMFs), with genetic damage/alterations

(DNA damage, chromosome damage and mutations, among others), cell death and related effects (1-4). Most findings concern exposure to wireless communication (WC) EMFs [from mobile phones/antennas, cordless domestic phones (DECT: digitally enhanced cordless telecommunications), internet (Wi-Fi: wireless fidelity) or 'Bluetooth' wireless connections, among others], which necessarily combine RF/microwave carrier frequencies with ELF pulsing and modulation, and ultra low frequency (ULF) (0-3 Hz) random variability of the signal. Today, almost all technical RF EMFs (not only of WC, but also from radars, radio and television antennas, among others) contain ELF/ULF components in the form of on/off pulsations, modulation, and signal variability. These are usually called simply 'RF', but actually they are a combination of RF and ELF/ULF (4).

The number of experimental-laboratory studies showing genetic damage and related effects induced by human-made ELF or RF (combined with ELF) EMFs on a variety of organisms/cell types under different experimental conditions has rapidly increased, especially in recent years (5-55).

Several of the aforementioned findings involve DNA damage and consequent cell death in reproductive cells of different animals, resulting in decreased reproduction. In particular, the effects of pulsing WC EMFs on the DNA of reproductive cells, as reported by different studies on a variety of animals (25,30,31,36,40,41,46), display a marked similarity and explain other findings that connect WC EMF exposure with insect, bird and mammalian (including human) infertility (56-64), or declines in bird and insect populations (especially bees) during the past 15 years (65-69). A significant decrease in reproduction (decrease in egg laying or embryonic death) after exposure to mobile telephony (MT) radiation was identically observed in fruit flies (30,40,57,58), chicken eggs (61), birds (65-67), and bees (63). Similar effects are reported for amphibians (70,71), rats (31,62), and human sperm (decreased number and motility of spermatozoa) (59,60). These markedly similar findings in different organisms by different research groups can be explained by the observed cell death in reproductive cells after DNA damage, as seen in fruit fly ovarian cells (30,40,41,46), human sperm cells (36), mouse and rat sperm cells (25,31). Decreased reproduction after DNA damage and cell death in reproductive cells or embryonic death induced by purely ELF EMF-exposure is also reported (4,9,14,22,47).

At the same time, epidemiological/statistical studies increasingly link man-made EMF exposure with health problems, genetic damage and cancer in human populations. More specifically, ELF EMFs from power lines and high-voltage transformers (mainly 50-60 Hz plus additional frequencies due to harmonics, noise and discharges, among others) are linked with childhood leukemia (72-82) for magnetic field intensities down to 2 mG (0.2 μT) (76,82), or distances from power lines up to 600 m (81), and electric field intensities down to 10 V/m (78). RF exposure from various antennas always containing ELF components, especially MT antennas, is linked to various forms of cancer. Hallberg and Johansson (83) found a connection between skin cancer (melanoma) incidence in humans and residential exposure to radio broadcasting antennas, while two recent studies found significantly increased genetic damage in the peripheral blood lymphocytes of people residing in the vicinity of MT base antennas (84,85). During the past 15 years, epidemiological studies have found an increasing association between mobile or cordless phone use and brain tumors in humans (86-98). Moreover, during the past 20 years, statistical studies have found associations between exposure to MT base station antennas and devices, and reported symptoms of un-wellness referred to as 'microwave syndrome' or 'electro-hypersensitivity' (EHS). The symptoms include headaches, fatigue, sleep disorders, etc. (99-107). A high percentage (~80%) of EHS self-reporting patients were recently found with increased oxidative stress (OS) [intracellular increase in free radicals/reactive oxygen species (ROS)] in their peripheral blood (108).

A review of studies involving exposure to complex RF EMFs with ELF pulsation/modulation revealed that 93% of them reported induction of OS/ROS overproduction in biological systems (109).

Induction of cancer in experimental animals by long-term MT exposure, including ELF pulsations, has also been reported (110,111). A recent study of the USA National Toxicology Program (NTP) found that rats exposed for 2 years, 9 h per day, in the near-field of simulated 2nd generation (2G) or 3rd generation (3G) MT emissions, developed brain cancer (glioma) and heart cancer (malignant schwannoma), with both lower and higher radiation levels than the officially accepted limits (112). Moreover the study found significantly increased DNA damage (strand breaks) in the brains of exposed animals (113), confirming that DNA damage is closely related to carcinogenesis. An Italian life-span exposure study of rats in a simulated 2G MT far-field also found induction of heart schwannomas and brain glial tumors, confirming the results of the NTP study (114).

These findings on animal carcinogenicity along with the epidemiological cancer findings on humans, the DNA damage and OS findings, and the adverse effects on reproduction due to DNA damage in the gametes or embryonic death, point towards the same direction, i.e., that human-made EMF exposure causes OS and DNA damage that may lead to cancer, reproductive declines and related diseases. It is important to note that the exposure levels in the vast majority of all the aforementioned studies (1-114) were significantly below the officially accepted exposure limits for ELF and RF EMFs, which have been set to prevent discharges on humans in the case of ELF and heating of living tissues in the case of RF (115,116).

At the same time, several other studies have reported no effects of ELF or RF EMFs in all the aforementioned end-points (1-4,47,57,115-124), especially studies that employed simulated MT/WC exposure from generators with invariable parameters (intensity, frequency and pulsations, among others) and no modulation or random variability. By contrast, more than 95% of the studies that employed real-life MT/WC exposure from commercially available devices (mobile/cordless phones and Wi-Fi, among others) with high signal variability found effects (4,121,122). Regardless of real-life or simulated exposure, the majority of experimental studies (more than 70%) both in the RF (combined with ELF) and purely ELF bands do find effects (4,109,123,124). In a recent review of 138 RF studies with frequencies >6 GHz evaluating potential effects of the under deployment 5th generation (5G) MT/WC system, it was not specifically examined whether there were

ELF components in the exposure and what type, or whether there was any similarity between the signals produced by generators in the studies, and those of the 5G, apart from the carrier frequency. While most of the reviewed studies reported effects, they were criticised in this review for not being 'independently replicated' and for employing 'low quality methods of exposure assessment and control' (125). Thus, despite the incomplete review methodology, the authors of the review attempted to downgrade any reported effects.

Under the increasing weight of scientific evidence, the International Agency for Research on Cancer (IARC) has for a long time now classified both ELF and RF EMFs as possibly carcinogenic to humans (group 2B) (117-119). Based on additional scientific evidence after the 2011 IARC classification for RF EMFs, several studies have suggested that RF/WC EMFs should be re-evaluated and classified as probably carcinogenic (group 2A) or carcinogenic (group 1) to humans (92,97,126,127). As already emphasized, in the vast majority of studies characterized as 'RF', the ELF/ULF components were present.

While the reported effects in the vast majority of the above studies (1-124) induced by ELF or complex RF (containing ELF) EMFs were not accompanied by any significant heating of the exposed living tissues, it is well established that purely RF/microwave EMFs cause heating of exposed materials (e.g. microwave ovens). The heating becomes significant for high power/intensity (≥0.1 mW/cm^2) and high frequency (at GHz range) microwaves (128). In addition, purely RF EMFs, which are of very limited technological use, are scarcely reported to induce non-thermal effects, and it is questionable in such cases, whether the presence of any ELFs was carefully excluded (129).

DNA damage and related pathologies. It is well documented that DNA damage is connected with cell senescence (cell aging and loss of replicative capacity), cell death, neurodegenerative diseases and aging of an organism, and is the main cause of carcinogenesis induced by environmental stressors (3,130-138). DNA damaging events take place at any time in the cells of any living organism due to a variety of events (such as exposure to ultraviolet radiation, natural radioactivity or cytotoxic chemicals), but efficient DNA repair mechanisms have evolved to provide protection. Damage in the DNA is any modification in a nucleotide base, deoxyribose, a break in a covalent bond between deoxyribose and nucleotide base, or a break in a phosphodiester bond in one or both strands (3,130-139).

Replication of damaged (or inaccurately repaired) DNA that may occur before repair or blocking can lead to gene mutations, which will then give rise to altered proteins. Mutations in oncogenes, tumor-suppressor genes, DNA repair genes or genes that control the cell cycle can generate a clonal cell population with a distinct ability to proliferate. DNA methylation that may prohibit the expression of DNA repair genes and synthesis of related proteins can result in inaccurate ('error-prone') DNA repair. Many such events, which may accumulate over a long period of time in cases of chronic exposure to carcinogens, can lead to genomic instability and cancer (133,134,136,139).

When the genomic DNA of a cell is damaged by an external stressor and the damage is either not reparable or inaccurately repaired, the following outcomes are possible: i) The cell dies (necrosis) or is led to suicide (induced apoptosis). In the case of cell types with the ability to proliferate, the organism compensates for their loss by creating new cells, practically with no adverse consequences apart from energy consumption, which may lead to accelerated aging when such events occur at a high rate. In the case of cell types that do not have ability to proliferate, such as neural cells or chondrocytes, the loss of a significant number of cells will probably result in the inability of certain tissues/organs to operate normally. In the case of neural cells, this may lead to neurodegenerative diseases such as Alzheimer and Parkinson, and autoimmune disorders, among others. ii) The cell does not die but survives with modified DNA. In the case of somatic cells that proliferate, the modified genome will reproduce itself. Even though the organism may recognize such mutant cells as foreign and try to isolate them and remove them, they strive to survive and may start proliferating uncontrollably, initiating cancer. In the case of reproductive cells (oocytes and spermatocytes), this may lead to mutated new organisms that may be problematic in many ways or cancer-prone. In both cases (somatic or reproductive cells) cell senescence is an alternative pathway for eliminating surviving genetically defective cells. Thus, cells with irreparably damaged genomic DNA will result in cell senescence, cell death, cancer or mutated offspring, depending on cell type and specific biological/environmental conditions (3,4,122,130-132,135-137).

The duration of cancer development (latency period) after irreparable DNA damage may be a number of years, depending on the organism and the type of cancer. The latency period for gliomas (a type of brain cancer) is usually >20 years in humans (140). This probably explains why only during the past ~15 years epidemiological studies have started showing an association between mobile phone use and cancer (86), whereas cancer from power lines, which are several decades older than MT/WC, has been indicated long before (72).

Purpose of the present study. As aforementioned, a growing number of experimental and epidemiological/statistical findings connect man-made EMF exposure with genetic damage and cancer, and this involves the breakage of chemical/electronic bonds in molecules/atoms, in other words ionization. The human-made EMFs with frequencies up to the lower limit of infrared (0-3×10^{11} Hz) discussed in the present study cannot directly cause ionization, except for very strong field intensities (≥10^6 V/m) (141,142). Such field intensities rarely exist environmentally, apart from atmospheric discharges (lightning) or in very close proximity to high-voltage power lines and transformers. The question therefore is how human-made EMFs at environmental intensities are capable of damaging DNA and other biological molecules. Obviously they have the ability of breaking chemical bonds indirectly through the action of some primary biophysical mechanism(s) and subsequent initiation of intracellular biochemical processes.

Visible and infrared natural light cannot break chemical bonds, even though they expose us at higher frequencies and radiation intensities than human-made EMFs in daily life (143). There must be a unique property of the human-made EMFs that makes them capable of inducing adverse biological/health effects and ionization, in contrast to natural infrared and visible light. This unique property is that human-made EMFs/radiation are totally polarized and coherent, meaning that they possess net electric and magnetic fields, apart from radiation intensity, which exert forces on any electrically charged (or polar) particle/molecule such as mobile/dissolved ions and charged macromolecules in any biological system (143).

The purpose of the present study is to suggest a realistic primary biophysical mechanism for polarized and coherent EMFs at environmentally relevant intensities, to impair cellular function and initiate plausible intracellular biochemical processes resulting in genetic damage and carcinogenesis, as reported in the aforementioned studies.

2. Biophysical action of polarized/coherent EMFs resulting in voltage-gated ion channel (VGIC) dysfunction and disruption of cell electrochemical balance

It has been shown that polarized/coherent EMFs, even at very low field intensities in the ULF and ELF bands, can cause irregular gating of electro-sensitive ion channels or VGICs on the cell membranes through the 'ion forced-oscillation mechanism' (143-146), with consequent disruption of the cell's electrochemical balance (the electrical and osmotic equilibrium maintained by specific concentrations of all dissolved/mobile ions across all cell membranes according to the Nernst equation) (144,147,148). Since, as explained, ELF/ULF components exist also in the complex WC/RF EMFs, this mechanism, which will be thoroughly reviewed next, accounts for the biological effects of the vast majority of human-made (polarized and coherent) EMFs.

The mechanism is based on molecular/physical data, and the forces on mobile ions, in the vicinity of the voltage-sensors of VGICs, exerted by an applied polarized oscillating EMF. The oscillating field will force mobile ions to oscillate on parallel planes and in phase with the field. This coordinated motion of electrically charged particles exerts electric forces on the voltage-sensors, similar to the forces exerted on them by changes in the transmembrane electric field known to physiologically gate these channels, and thus the channels are gated irregularly by the applied EMF. The forces are proportional to the amplitude of the forced-oscillation, and thus, the amplitude is a direct measure of the bioactivity of the applied EMF. It has been shown that the amplitude (bioactivity) is proportional to EMF intensity, inversely proportional to EMF frequency and doubles for pulsed EMFs. The validity of the proposed mechanism has been verified by numerical testing, while other previously suggested mechanisms have failed to pass the same test (149,150). Repeated irregular gating of electro-sensitive ion channels disrupts cellular electrochemical balance and homeostasis (147,148), leading to overproduction of ROS/free radicals as described next.

It is known from a plethora of experimental data that the most bioactive EMFs are the lower frequency ones (ELF/ULF). In numerous cases of induced biological effects by complex RF EMFs modulated by ELFs, it has been found that the modulation (ELF) and not the carrier (RF) is responsible for the recorded effects. In addition, it has been repeatedly found that pulsing RF EMFs with ELF pulse-repetition rates are more active biologically than continuous (non-pulsed) fields of identical other parameters (1-5,44,45,47,151-159). These findings are in direct agreement with the described mechanism.

Biological molecules of critical importance such as ions, water molecules, proteins, nucleic acids and lipids, among others, are either polar or carry a net electric charge (147,148). The net electric field from an infinite number of individual electric pulses of random polarization and/or random phase (as e.g. photons of natural light) tends to zero at any moment (and similarly the net magnetic field).

$$\lim_{n\to\infty}\sum_{i=1}^{n}\vec{E}_i = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots + \vec{E}_n = 0 \qquad (1)$$

Thus, non-polarised/incoherent EMFs (as e.g. light and cosmic microwaves) at any radiation intensity cannot cause any parallel/coherent oscillation of charged/polar molecules (143). On the contrary, polarized and coherent (human-made) oscillating EMFs force all charged/polar molecules in biological tissue to oscillate on planes parallel to their polarization and in phase with them. This is crucially important for understanding the mechanism described. The forced-oscillation will be most intense on the mobile ions, the smallest charged particles dissolved in large concentrations in the cytosolic and extracellular aqueous solutions in all living cells/tissues controlling practically all cellular/biological functions (147,148).

Even though all molecules move randomly with much greater velocities/displacements due to thermal energy, this has no biological effect other than increasing tissue temperature. By contrast, a polarized and coherent oscillation of much lower energy than average thermal molecular energy can initiate biological effects (143-145).

The majority of cation channels (Ca^{2+}, K^+, Na^+ and H^+, among others) on the membranes of all animal cells are voltage-gated (147,148). These ion channels convert between open and closed states when the electrostatic force on their voltage sensors, due to transmembrane voltage changes, exceeds some critical value. The voltage sensors are four symmetrically arranged, transmembrane, positively charged α-helices, each one named S4. The S4 helices occupy the 4th position in a group of 6 parallel α-helices (S1-S6). The channel consists of four identical such groups in symmetrical positions around the pore of the channel. The S5-S6 helices of the four groups form the pore walls (147,148). More specifically, the sensors are positive Lys and Arg amino acids in the S4 helices. Changes in the transmembrane voltage of the order of ~30 mV are normally required to gate electrosensitive channels (change their status from opened to closed and vice-versa) (160,161). Among the S1-S4 α-helices, the S4 helices are the closest to the pore-forming S5-S6 helices, being <1 nm in distance from the pore (162,163). Several ions may interact simultaneously at any instant with an S4 sensor from a distance of the order of 1 nm, as, except for the ion(s) that may be passing through the pore any moment or are just outside the gate ready to pass, a few more ions are bound close to the pore at specific ion-binding sites (e.g. three in potassium channels) (164,165). Proton voltage-gated channels studied more recently also contain S4 transmembrane helices with charged Arg residues as voltage-sensors, similar to the metallic cation channels (166,167).

Let us consider four identical mobile ions at distances of the order of 1 nm from the channel-sensors (S4) and an externally applied oscillating EMF. The average electric (and magnetic) force on each ion due to any non-polarized EMF is zero (Eq. 1). By contrast, the force due to a polarized field with an electrical component E, is $F=Ezq_e$, (with zq_e the electric charge of the ion).

In the most usual and simplest case of a sinusoidal alternating electric field, $E=E_o \sin\omega t$, the motion (forced-oscillation) equation of a mobile ion is as follows (143-146):

$$m_i \frac{d^2r}{dt^2} + \beta \frac{dr}{dt} + m_i \omega_o^2 r = E_o z q_e \sin\omega t \quad (2)$$

where m_i is the mass of the ion, r is the displacement of the ion due to the forced-oscillation, z is the valence of the ion (z=1 for K^+, Na^+ or z=2 for Ca^{2+} ions), q_e=1.6×10^{-19}C is the elementary charge, β is the damping coefficient (being within channels $\beta = \frac{E_m z q_e}{u_o} \cong 6.4z\times10^{-12}$ kg/s, with E_m (~10^7 V/m) the transmembrane electric field, and u_o=0.25 m/s the velocity of the ion through an open channel calculated from patch-clamp measurements of channel ion-currents). $\omega_o=2\pi\nu_o$ (ν_o the ion's oscillation self-frequency accepted to be equal to the recorded spontaneous intracellular ionic oscillation frequencies on the order of 0.1 Hz), $\omega=2\pi\nu$ (ν the frequency of the applied field) and E_o is the intensity amplitude of the applied oscillating field. Detailed calculations of the parameters are provided in Panagopoulos *et al* 2000 (144).

The right part of Eq. 2 is the force on the ion due to the applied E-field. The first term of the left part ($m_i \frac{d^2r}{dt^2}$) is the resultant force on the ion, the second term ($\beta \frac{dr}{dt}$) is a damping force and the third term ($m_i \omega_o^2 r$) a restoration force exerted by the medium (144,145). While an oscillating ion close to the S4 sensors exerts gating forces on them, it receives zero opposite force, as the S4 charges are paired with opposite charges from adjacent helices of the channel (148). Eq. 2 is a second-order linear differential equation with constant coefficients, which is solvable once we know the values of the different parameters.

The general solution of Equation 2 (144) is:

$$r = \frac{E_o z q_e}{\beta\omega} \cos\omega t + \frac{E_o z q_e}{\beta\omega} \quad (3)$$

The constant term $\frac{E_o z q_e}{\beta\omega}$ in the solution represents a constant displacement of the ion and has no effect on the oscillating term $\frac{E_o z q_e}{\beta\omega}\cos\omega t$. This constant displacement represents a jump of the whole oscillation at a distance equal to the amplitude, in other words it doubles the amplitude $\frac{E_o z q_e}{\beta\omega}$ of the oscillation at the moment when the field is applied or interrupted. For pulsed fields (such as the vast majority of human-made complex RF/microwave EMFs, especially those employed in modern WC), this interruption/repetition occurs constantly with every repeated pulse. Therefore, pulsed fields are predicted to be twice as bioactive as continuous/non-pulsed fields of the same other parameters, and this explains a plethora of experimental findings showing increased bioactivity of pulsed compared with non-pulsed RF EMFs, which were previously unexplained (44,45,154, 155,157-159).

Ignoring the constant term in Eq. 3, the amplitude of the forced-oscillation is:

$$A = \frac{E_o z q_e}{\beta\omega} \quad (4)$$

An oscillating ion of charge zq_e (whose motion is described by Eq. 3) close to the S4 helices of a voltage-gated channel exerts a force F on the effective charge q of each S4, as described by Coulomb's law: $F = \frac{1}{4\pi\varepsilon\varepsilon_o} \cdot \frac{q \cdot zq_e}{r^2}$, ($r$ here is the distance of the oscillating ion from the S4). The ion displaced by dr during its oscillation, induces an additional force dF on each S4 sensor:

$$dF = -\frac{q \cdot zq_e}{2\pi\varepsilon\varepsilon_o r^3} dr \quad (5)$$

While in the case of a random/chaotic movement of the ion due to e.g. thermal motion $\lim \sum d\vec{r} = 0$, and $\lim \sum d\vec{F} = 0$, in the case of a coordinated polarized and coherent forced-oscillation, the sum force on each S4 from all four ions, is:

$$4dF = -2\frac{q \cdot zq_e}{\pi\varepsilon\varepsilon_o r^3} dr \quad (6)$$

The effective charge of each S4 domain is found to be: q=1.7q_e (161). The force on this charge exerted by a change of 30 mV in the transmembrane voltage required normally to gate the channel, is calculated to be (144): dF=8.16×10^{-13} N.

The displacement of one single-valence ion within the channel corresponding to this minimum force, according to Eq. 5 (for z=1, $\varepsilon \cong 4$, and r ~1 nm), is: dr=4×10^{-12} m.

The dielectric constant within proteins is significantly lower than in the aqueous solutions (4/80), and ion concentration in cells is of the order of 1 ion per nm^3 (144,147,148).

For 4 single-valence ions oscillating on parallel planes and in phase with an applied polarized (and coherent) oscillating field, the minimum displacement is (according to Eq. 6) reduced to: dr=10^{-12} m. The corresponding necessary displacement for ions outside the channel would be about 20-fold higher due to the higher dielectric constant of the aqueous solutions.

Thus, a crucial finding has been reached: Any external polarized and coherent oscillating EMF (like all technical/human-made EMFs) able to force mobile ions to oscillate with amplitude

$$\frac{E_o z q_e}{\beta\omega} \geq 10^{-12} \text{ m} \quad (7)$$

is able to irregularly gate VGICs on cell membranes.

For z=1 (e.g. K^+ ions), and replacing q_e, β by their values in Condition 7, we get:

$$E_o \geq 0.25\nu\times10^{-3} \quad (8) \quad (\nu \text{ in Hz}, E_o \text{ in V/m})$$

For double-valence cations (z=2) (e.g. Ca^{2+}) the condition becomes:

$$E_o \geq 1.2\nu\times10^{-4} \quad (9) \quad (\nu \text{ in Hz}, E_o \text{ in V/m})$$

For pulsed fields (such as all MT/WC fields) the right part of Condition 9 is further divided by 2, becoming:

$$E_o \geq 0.6\nu\times10^{-4} \quad (10) \quad (\nu \text{ in Hz}, E_o \text{ in V/m})$$

It is clear that the amplitude of the forced-oscillation given by Eq. 4 is the critical parameter to determine the ability of a polarized/coherent EMF to induce biological/health effects. We shall name it 'Bioactivity of the EMF' or 'EMF-Bioactivity'. Thus:

$$\text{EMF-Bioactivity} = \frac{E_o z q_e}{\beta\omega} = k \cdot \frac{E_o}{\nu} \quad (11)$$

where $k = \frac{zq_e}{2\pi\beta} = \frac{u_o}{2\pi E_m} \cong 4\times10^{-9}$ C·s/kg is a constant quantity (depending upon the membrane electric field E_m and the velocity of the ion through an open channel u_o), E_o is the intensity amplitude and ν is the frequency of the applied electric field. We shall name k the 'bioactivity constant'.

Thus, a most reasonable and elegant result is reached, that the bioactivity of a polarized oscillating EMF is proportional to its maximum intensity (E_o) and inversely proportional to its frequency (ν), meaning that lower frequency fields are predicted to be more bioactive than higher frequency ones of the same intensity and waveform. Although this result was obtained considering the most usual/simple case of harmonically oscillating polarized EMFs, it is evident that non-harmonically oscillating polarized fields can also be approximately described in terms of their bioactivity by Eq. 11.

For pulsed EMFs with harmonically oscillating carriers, the amplitude doubles and so does the bioactivity:

$$\text{Pulsed EMF-Bioactivity} = 2k \cdot \frac{E_o}{\nu} \quad (12)$$

The same mechanism explains the biological action of polarized oscillating magnetic fields as well, if we replace in Eq. 2 the electric force $F_E=Ezq_e$, by a magnetic force:

$$F_B = B\,u\,zq_e \quad (13)$$

exerted on an ion with charge zq_e, moving with velocity u, vertically to the direction of a magnetic field of intensity B (in which case the magnetic force is maximum). In the simplest (and most usual) case of an alternating magnetic field $B=B_o sin\omega t$ with intensity amplitude B_o and based on the same reasoning as aforementioned, corresponding bioactivity conditions are obtained for an oscillating magnetic field.

For one single-valence ion moving through an open channel vertically to the direction of the applied magnetic field with $u=u_o=0.25$ m/s (the velocity calculated for ions moving through an open channel) (144) and for the case of a continuous oscillating magnetic field, the corresponding bioactivity condition is:

$$\frac{B_o u_o q_e}{\beta\omega} \geq 4\times10^{-12}\,\text{m} \quad (14) \quad (\omega \text{ in rad/s, } u \text{ in m/s, } B_o \text{ in T}),$$

from which is obtained:

$$B_o \geq 4\times10^{-3}\,\nu \quad (15) \quad (\nu \text{ in Hz, } B_o \text{ in T), or}$$

$$B_o \geq 4\times10^{3}\,\nu \quad (16) \quad (\nu \text{ in Hz, } B_o \text{ in } \mu\text{T})$$

For double-valence ions the right part of Condition 16 is divided by 2:

$$B_o \geq 2\times10^{3}\,\nu \quad (17) \quad (\nu \text{ in Hz, } B_o \text{ in } \mu\text{T})$$

For double-valence ions and pulsing magnetic field the right part of Condition 17 is further divided by 2, and the bioactivity condition becomes:

$$B_o \geq 10^{3}\,\nu \quad (18) \quad (\nu \text{ in Hz, } B_o \text{ in } \mu\text{T})$$

It should be noted that apart from the drift velocity of the ion through the channel (u_o=0.25 m/s) that is accepted as initial velocity, the ion will acquire an additional velocity *dr/dt* due to the forced-oscillation. From Eq. 3, the following is obtained:

$$\frac{dr}{dt} = -\frac{E_o z q_e}{\beta} \sin\omega t \quad (19)$$

(or respectively: $\frac{dr}{dt} = -\frac{B_o u_o z q_e}{\beta} \sin\omega t$ for a sinusoidal magnetic field)

The corresponding magnetic force due to this additional velocity, $Bzq_e(dr/dt)$, is negligible (more than 10^8 times smaller) compared with the damping force $\beta(dr/dt)$, and thus, it is not taken into account in Eq. 2.

The maximum ($\frac{E_o z q_e}{\beta}$ or $\frac{B_o u_o z q_e}{\beta}$) of this additional velocity is independent of the frequency of the field (ω), and is much smaller for usual field intensities than the ion velocity through an open channel (u_o=0.25 m/s), which in turn is more than 10^3 times smaller than its corresponding average thermal velocity u_{kT} (168). Thus, the described ion forced-oscillation does not add to tissue temperature and this mechanism is 'non-thermal', in contrast to the known heating ability of the high intensity microwaves (128). The non-thermal nature of human-made EMF-bioeffects, including those of low power modulated/pulsing RF/microwaves, in contrast to high power microwaves, has also been discussed in previous studies (169,170).

This theory allows certain predictions for the bioactivity of some human-made EMFs widely present in the modern environment: For the sinusoidal alternating (continuous) 50-Hz E and B fields of high-voltage power lines with intensities of the order of E ~10 kV/m and B ~0.1-1 G (or ~10-100 μT) at close distances (10-20 m) from such lines the conditions 9 and 17 for double valence cations (e.g. Ca^{2+}) give: $E_o \geq 6\times10^{-3}$ V/m or $E_o \geq 6$ mV/m (which is satisfied by more than 10^6 times), and $B_o \geq 10^5$ μT, which is not satisfied, showing that the recorded effects from high-voltage power lines are due to the electric rather than the magnetic component of the resultant EMF, in contrast to what is usually considered. Thus, the electric component of power line EMFs is certainly capable of inducing biological effects in living organisms according to the mechanism presented, even for intensities down to 1-10 V/m, which exist in most homes and work places.

For the pulsing ELF E and B fields of MT/WC EMFs with a pulsing repetition frequency of ~100 Hz (3G/4G MT, DECT), E ~10 V/m and B ~1 mG (or ~0.1 μT) (30,40,54,55), the bioactivity conditions 10 and 18 respectively give: $E_o \geq 6\times10^{-3}$ V/m or $E_o \geq 6$ mV/m, which is satisfied by more than 10^3 times, and $B_o \geq 10^5$ μT, which is not satisfied for direct action, but it may be satisfied by the magnetically induced electric field, which is significant in this case due to the short rise/fall times of the pulses (143). Similar results are obtained for the 217-Hz pulsing E/B fields of 2G MT (30,40).

For Wi-Fi and Bluetooth wireless connections with a pulsing frequency of ~10 Hz, E ~1 V/m and B ~0.1 mG

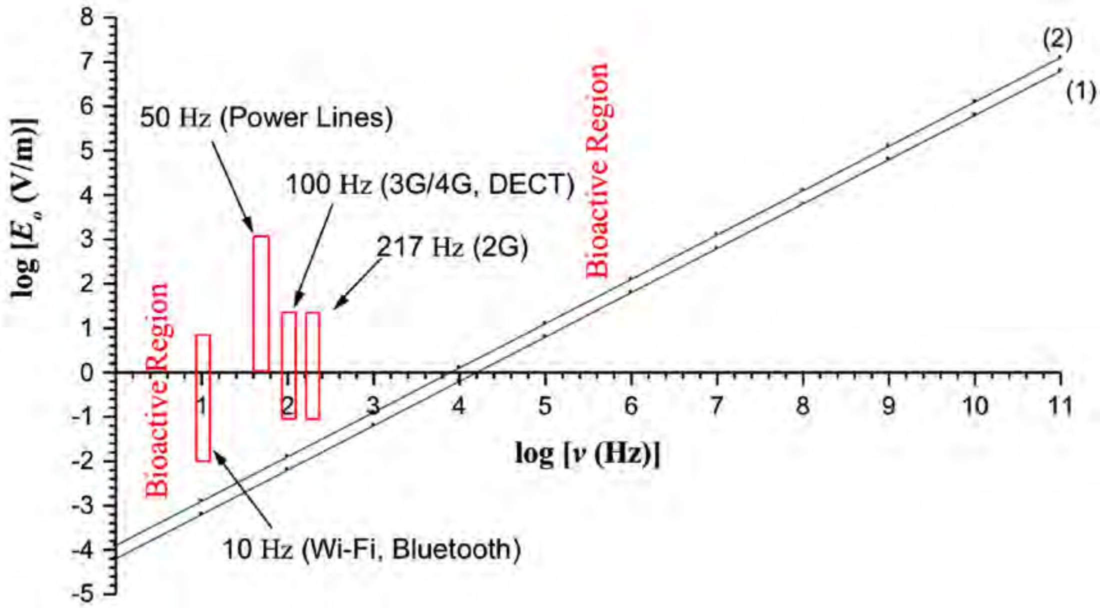

Figure 1. E-field bioactivity diagram showing the bioactive combinations of electric field intensity and frequency capable of inducing biological/health effects according to the ion forced-oscillation mechanism for dysfunction of voltage-gated ion channels in cells. The ELF electric fields of power lines, 2G/3G/4G MT, DECT, Wi-Fi and Bluetooth, are within the bioactive region (above lines 1 and 2). Line 1 refers to pulsed fields, such as the ELF pulsations of WC EMFs (Condition 10), while line 2 refers to continuous (non-pulsed) fields such as those from power lines (Condition 9).

(or ~0.01 μT) (171), the bioactivity conditions 10 and 18 respectively give: $E_o \geq 0.6\times10^{-3}$ V/m or $E_o \geq 0.6$ mV/m, which is satisfied by more than 10^3 times, and $B_o \geq 10^4$ μT, which is not satisfied for direct action.

The aforementioned numerical examples show that it is the electric field that seems to be the bioactive component of an EMF and not the magnetic field, in contrast to what has been considered before by health agencies (117). The magnetically induced electric field can also be bioactive in the case of ELF pulses of WC signals with short rise/fall times (143).

The bioactivity conditions 9 and 10 for continuous and pulsed electric fields respectively are depicted in Fig. 1. The region above line 1 (including the line) represents the bioactive combinations of intensity amplitude (E_o) and frequency (ν) for pulsed fields, and above line 2 (including the line) for continuous fields. The ELF electric field of power lines, 2G/3G/4G MT, DECT, WiFi and 'Bluetooth', lie within the bioactive region predicted by the presented theory.

3. Biochemical processes activated by irregular gating of VGICs, leading to DNA damage

Irregular gating of ion channels and ROS. Irregular gating of VGICs by oscillating polarized and coherent ELF EMFs as described [and originally in (143-146)] has been verified experimentally for calcium (Ca^{2+}), potassium (K^+) and sodium (Na^+) VGICs (172-174). This can alter intracellular ionic concentrations, disrupting the electrochemical balance of the cell and leading to DNA damage by OS/ROS overproduction (175-179).

Most ROS are free radicals. Free radicals are highly unstable molecules containing an unpaired electron, which is denoted by a dot (•), and have a tremendous tendency to chemically react with surrounding molecules and/or with each other in order to couple the unpaired electron and become stable. This is the reason why they have extremely short lifetimes. Most ROS react rapidly with surrounding biomolecules inducing chemical alterations (180). Overproduction of ROS in living cells due to EMF exposure has been reliably documented, with two important ROS found after EMF exposure being superoxide anion ($O_2^{\bullet-}$) and nitric oxide ($NO^\bullet$) (109). These may result in hydroxyl radical ($OH^\bullet$) and peroxynitrite ($ONOO^-$) correspondingly, both of which ROS are very reactive with biological molecules and specifically DNA, as discussed next. $ONOO^-$ may interact directly with DNA, as, similarly with $NO^\bullet$, it can be diffused everywhere in the cell (181). Superoxide anion radical ($O_2^{\bullet-}$) is catalyzed by superoxide dismutase enzymes in the cytosol or the mitochondria and is converted to hydrogen peroxide (H_2O_2) (109,182):

$$2O_2^{\bullet-} + 2H^+ \rightarrow H_2O_2 + O_2 \quad (20)$$

H_2O_2 is a critical molecule in oxidative damage since it can move to any intracellular site (including the nucleus), where it can be converted to the most potent $OH^\bullet$, which can damage any biological molecule, including DNA (183-187).

DNA damage by ROS leading to mutations and disease has been well studied (188,189). Pall (190), in a review of EMF-bioeffects studies with calcium channel blockers, noted a connection between voltage-gated calcium channels (VGCCs) and $NO^\bullet/ONOO^-$ overproduction. This verified earlier observations of EMF-induced effects on intracellular calcium concentrations, and the unique role of VGCCs (1,151-153,191,192).

It is known that the intracellular redox status can activate Ca^{2+}, Na^+ and K^+ channels in order to reinstate homeostasis (178), and inversely, activation of these channels determines the redox status and the electrochemical balance of the cell (179). Multiple studies have found connections between the impaired function of calcium, potassium, sodium and chloride channels with the induction of OS and related pathologies (175-177). These studies provide additional evidence for the validity of the presented biophysical mechanism (143-146).

Calcium signaling and mitochondrial ROS production. Alteration of intracellular ionic concentrations will affect key cellular signaling pathways, including the Ca^{2+} signaling system, which regulates a variety of cellular functions including cell proliferation, differentiation, the ROS regulatory system and apoptosis (192-196). Impaired function of VGCCs in the plasma or in the mitochondrial membranes leading to critical changes in cytosolic or mitochondrial concentrations of Ca^{2+} ions, such as those following EMF exposure, is connected with pathogenesis and cytotoxicity (195,196).

Voltage-gated anion channels in the outer membrane of the mitochondria regulate Ca^{2+} entry into the intermembrane space and in the matrix, which is crucial for mitochondrial ROS production. Increased level of Ca^{2+} stimulates $O_2^{\bullet -}$ production by the electron transport chain in the mitochondria and/or activation of nitric oxide synthase (NOS), to generate more $NO^{\bullet}$. $NO^{\bullet}$ inhibits complex IV of the electron transport chain, triggering production of even more ROS (109,193). ROS overproduction in the mitochondria can damage DNA both in the mitochondria and the nucleus, and initiate a signaling cascade leading to apoptosis, as found in human spermatozoa after MT EMF exposure (36). Moreover, increased concentrations of $NO^{\bullet}$ in living cells due to activation of NOS at different locations of the cell may lead to formation of $ONOO^-$ (181,182).

Regulation of apoptosis is crucial for anticancer control (197). However, excessive apoptosis, induced by increased ROS levels, is connected with inflammatory diseases and cancer (198). When overproduction of ROS in a cell overloads the capacity of the antioxidant system of the cell, the cell/organism is under OS. This condition may lead to significant DNA damage with consequent genomic instability and carcinogenesis (182,183,194-198).

K^+ channels have also been shown to be involved in the activation of apoptosis (194), and voltage-gated Ca^{2+} and K^+ channels have been shown to be connected with cell proliferation and carcinogenesis (199). Thus, cytosolic concentrations of Ca^{2+} and K^+ ions play major roles in cellular function and metabolism. In addition, voltage-gated calcium and potassium channels play important roles in iron entry into the cells. Iron catalyzes the production of $OH^{\bullet}$ via the Fenton reaction and thus, impaired function of these channels can promote cellular toxicity (200-202).

NADPH oxidase and ROS production. Apart from the effect of EMFs on metallic cation voltage-gated channels (such as Ca^{2+}, Na^+ and K^+), proton (H^+) voltage-gated channels will be affected as well, as they operate in a very similar way (166,167). This in turn would affect the function of NADPH oxidase, a plasma membrane enzyme found in abundance in all cells, which normally generates ROS for the elimination of invading microorganisms (203,204). The activity of NADPH oxidase is strongly associated with H^+ channels and it may even act directly as a H^+ voltage-gated channel due to its $gp91^{phox}$ transmembrane subunit (205,206). NADPH oxidase generates an electron flux for the reduction of extracellular O_2 to $O_2^{\bullet -}$ (203,207).

NADPH oxidase is activated by cytosolic Ca^{2+} and possesses a Ca^{2+}-binding site in addition to its H^+ voltage-gated channel ($gp91^{phox}$ transmembrane region) (204). Thus, perturbation of intracellular concentrations of either H^+ or Ca^{2+}, after irregular gating of their voltage-gated channels, will affect the function of NADPH oxidase and trigger irregular ROS production.

NADPH oxidase has been reasonably suggested as a primary target of EMF exposure in living cells. In 2007, Friedman *et al* (208) found rapid ROS production in cultured cells after a few min of exposure to RF EMF emitted by a generator.

Na^+/K^+-ATPase and ROS production. Impaired function of Na^+, K^+, Mg^{2+} and Ca^{2+} voltage-gated channels may also affect the function of the Na^+/K^+ pump (ATPase) and Ca^{2+} pumps in the plasma membranes of all cells. The ion pumps (active ion transporters) across all cell membranes in coordination with the ion channels (passive ion transporters) determine the membrane voltage, the volume of the cell and the electrochemical balance (147,148). A positive-feedback amplification loop between Na^+/K^+-ATPase signaling and ROS production by the mitochondria was experimentally demonstrated in primary cultures of cardiac myocytes (209). Na^+/K^+-ATPase became a target for ROS-initiated signaling, and in turn, stimulation of Na^+/K^+-ATPase signaling function led to increased ROS production. This model can definitely be associated with dysfunction in living cells under EMF-exposure.

Therefore, it is clearly indicated that irregular gating of VGICs on plasma and intracellular membranes due to EMF-exposure will most likely trigger ROS overproduction and consequent cellular damage. Although plenty of data connecting ion channel dysfunction and the induction of cell death or cancer have been available for a long time (194,199), the connection between the dysfunction of VGICs and ROS overproduction (175-179,190-192) leading to DNA damage has not perhaps gained the attention it deserves.

Apart from action via ROS/free radicals, DNA damage may be brought about by irregular activation of DNases after alteration of intracellular ionic concentrations. Of the two forms of endonucleases implicated in the initiation of apoptosis, one of them is Ca^{2+}-dependent (DNase I). An increased level of intracellular Ca^{2+} in some cases is associated with increased apoptosis, possibly due to the activation of DNase I (210). Thus, the possible activation of DNase I by increased levels of intracellular Ca^{2+} may be an alternative way for DNA damage and related pathologies.

ROS and DNA damage. $OH^{\bullet}$ is considered the most potent oxidant of DNA. The main mechanism for $OH^{\bullet}$ production involves the iron-catalyzed conversion of H_2O_2 via the Fenton reaction (211): Fe^{2+} is oxidized by H_2O_2 to Fe^{3+}, producing an $OH^{\bullet}$ radical and a hydroxide ion (OH^-) (Eq. 21). Fe^{3+} is then reduced back to Fe^{2+} by another molecule of H_2O_2, producing a hydroperoxyl radical and a proton (Eq. 22).

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^{\bullet} + OH^- \qquad (21)$$

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + HOO^{\bullet} + H^+ \quad (22)$$

The net effect is the conversion of two hydrogen peroxide molecules to produce two different oxygen-radical species, with water ($H^+ + OH^-$) as a byproduct.

$$2H_2O_2 \rightarrow OH^{\bullet} + HOO^{\bullet} + H_2O \quad (23)$$

The $OH^{\bullet}$ radical reacts with any biological molecule in its immediate environment, including DNA. For example, it can break macromolecules (R-R or R-H) or abstract atoms from them (such as the various hydrogen atoms of the deoxyribose) by breakage of covalent bonds. This results in chemical alterations of the macromolecules and production of new free radicals ($R^{\bullet}$ or $RO^{\bullet}$):

$$R\text{-}R + OH^{\bullet} \rightarrow ROH + R^{\bullet} \quad (24)$$

$$RH + OH^{\bullet} \rightarrow R^{\bullet} + H_2O \quad (25)$$

$$\text{or } RH + OH^{\bullet} \rightarrow RO^{\bullet} + H_2 \quad (26)$$

The new free radicals will further react with other molecules resulting in additional chemical alterations. Corresponding evidence for DNA damage by $ONOO^-$ is available as well (181).

In conclusion, there is a clear sequence of events starting from the irregular gating of VGICs by EMFs up to DNA damage and related pathologies, including carcinogenesis.

4. Discussion

The present study reviewed experimental and epidemiological findings connecting exposure to purely ELF, and RF (containing ELF) human-made EMFs, with DNA damage and related pathologies, including cancer. It is documented that both such types of human-made EMF-exposure can induce OS (3,34,36-39,43,45,109), DNA damage (1-55,84,85) and infertility (56-71). It is also documented that the same types of EMF-exposure are linked with increased cancer risk both in humans and experimental animals (72-83,86-98,110-114).

We attempted to provide a complete, plausible explanation of these DNA damage-related findings on a biophysical and biochemical basis. According to the ion forced-oscillation mechanism for dysfunction of VGICs (143-146), human-made (polarized and coherent) ELF/ULF EMFs or the ELF/ULF modulation/pulsing/variability components of modern RF/WC EMFs can alter intracellular ionic concentrations by irregular gating of VGICs on cell membranes. This leads to immediate OS by ROS (over)production in the cytosol and/or the mitochondria, which can damage DNA when cells are unable to reinstate electrochemical balance (normal intracellular ionic concentrations). Consequently, DNA damage can lead to reproductive disabilities, neurodegenerative diseases, aging, genetic alterations and cancer.

According to the presented biophysical mechanism, the bioactivity of a polarized/coherent EMF is proportional to its intensity, inversely proportional to its frequency and doubles for pulsed fields, meaning that the ELF/ULF EMFs and even more the pulsing RF EMFs with ELF pulsations such as all WC EMFs, are predicted to be the most bioactive. This explains the recorded effects of purely ELF EMFs (1-5,9,13-18,22,47, 50,72-82,117,212) and those of modulated/pulsing/variable RF EMFs (1,3,4,6-8,19-21,23-46,48,49,51-55,57-71,84-107, 109-114,118,121-126). As emphasized, all types of RF exposure from all types of antennas and WC devices (WC EMFs) necessarily combine RF carrier signals with ELF/ULF components in the form of pulsing, modulation and random variability. The RF carrier signal alone does not contain information. The information is always contained in the ELF signals that modulate the RF (4). Significant experimental evidence shows that the bioactive parameters in a complex signal are its ELF components, and that non-modulated and non-pulsed RF signals alone do not usually induce biological effects (4,44,45,151-159), apart from heating when they possess high enough frequency and intensity (128,168-170). Therefore, the present study suggests that the vast majority of non-thermal effects attributed till now to various types of RF EMF-exposure, are actually due to their ELF/ULF components.

The presented biophysical mechanism and the provided numerical examples show that it is the direct ELF electric fields (and the magnetically induced electric fields in the case of sudden pulses), not the magnetic, that are the bioactive components, in contrast to what has been considered before by health agencies (117), and in agreement with previous experimental findings (191). Although electric fields are less penetrating in living tissue than magnetic fields, penetration depends upon the inverse square root of frequency, and thus ELF electric fields are significantly penetrating. Penetration depends also upon the inverse square root of the medium conductivity (213). Even though seawater is much more conductive than living tissue, ELF electromagnetic waves (thus both the electric and the magnetic parts of the waves) are penetrating several meters into seawater, accommodating communications with submarines (214). Moreover, it is known that isolated tissues respond to externally applied pulsed or sinusoidal ELF electric fields at very low thresholds ($\sim 10^{-3}$ V/m) similar to those predicted by this theory (143,215-217). This evidence shows that ELF electric fields penetrate enough to induce effects into living tissue, even at very low field intensities. Finally, skin cells, nerve terminals, eyes and organs close to the surface, such as the brain and heart, are directly exposed to externally applied EMFs. For all these reasons, no distinction is made between externally applied ELF electric fields and internally induced ones.

The ion forced-oscillation mechanism/theory was described in the present study by realistic equations based on the forces exerted on mobile ions in the vicinity of the voltage-sensors of VGICs on cell membranes by externally applied human-made (polarized) EMFs. The solution of the basic Eq. 2 resulted in bioactivity conditions connecting the intensity of an applied polarized EMF with its frequency. The bioactivity conditions 8-10, and 16-18, provided the bioactive intensity-frequency combinations for continuous and pulsed electric and magnetic fields. The final numbers explain almost all the experimental and epidemiological findings connecting biological/health effects with human-made EMF-exposure.

Although the mechanism was first published in 2000 (144) based on the available data on the structure and function of the

VGICs, newer details on the roles of S1-S6 helices, channel structure, relaxation, hysteresis and gating, have not refuted but verified and extended that knowledge (162,163,165,218-221).

What is more difficult to explain is the existence of non-linear phenomena such as the increased bioactivity 'windows' reported occasionally in the EMF-bioeffects literature, where certain effects are intensified within certain values of an EMF-exposure parameter (intensity in most cases, or frequency) (1,40,151-153,222). The existence of 'windows' shows that the response of living cells/organisms to EMFs is not generally proportional to the aforementioned EMF-parameters. Non-linear responses of living cells have not been explored in depth and it will take a number of years until they are. A possible explanation of observed intensity 'windows' according to the described mechanism has been suggested as being due to an existing upper limit in the membrane gating voltage change (222). Indeed, such an upper limit seems to exist. The VGICs respond to membrane voltage changes from ~30 mV (minimum) to ~100 mV (maximum) where the conductivity of the channel saturates (218,221). Apart from this possible explanation, no other explanation for the observed 'window' effects has been provided so far.

An effect not included in the bioactivity Eqs. 11 and 12 is the increased bioactivity of highly and unpredictably varying exposure such as those from WC devices (including mobile phones and Wi-Fi) and corresponding antennas (4,121,122). The described mechanism results in accurate predictions when the applied EMFs have constant parameters (intensity and frequency, among others). When the parameters are highly and unpredictably variable, the mechanism, and any possible mechanism, can only estimate effects according to the average and maximum exposure values of the varying EMFs. Finally, the bioactivity equations include field (and tissue) parameters and not exposure variables such as exposure duration or intermittence, which are also very important (16,17,19,41,55,122). One way to include such parameters is to multiply the right parts of Eqs. 11 and 12 by certain coefficient(s), which would be estimated experimentally. This could be a subject for future development of the theory.

This theory has successfully explained for the first time the sensing of upcoming earthquakes by animals, and the sensing of upcoming thunderstorms by sensitive individuals through the action of the partially polarized natural EMFs associated with these phenomena (146,223).

Any 'mechanism' in science (particularly in physics) must be based on simple and reasonable postulates, and must necessarily be expressed quantitatively (by solvable equations and numbers). The values of the different parameters in the equations must be based on physical/molecular data. Qualitative descriptions alone or incomplete quantitative descriptions based on incomplete or unsolvable equations do not constitute a 'mechanism'. The presented biophysical mechanism (143-146) is the only one that fulfills the aforementioned criteria in the case of EMF-induced bioeffects. Previous important attempts on mechanisms focusing on ions moving inside membrane channels or other proteins (224-227) were not successful, mainly for the following reasons: i) They had not taken into account damping and restoration forces (224,226), or did not calculate them (225,227). The difficulty was not related with considering such forces, as this is standard in oscillation mechanics, but with calculating their parameters such as β and ω_o, or the maximum velocity of the ion (u_o) within a channel. ii) They did not consider coordinated motion of several ions oscillating in parallel and in phase due to polarization and coherence, exerting additive forces on channel sensors, which prevail against the greater but chaotic forces due to the random thermal motion of the ions. iii) They focused on magnetic fields and magnetically induced electric ones, and ignored externally applied electric fields, which eventually seem to be more bioactive (191). iv) They did not result in numbers for field intensity versus frequency necessary to affect cells, although some experimental reports have indicated bioactive frequencies close to those predicted by Liboff's ion cyclotron resonance (ICR) model (224,228), possibly indicating some additional/secondary resonance mechanism involving ICR phenomenon (169). v) Apart from the study by Balcavage *et al* (226), there was no focus on the gating of VGICs, which is by far a more probable event to initiate biological effects, but simply on the motion of ions within channels/proteins.

Several other suggestions on possible mechanisms also face problems on fundamental issues (229-231). What is termed by Pall 'VGCC activation mechanism' and presented as his own discovery is none other than the mechanism presented here. A commentary paper/letter to the editor was published on this major ethical issue (129). An extended review of suggested mechanisms has been written by Creasey and Goldberg (169).

It has been claimed that the ELF components of complex RF-ELF EMFs of WC need to be 'demodulated' in order to be sensed by living organisms (232). 'Demodulated' or not, the fact is that the ELF components of modulated/pulsed WC signals can be directly sensed by both ELF meters/spectrum analyzers and living organisms (40,55).

Although there have been successive publications of this mechanism since 2000 (144), the subject is of great importance and in each consecutive publication additional important aspects are elucidated and/or refined. In our previous study in 2002 (145), the mechanism was extended to include oscillating magnetic fields and the thermal noise problem was discussed in more depth, while in 2015 (143) the mechanism was applied to reveal the importance of polarization/coherence in the bioactivity of man-made EMFs. In 2017 (223) and 2020 (146), it was applied to explain the sensing of upcoming thunderstorms and earthquakes, respectively, by sensitive humans/animals. In the present study, several aspects are further refined, including: i) The distance of S4 sensors from the channel pore; ii) more details on damping coefficient β and bioactivity constant k (Eq. 11); iii) further explanation of the role of the constant term in the solution (Eq. 3); iv) the similarity of proton voltage-gated channels with the other VGICs; v) numerical examples demonstrating the ability of the pulsing ELF electric and magnetic fields of 2G/3G/4G MT, DECT, Wi-Fi, Bluetooth, and the power line ELF fields to induce biological/health effects; vi) the velocity of oscillating ions; vii) bioactivity diagram extended to intensities down to 10^{-5} V/m; and viii) discussion on other suggested mechanisms.

Moreover, the present study documented how the impaired function of VGICs on the membranes of living cells triggers (over)production of free radicals/ROS, such as the most potent

$OH^•$ produced by H_2O_2 via the Fenton reaction, and $ONOO^-$ produced by $NO^•$. These are considered the main damaging species for DNA and other critical biological molecules. It is estimated that approximately two-thirds of the DNA damage caused by ionizing radiation is due to $OH^•$ (233,234). Although $OH^•$ can only diffuse at distances comparable to the length of a macromolecule, H_2O_2 can move to any intracellular site. Thus, even though the most potent $OH^•$ due to its high reactivity has an extremely short lifetime (of the order of 10^{-9}-10^{-4} s depending on the presence of other molecules) it can be formed by H_2O_2 at any location within the cell (including the nucleus) and act instantly upon DNA or other macromolecules (233,234). As for $NO^•/ONOO^-$, they can be diffused anywhere in the cell and thus directly affect any molecule, including DNA (181). Even though the present study identified specific pathways of ROS overproduction or the release of DNases connected with disrupted ionic concentrations in EMF-exposed cells, the exact molecular mechanisms need to be further explored and elucidated.

Finally, the present study discussed how unrepaired/misrepaired DNA lesions/damage such as strand breaks, covalent bond breakage or nucleotide base damages, lead to cell senescence, cell death or mutations, and related pathologies, including cancer. Even though effective mechanisms have evolved in all animals/cells for repairing DNA damage induced by environmental stressors, it is very different when the damaging events are isolated or random (e.g. radioactive particles or γ-photons of cosmic/natural radioactivity, or sporadic x-ray diagnostic exposure), compared with persisting/repeated exposure to cytotoxic agents, even when these agents are relatively weaker. Exposure to human-made EMFs and especially to the most detrimental ones from WC antennas/devices and high-voltage transmission lines (4) has become a new reality in modern life. Billions of people are exposed to such EMFs on a daily basis. Although they are less cytotoxic than radioactivity or certain cytotoxic chemicals, they represent the most persistent daily cytotoxic stressors against which any repair mechanisms cannot be efficient enough. By contrast, previously existing cytotoxic agents expose us randomly as isolated events. When an organism is constantly under OS due to a totally new cytotoxic agent such as human-made EMFs, no protective mechanism, evolved in the billions of years of biological evolution to protect from natural (non-polarized) EMFs/radiation or isolated hazardous events, can be effective enough.

The repair capability of cells in response to DNA damage is crucial for the final outcome. The threshold of damage above which it becomes irreparable depends on cell type and the health and status of the organism. An organism with poor health and/or under stress and inflammation due to OS is expected to have decreased repair capability and increased cancer risk. Epigenetic effects such as altered gene expression may also lead to cellular dysfunction and carcinogenesis (133,235,236).

Both DNA damage and alterations in protein synthesis, especially increased levels of stress proteins, are reported to be induced similarly by both ELF and pulsing RF EMFs (237,238). However, the effects of pulsing RF were attributed to the carrier frequency, and it was not considered that perhaps in both cases (ELF and pulsing RF) the ELF components might be responsible for the effects, as suggested now by the present study.

To the best of our knowledge, the present study provides for the first time a complete and precise biophysical/biochemical picture to explain the great number of experimental and epidemiological findings connecting human-made EMF exposure with DNA damage and related pathologies such as cancer, infertility and neurodegenerative diseases.

The long-existing experimental and epidemiological findings connecting exposure to human-made EMFs and DNA damage, infertility and cancer, are now explained by the presented complete mechanism. The present study should provide a basis for further research and encourage health authorities to take measures for the protection of life on Earth against unrestricted use of human-made EMFs.

Acknowledgements

Not applicable.

Funding

The study is supported by the Special Account for Research Grants of the National and Kapodistrian University of Athens (grant number 16599).

Availability of data and materials

Not applicable.

Authors' contributions

DJP designed the study and wrote the main manuscript. AK verified all equations and calculations. IY coauthored section 3 on biochemical processes. GPC reviewed and evaluated all data. All authors have read and approved the manuscript. Data authentication is not applicable.

Ethics approval and consent to participate

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Radio-Frequency Electromagnetic Field Exposure of Western Honey Bees

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Radio-frequency electromagnetic fields (RF-EMFs) can be absorbed in all living organisms, including Western Honey Bees (*Apis Mellifera*). This is an ecologically and economically important global insect species that is continuously exposed to environmental RF-EMFs. This exposure is studied numerically and experimentally in this manuscript. To this aim, numerical simulations using honey bee models, obtained using micro-CT scanning, were implemented to determine RF absorbed power as a function of frequency in the 0.6 to 120 GHz range. Five different models of honey bees were obtained and simulated: two workers, a drone, a larva, and a queen. The simulations were combined with *in-situ* measurements of environmental RF-EMF exposure near beehives in Belgium in order to estimate realistic exposure and absorbed power values for honey bees. Our analysis shows that a relatively small shift of 10% of environmental incident power density from frequencies below 3 GHz to higher frequencies will lead to a relative increase in absorbed power of a factor higher than 3.

Wireless communication is a widespread and growing technology. Most of the wireless networks and personal devices operate using Radio-Frequency (RF) electromagnetic fields (EMFs). The current networks rely on frequencies between 0.1 GHz and 6 GHz[1]. These EMFs can be absorbed in dielectric media and can cause dielectric heating[2]. This dielectric heating can occur in any living organism, including insects.

Absorption of RF EMFs in insects has been studied previously. Wang *et al.*[3] studied absorption of RF EMFs in mashed codling moth larvae at 27 MHz and 915 MHz. Shrestha *et al.*[4] studied dielectric heating of Cryptolestes ferrungineus S. in different stages (eggs, larvae, pupae, and adults) at 27 MHz. Shayesteh *et al.*[5] exposed Tribolium confusum and Plodia interpunctella to RF EMFs at 2450 MHz[6–8]. are reviews of RF heating of insects. Dielectric porperties of insects are measured by Nelson *et al.*[9] from 0.2 to 20 GHz through the determination of loss of RF EMF power in insect samples (rice weevil, red flour beetle, saw-toothed grain beetle, and lesser grain borer). Absorption of RF EMFs was studied by Halverson *et al.*[10] in insects between 10–50 GHz. Thielens *et al.*[11] used numerical simulations to study absorption of RF EMFs from 2–120 GHz in four insect models. The main conclusions from the aforementioned studies are that (i) RF EMFs can be absorbed and can cause dielectric heating in insects and (ii) this absorption of RF-EMFs is frequency dependent. This frequency dependency is important since 5th generation (5 G) networks are expected to partially operate at higher frequencies (up to 300 GHz)[12,13]. This shift might induce a change in RF EMF absorption for insects[11].

Western Honey Bees (*Apis Mellifera*) are particularly important insects because of the environmental and economical importance of this species. Therefore, previous studies have focused on the potential effects of EMF exposure of Western Honey Bees. Low-frequency EM properties and exposure of honeybees was studied in[14]. The influence of Low-frequency magnetic fields on honey bee orientation has been studied in[15]. There have also been some studies on effects of RF EMF on honey bees. Potential effects of RF EMF exposure on reproduction of honey bee queens were investigated in[16]. Behavioral effects potentially caused by exposure to RF EMFs in honey bees have been investigated in[17–19]. A disadvantage is that these studies are lacking a quantification of the amount of power that is absorbed in the studied honey bees, so called RF dosimetry[20]. On the other hand, this absorption has been determined for a single honey bee worker in[11]. However, Thielens *et al.*[11] do not provide any coupling of this absorption to a real RF-EMF exposure situation and only study a single honey bee, which provides no

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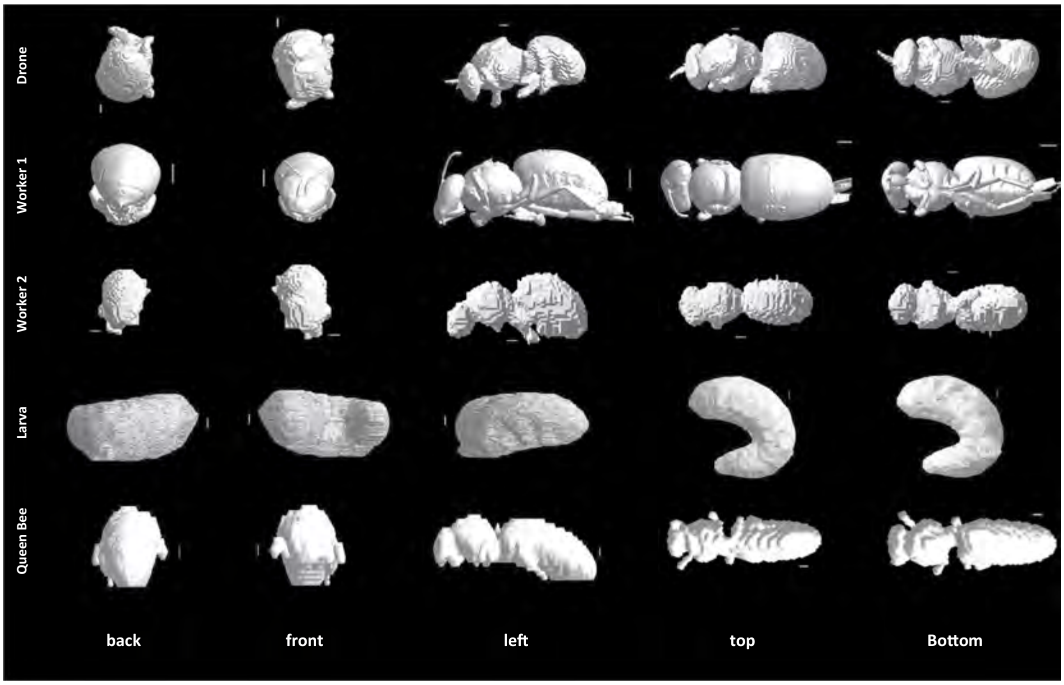

Figure 1. Studied Honey Bee Models, from top to bottom: Male Drone, Worker Bee 1, Worker Bee 2, Worker Larva and Queen Bee. Columns show different perspectives: back, front, left, top, and bottom view, respectively. The white lines show a 1 mm scale for reference.

information on the evolution of such absorption as a honey bee goes through different developmental stages. Nor is it clear whether this RF absorption is realistic for other castes, such as drones or queens, in a bee colony.

Therefore, the aims of this study were to numerically evaluate RF-EMF absorption in western honey bees and validate the frequency dependency of this absorption during various developmental stages and experimentally quantify real-life exposure of bees. To this aim, numerical simulations were executed to determine the absorption of RF-EMFs in five different honey bee models: a larva, a queen, two workers, and one drone, obtained using micro-CT imaging. These simulations were implemented as a function of frequency in a broad band, 0.6 GHz up to 120 GHz, that can be used to model both current and future telecommunication frequencies. In parallel, RF-EMF exposure measurements were executed near five bee hives in Belgium, in order to quantify the real exposure of such honey bees. Finally, these measured values were used to rescale the numerical simulations in order to quantify real honey bee absorption and assess a potential change in absorption in case a shift in operation frequencies in future telecommunication networks would occur.

Methods

Studied honey bees, imaging technique, and model development. Images of the studied insects are shown in Fig. 1. All studied insects are western honey bees (*Apis mellifera*), which is the most commonly used honey bee worldwide. Honey bees within a colony are subdivided into different castes. An active viable honeybee colony contains only one queen bee who spends most of her time laying 2,000 to 3,000 eggs per day. The queen is the only reproductive female within the colony and her health is vitally important to the survival of her colony. Damage to her ovaries has the potential to effect the function and survival of her progeny. A queen typically lives between approximately three and five years. From early spring time to mid-summer the queen lays unfertilized "haploid" eggs which develop into drone bees. All drones are males. Their specific role is to mate with a virgin queen so that she can initiate the propagation of a new colony. During this mating season, there are approximately 3,000 to 5,000 drones within any given colony. Drones typically live between one to two months.

A healthy honey bee colony can contain approximately 50,000 individuals. Most of these are sterile, female, worker bees. Worker bees perform all the tasks within a colony to keep it full of provisions and free from disease. This involves feeding and nursing larvae, foraging for nectar and pollen, storing nectar and pollen, guarding the entrance, tending to the hygiene of the queen-workers-drones and maintaining a clean hive environment. Workers live for three to four weeks during the active seasons (spring-summer-autumn) and approximately three months during the colder inactive season (winter). There are approximately 3,000 (winter) to 10,000 (summer) larvae present at any given time.

We chose representatives from all three castes within a honeybee colony, one queen bee, two worker bees, one drone bee and one worker larva. All honey bees were scanned at the Western Sydney University National Imaging Facility (Sydney, Australia) using a bench-top MicroCT scanner (Quantum GX MicroCT Imaging System, PerkinElmer, Hopkinton, MA, USA). The parameters used during this scanning depended on the scanned bee. Such scans are made using different projections, at different time intervals on the scanners settings.

The rotation between projections also depends on the scanner's settings and the studied honey bee (see below for full description).

Worker 1. The insect named 'Worker 1' is the same bee studied in[11], which had a full body length of approximately 11.0 mm long, is 5.0 mm wide, and had a mass of approximately 900 mg. During the scanning of Worker 1, the Micro-CT scanner was operated using the following parameters: 50 kVp, 80 mA, and a 2048 × 2048 pixels image matrix. This resulted in scans with a 20 μm isotropic voxel size. Each projection had a scanning time of 3.0 s, with 3.0 s rotation time in between projections. The total scan time for Worker 1 was approximately 18 min.

Worker 2. The second honey bee worker (Worker 2) has a full body length of 13 mm with cross sectional dimensions of 6.8 mm and 5.4 mm and a mass of approximately 900 mg. For Worker 2, the scanner was operated using the following parameters: 40 kVp, 70 mA, and a 2048 × 2048 pixels image matrix. The isotropic voxel size was 100 μm. Each projection had a scanning time of 1.5 s. There was a 3.0 s rotation time in between each projection. The total scan time for the whole bee was approximately 10 min.

Larva. Larvae of this age (three weeks) are typically approximately 16 mm long with an approximate mass of 900 mg. The scanned larva was curled up, which made estimating its full body dimensions difficult, but the sample fitted within a $14 \times 7 \times 15\ mm^3$ box. This scanning of the larva was done using the following parameters: 50 kVp, 80 mA, and a 2048 × 2048 pixels image matrix. This resulted in scans with a 20 μm isotropic voxel size. Each projection had a scanning time of 3.0 s. and with a 3.0 s rotation time this resulted in a total scan time for the larva of 18 min.

Male drone. The drone has a full body length of 18 mm with cross sectional dimensions of 7.2 mm and 9.4 mm and an approximate mass of 1 g. During the scanning of the drone, the Micro-CT scanner was operated using the following parameters: 40 kVp, 70 mA, and a 2048 × 2048 pixels image matrix. The isotropic voxel size was 100 μm. Each projection had a scanning time of 1.5 s. The full scan took 180 projections and there was a 3.0 s rotation time in between each projection. The total scan time for the whole bee was approximately 10 min.

Queen bee. The QB has a full body length of 19 mm and cross sectional dimensions of 7.5 times 7.1 mm^2 and an approximate mass of 1100 mg. The queen was scanned was using the following parameters: 40 kVp, 70 mA, and a 2048 × 2048 pixels image matrix. The isotropic voxel size was 250 μm. Each projection had a scanning time of 1.5 s. There was a 1.5 s rotation time in between each projection. The total scan time for the queen bee was approximately 10 min.

Development of 3D models. The software running on the Quantum GX, bench-top MicroCT scanner was used for all honey bees to reconstruct the 180 projection images. Those were then converted into a 2D rendered image stack of 512, 16 bit bitmap images. Finally, the BeeView volume rendering software (DISECT Systems Ltd, Suffolk, UK) was used to acquire Bee volume data from the image stack. All 3D models of the insects were created using the software TomoMask (www.tomomask.com). We used the same approach as in[11]. The image stack for each honey bee was imported into TomoMask, which also required the pixel and slice spacing. The software generated a 3D model using a marching cubes algorithm[21]. This model was then exported as an STL (STereo Lithography)[22] file. This is a commonly used format to describe surface geometry. The models were also smoothed using the Taubin λ/μ smoothing scheme[23] implemented in MeshLab[24]. The dimensions of the models and mesh integrity were checked (and corrected if necessary) before simulations using Netfabb (Autodesk, San Rafael, CA, USA).

Numerical simulations and RF EMF exposure conditions. Electromagnetic, numerical simulations were executed to estimate electromagnetic fields in and around the honey bees under far-field exposure. Far-field exposure is in this manuscript defined as RF-EMF sources being more than $2D^2/\lambda$ away from the insects, with D the largest dimension of the RF source and λ the wavelength of the RF-EMFs. This is often referred to as the Fraunhofer far-field limit[25]. In general, far-field RF-EMF sources can be located in any direction from the honey bees. Therefore, different approaches exist to model such far-field exposure to RF-EMFs: a stochastic method where far-field exposure is decomposed in sets of plane waves according to certain statistics is used in[26,27], while a more limited set of plane-wave exposures coming from six predefined directions along the main axis of the exposed subject or animal are considered in[11,28]. In this study, we have chosen to work with the latter method. We have modeled exposure of the studied honey bees by a set of 12 incident plane waves traveling along six directions defined by a Cartesian coordinate system, see Fig. 2. For each direction, two orthogonal incident electric field polarizations were chosen, since any other free-space E-field polarization can be obtained using a linear combination of both. All incident plane waves have a root-mean squared electric field strength of 1 V/m. This value is chosen to facilitate renormalization to any potential value of incident field strenght.

Numerical simulations were executed using the Finite-Difference Time-Domain (FDTD) method implemented in Sim4life (ZMT, Zurich, Switzerland). This is a common technique used to determine RF-EMF in and near homogeneous and heterogeneous dielectric objects[11,26,28], such as the honey bees studied in this paper. In this method, the simulation domain is divided in cubes using a three-dimensional rectilinear grid. Depending on the wavelength, feature sizes of the objects in the simulations, and the desired spatial accuracy, a different spatial step is used to discretize the simulation. The FDTD algorithm requires a grid step smaller than one tenth of the smallest wavelength in the simulation domain in order to return stable solutions[29]. Since this is a time-domain technique, it requires a predefined simulation time in order to reach a steady-state solution, which will again depend on the chosen spatial resolution, the wavelength, and the size of the simulation domain.

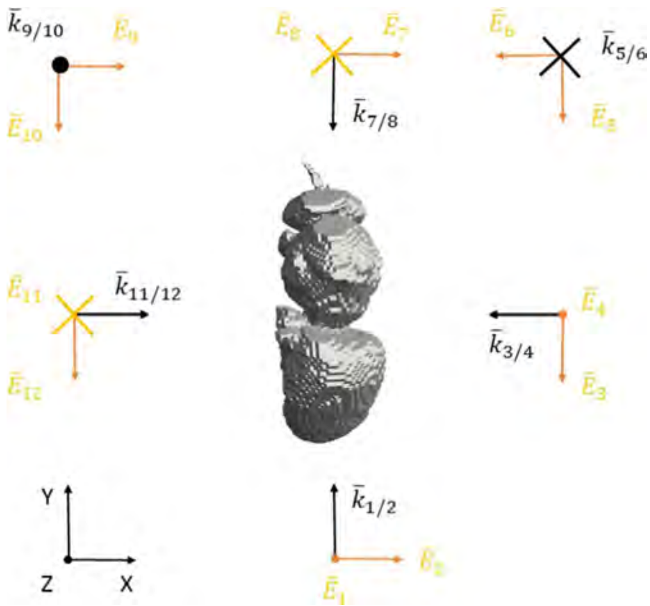

Figure 2. Configuration of the RF-EMF plane-wave simulations. Twelve potential RF plane waves incident from six directions are incident on the insect (honey bee drone shown here in grey, top view). Orange arrows indicate the electric field $\overline{E}_i$ polarizations, while the black arrows indicate the direction of propagation with wave vector $\overline{k}_{i/j}$ of the plane waves. *i* and *j* indicate the simulations' configuration number, from 1 to 12.

	0.6 GHz	1.2 GHz	2 GHz	3 GHz	6 GHz	12 GHz	24 GHz	60 GHz	120 GHz
Maximal grid step (mm)									
Larva	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Others	0.1	0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Simulated Periods									
Worker Bee 1	20	30	60	30	30	30	30	40	40
Others	10	20	20	30	30	30	30	30	30
ε_r	45.6	44.2	39.9	38.8	38.0	28.6	14.9	7.018	5.46
σ (S/m)	0.688	0.924	1.35	2.05	5.05	12.0	21.1	27.9	29.2

Table 1. Simulations Settings and Dielectric Properties of the Honey Bees.

We executed numerical simulations at nine harmonic frequencies from 0.6–120 GHz (sinusoidal waves at a single frequency). The lower and upper frequency limits were chosen because they correspond to the current limits in terms of simulation size and length that can realistically be supported by our simulation hardware. The simulated frequencies are listed in Table 1 alongside the chosen grid steps in the simulation domain and the number of periods used for every simulation. These settings were the same for each of the five studied honey bee models. The studied insects have certain dielectric properties, quantified using the relative permittivity (ε_r) and conductivity (σ). We did not measure the dielectric properties of the studied insects. Instead, we assigned dielectric parameters obtained from[11]. The value at 1 GHz is obtained using the same literature database and interpolation presented in[11]. Table 1 lists these properties. All insects were modeled as homogeneous objects. These configurations resulted in 12 (plane waves) × 9 (frequencies) × 5 (honey bees) = 540 simulation results.

After each simulation, the internal electric field in the insect model was extracted and used to calculate the total absorbed RF-EMF power (P_{abs}) in the honey bee. P_{abs} is calculated as the integrated product of the conductivity and the squared internal electric field strenght ($\overline{E}_{int}$) over the total volume (V) of the insect:

$$P_{abs} = \int_V \sigma \times |\overline{E}_{int}|^2 . \, dV \tag{1}$$

We report P_{abs} rather than specific absorption rate (SAR) values since we did not measure the mass and density of all the simulated honey bees. P_{abs} is an important quantity since dielectric heating of an insect is proportional to absorbed RF-EMF power[2].

In order to validate our simulations we tested the influence of four simulation settings on the RF-EMF P_{abs}: grid step size, dielectric parameters, angle of incidence, and number of simulated periods. The influence of the grid step is expected to be the most significant at the highest simulated frequency (120 GHz), since the chosen maximal grid step of 0.05 mm is closest to the smallest wavelength in the simulation domain at that frequency in the tissue (0.05 $mm = 0.045\ \lambda$). Therefore the maximal grid step was set to 25 μm for exposure configuration number 2 in Fig. 2 for both the Larva and Worker 2 phantoms. In[11], it was demonstrated that the maximal uncertainty on the dielectric parameters occurs between 2 and 3 GHz, with maximal relative deviations of 40%. In order to test the dependency of our simulation results on the chosen dielectric parameters, we executed four additional FDTD simulations in exposure configuration number 2 shown in Fig. 2 using the Worker 2 phantom. In these simulations the dielectric parameters (ε,σ) were changed to: (1.5.ε, 1.5.σ), (0.5.ε, 1.5.σ), (1.5.ε, 0.5.σ), and (0.5.ε, 0.5.σ), respectively, allowing for a potential 50% deviation on the dielectric parameters, which should be larger than the uncertainty on the chosen dielectric parameters. We chose to model RF-EMF exposure of the studied honey bees using plane waves incident from 6 directions. However, it is uncertain whether this set of plane waves provides a complete overview of the full range in P_{abs} as function of the angle of incidence. In order to validate our exposure set up, we have executed 20 additional FDTD simulations at 6 GHz using the Worker 2 phantom, where the elevation, azimuth, and polarization angles were generated according to uniform distributions between $[0, \pi]$, $[0, 2\pi]$, and $[0, 2\pi]$, respectively. The settings of these FDTD simulations were the same as those shown in Table 1. Finally, the number of simulated periods was tested at 120 GHz for the Worker 2 phantom in exposure configuration number 2 shown in Fig. 2 by increasing the number of simulated periods to 120 instead of 30, see Table 1. After each of these validation simulations, the P_{abs} was extracted and compared to the one obtained in the original simulation set.

RF-EMF field measurements. In order to quantify current RF-EMF exposure of honey bees in real exposure scenarios, we executed RF-EMF exposure measurements at five sets of bee hives in Belgium at: Aalter, Merelbeke, Eeklo, Zomergem, and Drongen, see Fig. 3(a). At each measurement site, three different measurements were executed in order to quantify RF-EMF exposure.

First, a spectrum analyzer of the type FSL6 (R&S Belgium, Excelsiorlaan 31 1930 Zaventem Belgium) connected to a triaxial isotropic antenna was used to perform a broad-band RF overview measurement from 80 MHz to 6 GHz. These measurements were executed in two steps: first spectral overview measurements were executed from 0.08–3 GHz using a tri-axial antenna TS-EMF (Rhode and Schwartz, dynamic range of 1 mV/m–100 V/m for the frequency range of 80 MHz–3 GHz), followed by measurements from 3–6 GHz using a Clampco AT6000 antenna. At one out of five measurement sites, Drongen, a conical dipole antenna PCD 8250 (Seibersdorf Laboratories, Seibersdorf, Austria) was used for the 80 MHz - 3 GHz measurements. This antenna was rotated to obtain three orthogonal polarizations of the electric field. During these overview measurements, the spectrum analyzer measured in maximum-hold modus during 17 and 9 minutes in the lower and higher frequency bands, respectively. The antennas were supported by a plastic tripod and were placed at 1 m in front of the bee hive at a height of 1.5 m from the ground level. Figure 3 shows the studied bee hives and the measurement set up in the field. The 1.5 m height is a typical height at which such EM field measurements[30]. Additionally, this height is mentioned in the ECC(02)04 standard[31]. The purpose of these measurements was to get an overview of which frequency bands were in use at the respective sites. These frequency bands were then investigated further in the second measurements.

Second, the same spectrum analyzer was connected to the tri-axial antenna TS-EMF which was again supported by the same tripod at a height of 1.5 m. The tripod was placed at two distances of 1 and 2 m from the central bee hive. The spectrum analyzer performed root-mean square electric field strength (E_{RMS}) measurements over a measurement period of 6 minutes[2] in each of the telecommunication frequency bands identified using the first measurement. Each of the three electric field components (E_x, E_y, E_z) were measured individually. E_{RMS} was then obtained as the square root of the sum of squares of the individual components.

$$E_{RMS} = \sqrt{E_x^2 + E_y^2 + E_z^2} \tag{2}$$

The spectrum analyzer measurements in terms of received power on the antenna were then recalculated using the known antenna factor of the tri-axial antenna to incident root-mean-squared electric field strength. The $E_{RMS,i}$ values in each frequency band (i) were then summed quadratically and the square root of that sum is listed as the total instantaneous electric field strength ($E_{RMS,tot}$).

$$E_{RMS,tot} = \sqrt{\sum_i E_{RMS,i}^2} \tag{3}$$

The measurement procedure and measurement settings for these RF-EMF exposure measurements are presented in[32]. The expanded measurement uncertainty (95% confidence interval) for electric field strength measurements using this set up is $\pm 3\ dB$[30].This measurement setup enables the most accurate assessment of *in situ* exposure from various RF-EMF sources[30].

Third, a broadband exposure measurement was executed using a Narda NBM-550 probe (Narda, Hauppauge,NY, USA) connected to an EF 0691 broad-band probe (Narda, Hauppauge, NY, USA) which has a frequency span from 100 kHz to 6 GHz, thus including so-called intermediate frequencies (IF). These IF fields are not considered in our numerical simulations. However, we measured those to provide a complete overview of the exposure to electromagnetic field below 6 GHz. The NMB probe was placed on top of the central bee hive and was left there during both RF measurements. The device measured and registered root-mean-squared electric field strengths with a period of 1 s. From those time series of measurements, we obtained the time average and the maximal value.

Figure 3. Five measurement locations near bee hives in Belgium: (**a**) Overview of the measrurement locations (source: https://www.google.com/maps, Google Maps, Google, Alphabet inc., Mountain View, CA, USA) Map data: Google, GeoBasis-DE/BKG (**b**) Aalter, (**c**) Merelbeke, (**d**) Eeklo, (**e**) Zomergem, and (**f**) Drongen.

The researchers that executed the RF-EMF field measurements did not use personal devices during the measurements. All wireless devices brought to the measurement site by the researchers were operated in flight mode, i.e. any wireless transmissions by those devices were not allowed.

Estimation of realistic RF-EMF absorbed power in honey bees. Realistic P_{abs} absorbed in honey bees can be obtained by rescaling the simulated P_{abs} values using the measured incident field strengths. Therefore, we linearly averaged the total E_{RMS} values measured near the five bee hives at two different positions to obtain an average $E_{RMS,avg}$ value. In order to estimate exposure of honey bees in current wireless networks, we averaged the P_{abs} values using:

$$P_{abs,av}(f < 3\ GHz) = \frac{1}{4}\sum_{i=1}^{4} P_{abs}(f_i) \tag{4}$$

with $f_i = 0.6, 1.2, 2, 3\ GHz$. We only considered P_{abs} values < 3 GHz, since our measurements will show that there are only incident RF-EMFs below 3 GHz in the current environment of honey bees in Belgium. This value is then rescaled using:

$$P_{abs,real}(f < 3\ GHz) = \frac{E_{RMS,avg}^2}{1\ V^2/m^2} \times P_{abs,av}(f < 3\ GHz) \tag{5}$$

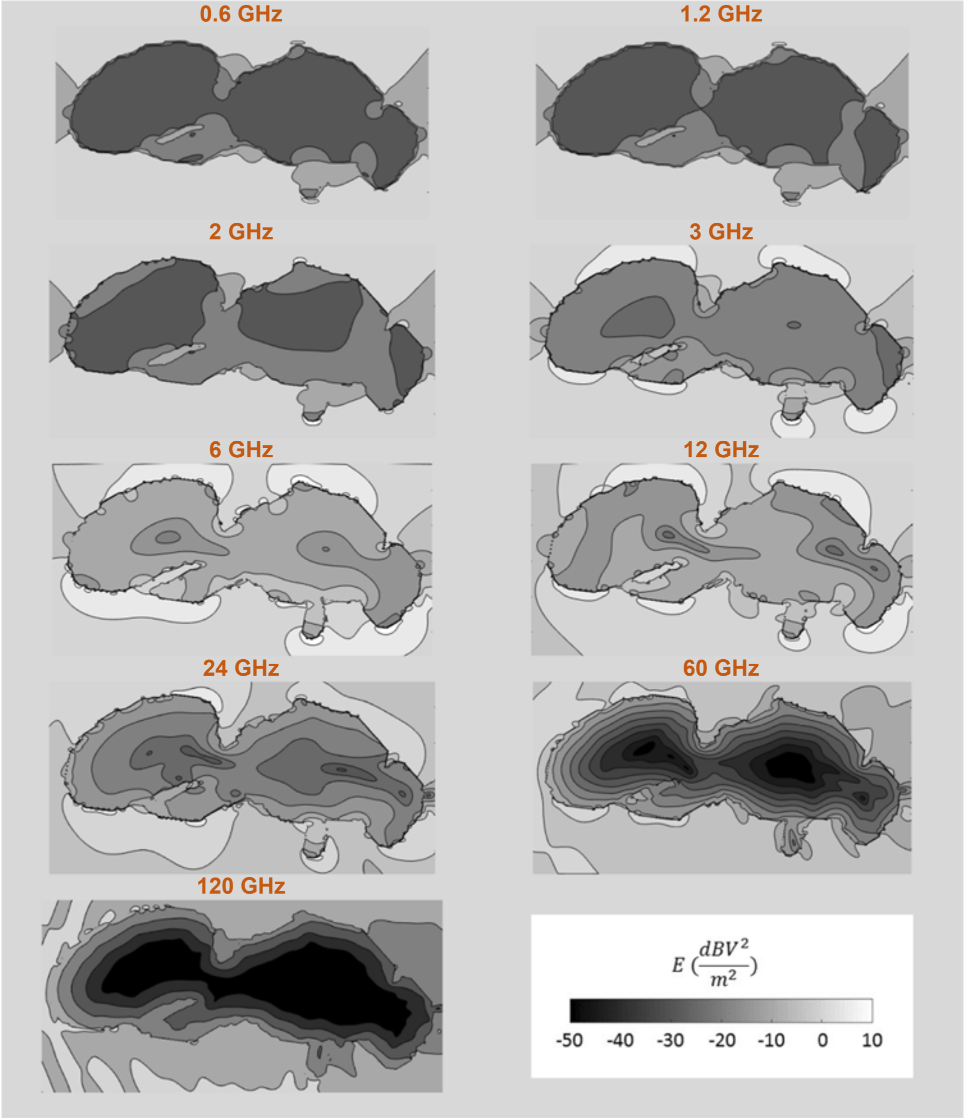

Figure 4. Relative electric field strength in and around a mid-sagittal plane of the Honey Bee Drone at the nine studied frequencies. Grey scale shows the electric field strengths relative to 1 V/m electric field strength.

In order to estimate the effect of a fraction ($p \in [0, 1]$) of the RF-EMF incident fields shifting to frequencies higher than 3 GHz we also determine the average P_{abs} for frequencies higher than 3 GHz, using:

$$P_{abs,av}(f > 3\ GHz) = \frac{1}{5}\sum_{j=1}^{5} P_{abs}(f_j) \tag{6}$$

with $f_j = 6, 12, 24, 60, 120\ GHz$. The realistic $P_{abs,real}(p)$ for a fraction p of the power shifted to frequencies higher than 3 GHz is then calculated as:

$$\begin{aligned} P_{abs,real}(p) \;&=\; p \times \frac{E^2_{RMS,avg}}{1\ V^2/m^2} \times P_{abs,av}(f > 3\ GHz) + (1 - p) \\ &\times \frac{E^2_{RMS,avg}}{1\ V^2/m^2} \times P_{abs,av}(f < 3\ GHz) \end{aligned} \tag{7}$$

Results

Numerical simulations. Figure 4 shows the relative electric field strength (electric field strength divided by the maximum electric field strength in the simulation domain) in and around the studied drone in a mid-sagittal plane as function of frequency for exposure configuration number 1 shown in Fig. 2. The internal electric fields increase up to 12 GHz and shift towards the outside of the phantom at higher frequencies. At 120 GHz the electric

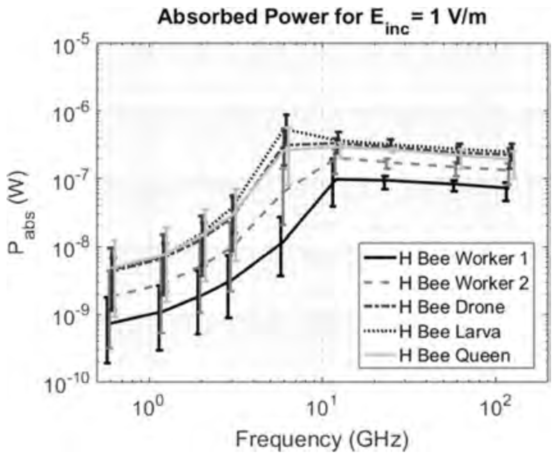

Figure 5. Total absorbed power (P_{abs}) in the five studied honey bees as function of frequency, normalized to an incident plane-wave field strength of 1 V/m at each frequency. The curves indicate the mean values over the twelve plane wave simulations, while the whiskers indicate the maximum and minimum values found at each frequency. The whiskers are slightly offset in order to avoid visual overlap but are all determined at the simulated frequencies described in the Methods Section.

field strengths decreases very rapidly within the phantom and electric fields are basically only present in the outer layers of the insect. This is caused by a decrease in skin depth that is driven by the increase in conductivity at higher frequencies, see Table 1. Note that the total RF-EMF absorbed power in the insect scales both with the internal electric field strength and the conductivity.

Figure 5 shows the normalized RF-EMF P_{abs} as a function of frequency for the five studied insects from 0.6 GHz up to 120 GHz. The curves connect the linear averages of the 12 P_{abs} values obtained for each honey bee at each simulated frequency, while the whiskers indicate the minimum and maximum P_{abs} values found at those frequencies. All P_{abs} values are normalized to an incident field strength of 1 V/m. Figure 5 shows an increase of P_{abs} over frequency for all studied phantoms up to 6 GHz. When comparing the average P_{abs} at 0.6 GHz and 6 GHz, we found relative increases of factors of 16, 35, 72, 121, and 54 for the Worker Bee 1, Worker Bee 2, Drone, Larva, and queen Bee, respectively. The P_{abs} slightly decreases over frequency beyond 12 GHz for all the studied honey bees. When comparing P_{abs} at 12 GHz and 120 GHz, we found relative decreases of 26%, 34%, 33%, 32%, and 34% for the Worker Bee 1, Worker Bee 2, Drone, Larva, and Queen Bee, respectively. The spread on the P_{abs} values obtained at each individual frequency reduces from up to a factor of 13 below 12 GHz to smaller than a factor 2.5 beyond 12 GHz. Figure 5 shows a general increase of P_{abs} with increasing volume and surface area of the studied insects. Previous studies on whole-body averaged absorbed RF power and specific absorption rate of humans have shown a dependency of these quantities on the absorption cross section, a quantity that scales with volume and/or surface area of an exposed subject. When the diagonals of the smallest rectangular brick that contain the insect phantoms are considered, the honey bee with the smallest diagonal, Worker Bee 1 with a diagonal of 13 mm has the overall lowest average P_{abs}. The Larva, Queen Bee, and Drone all have associated diagonals of 22 mm and have similar average P_{abs} values as function of frequency. The Worker Bee 2 has a diagonal that falls in between Worker 1 and the other insects of 16 mm and also has an average P_{abs} that falls in between the curve for the smaller worker and the other honey bee models, see Fig. 5. We attribute he differences between the two Worker Bee phantoms mainly to the difference in size of both phantoms. The larger Worker Bee 2 phantom has a larger diagonal, surface area, and volume. This leads to a higher absorption cross section[33] and higher P_{abs}.

The maximal P_{abs} for the five studied insect models occurs at those wavelengths that are close to the double of this diagonal, which suggests an absorption peak around half a wavelength. The maximum P_{abs} for the Larva model lies in between 3 and 12 GHz, i.e. in between 25 and 100 mm in terms of λ, while the diagonal of said bounding box is 22 mm for the phantom. For the other studied insect models the maximum P_{abs} lies in between 6 and 24 GHz, i.e. in between 23 and 50 mm in terms of λ, with associated phantom diagonals ranging from 16 mm to 22 mm.

As mentioned in the Methods section, the influence of dielectric parameters was studied with simulations using Worker 2 at 2 GHz with altered dielectric parameters. These resulted in P_{abs} values of 6.3×10^{-10} W, 6.3×10^{-9} W, 3.1×10^{-9} W, and 1.8×10^{-9} W, in comparison to 2.0×10^{-9} W for an incident field strength of $1\ V/m$. This corresponds to relative deviations of −69%, +210%, +50%, and −10%. These deviations are significant but smaller than the full range of a factor of 5 we observed for the larva at 2 GHz as a function of changing incident angle and polarization. These relative differences are small in comparison to the differences we observe over frequency for the same phantom: a factor of 121 over frequency from 0.6 to 6 GHz.

At 120 GHz we find a deviation on P_{abs} smaller than 0.1% when 120 simulation periods are executed in comparison to 30 simulation periods in configuration number 2 shown in Fig. 2 for the Worker 2 phantom. Indicating that the number of simulated periods is sufficient for these simulations. At the same frequency and in the same simulation configuration, a reduction of the grid step with a factor of 2 resulted in a P_{abs} of 8.6×10^{-8} W and 3.1×10^{-7} W for the Worker 2 and Larva phantoms, respectively, while the regular simulations with 0.1 mm

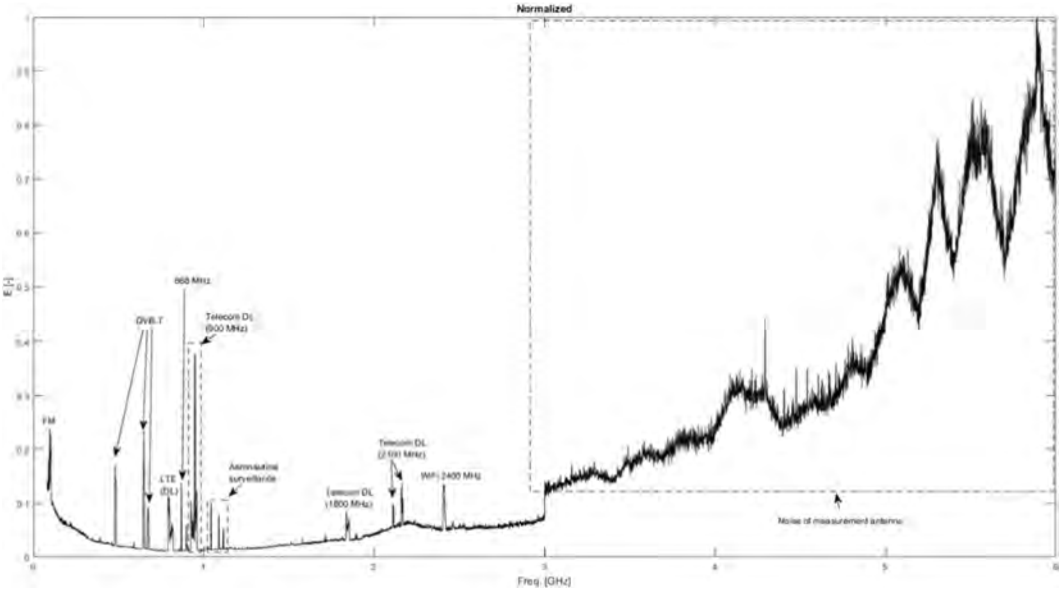

Figure 6. Overview measurement of electric field strength (normalized to maximally measured electric field strength), between 0.8 and 6 GHz, in Aalter. The wireless technologies associated with the different peaks are indicated in the figure as well.

and 0.05 mm grid steps, respectively, resulted in P_{abs} values of 8.4×10^{-8} W and 3.1×10^{-7} W for an incident field strength of 1 V/m. This corresponds to relative deviations of 0.3% and 0.5% for the Worker 2 and the Larva phantoms, respectively, indicating that the chosen grid step was small enough to result in stable numerical results.

The set of 20 incident plane waves with randomized angles of incidence and polarization at 6 GHz using the Worker 2 phantom resulted in an average P_{abs} of $4.5 \times 10^{-8} \pm 1.6 \times 10^{-8}$ W for an incident field strength of 1 V/m, while the set of 12 incident plane waves used to model far-field exposure results in an average P_{abs} of $6.5 \times 10^{-8} \pm 5.3 \times 10^{-8}$ W at the same frequency. The value are fairly close, which indicates that the set of 12 incident plane waves along the main axes is a good proxy for average exposure under a randomized angle of incidence and polarization. The set of twelve plane waves does seem to overestimate exposure at the higher percentiles, since they are significantly higher than those obtained using the random set of plane waves.

RF-EMF field measurements. Figure 6 shows an example of an RF-EMF overview measurement at one of the five studied bee hives (Aalter). Figure 6 shows the relative electric field strength, normalized to the maximally measured electric field strength. The different peaks correspond to several individual frequency bands that are used for telecommunication and broadcasting signals. These frequency bands were then measured individually using the same set-up with triaxial antenna and spectrum analyzer at two positions relative to the bee hive on each measurement site using the measurement procedure described in[32].

Table 2 lists the measured E_{RMS} values at the five studied bee hives shown in Fig. 3. As all these measurement sites were rural, private areas, there were no uplink (emissions from a user device to the network) transmissions found. Downlink (DL, this is network to user communication) signals were found at all measurement sites. These signals were generated by three different mobile telecommunications providers in fourteen different frequency bands. The wireless technologies used by the telecommunication operators were: Long Term Evolution (LTE) in frequency bands close to 800 MHz and 1800 MHz, Global System for Mobile telecommunications (GSM) in frequency bands close to 900 MHz, and Universal Mobile Telecommunications Service (UMTS) in frequency bands close to 900 MHz and 2100 MHz. Four other telecommunication bands were identified: TETRA (Terrestrial Trunked Radio, 390–395 MHz) which is a technology used by public services (police, firefighters, etc.), an Industrial, Scientifical, and/or Medical (ISM) application around 870 MHz, Digital Enhanced Cordless Telecommunications (DECT) close to 1900 MHz, and Wireless Fidelity (WiFi) at 2400 MHz. Additionally, several frequency bands with RF signals for broadcasting were measured: Frequency Modulated (FM) Radio around 100 MHz, Digital Audio Broadcasting (DAB) around 200 MHz, Digital Video Broadcasting (DVB) at 480–680 MHz. We found one unidentified RF wireless transmission at 592 MHz on two measurement sites: Merelbeke and Eeklo. The total E_{RMS} values ranged from 0.016 V/m on both positions in Merelbeke up to 0.226 V/m on position 1 in Drongen. The average E_{RMS} over the ten studied measurement sites was 0.06 V/m. FM Radio was the dominant source of RF exposure on 7/10 measurement positions. In Drongen and in Aalter, GSM 900 DL was the dominant contributor to the RF-EMF exposure. The field strength of WiFi signals depends strongly on the duty cycle used by the wireless technology[34]. The measured E_{RMS} values can be extrapolated to peak values under the assumption of 100% duty cycle. In the case of Aalter, this would result in 0.027 V/m and 0.032 V/m on positions 1 and 2, respectively. In the case of Zomergem, this extrapolation would result in peak E_{RMS} values of 0.059 V/m and 0.016 V/m on positions 1 and 2, respectively. On both measurement sites, a theoretically maximal 90% duty cycle would make WiFi the dominant source of exposure. However, such a network load is unlikely in a rural

$E_{RMS}(V/m)$	Aalter		Merelbeke		Eeklo		Zomergem		Drongen	
Frequency Band	**Pos 1**	**Pos 2**	**Pos 1**	**Pos 2**	**Pos 1**	**Pos 2**	**Pos 1**	**Pos 2**	**Pos 1**	**Pos 2**
FM[a] radio	**0.019**	**0.021**	**0.009**	**0.009**	**0.018**	**0.014**	**0.011**	**0.011**	0.009	0.008
T-DAB	—[b]	—	—	—	—	—	0.004	0.005	0.005	0.004
TETRA (390 MHz-395 MHz)	0.001	0.001	0.002	0.001	0.001	0.001	—	—	0.001	0.002
DVB-T 482 MHz	0.009	0.006	—	—	0.003	0.003	0.008	0.006	0.004	0.002
Freq. 592 MHz	—	—	0.001	0.002	0.002	0.002	—	—	—	—
DVB-T 650 MHz	0.008	0.008	0.003	0.003	0.002	0.003	0.006	0.006	0.006	0.004
DVB-T 674 MHz	0.004	0.008	0.004	0.004	0.002	0.002	0.006	0.005	0.004	0.004
ISM 868 MHz (869.5 MHz)	0.001	0.001	—	—	—	—	—	—	—	—
LTE 800 DL Prov. 1[c]	0.003	0.004	0.001	0.001	0.006	0.004	0.002	0.002	0.002	0.002
LTE 800 DL Prov. 2	0.002	0.002	0.004	0.004	0.002	0.002	0.002	0.002	0.047	0.031
LTE 800 DL Prov. 3	0.003	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.087	0.073
GSM 900 DL Prov. 1	0.005	0.004	0.001	0.002	0.005	0.007	0.003	0.004	0.004	0.004
GSM 900 DL Prov. 2	**0.019**	**0.036**	0.008	0.009	0.002	0.003	0.003	0.004	0.065	0.083
GSM 900 DL Prov. 3	0.004	0.004	0.003	0.002	0.002	0.003	0.003	0.004	**0.180**	**0.137**
UMTS 900 DL Prov. 1	0.001	0.002	0.001	0.001	0.003	0.003	0.002	0.002	0.002	0.001
UMTS 900 DL Prov. 2	0.001	0.001	0.005	0.006	0.001	0.001	0.001	0.001	—	—
UMTS 900 DL Prov. 3	0.002	0.002	0.001	0.001	0.001	0.001	0.002	0.001	0.055	0.055
LTE 1800 DL Prov. 1	—	—	—	—	0.004	0.005	—	—	—	—
LTE 1800 DL Prov. 3	0.004	0.004	—	—	—	—	—	—	—	—
DECT 1880 MHz	—	—	—	—	—	—	0.002	0.003	0.002	0.001
UMTS 2100 Prov. 1	—	—	—	—	0.006	0.007	—	—	—	—
UMTS 2100 DL Prov. 2	0.003	0.003	0.004	0.004	—	—	—	—	0.039	0.026
UMTS 2100 Prov. 3	0.005	0.006	—	—	—	—	—	—	—	—
WiFi 2400 MHz instantaneous[d]	0.007[e]	0.008[e]	—	—	—	—	0.006[f]	0.002[f]	—	—
Total instantaneous	**0.032**	**0.046**	**0.016**	**0.016**	**0.022**	**0.020**	**0.019**	**0.018**	**0.226**	**0.189**

Table 2. Measured root-mean squared electric field strengths (E_{RMS}) in the 80 $MHz - 6\ GHz$ frequency band in V/m. [a]'FM' = Frequency Modulated,'TETRA' = Terrestrial Trunked Radio, 'DVB-T' = Digital Video Broadcasting - Terrestrial, 'ISM' = Industrial, Scientifical, and Medical'LTE' = Long Term Evolution, 'GSM' = Global System for Mobile Communication, 'UMTS' = Universal Mobile Telecommunications System, 'DECT' = Digital Enhanced Cordless Telecommunications, 'WiFi' = Wireless Fidelity. [b]'—' indicates that the frequency band was not present at the measurement site. [c]Three identified Providers are denoted as Prov. 1, 2, and 3. [d]E_{RMS} values for Wireless Fidelity (WiFi)depend on the used duty-cycle, which depends on the use of the network. [e]Duty cycle of 7%. [f]Duty cycle of 1%.

Location	Maximum E-field (1 s interval) (V/m)	Avg E-field (1 s interval) (V/m)
Aalter	0.430	0.272
Merelbeke	0.233	0.1675
Eeklo	0.652	0.532
Zomergem	0.665	0.346
Drongen	0.397	0.297
Average	0.503	0.344

Table 3. Measured maximum and time-averaged broadband incident electric field strengths ($100\ kHz - 6\ GHz$).

area. WiFi was not measured at three out of five measurement sites. Additionally, at all measurement sites, RF EMFs emitted by a pulsed radar or other wireless technologies used in aeronautical surveillance were observed. The E_{RMS} value of RF EMFs emitted by a radar cannot be accurately measured without having the specifications of the radar. Therefore, we can only measure the peak value over the 6 min measurement interval. These fields were the highest in Merelbeke, where at position 1 peak E-field values of 0.017 V/m and 2.2 V/m were measured at 1.09 GHz and 1.3 GHz, respectively, while at position 2 peak E-field values of 0.02 V/m and 2.9 V/m were measured at at 1.09 GHz and 1.3 GHz, respectively.

In order to provide the readers with a complete overview of the exposure to EMF fields below 6 GHz at the chosen measurement sites, Table 3 lists measured values in the 100 kHz to 6 GHz range using a broadband field

Fraction $< 3\,GHz$ $(1-p)$ (%)	Fraction $> 3\,GHz$ p(%)	$P_{abs,real}(p)(nW)$					$\frac{P_{abs,real}(p)}{P_{abs,real}(100\,\% < 3\,GHz)}(.)$				
		Drone	Worker 1	Worker 2	Larva	Queen Bee	Drone	Worker 1	Worker 2	Larva	Queen Bee
100	0	0.63	0.010	0.26	0.73	0.71	1	1	1	1	1
90	10	2.5	0.57	1.2	3.0	2.3	3.9	5.7	4.6	4.2	3.3
80	20	4.3	1.0	2.1	5.3	3.9	6.8	10	8.2	7.4	5.6
70	30	6.2	1.5	3.1	7.6	5.6	9.7	15	12	11	7.8
60	40	8.0	2.0	4.0	9.9	7.2	13	20	15	14	10
50	50	9.8	2.4	5.0	12	8.8	16	25	19	17	12
40	60	12	2.9	5.9	15	10	18	29	23	20	15
30	70	14	3.4	6.9	17	12	21	34	26	23	17
20	80	15	3.9	7.8	19	14	24	39	30	26	19
10	90	17	4.3	8.8	22	15	27	43	33	30	21
0	100	19	4.8	9.7	24	17	30	48	37	33	24

Table 4. Absorbed power in the four studied insects for an incident electric field strength of 0.06 V/m, distributed uniformly over frequencies lower and higher than 3 GHz for different relative fractions.

probe. All the average values are higher than what is obtained from the frequency-selective measurements presented in Table 2, as should be the case since a broader band is considered.

Estimation of realistic RF-EMF absorbed power in honey bees. Using the results presented in Table 2, one can rescale the P_{abs} values shown in Fig. 5 in order to obtain a realistic estimate of the absorbed RF-EMF power in honey bees $P_{abs,real}$. The third to eight columns of the top row of Table 4 list $P_{abs,real}$ assuming that all incident $E_{rms} = 0.06\ V/m$ is uniformly distributed over the simulated P_{abs} values lower than 3 GHz. These values range from 0.1 nW for Worker 1 until 0.7 nW for the Larva and Queen Bee. In each subsequent row, 10% of the incident power density is transferred to frequencies higher than 3 GHz. This causes an increase in the estimated $P_{abs,real}(p)$. In order to quantify this increase, the five columns to the right show the relative increase in $P_{abs,real}(p)$ as p increases from 0 to 1. A full shift of all RF-EMF power to frequencies higher than 3 GHz - without changing the incident field strength - would result in relative increases in absorbed power between a factors 24–48 for the studied honey bee models. Even a relatively small shift of 10% of the incident power density to higher frequencies will lead to a relative increase in P_{abs} of a factor higher than 3, see Table 4.

Discussion

This study investigates RF-EMF absorption in Western Honey Bees as a function of frequency in the 0.6 to 120 GHz range. To this aim, we used five different models of different honey bees: two workers, a drone, a larva, and a queen. These models were obtained using micro-CT imaging and used for FDTD simulations. These were used to evaluate far-field exposure of honey bees. This far-field exposure is modeled as a set of plane waves at harmonic frequencies between 0.6 and 120 GHz. The numerical simulations resulted in P_{abs} as a function of frequency for the different studied honey bees. These simulations were combined with real RF-EMF exposure measurements near bee hives in Belgium in order to estimate realistic exposure values for honey bees.

Micro-CT imaging is a technique that has previously been shown to accurately scan insects[35,36]. The models used in this study have resolutions between 0.02 mm and 0.25 mm, which is larger than the resolution of the micro-CT models using in[11]. Since the smallest grid step used in our simulations is 0.05 mm, the ideal resolution of the insect models would be smaller than that. The larger resolution of the scanning is not a problem for the stability of the FDTD algorithm, but more spatial resolution could be obtained with the same simulation settings. It is expected that the micro-CT models used in this study lead to a better estimation of P_{abs} and the spatial distribution of the electric fields than approximate models such as ellipsoids or cylinders[37].

The results of our numerical simulations, see Fig. 5, show an increase of P_{abs} with frequency up to 6–12 GHz. Figure 4 illustrates the mechanism behind this increase: as the frequency increases the EMFs are less likely to diffract around the honey bees, that are relatively small in comparison to the wavelengths $<6\,GHz$, and can penetrate further in the models, generating higher internal electric fields and consequently higher P_{abs} values. Figure 4 also shows why the whole-body averaged P_{abs} does not increase beyond 12 GHz. As the conductivity increases, see Table 1, the electric fields will decay faster within the honey-bee phantoms, which leads to larger relative volumes within the insect with lower fields, see Fig. 4, which will also contribute to the whole-body averaged P_{abs}. This effect also causes the P_{abs} to have a smaller dependency (variation) on incident angle and polarization, see Fig. 5. We also observe that both the frequency-dependency of the P_{abs}, i.e. the transition point between sharp increase in P_{abs} over frequency and slight decrease over frequency, and the magnitude of the P_{abs}, i.e. the offset of the P_{abs} curve, depend on the honey bee's size. This effect was previously observed in[11]. In general, the results presented in this manuscript are in excellent agreement with those presented in[11]. The results in terms of P_{abs} obtained for the honey bees in this study fall right in between those obtained in[11] for the smaller Australian Stingless Bee and the larger Desert Locust, which confirms again the dependency of P_{abs} on phantom size. The same size-related effect was described for humans in[28,33,38] and comparable frequency trends were observed in humans that have larger full-body sizes at MHz frequencies[28,38]. It should be noted that this manuscript focused on exposure of individual insects in free space. In reality, honey bees might cluster, creating a larger absorption cross section and potentially higher absorption at lower frequencies.

The FDTD simulations presented in this manuscript use dielectric properties that were obtained from the literature survey executed in[11]. Ideally, these dielectric parameters would be obtained for the honey bees studied in this manuscript. However, as shown in[11], most studies on dielectric properties of insects in literature[3,39–41] show similar frequency dependencies of those dielectric parameters. We have executed additional numerical simulations to test for the uncertainty on the dielectric parameters and found deviations up to 210% on P_{abs}, which is significant but still smaller than the variations that exist due to changing angle of incidence and polarization at a fixed frequency, or changes in frequency. We modeled the insects as homogeneous dielectric objects, while in reality they have heterogeneous dielectric parameters. Even though the FDTD algorithm will always require an averaging of dielectric parameters over the cube size, further developments in honey bee and insect phantoms should be focused on the inclusion of multiple tissues in order to refine these models.

In-situ RF-EMF measurements were executed using a measurement set up consisting out of a spectrum analyzer connected to an isotropic, triaxial antenna according to the measurement procedure listed in[32]. We measured total incident E_{RMS} between 0.016 V/m and 0.226 V/m in five rural environments with a linear average of 0.06 V/m and a quadratic average of 0.1 V/m. Joseph *et al.*[32] measured a median total E_{RMS} value of 0.09 V/m over several rural locations in Belgium, the Netherlands, and Sweden. Bhatt *et al.*[1] measured an average E_{RMS} value of $0.07 \pm 0.04\ V/m$ in rural environments in Belgium. Both previous studies of rural RF-EMF exposure are close to what we found in this manuscript and certainly within the measurement uncertainty of 3 dB on our measurements.

As our RF-EMF exposure measurements near bee hives demonstrate, see Table 2, most of the current RF-EMF exposure is located at frequencies $\leq 1\ GHz$. Additionally, Fig. 5 demonstrates that the P_{abs} in all studied Honey bee models is lowest at frequencies $\leq 1\ GHz$. This implies that in reality, potential shifts in telecommunication frequencies to higher frequencies might induce even larger increases that the ones estimated in Table 4 since in that analysis an average value over all P_{abs} values $\leq 3\ GHz$ is assumed.

Strengths and limitations. This manuscript presents several contributions to the state of the art in the field of RF-EMF exposure assessment of insects. First, to the best of the authors' knowledge, this is the only paper where a numerical RF dosimetry is presented for different developmental stages of honey bees. Second, this is the only study that combined real, *in-situ* exposure measurements with numerical simulations of RF-EMF exposure of insects in order to estimate a realistic exposure of honey bees. In comparison to our previous study[11], we considered a broader frequency range from 0.6 GHz up to 120 GHz, which is more in line with the frequencies used in the current telecommunication networks (3 G and 4 G). Finally, this study presents a unique quantification of real-life exposure of honey bees and estimations of how this might change if future frequency shifts in that exposure might occur. A disadvantage of this study is that we did not executed dielectric and thermal measurements in order to obtain dielectric and thermal properties of the studied honey bees. We obtained dielectric properties from literature and were able to execute electromagnetic simulations. We did not perform thermal simulations in this study. Another disadvantage is that we modeled far-field exposure by a limited number of plane waves, while previous studies have shown that a large set of plane waves is necessary to properly model far-field exposure[26]. We did executed a validation of our exposure set up by comparing it with a set of random plane wave exposures and found good correspondence, certainly close to the mean/median. Finally, we used FDTD simulations that are faced with uncertainties[29] and used models that have a limited spatial resolution. This is a disadvantage of any RF-EMF simulation study in comparison to a study that relies on measurements of real insects.

Future research. Our future research will focus on executing exposure measurements of insects in order to validate the RF-EMF P_{abs} values and the dielectric parameters. Additionally, we would like to execute thermal simulations of honey bees and other insects under RF-EMF exposure. Finally, we aim to work on the development of more insect phantoms, with more spatial accuracy and potentially several independently identified tissues.

Conclusions

Exposure of Western Honey Bees (*apis mellifera*) to radio-frequency (RF) electromagnetic fields was studied using a combination of *in-situ* exposure measurements near bee hives in Belgium and numerical simulations. The simulations use the finite-difference time-domain technique to determine the electromagnetic fields in and around five honey bee models exposed to plane waves at frequencies from 0.6 GHz up to 120 GHz. These simulations lead to a quantification of the whole-body averaged absorbed radio-frequency power (P_{abs}) as a function of frequency. The average P_{abs} increases by factors 16 to 121, depending on the considered phantom, when the frequency is increased from 0.6 GHz to 6 GHz for a fixed incident electric field strength. A relatively small decrease in P_{abs} is observed for all studied honey bees between 12 and 120 GHz. RF exposure measurements were executed on ten sites near five different locations with bee hives in Belgium. These measurements resulted in an average total incident RF field strength of 0.06 V/m, which was in excellent agreement with literature. This value was used to assess P_{abs} for those honey bees at those measurement sites. A realistic P_{abs} is estimated to be between 0.1 and 0.7 nW for the studied honey bee models. Assuming that 10% of the incident power density would shift to frequencies higher than 3 GHz would lead to an increase of this absorption between 390–570%. Such a shift in frequencies is expected in future networks.

Received: 1 October 2019; Accepted: 19 December 2019;
Published online: 16 January 2020

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Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665501 with the research Foundation Flanders (FWO). A.T. is an FWO [PEGASUS][2] Marie Skłodowska-Curie Fellow. The authors would like the thank the bee keepers who allowed us to perform measurements at their bee hives.

Author contributions

A.T. conducted the numerical simulations, analyzed the results, and drafted the manuscript. L.V. conducted the measurements. M.K.G. conducted the imaging and post processing of the imaging. W.J and L.M. contributed to analyzing the methodology and results. All authors reviewed the manuscript and provided input to the different sections.

Competing interests

The authors declare no competing interests.

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Science of the Total Environment 572 (2016) 554–569

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Radiofrequency radiation injures trees around mobile phone base stations

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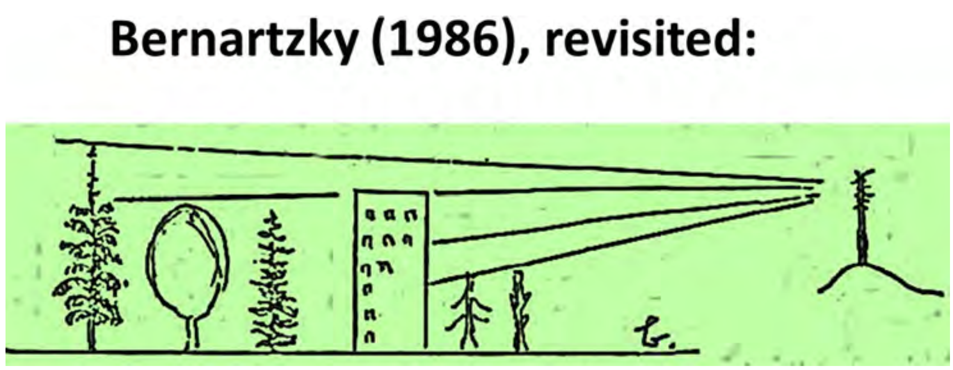
HIGHLIGHTS

- High frequency nonionizing radiation is becoming increasingly common.
- This study found a high level of damage to trees in the vicinity of phone masts.
- Deployment has been continued without consideration of environmental impact.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 6 June 2016
Received in revised form 19 July 2016
Accepted 6 August 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Electromagnetic radiation
Effects on trees
Phone masts
Radiofrequencies

ABSTRACT

In the last two decades, the deployment of phone masts around the world has taken place and, for many years, there has been a discussion in the scientific community about the possible environmental impact from mobile phone base stations. Trees have several advantages over animals as experimental subjects and the aim of this study was to verify whether there is a connection between unusual (generally unilateral) tree damage and radiofrequency exposure. To achieve this, a detailed long-term (2006–2015) field monitoring study was performed in the cities of Bamberg and Hallstadt (Germany). During monitoring, observations and photographic recordings of unusual or unexplainable tree damage were taken, alongside the measurement of electromagnetic radiation. In 2015 measurements of RF-EMF (Radiofrequency Electromagnetic Fields) were carried out. A polygon spanning both cities was chosen as the study site, where 144 measurements of the radiofrequency of electromagnetic fields were taken at a height of 1.5 m in streets and parks at different locations. By interpolation of the 144 measurement points, we were able to compile an electromagnetic map of the power flux density in Bamberg and Hallstadt. We selected 60 damaged trees, in addition to 30 randomly selected trees and 30 trees in low radiation areas (n = 120) in this polygon. The measurements of all trees revealed significant differences between the damaged side facing a phone mast and the opposite side, as well as differences between the exposed side of damaged trees and all other groups of trees in both sides. Thus, we found that side differences in measured values of power flux density corresponded to side differences in damage. The 30 selected trees in low radiation areas (no visual

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http://dx.doi.org/10.1016/j.scitotenv.2016.08.045

contact to any phone mast and power flux density under 50 μW/m^2) showed no damage. Statistical analysis demonstrated that electromagnetic radiation from mobile phone masts is harmful for trees. These results are consistent with the fact that damage afflicted on trees by mobile phone towers usually start on one side, extending to the whole tree over time.

1. Introduction

For many years, there has been a discussion in the scientific community about whether artificial radiofrequency radiation has harmful effects on living organisms and, more specifically, on the environmental impact from mobile phone base stations (Panagopoulos et al., 2016). Trees have several advantages over animals as experimental subjects: they are continuously exposed to radiation in a constant orientation in the electromagnetic field due to their inability to move (Vian et al., 2016). Additionally, it is possible to easily document changes over time, such as disturbed growth, dying branches, and premature colour change of leaves. Moreover, the damage to trees is objective and cannot be attributed to psychological or psychosomatic factors.

Plants are specialized in the interception of electromagnetic radiation (light) but radiofrequency radiation impact on plants, which is becoming common in the environment because of the exponential use of mobile phone technology, has received little attention and his physiological effect has long been considered negligible.

Since the mid-twentieth century, several researchers have investigated the effects of electromagnetic radiation on plants, both in the laboratory (Kiepenheuer et al., 1949; Brauer, 1950; Harte, 1950, 1972; Jerman et al., 1998; Lerchl et al., 2000; Sandu et al., 2005; Roux et al., 2006, 2008; Sharma et al., 2009; Tkalec et al., 2005, 2009; Beaubois et al., 2007; Kundu and IEEE, 2013; Pesnya and Romanovsky, 2013; Cammaerts and Johansson, 2015; Grémiaux et al., 2016; Vian et al., 2016), and in nature (field observations) (Bernatzky, 1986; Volkrodt, 1987, 1991; Selga and Selga, 1996; Balodis et al., 1996; Haggerty, 2010). Both kinds of study have frequently found pernicious effects.

Around the world, phone masts have been deployed in the last two decades everywhere. Preliminary published studies have indicated deleterious effects of radiofrequency radiation on trees (Balmori, 2004; Van't Wout, 2006; Schorpp, 2011; Waldmann-Selsam, 2007; Waldmann-Selsam and Eger, 2013), cautioning that research on this topic is extremely urgent (Balmori, 2015). However, these early warnings have had no success and deployment has been continued without consideration of environmental impact.

In a review of the effects of environmental microwaves on plants (Jayasanka and Asaeda, 2013), it was indicated that effects depend on the plant family and the growth stage, as well as the exposure duration, frequency, and power density. This review concluded that most studies that address the effects of microwaves on animals and plants have documented effects and responses at exposures below limits specified in the electromagnetic radiation exposure guidelines and it is therefore necessary to rethink these guidelines (Jayasanka and Asaeda, 2013).

Since 2005, on the occasion of medical examinations of sick residents living near mobile phone base stations, changes in nearby trees (crown, leaves, trunk, branches, growth…) were observed at the same time as clinical symptoms in humans occurred. Since 2006 tree damages in the radiation field of mobile phone base stations were documented (http://kompetenzinitiative.net/KIT/KIT/baeume-in-bamberg/). In the radio shadow of buildings or that one of other trees, the trees stayed healthy.

Additionally, unilateral crown damage, beginning on the side facing an antenna, pointed to a possible link between RF-EMF (Radiofrequency Electromagnetic Fields) and tree damage. We carried out measurements on both sides of unilaterally damaged trees. Most of the trees had been exposed to RF-EMF for at least five years. Each time we found considerable differences between the measured values on the damaged and on the healthy side.

The aim of the present study was to verify whether there is a connection between unusual (generally unilateral) tree damage and radiofrequency exposure.

2. Materials and methods

The official information of 65 mobile phone sites in the neighbouring cities Bamberg and Hallstadt was extracted from the EMF database (EMF-Datenbank) of the German Federal Network Agency (Bundesnetzagentur, in March 2011 and October 2015). Each site certificate ("Standortbescheinigung") provides information on the mounting height of antennas, the number and main beam direction of the sector antennas, the number of omnidirectional antennas (ND), the number of other transmitters, as well as the horizontal and vertical safety distances. The current specifications of the transmission facilities are available at: http://emf3.bundesnetzagentur.de/karte/Default.aspx

On most of the 65 mobile phone sites several sector antennas emitting RF-EMF with differences in frequency, modulation and other physical characteristics are installed (GSM 900, GSM 1800, UMTS, LTE (4th generation), TETRA). In 2011 there was a total of 483 sector antennas, in 2015 a total of 779 sector antennas.

Numerical code, address and UTM 32N coordinates for the 65 Mobile phone (base stations) sites in Bamberg and Hallstadt are shown in Table 1.

Between 2006 and 2015 there was observation and documentation of tree damages. There were some preliminary measurements on both sides of unilaterally damaged trees and approximately 700 trees in Bamberg and Hallstadt were visited. The condition of numerous trees has been documented in photographs. The photographs record the state of trees showing damage patterns not attributable to diseases, pests, drought or other environmental factors in order to monitor damage and growth over several years (in 2006, Olympus FE-100 was used; since 2007, Panasonic DMC-FZ50 was used).

In 2015 we selected a polygonal study site, with an approximate area of 30 km^2, which includes partial municipalities of Bamberg and Hallstadt (70 km^2). The study area with the location of the phone masts in the layer of natural areas and municipalities is shown in Fig. 1. In this area, different measurements (see below) were done both for having a radiation map and for knowing which are the incident power densities beside different trees. In spite of the fact that measurements are changing continuously, they do not show significant differences between times (own data, see below).

In this polygon, we performed 144 measurements of the radiofrequency electromagnetic fields at a height of 1.5 m at different points in the city. These measurements were taken in streets and parks and allowed the preparation of an electromagnetic map of Bamberg and Hallstadt with their interpolation. The measurements were carried out with an EMF-broadband analyzer HF 59B (27–3300 MHz) and the horizontal-isotrope broadband antenna UBB27_G3, (Gigahertz Solutions). Measurements of the sum peak values of power flux density were in μW/m^2, which can be converted in V/m.

In general, a sector antenna covers an angle of 120° and the radiation of the sector antennas is distributed in main and secondary beams, bundled vertically and horizontally. The high-frequency emissions are reflected/diffracted and/or absorbed by buildings and trees. Therefore,

Table 1
Official information of the 65 mobile phone base stations in Bamberg and Hallstadt.

Code number	Adress in Bamberg and Hallstadt	X	Y	Code number	Adress in Bamberg and Hallstadt	X	Y
1	Altenburg	634268	5527019	34	Ludwigstr. 25 (Post)	636318	5529177
2	Am Borstig 2	636070	5531636	35	Luitpoldstr. 51	636241	5529232
3	Am Hirschknock	637511	5532267	36	Mainstraße, Ladekai 2	633924	5530319
4	An der Breitenau 2	637253	5530650	37	Mainstraße, Ladekai 3	633816	5530130
5	(An der Breitenau, P&R) ca.	637259	5526912	38	Margaretendamm 28	635341	5529331
6	(Artur-Landgraf-Straße)	635183	5526912	39	Memmelsdorfer Straße (Post) ca.	637769	5531392
7	Breitäckerstr. 9	632965	5529621	40	Memmelsdorfer Str. 208a	637568	5531191
8	Coburger Str. 6a	635877	5529951	41	Memmelsdorfer Str. 208a	634861	5528541
9	Coburger Str. 35	635252	5530468	42	Mußstr. 1	634949	5528827
10	Erlichstr. 47/51	637291	5527903	43	Pödeldorfer Str. 144	637828	5529305
11	Franz-Ludwig-Str. 7	635843	5528490	44	Rheinstr. 16 ca.	632910	5530367
12	Geisfelder Str. 30	637689	5528020	45	Robert-Bosch-Str. 40	637767	5528292
13	Grüner Markt 1	635624	5528370	46	Schildstr. 81	637049	5529049
14	Grüner Markt 23	635640	5528565	47	Schranne 3	635511	5528166
15	Gutenbergstr. 20	638448	5527180	48	Schützenstr. 23	636197	5527961
16	Hainstr. 4	635945	5528229	49	Schwarzenbergstr. 50	636762	5528732
17	Hainstr. 39	636341	5527550	50	Siemensstr. 37-43	638091	5528505
18	Hauptsmoorstr. 26a	638223	5530558	51	Theresienstr. 32	637487	5527866
19	Hauptsmoorwald, Pödeldorfer Straße	639683	5529635	52	Unterer Kaulberg 4	635350	5528084
20	Hauptsmoorwald, Geisfelder Straße	639890	5528022	53	Von-Ketteler-Str. 2	637905	5527553
21	Heiliggrabstr. 15	636054	5529240	54	Wilhelmsplatz 3	636316	5528259
22	Heinrichsdamm 1	635849	5528723	55	Zollnerstr. 181	637772	5530133
23	Heinrichsdamm 33a, P&R	636748	5527529	56	Heganger 18	634327	5530982
24	Hohenlohestr. 7	634794	5526480	57	Biegenhofstr. 13	633963	5531045
25	Kantstr. 33	637161	5530333	58	Seebachstr. 1	634399	5531764
26	Katzenberg	635374	5528266	59	Landsknechtstr.	634800	5531918
27	Kirschäckerstr. 37	636649	5530756	60	Lichtenfelser Str.	634864	5532621
28	(Kloster-Langheim-Str. 8)	637190	5529182	61	Michelinstr. 130 ca.	635629	5532106
29	Kronacher Str. 50	636722	5531496	62	Margaretendamm	634991	5529497
30	Lagerhausstr. 4-6	634850	5529871	63	Mainstr. 36a/Kiliansplatz	634326	5532386
31	Lagerhausstr. 19	634304	5530136	64	Bamberger Straße	635964	5526050
32	(Laurenziplatz 20)	635207	5527404	65	Würzburger Str. 76	635359	5526709
33	Ludwigstr. 2	635207	5529103				

due to existing obstacles there is an inhomogeneous radiofrequency field distribution. Buildings and vegetation (trees and foliage) can shield and reduce radiation and thus affect the quality of signal propagation (e.g. Meng and Lee, 2010). Living material is not a perfect dielectric object and interferes with high frequency electromagnetic fields in a way that depends upon several parameters, including the general shape, conductivity, and density of the tissue, and the frequency and amplitude of the electromagnetic radiation (Vian et al., 2016).

In the polygon mentioned before we selected 60 trees showing unilateral damage. The selection was limited by the fact that we were able to measure with the telescopic rod only up to a height of 6 m. Many trees (*Tilia, Betula, Quercus, Populus, Picea*) showing damage above the

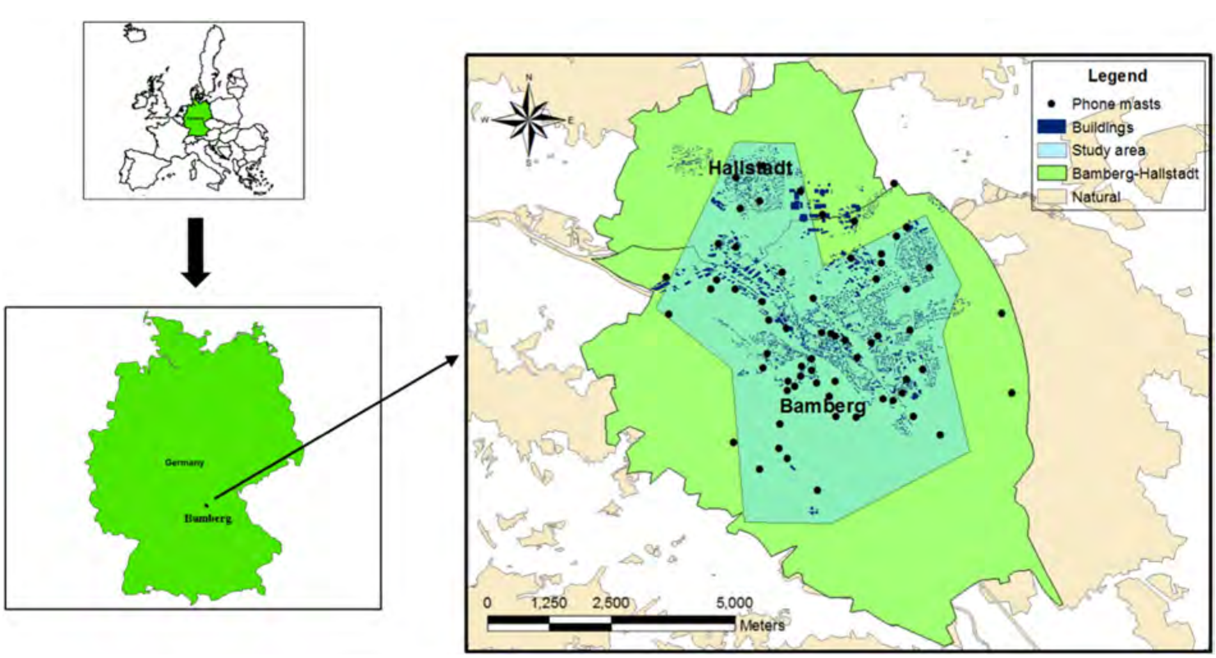


Fig. 1. The study area with the location of the phone masts in the layer of natural areas, buildings, and municipalities.

height of 6 m could not be included. The measurements at the trees were done between April and October 2015. *Acer platanoides*, *Carpinus betulus*, *Tilia* sp., *Taxus baccata* and *Thuja occidentalis* are widely spread in Bamberg and Hallstadt and can be reached for measurements. Therefore they are the most represented species.

The selected 60 trees from the study polygon show damage patterns that are not usually attributable to harmful organisms, such as diseases (fungi, bacteria, viruses) and pests (insects, nematodes) or other environmental factors (water stress, heat, drought, frost, sun, compaction of the soil, air and soil pollutants).

The main features of damage from this source are:

- Trees are mainly affected on one side (showing side differences and unilateral damage) and can appear in any orientation. The damage only originates on one side.
- Damage appears without external indications that the tree is infested with insects, nematodes, fungi, bacteria or viruses.
- Damage appears on trees, which have previously grown well. Damage appears on once healthy trees within one or two years after Antennas were put into operation.
- Damage increases from the outside to the inner part of the crown over time.
- Trees of different species in the same location also show damage.
- Damage appears in favourable (gardens, parks) as well as in unfavourable locations.
- Trees in the same location, but that are shielded by buildings or other trees, are healthy.

For these damaged trees, we used 13 damage codes that may be recognised with the naked eye (for explanations, see Table 2). In order to explain each type of damage visually, a photograph was added for each damage code.

Table 2
Tree damage codes.

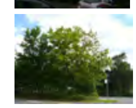
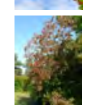
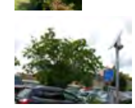
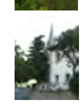
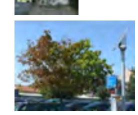
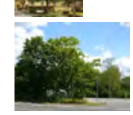
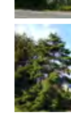
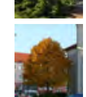
01 Damage only on one side: The tree shows damage only on one side. The damage can be recognized with the naked eye.	
02 Crown transparency (sparse leaves or needles): The number of leaves or needles is reduced. The crown transparency increases from year to year.	
03 Brown leaves (start at leaf margins): The leaves begin to turn brown in june. The browning starts at the leaf margins. It looks similar to effects by salt.	
04 Colour change of leaves prematurely: Leaves become yellow, red or brown (in the whole) early in the year.	
05 Tree leaves fall prematurely: The leaves begin to fall already from june on.	
06 Dead branches: Over a period of some years it can be observed how little and big branches die.	
07 Tip of the main guide dried.	
08 Irregular growth. The growth of deciduous and coniferous trees can be disturbed in different manners. One observation is that trees bend to a side.	
09 Not grow in height: Trees often stop to grow in height. The height was not measured. Only the visual impression was valuated.	
10 Colour change of needles. Needles can change their colour to yellow, red or brown.	
11 Dead parts were trimmed down: When bigger branches die, it becomes necessary to remove these parts for the sake of security of people passing.	
12 Damage on different sides: The trees show damages on different sides.	
13 No damage: The tree shows the typical habitus of its species. With the naked eye no damage can be seen.	

Table 3
144 selected points in Bamberg and Hallstadt with their measurements and UTM coordinates.

Number	Streets and parks in Bamberg and Hallstadt	Measurement μW/m²	X	Y	Number	Streets and parks in Bamberg and Hallstadt	Measurement μW/m²	X	Y
1	Wassermannpark	2300	637395	5530345	73	Ludwigstraße/Zollnerstraße	50	636228	5529444
2	Memmelsdorfer Str. 209	1830	637581	5531113	74	Landratsamt, Ludwigstraße, Einfahrt	670	636422	5529044
3	Holunderweg	10	638125	5530967	75	Wilhelmsplatz, Mitte	460	636250	5528263
4	Hauptsmoorstraße/Seehofstraße	3600	638039	5530857	76	Amalienstr. 16	16570	636303	5528086
5	Greifffenbergstr. 79	4210	638349	5530855	77	Otttostr. 7a	120	636133	5527878
6	Heimfriedweg 16	870	638393	5530621	78	Schönbornstr. 3	3640	636251	5527696
7	AWO, Innenhof, Parkplatz	3920	638223	5530584	79	Hainspielplatz	1530	636229	5527403
8	Ferdinand-Tietz-Str. 40	2600	637883	5530616	80	P&R Heinrichsdamm, Parkplatz bei Kirschen	3400	636706	5527667
9	Ferdinand-Tietz-Str. 38	80	637889	5530601	81	P&R Heinrichsdamm, südöstlich des Senders, Eichen	1690	636755	5527504
10	Petrinistr. 20	1340	637797	5530514	82	Luisenhain, Höhe Wasserwerk	260	636895	5526482
11	Petrinistr. 32	4700	637891	5530449	83	Kapellenstraße	2120	637050	5528148
12	Zollnerstraße 181	9300	637773	5530102	84	Geisfelder Str. 9, Gärtnerei	740	637410	5528164
13	Wassermannstr. 14	540	637424	5530125	85	Gereuthstr. 8	30	637621	5527424
14	Feldkirchenstraße/Kantstraße	2620	636803	5530069	86	Distelweg, Innenhof	15	637881	5527160
15	Breslaustr. 20	3890	637392	5530431	87	Am Sendelbach BSC 1920	30	637331	5526877
16	Berliner Ring	16920	637188	5530786	88	Am Sendelbach, Kleingartenanlage	10	637542	5526222
17	Rodezstr. 3	3780	637044	5530765	89	Robert-Bosch-Straße	2060	637504	5528200
18	Am Spinnseyer 3	880	637545	5530764	90	Ludwigstraße/Memmelsdorfer Straße	1000	635974	5529708
19	Kirschäckerstr. 24	4290	636655	5530857	91	Coburger Straße, Neubau Studentenwohnheim	3460	635867	5529878
20	Kammermeisterweg	810	636283	5530282	92	Coburger Straße, junge Platane	3400	635835	5529941
21	Eichendorff-Gymnasium, Hof	6340	637194	5529084	93	Gundelsheimer Str. 2	9000	635783	5529680
22	Starkenfeldstraße/Pfarrfeldstraße	3660	637092	5529138	94	Hallstadter Straße	12	635232	5530212
23	Parkplatz auf der Westseite der Polizei	9020	636921	5528970	95	Gerberstraße/Benzstraße	1280	635108	5530546
24	Starkenfeldstraße, Höhe Polizei	1120	636975	5529061	96	Coburger Straße, Einfahrt Fitnesszentrum	2000	635326	5530508
25	Starkenfeldstr. 2	860	637527	5529216	97	Kleintierzuchtanlage	890	635380	5530622
26	Pödeldorfer Str., Haltestelle	2180	636965	5529217	98	Margaretendamm, Eingang ehemaliges Hallenbad	1300	635455	5529178
27	Kindergarten St. Heinrich, Eingang	6450	637712	5529364	99	Margaretendamm/Europabrücke	1890	635200	5529365
28	Pödeldorfer Straße, Haltestelle Wörthstraße	1620	637654	5529433	100	Margartendamm 38, nahe Sendeanlage	5560	635003	5529497
29	Pödeldorfer Str. 142, Nordseite	30	637840	5529437	101	Hafenstraße/Regnitzstraße	7610	634719	5529740
30	Pödeldorfer Str. 142, Südseite	17060	637824	5529410	102	Lagerhausstraße	210	634556	5530102
31	Berliner Ring, Höhe Pödeldorfer Str. 144	4480	637900	5529380	103	Hafenstr. 28, Bayerischer Hafen	3200	634192	5530370
32	Schwimmbad Bambados, Vorgarten mit Bambus	1620	638074	5529315	104	Laubanger 29	160	634202	5530561
33	Schwimmbad Bambados, Parkplatz, Feldahorn	2540	638202	5529346	105	Heganger	1400	634341	5530812
34	Carl-Meinelt-Str.	5360	638043	5529094	106	Emil-Kemmer-Str. 2	5000	633822	5530863
35	Volkspark, FC Eintracht, Ostseite	120	638343	5529065	107	Emil-Kemmer-Str. 14	2500	634342	5531099
36	Michelsberger Garten, Teil Streuobst	5450	634831	5528673	108	Dr. Robert-Pfleger-Straße 60	90	634448	5530978
37	Michelsberger Garten, Terrassengarten, bei Eibe	2500	634988	5528508	109	Friedhof Gaustadt, Haupteingang	13100	632981	5529677
38	Michelsberger Garten, Südostecke, bei Holunder	910	635036	5528455	110	Friedhof Gaustadt, Ahornpaar	1400	632929	5529728
39	Michelsberg, Aussichtsterrasse, oberhalb Weinberg	1260	634924	5528463	111	Herzog-Max-Str. 21	1600	636245	5528071
40	Michelsberg, Aussichtsterrasse, Aussichtspunkt	780	634911	5528537	112	Gaustadter Hauptstr. 116	10	634042	5529457
41	Michelsberg, Nordostecke, bei jungen Linden	390	634874	5528565	113	Landesgartenschaugelände, Hafenerlebnispfad	2000	633789	5529894
42	Storchsgasse/Michelsberg	200	634725	5528415	114	Landesgartenschau, junge Baumgruppe	1270	633949	5529718
43	St. Getreu-Kirche, Südseite	55	634518	5528405	115	Würzburger Str.	340	635283	5527151
44	Villa Remeis, Garten	390	634295	5528203	116	Würzburger Straße/Arthur-Landgraf-Straße	1380	635355	5526862
45	Villa Remeis, Treppe	300	634400	5528237	117	Hohe-Kreuz-Straße/Würzburger Straße, Haltestelle	590	635383	5526733
46	Maienbrunnen 2	3920	634744	5528838	118	Hohe-Kreuz-Straße	10950	635469	5526729
47	Am Leinritt	2140	635071	5528617	119	Am Hahnenweg 6	3420	635332	5526729
48	Abtsberg 27	130	634526	5528935	120	Am Hahnenweg/Viktor-von-Scheffel-Straße	640	635307	5526710
49	Welcome Hotel, Garten	3200	634788	5529012	121	Am Hahnenweg 28 a	145	635028	5526654
50	Mußstraße, eingang Kindergarten	1670	634864	5529011	122	Schlüsselberger Straße	200	634712	5526534
51	Mußstraße/Schlüsselstraße	710	634846	5529034	123	Schlüsselberger Str./Haltestelle Hezilostr., Parkdeck	460	634749	5526549
52	Nebingerhof	2040	635069	5528901	124	Hezilostr. 13	70	634604	5526563
53	Graf-Stauffenberg-Platz	100	635120	5529009	125	Sückleinsweg, junge Hainbuchenhecke	75	634512	5526654
54	Don-Bosdo-Straße, Innenhof	10	635176	5529056	126	Rößleinsweg, oberes Ende	300	634708	5526789
55	Pfeuferstraße/Weide	1100	635222	5528820	127	Große Wiese	1500	634874	5526810

Table 3 (*continued*)

Number	Streets and parks in Bamberg and Hallstadt	Measurement μW/m²	X	Y	Number	Streets and parks in Bamberg and Hallstadt	Measurement μW/m²	X	Y
56	Weidendamm/Don-Bosco-Straße	1860	635166	5529195	128	Suidgerstraße	195	634508	5526409
57	Katzenberg/Karolinenstraße	1720	635316	5528239	129	Waizendorfer Straße	280	635317	5525864
58	Vorderer Bach	450	635305	5528141	130	Waizendorfer Straße, Einfahrt Gärtnerei	210	635326	5525582
59	Obere Brücke	8000	635565	5528289	131	Klinikum, Nähe Spielplatz	175	635732	5525672
60	Judenstraße	6	635479	5528040	132	Klinikum Weiher	100	635759	5525520
61	Tourist Information	4920	635674	5528172	133	Buger Straße/Bamberger Straße	2730	635829	5526082
62	Universität, Am Kranen 14, Innenhof	10	635501	5528535	134	Dunantstraße	470	635848	5526176
63	Fleischstraße	10	635703	5528683	135	Buger Straße/Paradiesweg	90	635743	5526286
64	ZOB	600	635882	5528541	136	Buger Straße/Abzweigung Münchner Ring	470	635528	5526499
65	Schönleinsplatz, Ostseite	900	636004	5528300	137	Hallstadt, Markplatz, bei Linde	2000	634582	5532426
66	Friedrichstraße, Parkplatz	165	635984	5528360	138	Hallstadt, Markplatz 21, Innenhof	8	634632	5532488
67	Franz-Ludwig-Straße/Luisenstraße	1720	636158	5528410	139	Hallstadt, Lichtenfelser Str. 12	4000	634659	5532474
68	Franz-Ludwig-Str, Strassenbauamt	90	636246	5528408	140	Hallstadt, Lichtenfelser Str. 8	9000	634720	5532516
69	Heiliggrabstraße, Nähe Sender	4740	636072	5529245	141	Hallstadt, Am Gründleinsbach/Kemmerner Weg	200	634743	5532784
70	Heiliggrabstr. 29, Landesjustizkasse	20	636063	5529399	142	Hallstadt, Valentinstraße/Seebachstraße	2200	634232	5532237
71	Heiliggrabstr. 57, Aussichtspunkt Schiefer Turm	4500	635797	5529410	143	Hallstadt, Johannisstr. 6	5000	634805	5532078
72	Bahnhof, ParkplatzWestseite	1600	636300	5529374	144	Hallstadt, Bamberger Straße/Michael-Bienlein-Straße	1860	634805	5531969

For each selected tree, the types of damage and the Universal Transversal Mercator (UTM) coordinates were recorded. In addition, two measurements were recorded: on the side showing damage and on the side without damage, generally corresponding to opposite sides of each tree. On both sides, the measurements were carried out at a variable height of 1–6 m (depending on the height of the tree), using a telescopic rod, a ladder, and the broadband radiofrequency meter.

Most measurements were done in the afternoon or in the evening on different days between April and October 2015. But the measurements on the two sides of each single tree were done one after another immediately on the same day and at the same time. The measurements took about 5 min on each side. When we stood on the ground or on a ladder we measured the peak values. When we used the telescopic rod we measured the peak hold values. Using the telescopic rod and measuring peak hold values it took longer, because the measurements had to be repeated often in cases where RF-EMF emitting cars or passengers disturbed the results. At each single tree the two measurements were done in the height where the damage had appeared. Because the height of the 120 trees differed, it was necessary to do the measurements at different heights.

In theory, although measurements are changing continuously there is no evidence about significant changes in power densities of electromagnetic radiation produced by phone masts over time. One study carried over one year in the city of Madrid showed no changes in terms of radiation intensity between the three rounds of measurements

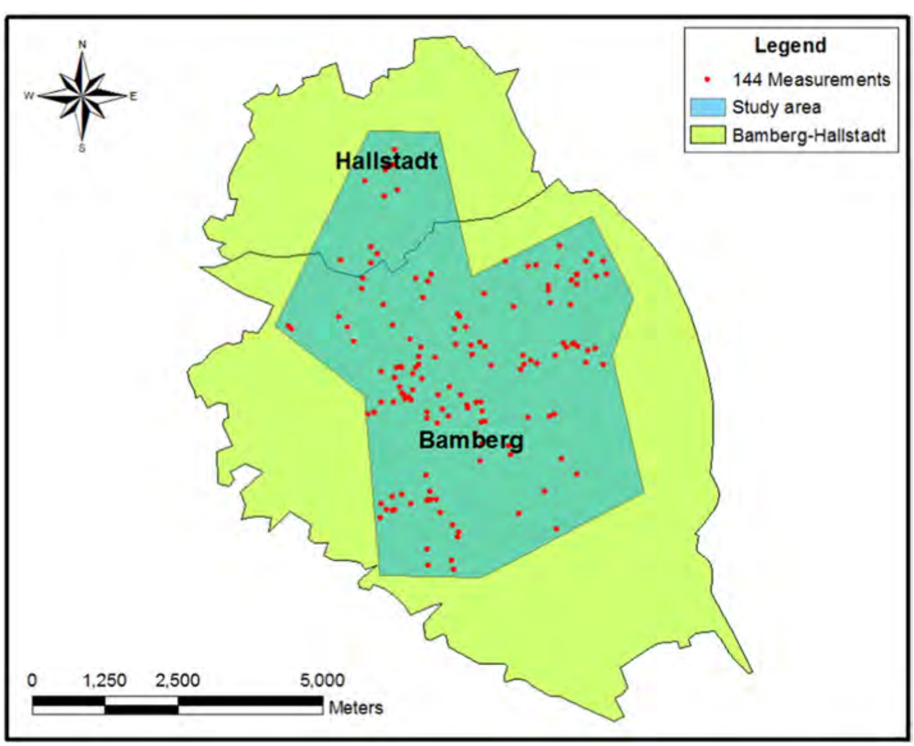


Fig. 2. Location of the 144 measurements points in Bamberg and Hallstadt in the study area.

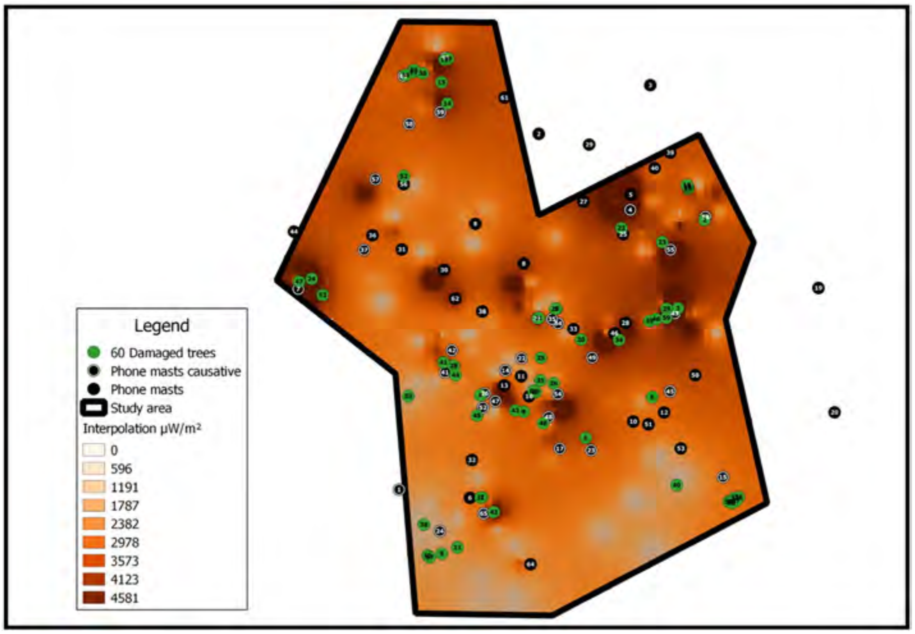


Fig. 3. Map showing the 60 damaged trees and phone masts (both with code numbers) over the interpolation electromagnetic map of the 144 measurement points.

performed in about 200 sampling points (own data). Repeatability analysis checked this. Despite the fact that the increase in sector antennas (observed between 2011 and 2015) would have probably increased the radiation in the environment of the study area, measurements used in this study were mostly done in 2015.

In an attempt to link the electromagnetic radiation measured at every tree to specific phone masts, the distances to the three nearest antennas that could be mainly responsible for the radiation measurements at each tree were calculated in meters with Geographical Information System (GIS) programs, following the general approach criteria of proximity. However, it must be taken into account that buildings and vegetation diminish radiation intensity and, in many cases, the nearest phone mast or masts may be obscured by obstacles. In other cases, the phone mast is in direct line of sight from the tree and the radiation can reach the tree directly.

Additionally, 30 random points were generated inside the polygonal study area and outside a layer of buildings, downloaded from: http://www.mapcruzin.com/free-germany-arcgis-maps-shapefiles.htm using a Random Points tool of QGIS 2.6.0-Brighton (QGIS Development Team, 2014) allowing create random points inside a specific layer. Therefore the points were randomly situated in specific places in the study area outside buildings but not frequently concur with the location of trees. That is why measurements were taken from the nearest tree for each random point, generating a random tree group. Measurements and damage characteristics were scored in the same way as with 60 damaged trees explained above, measuring the maximum value of radiation corresponding to opposite sides of each tree.

In areas of the city with low measurements of electromagnetic radiation (no visual contact to any phone mast and power flux density <50 μW/m^2), we scored another 30 trees in the same way as with 60 damaged trees and 30 random points. The UTM coordinates and the three nearest phone masts of each tree in these last two groups (random and low radiation trees) were also recorded.

To generate electromagnetic maps, we used ArcGis 9.3 (ESRI, 2008) and QGIS 2.6.0-Brighton (QGIS Development Team, 2014). To check possible differences between groups of data and taking into account that there were two measures made in each tree, repeated measures analysis of variance were applied, considering a repeated measures factor (within-subjects) and another between-subjects. The post hoc Bonferroni test was used in all cases to elucidate significant differences. Statistics were performed using STATISTICA 7 program (StatSoft, Inc, 2004).

3. Results

The results of radiation measurements obtained at 144 points in Bamberg and Hallstadt at a height of 1.5 m were between 6 μW/m^2 (0.047 V/m) and 17,060 μW/m^2 (2.53 V/m) (for measurements and UTM coordinates, see Table 3). The measured values are far below the current limit values (41 V/m for GSM system and 61 V/m for UMTS; ICNIRP, 1998).

The locations of these points in the study area are shown in Fig. 2. By interpolation of the 144 measurements points (Table 3), we prepared a map of the power flux density in Bamberg and Hallstadt (Fig. 3). This map is theoretical and approximate, since many factors affect the true electromagnetic values. However, the map is useful to provide approximate differences in exposure (electromagnetic pollution) throughout the city.

The 60 selected trees showing damage patterns not attributable to diseases, pests or other environmental factors are presented in Table 4. In this Table, we added the tree code number, the scientific name, the UTM coordinates, the measurements (power flux density) on both sides of each tree, and the distances (meters) and code numbers to the three nearest antennas for each tree, which may be mainly responsible for the electromagnetic radiation measured. We also included the orientation of the tree damage and the number of main (nearest) phone mast(s) in direct line of sight, whose lobe of radiation most directly affected each tree. Finally, we included the codes of damage observed in the 60 trees.

From all 60 selected trees, one or more phone mast(s) could be seen, with no obstacles between the phone mast and damaged tree. In many cases, one of the three closest antennas caused the main radiation on the tree surface. In ten trees (codes: 4, 7, 9, 10, 15, 26, 27, 31, 35, and 50), another antenna in direct line of sight caused the measured radiofrequency exposure. This was determined using topography and existing buildings (Table 4 and Fig. 3).

The 60 damaged trees (with their code number) and the phone masts are overlaid on the electromagnetic map prepared by interpolation of the 144 measurements points (Fig. 3). The likely antenna or antennas causing radiation damage to each tree are also shown (Fig. 3). The measurements at all selected trees revealed significant differences between the damaged side facing a phone mast and the intact (or less damaged) opposite side. On the side facing a phone mast, the measured values were 80–13,000 μW/m² (0.173–2.213 V/m). On the opposite side the values were 8–720 μW/m² (0.054–0.52 V/m).

Table 4
60 selected trees showing damage patterns not attributable to diseases, drought or other environmental factors.

														Effect codes												
														1	2	3	4	5	6	7	8	9	10	11	12	13
N°	Scientific name	X	Y	Side antenna measurement μW/m²	Opposite side measurement μW/m²	Number of Phone Mast 1	Distance a 1	Number of Phone Mast 2	Distance a 2	Number of Phone Mast 3	Distance a 3	Direction of damage	Number of main phone mast(s) causing the radiation	Damage only on one side	Sparse leaves or needles (crown transparency)	Brown leaves (start at leaf margins)	Colour change of leaves prematurely	leaves fall prematurely	Dead branches (Peak branches dried).	Tip of the main guide dried	Irregular growth	Not grow in eight	Color change of needles	Dead parts were trimmed down	damage on different sides	no damage
1	*Acer platanoides*	636298	5529366	970	130	35	145,6	34	190,1	21	274,6	S, SW	35,34,21	+	+	+		+	+	+		+				
2	*Acer platanoides*	638211	5530518	680	80	18	41,76	55	583,9	40	930,8	N	18	+	+	+		+	+			+		+		
3	*Acer platanoides*	637868	5529371	2100	290	43	77,18	28	703,9	55	768	S	43	+	+	+		+	+	+		+				
4	*Acer platanoides*	635316	5528245	2300	130	26	61,68	52	164,6	47	210,4	E, S	26,52,47, 14	+	+	+		+	+	+		+		+		
5	*Acer platanoides*	636677	5527688	3600	290	23	174,1	17	363,2	48	552,2	S	23	+	+	+		+	+	+		+		+		
6	*Acer platanoides*	637536	5528219	700	140	45	242,3	12	251	51	356,4	E	45	+	+	+		+	+	+						
7	*Acer platanoides*	635339	5526919	270	30	6	156,2	65	211	32	502,6	W	1	+		+		+	+	+		+		+		
8	*Acer platanoides*	635876	5528029	80	10	16	211,6	48	328,1	47	389,9	W	47	+	+	+		+								
9	*Acer platanoides*	634819	5526187	160	20	24	294,1	65	751,1	6	811,2	N	24, 1		+	+		+	+					+		
10	*Acer platanoides*	634638	5526163	180	55	24	353,3	65	904,4	6	926,3	N	24, 1		+	+		+	+							
11	*Acer platanoides*	635022	5526270	95	20	24	310	65	553,4	6	661,9	NW	24	+	+			+								
12	*Acer platanoides*	634854	5532596	11800	400	60	26,93	63	568,2	59	680,1	N	60	+	+	+		+	+	+		+				
13	*Acer platanoides*	634455	5532438	9900	620	63	139,1	60	448,1	59	624	W	63	+			+							+		
14	*Acer platanoides*	634890	5532028	3380	500	59	142,1	58	557,5	60	593,6	SW	59	+	+	+		+	+	+		+		+		
15	*Acer platanoides*	634815	5532307	1050	50	60	317,8	59	389,3	63	495,3	SW	58	+	+	+		+	+	+		+		+		
16	*Carpinus betulus*	638001	5530928	1210	120	18	431,5	40	506,6	39	518,8	S	18	+	+	+		+	+							
17	*Carpinus betulus*	637996	5530945	2520	150	18	448,7	40	493,7	39	501,3	S	18	+	+	+		+	+							
18	*Carpinus betulus*	637987	5530959	890	90	18	465,3	40	478,9	39	484,8	S	18	+	+	+		+								
19	*Carpinus betulus*	637984	5530970	670	10	40	471,1	39	473,6	18	476,3	S	18	+	+	+		+								
20	*Carpinus betulus*	636619	5528966	1000	200	33	169,6	49	274,2	34	367,6	SE	49		+	+		+	+			+		+		
21	*Carpinus betulus*	636068	5529245	430	20	21	14,87	35	173,5	34	259,1	W	21	+	+	+		+				+		+		
22	*Carpinus betulus*	637138	5530413	4340	110	25	83,24	4	263,4	5	450,6	NE	4	+	+	+		+	+	+		+				
23	*Carpinus betulus*	637664	5530231	990	60	55	145,8	25	513,2	4	586,9	E	55	+	+	+		+	+							
24	*Carpinus betulus*	633137	5529754	2700	50	7	217,4	44	653,7	37	776,2	E	37	+	+	+		+	+							
25	*Tilia sp.*	636098	5528729	870	150	22	249,1	11	349,5	14	486,5	W	22	+	+	+		+	+							
26	*Tilia sp.*	636261	5528398	410	20	54	149,5	16	358,4	11	428	W	14	+		+		+								
27	*Tilia sp.*	636030	5528283	680	160	16	100,7	11	279	54	287	S	48	+	+		+	+	+					+		
28	*Tilia sp.*	634972	5528626	660	170	41	139,8	42	202,3	26	539,6	SW	41	+	+	+		+	+	+		+		+		
29	*Tilia sp.*	636283	5529365	2450	160	35	139,5	34	191,2	21	260,9	SW	35, 34, 21	+		+		+				+		+		
30	*Tilia sp.*	634573	5532422	3800	420	63	249,6	60	352,5	59	552,8	NE	60	+	+	+		+	+					+		
31	*Tilia sp.*	635319	5526914	380	120	6	136	65	208,9	32	502,6	W	1	+	+		+	+	+	+						
32	*Quercus robur*	638598	5526911	860	130	15	308	53	944,7	12	1434	NW	15		+			+	+							
33	*Quercus rubra*	637501	5529207	1340	120	28	312	43	341,4	46	478,8	E	43	+	+			+	+							
34	*Quercus rubra*	637107	5528961	1650	250	46	105,4	28	236,1	49	414,1	SW	49	+	+				+							
35	*Aesculus hippocastanum*	636092	5528434	400	20	16	252,3	11	255,2	54	284,3	W	14	+	+	+		+	+	+		+				
36	*Robinia pseudoacacia*	638653	5526920	1300	40	15	331,1	53	979,9	12	1463	NW	15	+			+		+	+		+				

Table 4 *(continued)*

37	*Robinia pseudoacacia*	638619	5526874	660	240	15	350,5	53	985,3	12	1476	NW	15	+			+		+					+		
38	*Sorbus occuparia*	634587	5526564	84	8	24	223,4	1	555,7	6	690,2	N	1	+	+	+		+	+	+		+				
39	*Acer negundo*	637722	5529366	3060	310	43	122,3	28	562,9	46	743,9	SE	43	+	+			+	+			+		+		
40	*Acer saccharinum*	637852	5527078	840	180	53	477,9	15	604,7	51	868,4	E	15	+	+			+								
41	*Juglans regia*	634841	5528669	4500	590	41	129,6	42	191,4	26	668,2	N, E	42	+	+			+	+	+	+	+				
42	*Taxus baccata*	635767	5528046	300	70	16	255,3	47	282,7	13	354,2	NW	47	+	+				+				+	+		
43	*Taxus baccata*	635491	5526727	8970	190	65	133,2	6	359,3	32	734,2	W	65	+	+				+				+	+		
44	*Taxus baccata*	634997	5528506	2500	240	41	140,4	42	324,6	26	446,9	N,E,W	41,42		+				+				+	+		
45	*Taxus baccata*	635272	5527980	2700	70	52	130	47	302,8	26	303,6	NE	52	+	+				+				+	+		
46	*Taxus baccata*	637586	5529231	1520	190	43	253,1	28	399	46	567	E	43	+	+								+	+		
47	*Thuja occidentalis*	632975	5529719	910	30	7	98,51	44	651,3	37	936,1	S	7	+	+				+				+			
48	*Thuja occidentalis*	636128	5527881	120	10	48	105,6	16	393,2	17	393,6	S	17	+	+				+				+			
49	*Thuja occidentalis*	634900	5532611	13000	520	60	37,36	63	616,5	59	700,2	NW	60	+	+				+				+			
50	*Thuja occidentalis*	634387	5528232	290	50	41	565,8	42	818,5	52	974,3	S	1	+	+				+	+			+			
51	*Picea pungens*	638525	5526863	770	90	15	326,2	53	927,6	12	1427	NE	15	+	+				+				+			
52	*Picea pungens*	634328	5531086	3080	310	56	104	57	367,3	58	681,7	W	57		+				+			+	+			
53	*Picea pungens*	633280	5529546	1350	200	7	323,8	37	792,7	44	900,5	W	7	+	+				+		+		+			
54	*Pinus sylvestris*	638542	5526861	790	50	15	332,6	53	940,5	12	1439	NE	15		+				+		+	+	+			
55	*Pinus sylvestris*	634461	5532462	5300	130	63	154,9	60	433,2	59	641	SW	63	+	+								+			
56	*Pseudotsuga menziesii*	638560	5526844	1720	60	15	354,2	53	965,2	12	1463	NE	15	+	+				+	+		+	+			
57	*Juniperus communis*	634664	5526141	160	20	24	363,1	65	897,6	6	929,4	N	24	+	+				+				+			
58	*Corylus avellana 'Contorta'*	634355	5532399	420	80	63	31,78	60	555,3	58	636,5	W	63	+	+	+		+	+							
59	*Corylus avellana*	637720	5529249	3880	720	43	121,7	28	534,2	46	700,2	N	43	+	+	+		+						+		
60	*Symphoricarpos albus*	636002	5528299	1200	320	16	90,27	11	248,5	54	316,5	E	54	+	+			+	+					+		

In the five most represented species ($n \geq 4$) among the 60 affected trees, most trees showed damage only on one side: unilateral damage (Damage code 1, Tables 2 and 4). By species and percentages: *Acer platanoides* (86%), *Carpinus betulus* (88%), *Tilia* sp. (100%), *Taxus baccata* (80%) and *Thuja occidentalis* (100%). On the seven trees not given code 1, the damage spread over the whole tree, but trees still showed side differences. Most of these trees were characterized with sparse leaves or needles (crown transparency) (Damage code 2, Tables 2 and 4). By species and percentages: *Acer platanoides* (86%), *Carpinus betulus* (100%), *Taxus baccata* (100%) and *Thuja occidentalis* (100%). In many of the trees with the one-sided damage, the leaves turned prematurely yellow or brown in June – this always began at the leaf margins (Damage code 3, Tables 2 and 4). The species with higher percentages were: *Acer platanoides* (86%) and *Carpinus betulus* (100%). In many trees leaves fall prematurely: *Acer platanoides* (93%), *Carpinus betulus* (100%) and *Tilia sp.* (100%) (Damage code 5, Tables 2 and 4). Many trees of the species *Acer platanoides* (80%), *Taxus baccata* (80%) and *Thuja occidentalis* (100%) had dead branches (Peak branches dried) (Damage code 6, Tables 2 and 4). All the trees of the species *Taxus baccata* (100%) and *Thuja occidentalis (100%)* exhibited color change of the needles (Damage code 10, Tables 2 and 4). Finally, in all trees of the species *Taxus baccata*, dead parts were trimmed (Damage code 11, Tables 2 and 4). Some trees stopped growing in height while, in others, the main guide died (see Tables 2 and 4).

The 30 randomly selected trees are presented in Table 5 with the tree code number, the scientific name, the UTM coordinates, the measurements (power flux density) on both sides of each tree, the distance (meters) to the three nearest antennas, their code number and the damage codes. Trees in these locations may be in areas with either high or low radiation. Seventeen trees in this group were situated in places with low radiation and showed no signs of damage. The measurements were 8–50 $\mu W/m^2$ (0.054–0.137 V/m) and showed no difference between the two opposite sides. Thirteen trees stood in the radiation field of one or more phone mast. Six of these had damage only on the side facing a phone mast, and five had damages on other sides. The measurements on the exposed sides were 40–4600 $\mu W/m^2$ (0.122–1.316 V/m).

The 30 trees selected in areas with low radiation (radio shadow of hills, buildings or trees) are presented in Table 6 with the tree code number, scientific name, UTM coordinates, measurements (power flux density) on both sides of each tree, distance (meters) to the three nearest antennas, their code number and the damage codes. All trees selected in low radiation areas showed no damage (code 13). The power flux density values measured were 3–40 $\mu W/m^2$ (0.033–0.122 V/m) and no significant differences were found between the two opposite sides.

The trees in random points and the trees in areas of low radiation are represented In Fig. 4 over the electromagnetic map prepared by interpolation of the 144 measurements points.

We performed a Repeated Measures ANOVA analysis in order to include the measurements of the exposed and shielded side of each tree (R1 = within subjects factor) in the three groups of trees (damaged, random, and low radiation), and to avoid pseudoreplication. The comparisons of all factor levels revealed significant differences, including the interaction between factors. A post hoc Bonferroni comparisons test, recommended for different sized groups of samples, revealed significant differences between measurements from the exposed side of damaged trees and all other groups (Table 7). Fig. 5 shows the measurements (mean and standard error) in all groups.

In the "Random points" group of trees, we performed another Repeated Measures ANOVA (R1 = within subjects factor) for trees damaged and undamaged within this group (Table 8). The results showed significant differences in both factors, including the interaction, which means that depending on the group of tree (damaged or undamaged),

Table 5
Results of the tree measurements at the 30 random points.

												Effect codes												
												1	2	3	4	5	6	7	8	9	10	11	12	13
N°	Scientific name	X	Y	Side antenna measurement µW/m²	Opposite side measurement µW/m²	Number of Phone Mast 1	Distance a 1	Number of Phone Mast 2	Distance a 2	Number of Phone Mast 3	Distance a 3	Damage only on one side	Sparse leaves or needles (crown transparency)	Brown leaves (start at leaf margins)	Colour change of leaves prematurely	leaves fall prematurely	Dead branches (Peak branches dried).	Tip of the main guide dried	Irregular growth	Not grow in eight	Color change of needles	Dead parts were trimmed down	damage on different sides	no damage
1	*Salix viminalis*	634095	5532455	10	10	63	241,1	58	754,9	60	786,7													+
2	*Thuja occidentalis*	634760	5532680	500	120	60	119,6	63	524,2	59	763		+				+	+			+		+	
3	*Abies alba*	634030	5530490	2200	900	36	201,2	37	418,8	31	447,7		+				+			+	+		+	
4	*Acer campestre*	634545	5530739	890	320	56	326,5	31	649,4	57	657,5	+	+				+							
5	*Acer platanoides*	634557	5530005	4600	1100	31	284,9	30	322,2	62	668,1	+	+	+		+						+		
6	*Picea abies*	635311	5530644	1900	210	9	185,6	8	894,8	30	900									+	+			
7	*Thuja occidentalis*	635635	5529879	10	10	8	252,5	38	621,9	9	702,6													+
8	*Acer platanoides*	635693	5529848	2600	310	8	210,9	38	625,5	21	707,1	+	+			+	+					+		
9	*Cornus sanguinea*	636415	5530248	40	30	27	559,3	8	614,5	25	750,8													+
10	*Acer pseudoplatanus*	637525	5530896	50	50	5	270,5	40	298,1	4	366,7													+
11	*Syringa*	638111	5531436	10	10	39	344,8	40	595,7	18	885,1													+
12	*Acer platanoides 'Globorum'*	637928	5530541	30	30	18	295,5	55	436,8	4	683,7													+
13	*Acer platanoides*	637159	5529361	20	15	28	181,7	46	330,8	43	671,3													+
14	*Quercus rubra*	638342	5528994	1480	570	50	549,7	43	600,8	45	907,4		+			+	+					+	+	
15	*Thuja occidentalis*	638359	5528569	25	20	50	275,5	45	653,6	12	866,2													+
16	*Tilia sp*	637412	5527922	460	320	51	93,6	10	122,5	12	293,8											+		
17	*Quercus robur*	637363	5527807	45	33	10	120	51	137,3	12	389,4													+
18	*Larix decidua*	637804	5527628	4400	3170	53	125,8	51	396,4	12	408,5		+				+		+				+	
19	*Acer pseudoplatanus*	637919	5527135	760	120	53	418,2	15	530,9	51	849,1	+	+			+	+	+				+		
20	*Acer negundo*	637329	5526888	190	30	23	865,1	53	879,8	51	990,7	+										+		
21	*Quercus robur*	637115	5527423	46	26	23	382	10	511,2	51	578,5													+
22	*Thuja occidentalis*	637315	5526260	40	13	64	1367	23	1390	53	1421	+									+			
23	*Salix matsudana 'Tortuosa'*	635403	5525413	15	12	64	848,8	24	1229	65	1297													+
24	*Populus tremula*	635410	5525828	15	9	64	596,8	65	882,5	24	897													+
25	*Salix matsudana 'Tortuosa'*	634981	5526161	41	23	24	369,8	65	665,7	6	777,7													+
26	*Prunus sp.*	634829	5526050	28	21	24	431,4	65	845,7	6	931,9													+
27	*Picea pungens*	634791	5526809	470	340	24	329	6	405,3	1	563,6		+				+		+				+	
28	*Cornus sanguinea*	635164	5527863	15	15	52	288,9	26	454,4	47	460,7													+
29	*Cornus sanguinea*	634905	5528779	20	20	42	65,12	41	242	26	695,1													+
30	*Acer negundo*	634202	5529092	8	8	42	792,6	41	859	62	886,9													+

significant or non-significant respectively differences between the measurements of the two sides are seen (Fig. 6). A post hoc Bonferroni comparisons test showed significant differences between the measurements from the exposed side of damaged trees and all other groups in the random points group (Table 8).

Of the 120 trees, those with lower mean distance to the three closest antennas have usually higher values of radiation (Fig. 7). However, screening is common in cities due to a large amount of buildings, thus some trees that are close to antennas show lower radiation values than expected. This means that radiation measurements at points close to antennas are variable (high and low) while trees farther from antennas always have low values.

A dossier with documentation gathered over the years and the examples of tree damages is presented in: http://kompetenzinitiative.net/KIT/KIT/baeume-in-bamberg/

4. Discussion

In the present study it was useful, that tree damages in the vicinity of phone masts in Bamberg and Hallstadt had been documented starting 2006. We found a high level of damage to trees in the vicinity of phone masts. The damage encountered in these trees is not attributable to harmful organisms, such as diseases, pests or other environmental factors. These would impact upon the entire tree, whereas damage to trees in the present study was only found on parts of the tree and only on one side (unilateral). Therefore, these factors cannot explain the damage documented here. Generally in all trees of this study, damage is higher in areas of high radiation and occurs on the side where the nearest phone mast is located (Table 4 and Fig. 3). Moreover, areas with more antennas have more levels of radiation and damaged trees are found most often in these high electromagnetic polluted areas. These results showed that side differences in damage corresponded to side differences in measured values of power flux density. This paper look at the effects on trees, but also provides information on how electromagnetic radiation is distributed in a city (interpolation map and Fig. 7).

In this study deciduous and coniferous trees were examined under the real radiofrequency field conditions around phone masts in Bamberg and Hallstadt. From most phone masts a broad band of frequencies with different modulations and pulse frequencies and fluctuating power densities is emitted (GSM 900, GSM 1800, UMTS, LTE, TETRA). Different signals may have different effects due to their physical parameters (Belyaev, 2010; IARC, 2013). We do not discriminate between these different signals and cannot answer the question which part of the

Table 6
Results of the tree measurements in the 30 points with low radiation.

												Effect codes												
												1	2	3	4	5	6	7	8	9	10	11	12	13
Nº	Scientific name	X	Y	Side antenna measurement µW/m²	Opposite side measurement µW/m²	Number of Phone Mast 1	Distance a 1	Number of Phone Mast 2	Distance a 2	Number of Phone Mast 3	Distance a 3	Damage only on one side	Sparse leaves or needles (crown transparency)	Brown leaves (start at leaf margins)	Colour change of leaves prematurely	leaves fall prematurely	Dead branches (Peak branches dried).	Tip of the main guide dried	Irregular growth	Not grow in eight	Color change of needles	Dead parts were trimmed down	damage on different sides	no damage
1	*Acer platanoides*	636741	5529855	26	20	25	636,3	33	784,1	35	798,8													+
2	*Carpinus betulus*	634853	5529041	10	8	42	234,5	62	476,4	41	500,1													+
3	*Carpinus betulus*	638311	5528439	12	10	50	229,7	45	563,5	12	750													+
4	*Carpinus betulus*	636753	5529880	8	8	25	609,6	33	811,5	28	823,5													+
5	*Carpinus betulus*	637817	5527130	15	12	53	432,1	15	633	51	806,6													+
6	*Carpinus betulus*	634931	5526731	15	15	24	286	6	310,3	65	428,6													+
7	*Tilia sp.*	636500	5529673	8	8	35	511,4	34	528,3	33	570,3													+
8	*Tilia sp.*	636824	5529794	17	9	25	635,7	28	713,1	33	755,3													+
9	*Quercus robur*	636455	5526130	9	8	64	497,5	65	1240	17	1425													+
10	*Quercus robur 'Fastigiata'*	636178	5528932	10	10	34	282,2	35	306,5	21	332													+
11	*Aesculus hippocastanum*	636828	5529780	10	10	25	645,5	28	699	33	744,2													+
12	*Aesculus carnea*	636463	5529709	12	12	35	526,1	34	551,4	33	608,6													+
13	*Robinia pseudoacacia*	635507	5528534	15	15	14	136,6	13	201,5	26	299,2													+
14	*Robinia pseudoacacia*	634720	5532783	8	8	60	216,7	63	559,3	59	868,7													+
15	*Acer campestre*	635697	5528689	40	30	14	136,5	22	155,8	11	246,8													+
16	*Acer campestre*	636486	5526116	6	6	64	526,2	65	1273	23	1437													+
17	*Juglans regia*	635744	5528667	20	15	22	119	14	145,7	11	202,8													+
18	*Platanus hispanica*	635496	5528529	17	15	14	148,4	13	204,1	26	289,9													+
19	*Prunus avium*	637958	5530874	10	8	18	412,4	40	502,6	39	551,4													+
20	*Prunus sp.*	636079	5528463	10	10	11	237,5	16	269,7	54	312,7													+
21	*Taxus baccata*	638407	5528502	5	5	50	316	45	673,6	12	864,8													+
22	*Taxus baccata*	638222	5531032	10	10	18	474	39	578,6	40	673,1													+
23	*Thuja occidentalis*	636518	5529853	9	9	8	648,4	35	680	34	705													+
24	*Thuja occidentalis*	635318	5528784	20	15	42	371,5	14	389,4	13	514,8													+
25	*Picea pungens*	636512	5529735	17	17	35	571,4	34	590,8	33	632													+
26	*Juniperus communis*	636549	5529756	8	8	35	607,8	34	623,4	33	653,7													+
27	*Cornus sanguinea*	638167	5529098	8	6	43	397,2	50	597,9	45	899,8													+
28	*Sambucus nigra*	635529	5525601	5	5	64	625,2	65	1121	24	1146													+
29	*Corylus avellana*	636422	5526181	5	3	64	476,4	65	1187	17	1371													+
30	*Corylus avellana*	636625	5529834	6	6	35	714	34	725,2	25	732,3													+

radiation has caused the damage. Nevertheless broad bands of frequencies, modulation, pulse frequencies, interferences and other physical characteristics may play an important role, since in some cases, damage already appears at low intensities. This can be a shortcoming of the study.

The aim of the present study was to find out whether there is a causal relationship between the unilateral tree damages, which had been observed since 2006, and the RF-EMF emitted from phone masts and a preliminary observation to find out whether various species react differently to RF exposure.

The selection of the 60 unilaterally damaged trees was limited by the fact that we could do measurements only up to a height of 6 m. Trees with damages above the height of 6 m could not be included.

Many factors can affect the health of trees: Air and soil pollutants, heat, frost, drought, as well as composition, compaction and sealing of the soil, road salts, root injury due to construction work, diseases and pests. Most of these factors do not affect a tree only on one side over a period of >5 years. Industrial air pollutants could eventually cause unilateral damage in direction to an industrial emitter. But the observed unilateral damages appeared in all directions and were not oriented to the incineration plant or other industrial plants. Root injury due to construction work can produce damage on one side of a tree, but 24 of the 60 selected trees were situated in gardens, parks or on the cemetery where they could not be affected by construction damages.

From the damaged side there was always visual contact to one or more phone mast (s). In each case measurements of the power flux density on the damaged side which was facing a phone mast and on the opposite side without (or with less) damage were carried out and the difference between the measured values on both sides was significant (Fig. 5), as well as between the exposed side of damaged trees and all other groups. In all 60 trees the gradient of damage corresponded to a gradient of measured values. The attenuation of the RF-EMF within the treetop offers an explanation: a part of the RF-EMF is absorbed by leaves or needles and another part is reflected, scattered and diffracted.

In the randomely selected group of 30 trees, 17 trees were situated on places with low radiation. These 17 trees showed no damages, the measured values were below 50 µW/m² (0.137 V/m) and there was no difference between opposite sides as in the low radiation group. On the other hand, 13 trees grew in the radiation field of one or more phone mast (s). These trees showed unilateral damage or damage on different sides. The measured values at damaged trees showed differences between both sides as in the previous group above.

In the group of 30 trees in areas with low radiation (radio shadow of hills, buildings or trees and without visual contact to phone masts)

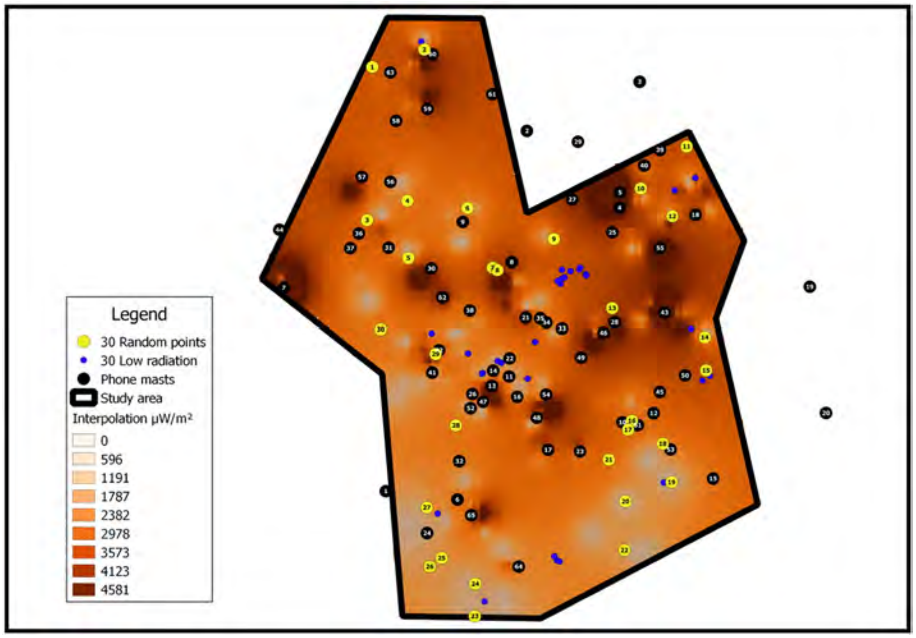


Fig. 4. Map showing the 30 trees at random points and the 30 trees in areas of low radiation (both with code numbers) over the interpolation electromagnetic map of the 144 measurement points. Phone masts (with code numbers) are also represented.

there were no unilateral damages. The measured values were below 50 μW/m^2 (0.137 V/m) and there was no difference between opposite sides. These results in the three groups point to a connection between unilateral tree damage and RF exposure.

In the electromagnetic field of all mobile phone base stations visited numerous tree damages were observed. The damage occurred in temporal relation with the putting into operation of new mobile phone base stations. Woody plants of all species are affected (deciduous and coniferous trees as well as shrubs).

In the five most represented species ($n \geq 4$) among the 60 damaged trees (*Acer platanoides*, *Carpinus betulus*, *Tilia* sp., *Taxus baccata* and *Thuja occidentalis*), most trees showed damage only on one side (Damage code 1, Tables 2 and 4). Most of these trees were characterized with sparse leaves or needles (crown transparency) (Damage code 2, Tables 2 and 4). In many of the trees with the one-sided damage, the leaves turned prematurely yellow or brown in June – this always began at the leaf margins (Damage code 3, Tables 2 and 4). In many trees leaves fall prematurely (Damage code 5, Tables 2 and 4) or had dead branches (Peak branches dried) (Damage code 6, Tables 2 and 4). Some trees stopped growing in height while, in others, the main guide died (see Tables 2 and 4).

The differences in susceptibility of different species could be related to radiofrequency energy absorption properties of the trees (e.g., dielectric property). Perhaps this study cannot answer questions about these differences, however it is quite possible that differences are related to the electrical conductivity, related also with the density of the wood (species of fast or slow growth) and particularly with the percentage of water in the tissues. Poplars and aspen that grow near rivers and water bodies in Spain seem to be particularly sensitive to the effects of radiation. But the waves reflection in the water could also influence.

The results presented here lead us to conclude that damage found in the selected trees is caused by electromagnetic radiation from phone

Table 7
Repeated measures ANOVA analysis and Bonferroni post hoc comparisons ($p < 0.01$ values with *) in the three types of trees (damaged, random, and low radiation). Measurement Side 1/2 correspond to the maximum/minumum value of radiation respectively for the opposite sides of each tree.

	SS	Degr. of	MS	F	p
Intercept	62663309	1	62663309	25.81460	0.000001*
Type of tree	52931692	2	26465846	10.90280	0.000046*
Error	284010086	117	2427437		
R1	33197069	1	33197069	18.28694	0.000039*
R1*Type of tree	44608664	2	22304332	12.28656	0.000014*
Error	212395158	117	1815343		

	Type of tree	R1	{1}	{2}	{3}	{4}	{5}	{6}
1	Damaged	Measurement Side1		0.000000*	0.001829*	0.000001*	0.000000*	0.000000*
2	Damaged	Measurement Side2	0.000000*		1.000000	1.000000	1.000000	1.000000
3	Random	Measurement Side1	0.001829*	1.000000		1.000000	1.000000	1.000000
4	Random	Measurement Side2	0.000001*	1.000000	1.000000		1.000000	1.000000
5	Low radiation	Measurement Side1	0.000000*	1.000000	1.000000	1.000000		1.000000
6	Low radiation	Measurement Side2	0.000000*	1.000000	1.000000	1.000000	1.000000	

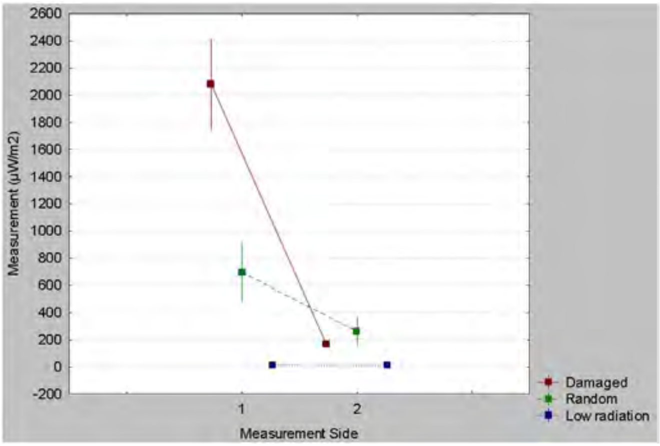


Fig. 5. Differences between measurements in both sides for the three different tree groups: damaged, random, and low radiation. Measurement Side 1/2 correspond to the maximum/minumum value of radiation respectively for the opposite sides of each tree. The bars represent means ± standard errors. The central point represents the mean and the straight line ± 0.95*SE.

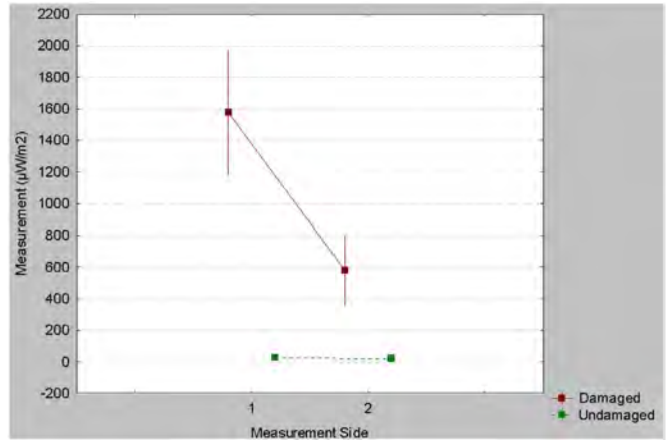


Fig. 6. Differences between measurements in both sides for the damaged and undamaged trees within the random trees group. Measurement side 1/2 correspond to the maximum/minumum value of radiation respectively for the opposite sides of each tree. The bars represent means ± standard errors. The central point represents the mean and the straight line ± 0.95*SE.

masts, as we proposed in previous studies (Balmori, 2004; Waldmann-Selsam, 2007; Waldmann-Selsam and Eger, 2013; Balmori, 2014). Interested parties are able to locate the damaged trees found in this work in Bamberg and Hallstadt with their UTM coordinates. However, trees with code numbers 20, 38 and 48 (Table 4) have been cut down and removed.

Research on the effects of radiation from phone masts is advancing rapidly. In February 2011 the first symposium on the effects of electromagnetic radiation on trees took place in Baarn, Netherlands (Schorpp, 2011 - http://www.boomaantastingen.nl/), where similar effects and results to those found in the current paper were presented.

Although there are some related experiments that show no effect of long-term exposure (3,5 years), 2450-MHz (continous wave) and power flux densities from 0.007 to 300 W/m^2 on crown transparency, height growth and photosynthesis of young spruce and beech trees (Schmutz et al., 1996), this result may not be transferred to modulated 2450-MHz or to other pulsed and modulated frequencies. In addiction, an increasing number of studies have highlighted biological responses and modifications at the molecular and whole plant level after exposure to high frequency electromagnetic fields (Vian et al., 2016). Plants can perceive and respond to various kinds of electromagnetic radiation over a wide range of frequencies. Moreover, a low electric field intensity (5 V/m) was sufficient to evoke morphological responses (Grémiaux et al., 2016). Electromagnetic radiation impacts at physiological and ecological levels (Cammaerts and Johansson, 2015), and evokes a multitude of responses in plants. The effects of high frequency electromagnetic fields can also take place at the subcellular level: it can alter the activity of several enzymes, including those of reactive oxygen species (ROS) metabolism, a well-known marker of plant responses to various kinds of environmental factors; it evokes the expression of specific genes previously implicated in plant responses to wounding (gene expression modifications), and modifies the growth of the whole plants (Vian et al., 2016). It could be hypothesized that membrane potential variations in response to electromagnetic radiation exposure may initiate electrical waves of depolarization (AP and/or VP) that could initiate immediate or delayed growth responses (Grémiaux et al., 2016). It has been proposed that electromagnetic fields act similarly in plants and in animals, with the probable activation of calcium channels via their voltage sensor (Pall, 2016).

Electromagnetic radiation (1800 MHz) interferes with carbohydrate metabolism and inhibits the growth of *Zea mays* (Kumar et al., 2015). Furthermore, cell phone electromagnetic radiation inhibits root growth of the mung bean (*Vigna radiata*) by inducing ROS-generated oxidative stress despite increased activities of antioxidant enzymes (Sharma et al., 2009). Germination rate and embryonic stem length of *Triticum aestivum* was also affected by cell phone radiation (Hussein and El-Maghraby, 2014). After soybeans were exposed to weak microwave radiation from the GSM 900 mobile phone and base station, growth of

Table 8
Repeated measures ANOVA analysis and Bonferroni post hoc comparisons (p < 0.01 values with *) in the random trees group. Measurement Side 1/2 correspond to the maximum/minumum value of radiation respectively for the opposite sides of each tree.

	SS	Degr. of	MS	F	p
Intercept	17829607	1	17829607	16.60985	0.000343*
13 code	16391606	1	16391606	15.27023	0.000538*
Error	30056202	28	1073436		
R1	3701923	1	3701923	16.73250	0.000329*
R1*13 code	3627579	1	3627579	16.39647	0.000368*
Error	6194761	28	221241		

	13 code	R1	{1}	{2}	{3}	{4}
1	Undamaged	Measurement Side 1		1.000000	0.002129*	0.416303
2	Undamaged	Measurement Side 2	1.000000		0.000034*	0.927155
3	Damaged	Measurement Side 1	0.002129*	0.000034*		0.000055*
4	Damaged	Measurement Side 2	0.416303	0.927155	0.000055*	

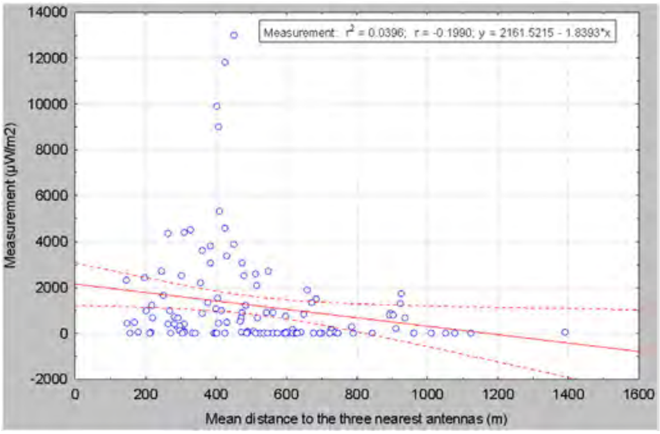


Fig. 7. Scatterplot showing the correlation between measurements from each of the 120 trees and the mean distance to the three nearest antennas. Dashed lines represent the 0.95 confidence interval.

epicotyl and hypocotyl was reduced, whereas the outgrowth of roots was stimulated. These findings indicate that the observed effects were significantly dependent on field strength as well as amplitude modulation of the applied field (Halgamuge et al., 2015). Phone mast radiation also affects common cress (*Lepidium sativum*) seed germination (Cammaerts and Johansson, 2015). In *Arabidopsis thaliana*, the long term exposure to non ionizing radiation causes a reduction in the number of chloroplasts as well as the decrease of stroma thylakoids and the photosynthetic pigments (Stefi et al., 2016). Finally, low-intensity exposure to radiofrequency fields can induce mitotic aberrations in root meristematic cells of *Allium cepa*; the observed effects were markedly dependent on the frequencies applied as well as on field strength and modulation (Tkalec et al., 2009).

In general, polarization from man-made electromagnetic radiation appears to have a greater bioactive effect than natural radiation, and significantly increases the probability for initiation of biological or health effects (Panagopoulos et al., 2015).

Tree damages as in Bamberg and Hallstadt were documented by the authors in several countries: Spain (Valladolid, Salamanca, Madrid, Palencia, León), Germany (Munich, Nürnberg, Erlangen, Bayreuth, Neuburg/Donau, Garmisch-Partenkirchen, Murnau, Stuttgart, Kassel, Fulda, Göttingen, biosphere reserve Rhön, Tegernsee Valley and in several small towns), Austria (Graz), Belgium (Brussels) and Luxemburg.

Each phone mast can harm many trees and each tree can be affected by several phone masts belonging to the same or different base stations. Damaged trees seem to exist around each antenna and the several million phone masts in the world could potentially be damaging the growth and health of millions of trees. This can occur not only in cities, but also in well-preserved forests, and in natural and national parks, where base stations are being installed without the necessary prior environmental impact studies, due to a lack of knowledge of the problem. For this reason, it is essential for an assessment on the environmental impact of any new base station prior to implementation.

Additionally, phone masts can cause a drop in timber productivity in plantations of pine, poplar, etc., as well as fruits, nuts, etc. Thus, the industry must be required to pay damages to plantation owners. Similarly, as trees are a common social good, the industry should compensate for damaged and dead trees around the world due to radiation. Further, the money spent by municipalities to repair or replace damaged trees should enter into the computation of costs/benefits of this technology. For installation of any new technology, the burden of proof should be to the industry that requires demonstration of safety prior to deployment.

Electromagnetic radiation from telecommunication antennas affected the abundance and composition of wild pollinators in natural habitats and these changes in the composition of pollinator communities associated with electromagnetic smog may have important ecological and economic impacts on the pollination service that could significantly affect the maintenance of wild plant diversity, crop production and human welfare (Lázaro et al., 2016).

Evidence for plant damage due to high frequency electromagnetic radiation was not taken into account in determining the current statutory regulations (the limit values). Once the problem becomes evident, the guidelines of radiation emitted by the antennas should be reviewed. Proper risk assessment of electromagnetic radiation should be undertaken to develop management strategies for reducing this pollution in the natural environment (Kumar et al., 2015).

Moreover, due to the lack of recognition, certain modern projects with interesting ideas for decreasing environmental pollution could have opposite effects than expected. For example, in the Netherlands, the TreeWiFi project (http://treewifi.org/), which aims to motivate people to use bikes and public transport in order to reduce the [NO2] pollution providing free WiFi when air quality improves, could be favoring electromagnetic pollution with even more harmful effects as it has been demonstrated in this manuscript (see also: http://www.greenpeace.org/canada/fr/Blog/le-wi-fi-tuerait-les-ar-bres/blog/33569/).

In addition, the number of sector antennas has increased in Bamberg and this increase appears to be accelerating: 483 sector antennas in 2011 and 779 sector antennas in 2015. Both radiation and damaged trees represent a loss of quality of life for citizens. This study began after finding that patients who claimed to be affected by phone masts, referred to as radiation, live in areas where affected trees and plants are located. Evidence of radiation damage was even found in potted plants inside patient homes (Waldmann-Selsam and Eger, 2013). Thus, this study is certainly complementary to the study by Eger and Jahn (2010) and other research that has shown effects on the health of people by phone masts located in their vicinity (Santini et al., 2002; Eger et al., 2004; Wolf and Wolf, 2004; Abdel-Rassoul et al., 2007; Khurana et al., 2010; Dode et al., 2011; Gómez-Perretta et al., 2013; Shahbazi-Gahrouei et al., 2014; Belyaev et al., 2015).

In the introduction to the International Seminar on "Effects of Electromagnetic Fields on the Living Environment" in 1999 in Ismaning, Germany, organized by WHO, ICNIRP and German Federal Office for Radiation Protection (BfS), M. Repacholi, head of the International EMF Project of the WHO, said: "By comparison, influences of these fields on plants, animals, birds and other living organisms have not been properly examined. Given that any adverse impacts on the environment will ultimately affect human life, it is difficult to understand why more work has not been done. There are many questions that need to be raised: …" and "…it seems that research should focus on the long-term, low-level EMF exposure for which almost no information is available. Specific topics that need to be addressed include: … EMF influences on agricultural plants and trees" (Matthes et al., 2000).

5. Conclusions

In this study we found a high-level damage in trees within the vicinity of phone masts. Preliminary laboratory studies have indicated some deleterious effects of radiofrequency radiation. However, these early warnings have had no success and deployment has been continued without consideration of environmental impact.

We observed trees with unilateral damage in the radiation field of phone masts. We excluded the possibility that root injury due to construction work or air pollutants could have caused the unilateral damage. We found out that from the damaged side there was always visual contact to one or more phone mast (s).

Statistical analyses demonstrated that the electromagnetic radiation from cellphone towers is harmful to trees. Results show that the measurements in the most affected sides of damaged trees (i.e. those that withstand higher radiation levels) are different to all other groups. These results are consistent with the fact that damage inflicted on trees by cellphone towers usually start on one side, extending to the whole tree over time.

The occurrence of unilateral damage is the most important fact in our study and an important argument for a causal relationship with RF-EMF, as it supplies evidence for non-thermal RF-EMF effects. This constitutes a danger for trees worldwide. The further deployment of phone masts has to be stopped. Scientific research on trees under the real radiofrequency field conditions must continue.

Acknowledgements

The work presented here was carried out without any funding. Francisco Cabrero and José Ignacio Aguirre from the Department of Zoology, University Complutense of Madrid suggested the interpolation points on the map of radiation. This paper is dedicated in memoriam to the great Swedish researcher and courageous man, Örjan Hallberg. Authors have not a conflict of interest to declare.

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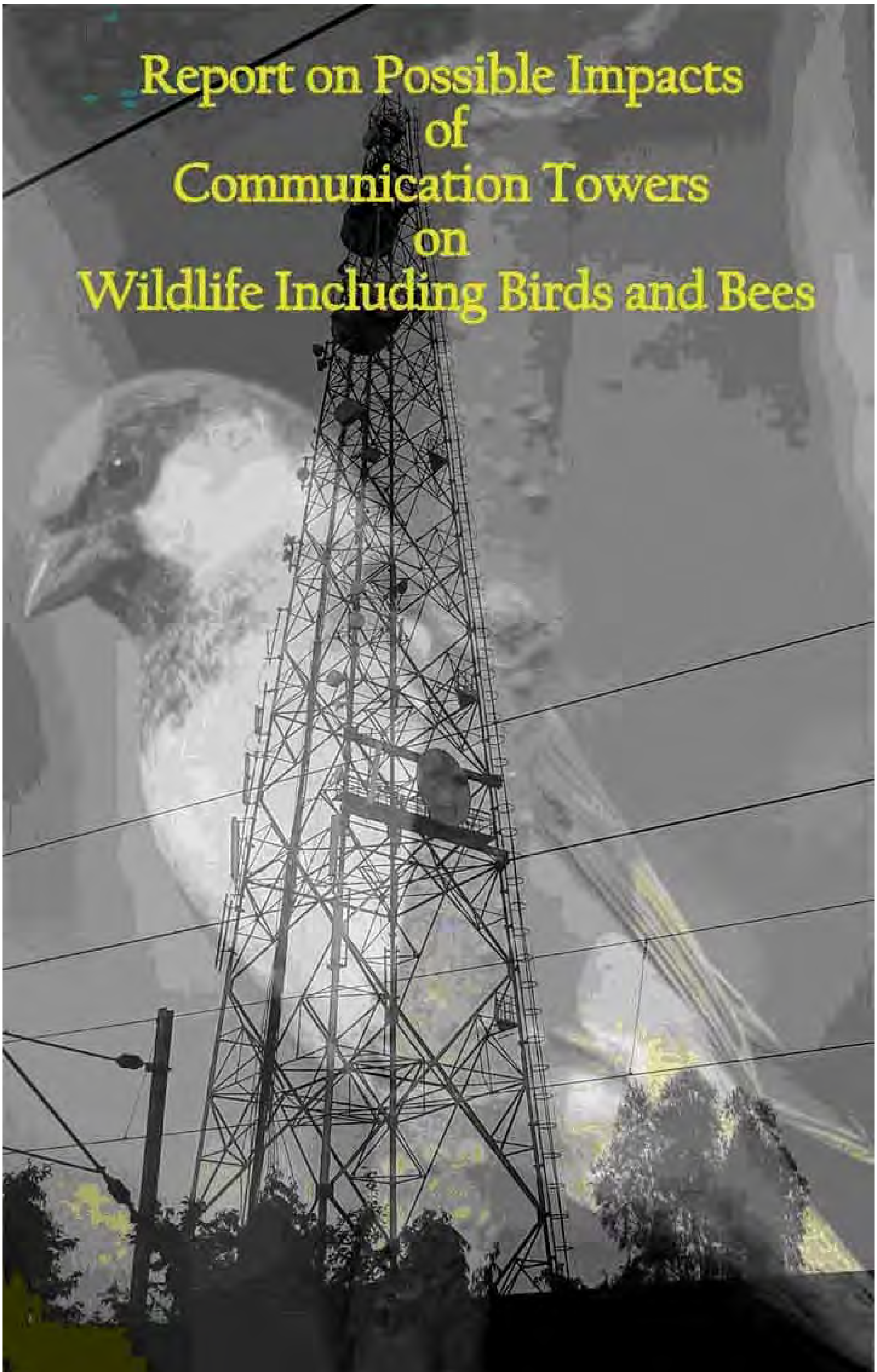
Report on Possible Impacts
of
Communication Towers
on
Wildlife Including Birds and Bees

Expert Group to study the possible impacts of communication towers on Wildlife including Birds and Bees

Executive summary

India is one of the fastest growing mobile telephony industries in the world. It is estimated that by 2013, 1 billion plus people will be having cell phone connection in India. To support this growth of cell phone subscriber in the country, there has also been a tremendous growth of infrastructure in the form of mobile phone towers. Today, in absence of any policy on infrastructure development and location of cell phone towers, large numbers of mobile phone towers are being installed in a haphazard manner across urban and rural areas including other sparsely populated areas in India.

The transmission towers are based on the electromagnetic waves, which over prolonged usage have adverse impacts on humans as well as on other fauna. The adverse effects of electromagnetic radiation from mobile phones and communication towers on health of human beings are well documented today. However, exact correlation between radiation of communication towers and wildlife, are not yet very well established.

The Ministry of Environment and Forests usually receives several questions regarding this issue. In view of one such Lok Sabha Starred question regarding 'Ill effects of Mobile Towers on Birds' received on 11th August, 2010, an 'Expert committee to Study the possible Impacts of Communication Towers on Wildlife including Birds and Bees' was constituted on 30th August, 2010 by Ministry of Environment and Forest, Government of India.

The Expert Committee had five important mandates which are as follows:

I. To review all the studies done so far in India and abroad on aspects of ill effects of mobile towers on animals, birds and insects.

II. To assess the likely impacts of the growth in the number of mobile towers in the country

III. To suggest possible mitigatory measures.

IV. To formulate guidelines for regulating the large-scale installation of mobile towers in the country

V. To identify the gap areas for conducting further detailed research.

The Committee studied all the peer reviewed articles/ journals published on the impact of radiations on wildlife throughout the world and compiled them. Subsequently, detailed analysis of the papers was done to find out the impacts of electronic magnetic fields (**EMF**) on wildlife including birds and bees and the gap areas for conducting further detailed research were identified.

The review of existing literature shows that the Electro Magnetic Radiations (EMRs) are interfering with the biological systems in more ways than one. There had already been some warning bells sounded in the case of bees and birds, which probably heralds the seriousness of this issue and indicates the vulnerability of other species as well. The electromagnetic radiations are being associated with the observed decline in the population of sparrow in London and several other European cities (Balmori, 2002, Balmori, 2009, Balmori & Hallberg, 2007). In case of bees, many recent studies have linked the electromagnetic radiations with an unusual phenomenon known as 'Colony Collapse Disorder'. A vast majority of scientific literature published across the world indicate deleterious effects of EMFs in various other species too.

In spite of the recent studies indicating possible harmful impact of EMF on several species, there are no long-term data available on the environmental impacts of EMRs as of now. Studies on impact of cell phone towers and EMR on birds and other wildlife are almost non-existent in India. Moreover, pollution from EMRs being a relatively new environmental issue, there is a lack of established standard procedures and protocols to study and monitor the EMF impacts especially among wildlife, which often make the comparative evaluations between studies difficult. In addition to the gap areas in research, the necessary regulatory policies and their implementation mechanism also have not kept pace with the growth of mobile telephoning. Our guidelines on exposure limits to EMF need to be refined since the ICNIRP Standard currently followed in India is coined based on only thermal impact of Radio Frequency and are dismissive of current epidemiological evidence on impacts of non-thermal nature on chronic exposure from multiple towers. Meanwhile, the precautionary principle should prevail and we need to better our standards on EMF to match the best in the world.

Along with the growth of phone towers and subscribers, India is also witnessing a rapid population growth. To feed and support this rapidly growing population the agricultural security and the factors influencing them should be of concern. However, the population of many species such as honey bees, which is one of the most important pollinator and important factor for agricultural productivity, has seen a drastic population drop. Unfortunately we do not have much data about the effects of EMR available for most of our free-living floral and faunal species in India. Therefore, there is an urgent need to do further research in this area before it would be too late.

Introduction

During recent years, there has been an increase in the usage of telecommunication devices, which has become an easy means for communication. The use of mobiles have become more conspicuous, during the last decade and this has led to construction of transmission towers in large numbers, both in the urban, as well as in rural areas including other sparsely populated areas. Transmission towers are based on the electromagnetic waves, which over prolonged usage have adverse impacts on humans as well as on other fauna. The adverse effects of electromagnetic radiation from mobile phones and communication towers on health of human beings are well documented today. Recently the electromagnetic fields from mobile phones and other sources have been classified as "possibly carcinogenic to human" by the WHO's International Agency for Research on Cancer (IARC). However, exact correlation between radiation of communication towers and wildlife, are not yet very well established. Though, there have been growing concerns about the impacts of mobile towers on wildlife, and couple of studies conducted in India and worldwide indicates the possibility of negative effects of radiation.

The Ministry of Environment and Forests (MoEF) usually receives questions on such subject during the last couple of years. One such question, that the Ministry of Environment and Forests replied to on 11^{th} August, 2010 was a Lok Sabha Starred question number 244 regarding 'Ill effects of Mobile Towers on Birds'. In the above mentioned question, Hon'ble Member of Parliament (Lok Sabha), wanted to know, whether any studies have been conducted on the ill effects of mobile towers on birds and bees and also whether the Government has set up any committee to look into the issue.

In view of this, an urgent need was felt to constitute an Expert Group to assess the level of possible impacts of growth of mobile towers in urban, sub-urban and even rural/forest areas on the wildlife including birds and bees and to suggest appropriate mitigative measures for the problem. Hence, the 'Expert committee to Study the possible impacts of communication towers on wildlife including Birds and Bees' was constituted on 30^{th} August, 2011 by Ministry of Environment and Forest, Government of India. The constitution and the terms of references of the committee are at **Annexure I.**

The committee had the following important five mandates to be completed:

I. To review all the studies done so far in India and abroad on aspects of ill effects of mobile towers on animals, birds and insects.

II. To assess the likely impacts of the growth in the number of mobile towers in the country

III. To suggest possible mitigatory measures.

IV. To formulate guidelines for regulating the large-scale installation of mobile towers in the country

V. To identify the gap areas for conducting further detailed research.

In order to achieve its mandate, the committee had convened three meetings and discussed the issue thread bare. After the discussions, in third meeting, the committee had decided to finalise its report. Subsequently, hundreds of research papers were collated, analyzed and reviewed. Detailed descriptions were noted of important and relevant papers. Drafts were circulated within the Committee members for comments.

It should be noted that this is not a complete review of the impact of the electromagnetic radiation on all life forms as **the mandate of the Committee was limited to birds and bees.** However, for the context purpose the committee has referred to many papers concerning other taxa (See Literature Cited).

The findings of the committee based on the above mandates are provided in detail in the following paragraphs.

Scientific background on the issue

Rapid developments in various fields of science and technology in recent years have intensified the human interference into the natural environment and associated physical, biological and ecological systems resulting in various unintended and undesirable negative impacts on environment. With economic, social and scientific development, increasingly fresh avenues for environmental pollution are being thrown open in recent times. Pharmaceutical, genetic, nano-particulates and electro-magnetic pollutions are the prominent ones among them which were in the limelight in recent times for all the negative reasons.

The intensity of manmade electromagnetic radiation has become so ubiquitous and it is now increasingly being recognized as a form of unseen and insidious pollution that might perniciously be affecting life forms in multiple ways (Balmori 2006a; Balmori 2006b; Balmori 2009; Tanwar 2006). The **electro-magnetic fields** (**EMF**) as a pollution called 'electro-smog' is unique in many ways. Unlike most other known pollutants, the **electro-magnetic radiations** (**EMR**) are not readily perceivable to human sense organs and hence not easily detectable. However, their impacts are likely to be insidious and chronic in nature. However, it is possible that other living beings are likely to perceive these fields and get disturbed or sometimes fatally misguided. Because the EMR pollution being relatively recent in origin and lately being recognized as a pollutant coupled with its expected long-term impacts and lack of data on its effect on organisms, the real impacts of these pollutants are not yet fully documented in the scientific literature.

The electromagnetic radiations (EMR) are extensively used in modern communication and technology. Radio waves and microwaves are forms of electromagnetic energy that are collectively described by the term "**radiofrequency**" or "**RF**". RF emissions and associated phenomena can be discussed in terms of "energy", “power”, "radiation" or "field". Electromagnetic "radiation" can best be described as waves of electric and magnetic energy moving together (i.e., radiating) through space (Cleveland, Fields, and Ulcek 1999).

The first mobile telephone service started on the non-commercial basis on 15 August 1995 in Delhi. During the last 16 years, India has seen exponential growth of mobile telephoning. With this growth, a number of private and government players are coming in to this lucrative and growing sector. At present nearly 800 million Indians have mobile phones, making it the second largest mobile subscribers in the world after China. At present, there are nearly 15 companies providing mobile telephoning. However, necessary regulatory policies and their implementation mechanism have not kept pace with the growth of mobile telephoning. Moreover, there have been not enough scientific studies on the impact of mobile phone towers on human health or its environmental impacts.

Most of the short-term studies primarily looking into the thermal impacts of EMR exposure on biological systems have neither succeeded to detect any statistically significant changes in the biological processes nor could prove any acute change in health conditions at the present background levels of exposures (Brent 1999; Hanowski Niemi and Blake 1996; Hoskote, Kapdi and Joshi 2008; Lönn *et al.* 2005; Mixson *et al.* 2009; Zach and Mayoh 1984; Zach and Mayoh 1986). On the other hand, long-term studies have reported alarming observations, detecting negative consequences on immunity, health, reproductive success, behaviour, communication, co-ordination, and niche breadth of species and communities (Preece *et al.* 2007; Levitt and Lai 2010; Hardell *et al.* 2008; Hardell *et al.* 2007; Fernie and Bird 2001).

- **Impact on birds and bees:** Of the non-human species, impacts on birds and bees appear to be relatively more evident. Exposure to EMR field is shown to evoke diverse responses varying from aversive behavioural responses to developmental anomalies and mortality in many of the studied groups of animals such as bees, amphibians, mammals and birds (Zach and Mayoh 1982; Zach and Mayoh 1982; Batellier et al. 2008; Nicholls and Racey 2007; Bergeron 2008; Copplestone et al. 2005; Sahib 2011). Honey bees appear to be very sensitive to EMF (Ho 2007; Sharma and Kumar 2010; Ho 2007) and their behavioural responses, if scientifically documented, could be used as an indicator of EMF pollution.

- **Impacts on other wildlife:** Other wildlife such as amphibians and reptiles also appear to be at high risk with possible interference of EMF with metamorphosis and sex ratios where temperature dependent sex determination is operational. Several investigations into environmental effects of EM fields are covered in some of the unpublished / grey literature and impact assessments submitted to various regulatory government agencies (Bergeron 2008a; Bergeron 2008b; Cleveland, Fields, and Ulcek 1999; Copplestone *et al.* 2005; G. Kumar 2010; Hutter *et al.* 2006). Such reports are either not in the public domain, or scattered and often difficult to access.

- **Impacts on Human**: Since its inception, there have been concerns about the ill-effect of the mobile towers and mobile phones. Despite being a relatively newly acknowledged form of pollution, EMRs and their negative impacts on biological systems and environment have already been reported by several studies. However most of the available scientific literature on the negative environmental effects of electromagnetic fields reports the results of experimental and epidemiological studies examining the impact on various aspects of human health (Tanwar 2006; Savitz 2003; Preece *et al.* 2007; Oberfeld *et al.* 2004; Navarro *et al.* 2003; Lönn *et al.* 2005; Kundi and Hutter 2009; Hardell *et al.* 2007; Kapdi, S. Hoskote and Joshi 2008; Hallberg and Johansson 2002).

Present scenario: At present, there could be more than 5 billion mobile phone subscribers globally (www.who.ilt/mediacentre/factsheets/fs193/en). Recently, in May 2011, the WHO's International Agency for Research on Cancer (IARC) has classified electromagnetic fields from mobile phones and other sources "possibly carcinogenic to human" and advised the public to adopt safety measures to reduce exposures, like use of hand-free devices or texting. For details please see Press Release No. 208, dated 31 May 2011 on IARC-WHO (http://www.iarc.fr/en/media-centre/pr/2011/pdfs/pr208_E.pdf). Their findings were published in the July 2011 issue of the medical journal ***Lancet***. Later, WHO clarified that some of the findings published in ***Lancet*** were not reported properly in the media and the risk is not as great as made out in the media. Some of the cell phone manufactures have objected to these findings (For example see www.Physorg.com). Some earlier investigators also have contended that there is no measurable risk of reproductive failure and birth defects from EMF exposures in humans (Brent *et al.* 1993), while several others do not agree with that conclusion (Gandhi 2005; Kapdi, Hoskote and Joshi 2008; Pourlis 2009; G. Kumar 2010). Studies carried out on the RF levels in North India, particularly at the mobile tower sites at Delhi have shown that people in Indian cities are exposed to dangerously high levels of EMF pollution (Tanwar 2006).

Existing world-wide standard and permissible limits

Two major transmission protocols currently in use for mobile telephony are GSM (900 to 1800 MHz) and CDMA (824-844 MHz paired with 869-889 MHz). The Telecom Engineering Centre (TEC) of DoT had proposed display of Specific Absorption Rate (SAR) value in handsets. As indicated in the table below, current Indian standards on exposure are much higher than many other countries.

Power Density (W/m²)	International Exposure limits adopted by various countries
10	FCC (USA) OET-65, Public Exposure Guidelines at 1800 MHz
9.2	**ICNIRP and EU recommandation 1998 – Adopted in India**
3	Canada (Safety Code 6, 1997)
2	Australia
1.2	Belgium (ex Wallonia)
0.5	New Zealand
0.24	Exposure limit in CSSR, Belgium, Luxembourg
0.1	Exposure limit in Poland, China, Italy , Paris
0.095	Exposure limit in Italy in areas with duration > 4hours
0.095	Exposure limit in Switzerland
0.09	ECOLOG 1998 (Germany) *Precaution recommendation only*
0.025	Exposure limit in Italy in sensitive areas
0.02	**Exposure limit in Russia (since 1970), Bulgaria, Hungary**
0.001	"Precautionary limit" in Austria, Salzburg City only
0.0009	*BUND 1997 (Germany) Precaution recommendation only*
0.00001	**New South Wales, Australia**

Table 1. Guidelines and Limits on Exposure Limits in Various Countries (Source: Girish Kumar 2010)

1. ICNIRP Guidelines (International Radiofrequency Guidelines):

In April 1998, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) published, guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields in the frequency range up to 300 GHz. These guidelines replaced previous advice issued in 1988 and 1990. The main objective of the ICNIRP Guidelines is to establish guidelines for limiting EMF exposure that will provide protection against known adverse health effects (ICNIRP, 1998). An adverse health effect is defined by ICNIRP as one which causes detectable impairment of the health of the exposed individual or of his or her offspring; a biological effect, on the other hand, may or may not result in an adverse health effect.

2. Guidelines and Limits followed by Other Countries:

Some countries have established new, low-intensity based exposure standards that respond to studies reporting effects that do not rely on heating. Consequently, new exposure guidelines are having hundreds or thousands times lower than those of Institution of Electronics and Electrical Engineers (IEEE) and ICNIRP. Table 2, shows some of the countries that have lowered their limits, for example, in the cell phone frequency range of 800 MHz to 900 MHz. The levels range from 10 microwatts per centimeter squared in Italy and Russia to 4.2 microwatts per centimeter squared in Switzerland. In comparison, the United States and Canada limit such exposures to only 580 microwatts per centimeter squared (at 870MHz) and then averaged over a time period (meaning that higher exposures are allowed for shorter times, but over a 30 minute period, the average must be 580 microwatts per centimeter squared or less at this frequency). The United Kingdom allows one hundred times of this level, or 580 x 100 microwatts per centimeter squared. Higher frequencies have higher safety limits, so that at 1000 MHz, for example, the limit is 1000 microwatts per centimeter squared (in the United States). The exposure standards for each individual frequency in the radiofrequency radiation range needs to be calculated. These are presented as reference points only. Emerging scientific evidence has encouraged some countries to respond by adopting planning targets, or interim action levels that are responsive to low-intensity or non-thermal radiofrequency radiation bio effects and health impacts.

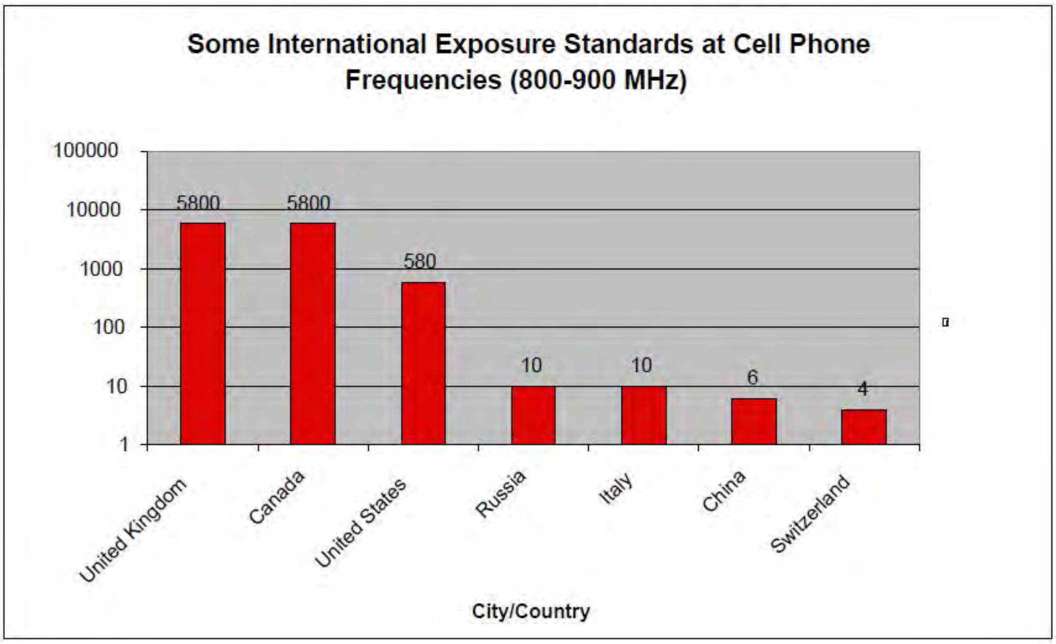

Table 2. Some International Exposure Standards at Cell Phone Frequencies (800-900 MHz) (Values of exposure in microwatts per centimeter squared)

Professional bodies such as IEEE and ICNIRP continue to support "thermal-only" guidelines:

a) by omitting or ignoring study results reporting bio-effects and adverse impacts to health and wellbeing from a very large body of peer-reviewed, published science because it is not yet "proved" according to their definitions;
b) by defining the proof of "adverse effects" at an impossibly high a bar (scientific proof or causal evidence) so as to freeze action;
c) by requiring a conclusive demonstration of both "adverse effect" and risk before admitting low-intensity effects should be taken into account;
d) by ignoring low-intensity studies that report bio-effects and health impacts due to modulation;
e) by conducting scientific reviews with panels heavily burdened with industry experts and under-represented by public health experts and independent scientists with relevant low-intensity research experience;
f) by limiting public participation in standard-setting deliberations; and other techniques that maintain the status quo.

(Source: "*Bio Initiative Report: A Rationale for a Biologically-based Public Exposure Standard for Electromagnetic Fields (ELF and RF)*" by 'Cindy Sage, and David Carpenter (2007)**)**

<u>Detailed analysis of the Issue vis-à-vis the TORs</u>

- **TOR I:** ***To review all the studies done so far in India and abroad on aspects of ill effects of mobile towers on animals, birds and insects.***

Though EMR is a relatively newly recognised pollutant, many recent studies have pointed to their harmful long-term impacts on health and environment. Hence the most important mandate of the committee was to study all the peer reviewed articles/ journals published on the impact of radiations on wildlife throughout the world and to compile them. Subsequently, detailed analysis of the papers was done to find out the impacts of electronic magnetic fields (**EMF**). The research papers were then listed in to three categories: showing impact on organisms, no impact and neutral or inconclusive evidence (See Table No. 3).

Literature review:

A review during the international seminar entitled "Effects of electromagnetic fields on the living environment" held in Ismaning, Germany in 1999, organized under WHO's International EMF Project, observed that the EMF impacts on environment are minimal and localized and has opined that the human EMF exposure limits recommended by the International Commission on Non-Ionizing Radiation (ICNIRP, 1998) would also be protective of the environment as well (Foster and Repacholi 1999). However, recent research reports are at odds with these propositions, including the latest report from WHO indicating a possible link with cell phone use and brain glioma (Baan *et al*, 2011).

Several species are known to have the capability to sense and respond to EM fields, especially the earth's magnetic field (Kirschvink 1982). However, little is known of the exact physiological mechanisms involved. Three major hypotheses of magnetic-field detection have been proposed (Lohmann and Johnsen 2000): a) *Electromagnetic induction* (as in Electro sensitive sharks and rays), b) *Biogenic magnetite* and c) *Chemical reactions modulated by magnetic fields*. Despite notable recent progress, primary magneto-receptors have not yet been identified unambiguously.

Most of the reported studies examined (n=919) deal with the EMF impacts on human subjects (81%), while only 3% of them reports impact on birds and just 2% on wildlife. The present report is based on relevant papers and documents obtained mainly from online archives of JSTOR (www.jstor.org) and Google scholar (http://scholar.google.co.in/). Salient features of the reported studies on the impact of EMF on different faunal groups are discussed below (can be included below).

An Analysis of Results of Literature Survey:

After careful screening that involved deletion of duplicate records and addition of new references, the 1080 references initially compiled for the analysis of literature (which formed the base for our overview) were reduced to 919 references. These final 919 study reports are used here for the present final analysis.

The studies were broadly classified based on the subject organisms into four categories- Birds, Bees, Other Animals (including wildlife) and humans. Based on the study's findings regarding the impact of EMFs on the subject, each category was further subdivided into three groups- Impact, No Impact or Neutral/ Inconclusive, as given in table 3 below. As noted below majority of the studies reported negative impacts by EMFs.

Table 3. Number of research studies (collected from Open access Bibliographic databases) collected and collated based on the study subjects and results

	Impact	**No Impact**	**Neutral/ inconclusive**	**Total (n)**
Birds	23	3	4	30
Bees	6	1	0	7
Human	459	109	174	742
Other Animals (+Wildlife)	85(+13)	16(+1)	10(+7)	111(+21)
Plants	7	0	1	8
Total	593	130	196	**919**

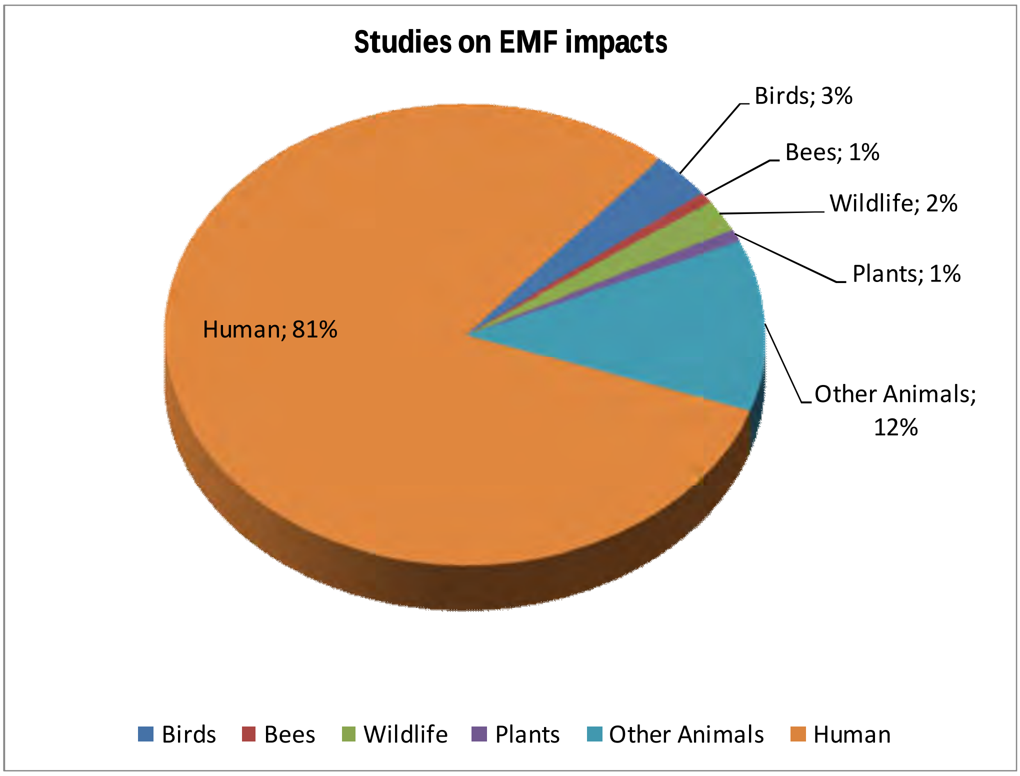

Fig 1. Proportion of studies on different groups of organisms

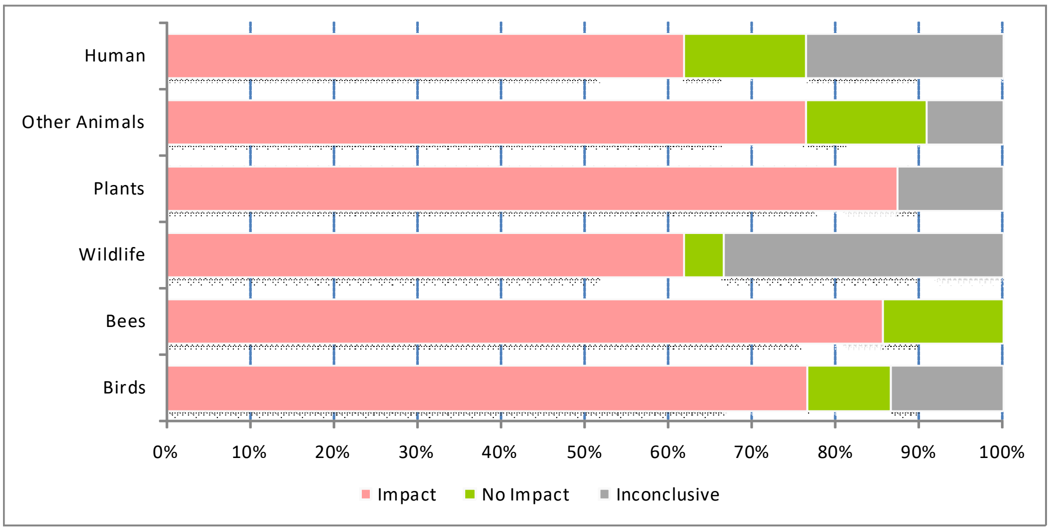

Fig 2. Proportion of study results in various groups of organisms (n=919). The 'Impact' (in red) indicates percentage of studies that reported harmful effect of EMR

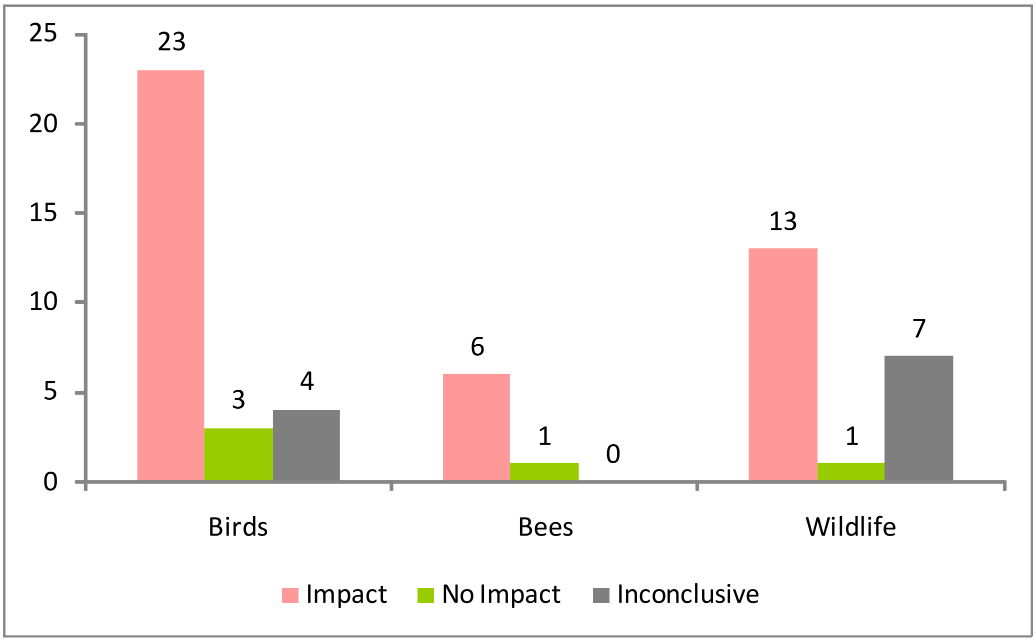

Fig 3. Proportion of study results in Birds, Bees and Wildlife (n=919).

- **TOR II:** ***To assess the likely impacts of the growth in the number of mobile towers in the country.***

India has the second largest population of mobile subscribers in the world and in the absence of any proper policy regulating the construction of mobile towers, the risk of the likely negative impacts of EMF on the health of humans and wildlife is huge. Based on the analysis of the reported studies, the impacts of EMF on different faunal groups were identified, the salient features of which are as discussed below:

Effect on Birds: The earliest reported study on impacts of microwave radiation on birds dates back to 1960s (Tanner, Romero-Sierra, and Davie 1967). In birds, their ability to fly expose them to a greater risk of direct irradiation and hence they appear to be at greater risk as far as effects of EMRs are concerned (Balmori 2005; Balmori and Hallberg 2007; Summers-Smith 2003; Zach and Mayoh 1982; Zach and Mayoh 1984; Zach and Mayoh 1982; Joris and Dirk 2007). Observed effects of exposure to non-ionizing radiation in avian species are mostly from radiation-induced temperature increases (Batellier *et al.* 2008). The incubating avian egg provides a model to study non-thermal effects of microwave exposure since ambient incubation temperature can be adjusted to compensate for absorbed thermal energy. Non-thermal levels of non-ionizing radiation can affect a bird's ability to recover from acute physiological stressors, apart from other potential physiological and behavioural repercussions. Although earlier research indicated that modulated radiofrequency radiation increased calcium-ion efflux in chick forebrain tissue, disagreement on experimental techniques and incongruous results among related studies have made final conclusions elusive. In an another study, which was carried out by National Research Centre of Canada on interaction of electromagnetic fields and living systems with special reference to birds, it was observed that following the onset of radiation, stabilizing period of the egg production in birds was affected (Bigu, 1973).

Birds have been shown to be able to reliably detect magnetic fields in both the field and laboratory. The rapidly increasing number of cell-phone subscribers is resulting in higher concentration levels of electromagnetic waves in the air, which clashes with the earth's electromagnetic field (Hyland, 2000). Some researchers have reported malformations in chicken embryos exposed to a sinusoidal bipolar oscillating magnetic field (Balmori and Hallberg 2007).

According to a thermal modelling study of a bird subjected to continuous wave (CW) microwave radiation (2.45 GHz), the model predicted that tolerance to microwave radiation for a bird was positively correlated with its mass and that ambient temperature is the environmental variable that has most influence on the level of tolerance for microwave radiation (Byman *et al.* 1986).

Effect on House Sparrows: House Sparrow (*Passer domesticus)* is associated with human habitation and it is one of the indicator species of urban ecosystems. A declining population of the bird provides a warning that the urban ecosystem is experiencing some environmental changes unsuitable for living in the immediate future (Kumar, 2010). London has witnessed a 75 per cent fall in House Sparrow population since 1994, which coincides with the emergence of the cell-phone (Balmori, 2002). Electromagnetic radiation may be responsible, either by itself or in combination with other factors, for the observed decline of the sparrows in European cities (Balmori, 2009, Balmori & Hallberg, 2007). Research in Spain proved that the microwaves released from these towers are harmful to House Sparrows and the increase in the concentration of microwaves results into decrease in House Sparrow populations (Everaert & Bauwen, 2007). Reproductive and co-ordination problems and aggressive behavior has also been observed in birds such as sparrows (Balmori, 2005). General methodology used for such study was, from each area, all sparrows were counted in addition to the mean electric field strength (Everaert & Bauwens, 2007). In similar studies in India, population of *Passer domesticus* was found fast disappearing from areas contaminated with electromagnetic waves arising out of increased number of cell phones, in Bhopal, Nagpur, Jabalpur, Ujjain, Gwaliar, Chhindwara, Indore & Betul (Dongre & Verma, 2009). It was also observed that when 50 eggs of House Sparrow, exposed to electromagnetic radiation (EMR) for durations of five minutes to 30 minutes, all the 50 embryos were found damaged in a study carried out by the Centre for Environment and Vocational Studies of Punjab University (Kumar 2010, Ram 2008).

Male sparrows were seen at locations with relatively high electric field strength values of GSM base stations, providing evidence of how long-term exposure to higher levels of radiation negatively affects the abundance or behavior of House Sparrows in the wild. Thus, electromagnetic signals are associated with the observed decline in the sparrow population in urban areas.

Effect on White Storks: In monitoring a White Stork (*Ciconia ciconia*) population in Valladolid (Spain) in vicinity of Cellular Phone Base Stations, the results indicated the possibility that microwaves are interfering with the reproduction of White Stork (Balmori, 2010).

Effect of Mobile Radiation on Honey Bees: Many recent studies have linked the electromagnetic radiations with an unusual phenomenon in bees known as 'Colony Collapse Disorder'. Colony Collapse Disorder (CCD) occur when a hive's inhabitants suddenly disappear, leaving only queens, eggs and a few immature workers. The vanished bees are never found, but thought to die solitarily far from home. The theory is that radiation from mobile phones interferes with bees' navigation systems, preventing them from finding their way back to their hives. Even the other animals, parasites and other bees, that normally would raid the honey and pollen left behind when a colony dies, refuse to go anywhere near the abandoned hives. Some scientists believe that CCD is the result of high electromagnetic radiation. As long back as early 1970s, Wellenstein (1973) had reported that the navigational skills of the honey bees were being impacted by high tension lines. In a recent study (Stefan *et al*. 2010) significant differences have been detected in returning of honeybees to their hives: 40% of the non-irradiated bees came back compared to 7.3% of the irradiated ones.

The alarm was first sounded in last autumn, but has now hit half of all American states. The West Coast is thought to have lost 60 per cent of its commercial bee population, with 70 per cent missing on the East Coast. CCD has since spread to Germany, Switzerland, Spain, Portugal, Italy and Greece. John Chapple, one of London's biggest bee-keepers, announced that 23 of his 40 hives have been abruptly abandoned (http://www.independent.co.uk/environment/nature/are-mobile-phones-wiping-out-our-bees-444768.html).

In India, studies conducted by Sainudeen (2011) have proved experimentally that once mobile phones in working condition with frequency of 900 MHz for 10 minutes were kept in the beehives, the worker bees stopped coming to the hives after ten days. He also found drastic decrease in the egg production of queen bees (100 eggs/ day compared to 350 eggs/ day in the control colonies). Earlier studies have also shown (e.g. Greenberg *et al*. 1981) lower eggs being laid in beehives exposed to high voltage transmission lines. Another possible impact of EMR on the bees is the eggs that are exposed to cell phone radiation produce only drones (Brandes and Frish, 1986). Similar studies on a larger scale and better sample size are required in India.

Other wildlife: Phone masts located in the living areas of animals and birds are continuously irradiating some species that could suffer long-term effects, like reduction of their natural defences, deterioration of their health, problems in reproduction and reduction of their useful territory through habitat deterioration. Electromagnetic radiation can exert an aversive behavioural response in rats, bats and birds such as sparrows. Therefore microwave and radiofrequency pollution constitutes a potential cause for the decline of animal populations and deterioration of health of plants living near phone masts (Balmori, 2005).

Arguably, the most serious concern about the impact of EMF on the living systems appears to be its long term effects on genes and reproductive fitness of species. Today, there is evidence that Electromagnetic Radiation is genotoxic (Blaasaas, Tynes, and Lie 2003; Joris and Dirk 2007; Pourlis 2009; Cherry 2000). An experiment on Common Frog (*Rana temporalis,* new name *Hylarana temporalis*) indicated that radiation emitted by phone masts in a real-time situation may affect the development and may cause rise in mortality of exposed tadpoles. This research may have huge implications for the natural world, which is now exposed to high microwave radiation levels from a multitude of phone masts (Balmori 2010). However, it requires long-term monitoring studies for establishing any causative link between reproductive fitness and EMFs and such data is presently lacking. Moreover, available short term studies are grossly inadequate. For instance a recent review that analysed the literature (till 2001) on the effects of EMF associated with mobile telephony on the prenatal and postnatal development of vertebrates reported that the majority of the studies examined indicated no strong impact on the animal reproduction and development (Pourlis 2009).

Effect on bats: Activity of bats seems to be much reduced in areas with Electro-magnetic fields with densities more than 2V/m (Balmori, 2009). Based on this fact it was recommended to use EMR to repel bats from wind farms (Nicholls and Racey, 2007). In another study in a Free-tailed bat colony (*Tadarida teniotis*) the number of bats decreased when several phone masts were placed 80m from the colony (Balmori *et al*., 2007).

- **TOR III: *To suggest possible mitigatory measures***

Decision was taken in the first and second meetings of the Expert Group to study all peer reviewed articles/ journals published on the impact of radiations on wildlife and to compile the list of the measures taken throughout the world to mitigate the effects of radiations on wildlife including birds and bees. Hence, the standards and exposure limits of radio frequency of different countries were studied in this regard.

Various organizations and countries have developed standards for exposure to radio frequency energy as discussed above. Some countries have established new, low-intensity based exposure standards that respond to studies reporting effects that do not rely only on heating. Currently, the World Health Organization is working to provide a framework for international harmonization of RF safety standards.

Emerging scientific evidence has encouraged some countries to respond by adopting planning targets, or interim action levels that are responsive to low-intensity or non-thermal radiofrequency radiation bio effects and health impacts. It is the WHO's view that scientific assessments of risk and science-based exposure limits should not be undermined by the adoption of arbitrary cautionary approaches. Therefore, throughout the world there has been a growing movement to adopt a precautionary approach.

- **TOR IV:** ***To formulate guidelines for regulating the large-scale installation of mobile towers in the country***

With the rapid growth of the mobile industry in India, mobile towers are being built in a haphazard manner without any prior planning and regulation. Hence in view of this, along with lack of any policy controlling the construction of such mobile towers, one of the main tasks of the committee is to formulate guidelines to regulate their installation. At the first meeting of the Expert Committee held on 09.2010, it was decided that few members of the Expert Group will participate in the meeting of the Inter-Ministerial Committee on EMF Radiation held in Ministry of Telecommunications on 06.12.2010, to share the concerns on human as well as wildlife health and to devise a common set of guidelines for mobile towers in the country. The minutes of the meeting was submitted to the Ministry.

- **TOR V:** ***To identify the gap areas for conducting further detailed research***

At the first meeting of the committee, all the members had agreed that the research in India on this issue is very scanty and much research has to be done in this field especially on birds and bees, as well as to find solutions to this issue. Hence, in the second meeting of the Expert Group held on 14.02.2011, a decision was taken to identify the gap areas in research on the issue of impact of radiations on wildlife including birds and bees.

Gap areas for research: Ample information on the impact of EMF on human health is available. However these results cannot be extrapolated to reflect impacts on wildlife impacts since the impact highly varies even within same species depending on multiple factors such as body size, age, earthing, fat content in the body, objects in the immediate vicinity and so on.

Not much data is also available on biological impacts on wild species except for a few species like sparrows and bees. Even this little available information is not reflective of the impact of present background levels of radiation. Information on effects with regards to specific frequencies and species response is lacking. Data on navigation and seasonal migrations as indicated by studies on homing pigeons (Kirchwink 1982) are lacking from the Indian context.

The current ICNIRP guidelines on EMF are developed based especially on laboratory studies, epidemiological data on humans, occupational exposures, in-vitro investigations, observations on cellular changes under control conditions etc. Ecological issues appear to be hardly taken care of. One needs to acknowledge that laboratory observations need not necessarily reflect field effects. Therefore we have to re-visit the guidelines taking account low level electro-smog on wild species especially birds, bees, amphibians etc and modify them accordingly. Our guidelines need to be refined since the ICNIRP Standard currently followed in India is coined based on only thermal impact of RF and is dismissive of current epidemiological evidence on impacts of non-thermal nature on chronic exposure from multiple towers. The limit on whole-body average SAR is 0.08 W/kg. It is a long way to go before we can have the required long-term 'Species specific data' to decide on the threshold exposure levels for various wildlife species. Till such time a **precautionary principle approach to be used to minimize the exposure levels and we may have to move ahead and adopt stricter norms followed in some other countries like Russia, China, New Zealand etc.**

Since EMF being an invisible form of pollution there needs to be an independent system for monitoring of EMF pollution across the country.

The EMF pollution has reportedly caused population declines on sparrows and bees (causing disorientation and Colony Collapse Disorder (CCD). It has also resulted in aversive behaviour in bats and sparrows, abnormal behaviour in Tits, Kestrels, reproductive failure in White Storks and also fatal bird collisions with involving communication towers causing the death of several million birds of 230 species each year in the USA alone. However, sound scientific investigations in this regard are lacking in India and such studies needs to be undertaken on an urgent basis.

The following areas for specific studies are suggested to be taken up:

- Field studies on impact of cell towers on bee colonies and apiculture,
- Bird/bat/insect mortalities at mobile phone towers with special reference to towers along bird migratory paths,
- Studies on birds / bats / bees to find the effect of EMR on their communication, orientation and co-ordination
- Effect of EMF on amphibian metamorphosis and sex determination in reptiles
- Laboratory studies to develop an understanding on certain species, on their physiological and behavioural aspects, making use of the techniques of bioassay/bio-monitoring
- Measurement, monitoring and mapping of background EMF levels and power density across India involving independent research agencies.
- Regulations/standards to include the ecological characteristics of an area while determining the location of transmission towers, relay stations etc
- Regulations to control installation of transmission towers in human residences/hospitals/dense habitations
- Conduct ecological impact assessment of transmission towers and base stations, with standardised protocols/parameters

Future Scenario

India is one of the fastest growing mobile telephony industries in the world. It is estimated that by 2013, 1 billion plus people will be having cell phone connection in India. With the growth of cell phone subscriber, it has also lead to growth of infrastructure in the form of mobile phone towers. Today, in absence of any policy on infrastructure development and location of cell phone towers, large number of mobile phone towers are being installed in a haphazard manner across urban and sub urban habitats in India.

Along with the growth of phone towers and subscribers, India is also witnessing a rapid population growth. To feed and support this rapidly growing population the agricultural security and the factors influencing them should be of concern. However, the population of many species such as honey bees, which is one of the most important pollinator and important factor for agricultural productivity, has seen a drastic population drop.

Precautionary approach

Throughout the world there has been a growing movement to adopt a precautionary approach. The WHO defines the Precautionary Principle as a risk management concept that provides a flexible approach to identify and manage possible adverse consequences to human health even when it has not been established that the activity or exposure constitutes harm to health.

It is the WHO's view that scientific assessments of risk and science-based exposure limits should not be undermined by the adoption of arbitrary cautionary approaches. The compliance of mobile phone networks and handsets with the ACMA regulations is regarded as a prudent and cautious approach to ensure that the community is not adversely affected by, but benefits from developments in communications.

The Department Of Telecom has constituted an Inter-Ministerial Committee to examine the effect of EMF Radiation on health. The report of the committee is placed in DOT website. The IMC report is under examination of DOT at present.

Recommendations

Following recommendations have been put forward by few members of the Committee:

1) EMF should be recognised as a pollutants/ regular auditing of EMF should be conducted in urban localities/educational/hospital/industrial/residential/recreational premises and around the protected areas and ecologically sensitive areas.
2) Introduce a law for protection of urban flora and fauna from emerging threats like ERM/EMF as conservation issues in urban areas are different from forested or wildlife habitats.
3) Bold signs and messages on the dangers of Cell phone tower and radiation which is emitted from it are displayed in and around the structures where the towers are erected. Use visual daytime markers in areas of high diurnal raptor or waterfowl movements.
4) To avoid bird hits, security lighting for on-ground facilities should be minimized and point downwards or be down-shielded.
5) Independent monitoring of radiation levels and overall health of the community and nature surrounding towers is necessary to identify hazards early.Access to tower sites should be allowed for monitoring radiation levels and animal mortality, if any.
6) Procedure for removal of existing problematic mobile towers should be made easy, particularly in and around protected area or urban parks and centres having wildlife .
7) Strictly control installation of mobile towers near wildlife protected areas, Important Bird Areas, Ramsar Sites, turtle breeding areas, bee colonies, zoos, etc up to a certain distance that should be studied before deciding and should also be practical. Ecological assessment / review of sites identified for installing towers before their installation also may be considered in wildlife / ecologically / conservational important areas.
8) The locations of Cell phone towers and other EMF radiating towers along with their frequencies should be made available on public domain. This can be at city/ district/ village level. Location wise GIS mapping of all cell phone towers be done by DoT. This information will help in monitoring the population of birds and bees in and around the mobile towers and also in and/or around wildlife protected areas.
9) Public consultation to be made mandatory before installation of cell phones towers in any area. The Forest Department should be consulted before installation of cell phone towers in and around PAs and zoos. The distance at which these towers should be installed should be studied case by case basis.
10) Awareness drive with high level of visibility in all forms of media and regional languages should be undertaken by the Government to make people aware about various norms in regard to cell phone towers and dangers from EMR. Such notices should be placed in all wildlife protected areas and in zoos.
11) To prevent overlapping high radiations fields, new towers should not be permitted within a radius of one kilometer of existing towers.

12) If new towers must be built, construct them to be above 80 ft and below 199 ft. tall to avoid the requirement for aviation safety lighting. Construct unguyed towers with platforms that will accommodate possible future co-locations and build them at existing 'antenna farms', away from areas of high migratory bird traffic, wetlands and other known bird areas.

Note: Many of the above recommendations have already been given by Government of Delhi and West Bengal (appendix III). The Supreme Court of India has sought explanation from all mobile phone operators and various government and semi-government agencies over the issue of alleged "illegal" and unregulated constructions of mobile phone towers on top of buildings across the country (see www.thehindubusinessline.in/2005/09/27/stories/2005092703950900.htm). Similarly, recent rulings in June 2011 by Punjab and Haryana High Courts also direct the government to inform public about the health hazards (www.indianexpress.com/news/Inform/public/about/health/hazards/of/mobile/tower//HC-to-Govt/800786/).

Conclusion

The review of existing literature shows that the EMRs are interfering with the biological systems in more ways than one and there had already been some warning bells sounded in the case on bees (Warnke 2007; vanEngelsdorp *et al.* 2010; Gould 1980; Sharma and Neelima R Kumar 2010) and birds, which probably heralds the seriousness of this issue and indicates the vulnerability of other species as well. Despite a few reassuring reports (Galloni *et al.* 2005), a vast majority of published literature indicate deleterious effects of EMFs in various species. The window of frequency range and exposure time required to make measurable impacts would vary widely among species and unfortunately we do not have any such data available for most of our free-living floral and faunal species in India. There is an urgent need to focus more scientific attention to this area before it would be too late.

Microwave and radiofrequency pollution appears to constitute a potential cause for the decline of animal populations (Balmori 2006; Balmori and Hallberg 2007; Balmori Martínez 2003; Joris and Dirk 2007; Summers-Smith 2003) and deterioration of health of plants and humans living near radiation sources such as phone masts. Studies have indicated the significant non-thermal long-term impacts of EMFs on species, especially at genetic level which can lead to various health complications including brain tumours (glioma), reduction in sperm counts and sperm mobility, congenital deformities, Psychiatric problems (stress, 'ringxity', sleep disorders, memory loss etc.) and endocrine disruptions. However similar aspects are yet to be studied among animal populations.

Pollution from EMRs being a relatively new environmental issue, there is a lack of established standard procedures and protocols to study and monitor the EMF impacts especially among wildlife, which often make the comparative evaluations between studies difficult. Moreover, there are no long-term data available on the environmental impacts of EMRs as of now. Well-designed long-term impact assessment studies would be required to monitor the impact of ever-increasing intensities of EMRs on our biological environment. Meanwhile the precautionary principle should prevail and we need to better our standards on EMF to match the best in the world.

Studies on impact of Cell phone tower radiation on Birds and wildlife are almost non-existent from India. There is an urgent need for taking up well designed studies to look into this aspect. Available information from the country on the subject of EMF impacts is restricted to few reports from honey-bees. However, these studies are not representative of the real life situations or natural levels of EMF exposure. More studies need to be taken up to scientifically establish if any, the link between the observed abnormalities and disorders in bee hives such as Colony Collapse Disorder (CCD).

Appendices

Appendix I: Photographs showing mobile towers

Appendix II: Precuationary boards about mobile towers

Appendix III: GRs of Delhi and West Bengal Governments

Appendix IV: Bibliography

Members of the Expert Committee

1. Dr. Asad Rahmani, Director, BNHS (Chairman)
2. Representative of Wildlife Institute of India (Dr. Dhananjai Mohan, Dr. B.C. Choudhary)
3. Representative of Deptt. of Telecommunications, New Delhi [Shri. P. K. Panigrahi, Sr. DDG (BW)]
4. Representative of the Centre for Environment & Vocational Studies, Punjab University
5. Representatives of WWF India (Gp Captain Naresh Kapalia, Dr. Parikshit Gautam)
6. Representative of Indian Institute of Science, Bangalore (Prof. H.S. Jamadagni)
7. Representative of Indian Institute of Technology, New Delhi (Prof. R.K. Patney, Deptt. of Electrical Engineering)
8. Representative of SACON (Dr. P.A. Azeez, Director, Dr. Arun Kumar)
9. Dr. Sainuddin Pattazhy, Associate Professor, Deptt. of Zoology, University of Kerala
10. Ms. Prakriti Srivastava, DIG(WL), MoEF (Member Secretary)

Appendix I

Cell phone Towers on commercial and residential Structures

Cell Phone Tower

26

Cell Phone towers near Keoladeo National Park, Bharatpur, Rajasthan

Appendix II

Precautionary Boards (Some samples)

AREA DEMARCATION

CAUTION

RADIOFREQUENCY RADIATION

- Area of Unrestricted Occupancy
- Minor Injury Possible from Misuse

WARNING

RADIOFREQUENCY RADIATION

- Area of Restricted Occupancy (RF Workers Only)
- Serious Injury Possible from Misuse

DANGER

RADIOFREQUENCY RADIATION

- Area of Denied Occupancy
- Critical Injury or Death Possible

Appendix III

Delhi
Government

Vivek Rao
Principal Secretary (Health & FW)

D.O.No. 141 / Exposure of Electromagnetic / PS secy hfw / 133-141 /
Dated 10/01/2008

Dear

The existing guidelines for granting permission for installation of towers on ground/roof tops for Cellular Mobile Phone Services finalized pursuant to a meeting held at Raj Niwas on 26.7.2002 have been reviewed on the basis of certain representations from the public and it has been decided that henceforth such towers in residential areas should be permitted only in consultation with the concerned Resident Welfare Associations and not left to bilateral negotiations between Telecom companies and individual residents/house owners. In this regard the following additional precautionary measures are also recommended for adoption by the local authorities:

* Installation of Base Station Antennas within the premises of schools and hospitals may be avoided because children and patients are more susceptible to Electro Magnetic Field.

* Installation of Base Station Antennas in narrow lanes should be avoided in order to reduce the risks caused by any earth quake or wind related disaster.

* The Base Station Antennas should be at least 3 m away from the nearby building and antennas should not directly face the building. Further, the lower end of the antenna should be at least 3 meter above the ground or roof.

* In case of multiple transmitter sites at a specific locality sharing of a common tower infrastructure, should be explored, as far as possible, which can be coordinated through a nodal agency.

* Access to Base Station Antenna sites should be prohibited for general public by suitable means such as wire fencing, locking of the door to the roof etc. Access to tower site, even for the maintenance personnel, should be for a minimum period as far as possible.

* Sign boards/Warning Signs are to be provided at Base Station Antenna sites which should be clearly visible and identifiable. A warning sign should be placed at the entrance of such zone.

Contd....2/-

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* The "Warning Sign" should discourage longer stay in the zone, even for the maintenance personnel. The sign board may contain the following text:

j. Danger! RF radiations, Do not enter!
ii. Restricted Area

* The operators and maintenance personnel, who are dealing with radio frequency devices, specially with Base Station Antennas installed on towers and at any other outdoor sites, should be protected from electromagnetic radiations. It is required that operators and maintenance personnel should be educated for possible hazards from these devices.

This issues with the approval of LG.

With regards,

Yours sincerely,

(Vivek Rae)

To

1. Shri Ashok Nigam, Commissioner, MCD, Delhi
2. Shri Dinesh Rai, VC, DDA, Delhi
3. Shri Parimal Rai, Chairperson, NDMC, New Delhi

Copy to the following:

1. Principal Secretary to LG, Raj Niwas, Delhi.
2. Principal Secretary to CM, Delhi
3 Pr.Secretary(Urban Development), GNCT of Delhi
4 Secretary (Environment), Govt. of NCT of Delhi, Delhi.
5 Shri T.V.Ramachandran, Director General, Cellular Operators Association of India, 14, Bhai Veer Singh Marg, New Delhi-01.
6 Shri S.C.Khanna, Secretary General, Association of Unified Telecom Service Providers of India, B-601, Gauri Sadan, 5, Hailey Road, New Delhi-01.

(Vivek Rae)

West Bengal Government

In case of non-compliance of the aforementioned directions, regulatory order will be issued in accordance with law.

By Order,
Sd/-
(M. L. Meena)
Principal Secretary,
Department of Environment

No. EN/ 939 /T-IV-1/001/2006 Dated: April 24th., 2008

Copy forwarded to :-

1. The Incharge, M/s. Bharti Mobitel Limited (Airtel), Infinity Building, 5th. Floor, Salt Lake Electronics Complex, Bidhannagar, Block G.P. Sector-V, Kolkata-700091.
2. The Incharge, Vodafone Essar East Limited (Vodafone), Constantia Office Complex, 4th. Floor, 11, Dr. U.N. Brahmachari Road, Kolkata-700017.
3. The Incharge, Aircel Business Solutions (Aircel), Benfish Bhavan, No. 31, GN Block, 5th. Floor, Sector-V, Salt Lake, Kolkata-700 091.
4. The Incharge, Tata Teleservices Limited (Tata Indicom), C/o. Videsh Sanchar Bhawan, Camp Office- 1/18, C.I.T. Scheme, VII M, Ultandaga, Kolkata-700054.
5. The Incharge, Bharat Sanchar Nigam Limited (BSNL Mobile), Telephone Kendra, P-10, New CIT Road, Kolkata-700073.
6. The Chairman, West Bengal Pollution Control Board.
7. The Member-Secretary, Central Pollution Control Board, Paribesh Bhawan, CBD-cum-Office Complex, East Arjun Nagar, Delhi-110032.
8. The Chief Environment Officer, Department of Environment, Govt. of West Bengal.
9. The Member-Secretary, West Bengal Pollution Control Board, 'Paribesh Bhawan', Salt Lake City, Kolkata-700098.
10. The Commissioner, Kolkata Municipal Corporation, 5, S.N. Banerjee Road, Kolkata-700013.
11. The Commissioner, Howrah Municipal Corporation, Howrah.
12. The Chief Executive Officer, ____________________
13. The Executive Officer, ____________________
14. The Secretary, ...Zilla Parishad.

with a request to circulate this memo. to the Panchayats for Information and necessary action.

15. The District Magistrate____________________

Sd/-

HENCE, in exercise of the powers conferred under Environment (Protection) Act, 1986 and rules made thereunder, all mobile phone service providers are hereby directed to follow the following guidelines strictly at the time of installation of the mobile towers.

- Installation of Base Station Antennas within the premises of schools and hospitals may be avoided because children and patients are more susceptible to Electro Magnetic Field.

- Installation of Base Station Antennas in narrow lanes should be avoided in order to reduce the risks caused by any earth quake or wind related disaster.

- The Base Station Antennas should be at least 3 m away from the nearby building and antennas should not directly face the building. Further, the lower end of the antenna should be at least 3 metre above the ground or roof.

- In case of multiple transmitter sites at a specific locality sharing of a common tower infrastructure, should be explored, as far as possible, which can be coordinated through a nodal agency.

- Access to Base Station Antenna sites should be prohibited for general public by suitable means such as wire fencing, locking of the door to the roof etc. Access to tower site, even for the maintenance personnel, should be for a minimum period as far as possible.

- Sign boards/Warning Signs are to be provided at Base Station Antenna sites which should be clearly visible and identifiable. A warning sign should be placed at the entrance of such zone.

- The "Warning Sign" should discourage longer stay in the zone, even for the maintenance personnel. The sign board may contain the following text :

  i. Danger ! RF radiations, Do not enter !
  ii. Restricted Area.

  The operators and maintenance personnel, who are dealing with radio frequency devices, specially with Base Station Antennas installed on towers and at any other outdoor sites, should be protected from electromagnetic radiations. It is required that operators and maintenance personnel should be educated for possible hazards from these devices.

All local authorities are also requested that before giving any permission for installation of the mobile towers aforementioned guidelines should be

Appendix IV

Bibliography

List of Scientific Papers (n=919) on Impact of EMFs classified Subject-wise
Each bibliographic entry is marked with category codes in squire brackets []

B= Birds; E= Bees; H = Humans; W= Animals/Wildlife; P= Plants
+ = Impact reported; - = No Impact; * = Inconclusive/ Impact not evaluated

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Examples of Published Research on 4G LTE

The fourth generation (4G) of cellular technology called Long Term Evolution (LTE) was launched without premarket safety testing for long term exposure. Published research has found adverse effects from exposure.

The study Early-Life Exposure to Pulsed LTE Radiofrequency Fields Causes Persistent Changes in Activity and Behavior in C57BL/6 J Mice found behavioral changes in mice (Broom et al., 2019)

The study Long-term exposure to 4G smartphone radiofrequency electromagnetic radiation diminished male reproductive potential by directly disrupting Spock3–MMP2-BTB axis in the testes of adult rats - ScienceDirect found damage to the testes and reproductive potential in mice (Yu et al., 2019).

The study Short-term radiofrequency exposure from new generation mobile phones reduces EEG alpha power with no effects on cognitive performance found a reduction to EEG alpha power (Vecsei et al., 2018).

The study Long-Term Evolution Electromagnetic Fields Exposure Modulates the Resting State EEG on Alpha and Beta Bands - Lei Yang, Qinghua Chen, Bin Lv, Tongning Wu, 2017 found modulation to resting state EEG on alpha and beta bands (Yang et al., 2017).

The study The alteration of spontaneous low frequency oscillations caused by acute electromagnetic fields exposure - ScienceDirect found alteration of spontaneous low frequency fluctuations induced by the acute LTE RF-EMF exposure (Lv et al., 2014).

The study Modulation of resting-state brain functional connectivity by exposure to acute fourth-generation long-term evolution electromagnetic field: An fMRI study - Wei - 2019 - Bioelectromagnetics - Wiley Online Library published in Bio Electro Magnetics, found that acute LTE-EMF exposure did modulate connectivity in some brain regions. The authors conclude that, "Our results may indicate that approaches relying on network-level inferences can provide deeper insights into the acute effects of LTE-EMF exposure with intensities below the current safety limits on human functional connectivity. In the future, we need to investigate the evolution of the effect over time" (Wei et al., 2018).

The study The effect of 4.5 G (LTE Advanced-Pro network) mobile phone radiation on the optic nerve found that exposure to 4.5 G mobile phone radiation for two hours per day over a six week period caused significant damage to the optic nerve in rats. The authors concluded:

“The optic nerve transmits all visual information to the visual cortex, and any damage in this nerve can cause permanent and serious vision loss. This study demonstrated that RF exposure may be an environmental risk factor for eye toxicity and potential eye disorders. Further studies are needed to reveal the potentiality of the risk in this area.”

The study Exposure to 1800 MHz LTE electromagnetic fields under proinflammatory conditions decreases the response strength and increases the acoustic threshold of auditory cortical neurons | Scientific Reports found in adult male rats undergoing acute neuroinflammation, an exposure to LTE-1800 MHz with a local SARACx of 0.5 W/kg resulted in changes in neuronal activity. “In conclusion, our study reveals that a single head-only exposure to LTE-1800 MHz can interfere with the neuronal responses of cortical neurons to sensory stimuli. In line with previous characterizations of the effect of GSM-signal, our results show that the impact of LTE signal on neuronal activity varies according to the health state. Acute neuroinflammation sensitize neuronal responses to LTE-1800 MHz, resulting in altered cortical processing of auditory stimuli.”

The study Electromagnetic pollution alert: Microwave radiation and absorption in human organs and tissues “conducted tests in 1 GHz to 105 GHz system settings, covering most microwave frequency uses: 2.4 GHz of 4G-LTE, Wi-Fi, Bluetooth, ZigBee and the 5G ranges: 28 GHz of 5G-mmW and 95 GHz of 5G-IoT. Trial human organs and tissues were placed in the wave propagation direction of 2.4 GHz and 28 GHz dipole antennas, and a waveguide port operating from 95 to 105 GHz. The quantitative data on the effects of 5G penetration and dissipation within human tissues are presented. The absorbance in all organs and tissues is significantly higher as frequency increases. As the wave enters the organ-tissue model, the wavelength is shortened due to the high organ-tissue permittivity. Skin-Bone-Brain layer simulation results demonstrate that both electric and magnetic fields vanish before passing the brain layer at all three focal frequencies of 2.4 GHz, 28 GHz and 100 GHz.”

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Report

Cite this article: Bartos P, Netusil R, Slaby P, Dolezel D, Ritz T, Vacha M. 2019 Weak radiofrequency fields affect the insect circadian clock. *J. R. Soc. Interface* **16**: 20190285. http://dx.doi.org/10.1098/rsif.2019.0285

Received: 22 April 2019
Accepted: 29 August 2019

Subject Category:
Life Sciences–Physics interface

Subject Areas:
biophysics, environmental science, biochemistry

Keywords:
radiofrequency field, circadian clock, magnetoreception, magnetic field, insects, free-running rhythm

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Electronic supplementary material is available online at https://doi.org/10.6084/m9.figshare.c.4656158.

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Weak radiofrequency fields affect the insect circadian clock

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It is known that the circadian clock in *Drosophila* can be sensitive to static magnetic fields (MFs). Man-made radiofrequency (RF) electromagnetic fields have been shown to have effects on animal orientation responses at remarkably weak intensities in the nanotesla range. Here, we tested if weak broadband RF fields also affect the circadian rhythm of the German cockroach (*Blatella germanica*). We observed that static MFs slow down the cockroach clock rhythm under dim UV light, consistent with results on the *Drosophila* circadian clock. Remarkably, 300 times weaker RF fields likewise slowed down the cockroach clock in a near-zero static magnetic field. This demonstrates that the internal clock of organisms can be sensitive to weak RF fields, consequently opening the possibility of an influence of man-made RF fields on many clock-dependent events in living systems.

1. Introduction

Radiofrequency (RF) fields accompanying modern man are suspected to interfere with biological processes and have been extensively examined (reviewed e.g. in [1,2]). The impact of electromagnetic noise on animal magnetoreception is well documented and the compass sense of birds [3–7], mice [8] and arthropods [9,10] was lost or biased [11] if animals were exposed to RF. RF fields have been suggested to interfere specifically with radical-pair (RP) magnetoreception mechanism [3,12–14], and it has been suggested that key steps in magnetic field (MF) reception may be mediated by Cryptochrome protein (Cry) ([12], reviewed in [15]). Gene silencing identified *Blatella germanica* Cry as essential for detection of directional changes in MFs [16]. Cry is known to be a component of the biological clock system. Two independent studies have shown that static MFs with intensities comparable to the Earth's MF changed the circadian rhythm in *Drosophila* [17,18]. The MF effect was dependent on functional *cry* gene and the wavelength of light. Aside from magnetoreception and the circadian clock, Cry is involved in several cellular and organismal functions [19,20] and pathologies [21,22]. The possibility that MF and especially widespread weak RFs interfere with Cry cellular tasks in general is both intriguing and pungent. Here, we set out to investigate if the circadian rhythm of *Blatella* is affected by MFs and weak broadband RF fields.

2. Results and discussion

To explore a role of magnetic and RF fields on the circadian clock, we investigated the free-running rhythm of locomotor activity of the German cockroach (*Blatella germanica*) in darkness and two intensities of UV 365 nm light combined with three intensities of static MF and three intensities of RF fields.

First, two intensities of UV 365 nm constant light which reliably lengthen but still not abolish the free-running period were set: dimmer: 1.7×10^{-6} Wcm^{-2} and

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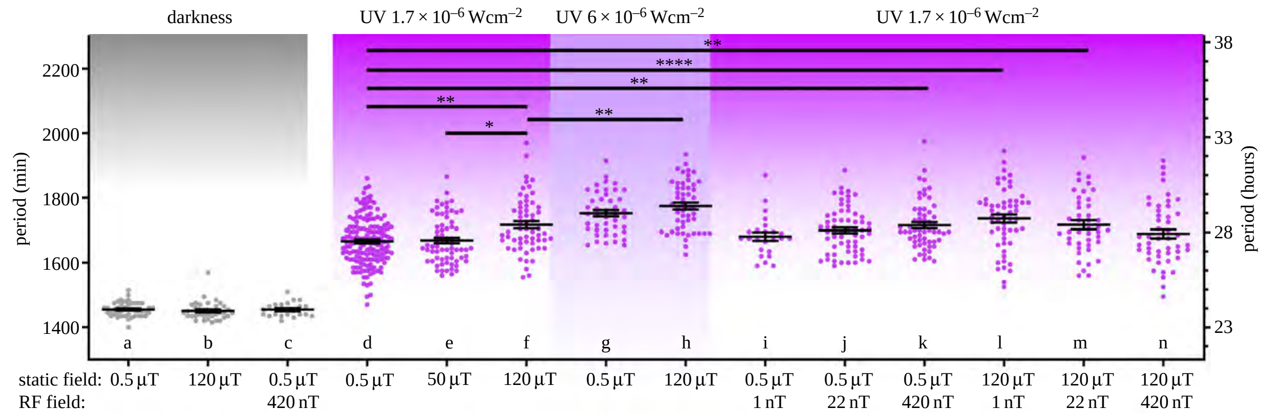

Figure 1. Periods of locomotor activity under permanent darkness or UV light 365 nm. The light lengthens the period proportionally to its intensity as well as static 120 µT and 420 nT RF field separately do. Light is necessary for both MF and RF fields effects. The threshold is between 50 and 120 µT for MF and between 22 and 420 nT for RF. Mean with s.e.m. are figured, Tukey's multiple comparisons test used, **$p < 0.05$, ***$p < 0.01$, ****$p < 0.001$, for all significant differences, *****$p < 0.0001$, see electronic supplementary material, figure S1. (Online version in colour.)

brighter: 6×10^{-6} Wcm^{-2}. When keeping the MF at both 0.5 µT and 120 µT, the observed lengthening of the free-running period in *Blatella* reflects the intensity of light (electronic supplementary material, figure S1 and figure 1f,h) and is consistent with *D. melanogaster* results [17].

As a second step, the role of a static MF was tested. In the dimmer UV light 1.7×10^{-6} Wcm^{-2}, we used three intensities: near-zero 0.5 µT (figure 1d), Earth-like 50 µT (figure 1e) and hypermagnetic 120 µT (figure 1f). While significant lengthening of the period was evident when the MF was strengthened from 50 µT to 120 µT, no change of the period occurred between 0.5 and 50 µT (figure 1). Under brighter light 6×10^{-6} Wcm^{-2}, lengthening of the period between 0.5 µT (figure 1g) and 120 µT (figure 1h) was not significant, likely to be due to getting close to saturation limit. The system clearly needs the light to become magnetosensitive as no change of the rhythm was detected in darkness. The static MF effects observed in our study are clearly dependent on the presence, intensity and wavelength of light—all in line with two *Drosophila* reports from Yoshii *et al*. [17] and Fedele *et al*. [18].

In our system, the application of a 120 µT MF slowed down the circadian rhythm compared to both 0.5 and 50 µT fields and resembles the impact of UV light (figure 1). However, the same-treatment under 505 nm green light 4.5×10^{-6} Wcm^{-2} shortened the period of the rhythm (electronic supplementary material, figure S2). Antagonistic effects of UV-blue versus blue-green parts of the spectra have been reported several times in animal magnetoreception (rev. e.g. in [23]) and provide the most likely explanation for ambiguous or opposite responses of *Drosophila* clock system to MFs [17,18]. The nature of this antagonism is beyond the scope of our work, but is clearly in line with involvement of light-dependent magnetoreception in animal clock systems.

Having established that static MF effects occur on the cockroach circadian clock, we turn to studying the effects of weak RF MFs. In this study, we choose to apply RF broadband noise of different intensities, because it has been argued that such fields may be a promising diagnostic test for the presence of an underlying RP mechanism [13].

Application of RF broadband noise in near-zero MF and dim 1.7×10^{-6} Wcm^{-2} UV light did not have a significant effect for a 1 nT (figure 1i) or 22 nT RF field (figure 1j), but reached significant level of slowing the rhythm for a 420 nT RF field (figure 1k), when compared with the near-zero MF dim UV light condition without an RF field (figure 1d). Therefore, the effect of the 400 nT RF field (figure 1k) was statistically indistinguishable from the effect of the 120 µT static MF (figure 1f). In contrast to the effects under dim UV light, no effect of a 420 nT broadband RF field could be observed in darkness (figure 1c), just as no effects of a 120 µT could be observed in darkness (figure 1b). This suggests a similar mechanism of action of the RF broadband field to the static MF. However, it is noteworthy that the intensity of the RF field required to slow down the circadian clock was much lower than that required for a static MF to do the same. The threshold for static MF field effects to occur lies between 50 and 120 µT, indicating that the clock system is between 100 and 300 times more sensitive to RF field than to static MF.

When RF broadband noise combined with 120 µT MF and dim 1.7×10^{-6} Wcm^{-2} UV light were applied, no significant effects on the circadian clock were seen for 1 nT (figure 1l) and 22 nT (figure 1m) RF fields again. Nevertheless, a subtractive relationship may be hypothesized for RFs and MF if applied simultaneously since a combination of maximal RF 420 nT and maximal MF 120 µT (figure 1n) did not differ from control near-zero condition (figure 1d). Such interference between MFs and RFs has its parallel in experiments on animal orientation discussed above but its physical nature, likely to be dependent on the (an)isotropy of hyperfine interactions within RP (P Hore 2018, personal communication), is beyond the scope of the work. The observed threshold of broadband RF field effects between 22 and 420 nT should be considered dependent on background MF and light intensities, hence potentially, even more sensitive. Should the sensitivity of the clock system be as high as to about tens of nT of cumulative intensity, biological experiments in standard laboratories or incubators may face biasing problems, because background RF intensity may often reach this level (electronic supplementary material, figure S3; 30 nT for bench measurement outside the shielded chamber).

3. Conclusion

Our data show that the circadian rhythm of the insect species *B. germanica* is sensitive to both static MF and RF fields in a light-dependent manner. While a number of studies have shown physiological effects of weak RF fields as mentioned in the Introduction, all of these effects were observed on magnetic orientation responses of the respective animals and one might therefore argue that the effects of RF fields may be limited to highly specialized responses of navigating animals. Having no ambitions to explain the nature of observed phenomena, our study provides evidence that weak broadband RF noise impacts the insect clock system which turned out to be even more sensitive to RF than to static MFs. Studies of free-running period are always performed under artificial conditions devoid of any natural synchronizing inputs (Zeitgebers) which limits all conclusions referring to normal conditions on the Earth. Nevertheless, since the number of circadian clock-dependent health problems grows in population and since urban areas are polluted by RF noise even more than it was used in this study (e.g. [6]), the evidence of interference between RF and clock controlling systems is worth of concern and deep investigation.

4. Material and methods

4.1. Testing scheme

Adult German cockroaches immobilized by CO_2 were individually and regardless of sex transferred into glass Petri dishes on a layer of transparent agarose gel. Forty dishes were placed on a glass pane on a wooden table into an electromagnetically shielded chamber illuminated from above and monitored by a camera from below. Silhouettes of cockroaches were captured every 5 min for 14 days and free-running movement rhythms were investigated. Thermal (23.8°C ± 0.6°C), light and magnetic conditions were held constant for the entire testing period and were checked prior to and after the experiment. Different experimental conditions alternated (see table of primary data available online). Experimenter and data evaluator were always blind as to what type of RF field and MF were set.

4.2. Light conditions

Two intensities of UV light (365 nm) and three intensities of green light (505 nm) and darkness were generated by LED lamps. Petri dishes had opaque white walls and a light-dispersing sheet of filter paper covered them.

4.3. Magnetic conditions

Three static MFs intensities were set: total vector 0.5 µT ± 0.4 µT (residual field, no current sent to coils), total vectors 50 µT and 120 µT (space deviation ± 0.5 µT) and inclinations 45° (chosen for technical reasons) were generated by three-dimensional Merritt coils (2.5 × 2.5 × 2.5 m) located inside the chamber and fed by custom-made, computer-controlled power supplies.

4.4. RF conditions

Four experimental intensities of the broad band RFs noise (of 0, 1, 22 and 420 nT) were generated by a loop antenna constructed as a single horizontal winding of coaxial cable around the walls of the chamber in the plane of the testing table. The shield of the coaxial cable was removed opposite the feed.

4.5. Evaluation and statistics

For motor activity detection, 4032 samples were analysed and the number of body shifts greater than 1 cm was calculated automatically using Matlab based custom-made image analysis software RoachLab. Actograms and their statistical significances were analysed by the Lomb–Scargle method plugin ActoJ of ImageJ software (1.49v; NIH). All tested conditions were visualized and statistically evaluated by ANOVA and Tukey's multiple comparisons test (GraphPad Prism 7.04). Only clearly rhythmic animals with statistical significance PN > 20 were scored and analysed (percentage of rhythmic animals is given in electronic supplementary material, figures S1 and S2).

Data accessibility. Complete list of primary data is available online at: https://is.muni.cz/www/vacha/supplementary_materials_blatella_rhythms/Blatella_rhythms_primary_data.xls.

Competing interests. We declare we have no competing interests.

Funding. M.V. acknowledges grant GAMU/MUNI/G/1391/2018. D.D. acknowledges GACR grant no. 17-01003S. T.R. acknowledges AFOSR grant no. FA9550-14-1-0409.

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frontiers in Public Health

REVIEW
published: 13 August 2019
doi: 10.3389/fpubh.2019.00223

Risks to Health and Well-Being From Radio-Frequency Radiation Emitted by Cell Phones and Other Wireless Devices

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OPEN ACCESS

Edited by:
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Specialty section:
This article was submitted to Radiation and Health,
a section of the journal Frontiers in Public Health

Received: 10 April 2019
Accepted: 25 July 2019
Published: 13 August 2019

Citation:
Miller AB, Sears ME, Morgan LL, Davis DL, Hardell L, Oremus M and Soskolne CL (2019) Risks to Health and Well-Being From Radio-Frequency Radiation Emitted by Cell Phones and Other Wireless Devices. Front. Public Health 7:223.
doi: 10.3389/fpubh.2019.00223

Radiation exposure has long been a concern for the public, policy makers, and health researchers. Beginning with radar during World War II, human exposure to radio-frequency radiation[1] (RFR) technologies has grown substantially over time. In 2011, the *International Agency for Research on Cancer* (IARC) reviewed the published literature and categorized RFR as a "possible" (Group 2B) human carcinogen. A broad range of adverse human health effects associated with RFR have been reported since the IARC review. In addition, three large-scale carcinogenicity studies in rodents exposed to levels of RFR that mimic lifetime human exposures have shown significantly increased rates of Schwannomas and malignant gliomas, as well as chromosomal DNA damage. Of particular concern are the effects of RFR exposure on the developing brain in children. Compared with an adult male, a cell phone held against the head of a child exposes deeper brain structures to greater radiation doses per unit volume, and the young, thin skull's bone marrow absorbs a roughly 10-fold higher local dose. Experimental and observational studies also suggest that men who keep cell phones in their trouser pockets have significantly lower sperm counts and significantly impaired sperm motility and morphology, including mitochondrial DNA damage. Based on the accumulated evidence, we recommend that IARC re-evaluate its 2011 classification of the human carcinogenicity of RFR, and that WHO complete a systematic review of multiple other health effects such as sperm damage. In the interim, current knowledge provides justification for governments, public health authorities, and physicians/allied health professionals to warn the population that having a cell phone next to the body is harmful, and to support measures to reduce all exposures to RFR.

Keywords: brain cancer, electromagnetic hypersensitivity, glioma, non-cancer outcomes, policy recommendations, radiofrequency fields, child development, acoustic neuroma

[1] Per IEEE C95.1-1991, the radio-frequency radiation frequency range is from 3 kHz to 300 GHz and is non-ionizing.

INTRODUCTION

We live in a generation that relies heavily on technology. Whether for personal use or work, wireless devices, such as cell phones, are commonly used around the world, and exposure to radiofrequency radiation (RFR) is widespread, including in public spaces (1, 2).

In this review, we address the current scientific evidence on health risks from exposure to RFR, which is in the non-ionizing frequency range. We focus here on human health effects, but also note evidence that RFR can cause physiological and/or morphological effects on bees, plants and trees (3–5).

We recognize a diversity of opinions on the potential adverse effects of RFR exposure from cell or mobile phones and other wireless transmitting devices (WTDs) including cordless phones and Wi-Fi. The paradigmatic approach in cancer epidemiology, which considers the body of epidemiological, toxicological, and mechanistic/cellular evidence when assessing causality, is applied.

CARCINOGENICITY

Since 1998, the *International Commission on Non-Ionizing Radiation Protection* (ICNIRP) has maintained that no evidence of adverse biological effects of RFR exist, other than tissue heating at exposures above prescribed thresholds (6).

In contrast, in 2011, an expert working group of the *International Agency for Research on Cancer* (IARC) categorized RFR emitted by cell phones and other WTDs as a Group 2B ("possible") human carcinogen (7).

Since the IARC categorization, analyses of the large international Interphone study, a series of studies by the Hardell group in Sweden, and the French CERENAT case-control studies, signal increased risks of brain tumors, particularly with ipsilateral use (8). The largest case-control studies on cell phone exposure and glioma and acoustic neuroma demonstrated significantly elevated risks that tended to increase with increasing latency, increasing cumulative duration of use, ipsilateral phone use, and earlier age at first exposure (8).

Pooled analyses by the Hardell group that examined risk of glioma and acoustic neuroma stratified by age at first exposure to cell phones found the highest odds ratios among those first exposed before age 20 years (9–11). For glioma, first use of cell phones before age 20 years resulted in an odds ratio (OR) of 1.8 (95% confidence interval [CI] 1.2–2.8). For ipsilateral use, the OR was 2.3 (CI 1.3-4.2); contralateral use was 1.9 (CI 0.9-3.7). Use of cordless phone before age 20 yielded OR 2.3 (CI 1.4–3.9), ipsilateral OR 3.1 (CI 1.6–6.3) and contralateral use OR 1.5 (CI 0.6–3.8) (9).

Although Karipidis et al. (12) and Nilsson et al. (13) found no evidence of an increased incidence of gliomas in recent years in Australia and Sweden, respectively, Karipidis et al. (12) only reported on brain tumor data for ages 20–59 and Nilsson et al. (13) failed to include data for high grade glioma. In contrast, others have reported evidence that increases in specific types of brain tumors seen in laboratory studies are occurring in Britain and the US:

- The incidence of neuro-epithelial brain cancers has significantly increased in all children, adolescent, and young adult age groupings from birth to 24 years in the United States (14, 15).
- A sustained and statistically significant rise in glioblastoma multiforme across all ages has been described in the UK (16).

The incidence of several brain tumors are increasing at statistically significant rates, according to the 2010–2017 *Central Brain Tumor Registry of the U.S.* (CBTRUS) dataset (17).

- There was a significant increase in incidence of radiographically diagnosed tumors of the pituitary from 2006 to 2012 (APC = 7.3% [95% CI: 4.1%, 10.5%]), with no significant change in incidence from 2012 to 2015 (18).
- Meningioma rates have increased in all age groups from 15 through 85+ years.
- Nerve sheath tumor (Schwannoma) rates have increased in all age groups from age 20 through 84 years.
- Vestibular Schwannoma rates, as a percentage of nerve sheath tumors, have also increased from 58% in 2004 to 95% in 2010-2014.

Epidemiological evidence was subsequently reviewed and incorporated in a meta-analysis by Röösli et al. (19). They concluded that overall, epidemiological evidence does not suggest increased brain or salivary gland tumor risk with mobile phone (MP) use, although the authors admitted that some uncertainty remains regarding long latency periods (>15 years), rare brain tumor subtypes, and MP usage during childhood. Of concern is that these analyses included cohort studies with poor exposure classification (20).

In epidemiological studies, recall bias can play a substantial role in the attenuation of odds ratios toward the null hypothesis. An analysis of data from one large multicenter case-control study of RFR exposure, did not find that recall bias was an issue (21). In another multi-country study it was found that young people can recall phone use moderately well, with recall depending on the amount of phone use and participants' characteristics (22). With less rigorous querying of exposure, prospective cohort studies are unfortunately vulnerable to exposure misclassification and imprecision in identifying risk from rare events, to the point that negative results from such studies are misleading (8, 23).

Another example of disparate results from studies of different design focuses on prognosis for patients with gliomas, depending upon cell phone use. A Swedish study on glioma found lower survival in patients with glioblastoma associated with long term use of wireless phones (24). Ollson et al. (25), however, reported no indication of reduced survival among glioblastoma patients in Denmark, Finland and Sweden with a history of mobile phone use (ever regular use, time since start of regular use, cumulative call time overall or in the last 12 months) relative to no or non-regular use. Notably, Olsson et al. (25) differed from Carlberg and Hardell (24) in that the study did not include use of cordless phones, used shorter latency time and excluded patients older than 69 years. Furthermore, a major shortcoming was that patients with the worst prognosis were excluded, as in Finland inoperable cases were excluded, all of which would bias the risk estimate toward unity.

In the interim, three large-scale toxicological (animal carcinogenicity) studies support the human evidence, as do modeling, cellular and DNA studies identifying vulnerable subgroups of the population.

The *U.S. National Toxicology Program* (NTP) (National Toxicology Program (26, 27) has reported significantly increased incidence of glioma and malignant Schwannoma (mostly on the nerves on the heart, but also additional organs) in large animal carcinogenicity studies with exposure to levels of RFR that did not significantly heat tissue. Multiple organs (e.g., brain, heart) also had evidence of DNA damage. Although these findings have been dismissed by the ICNIRP (28), one of the key originators of the NTP study has refuted the criticisms (29).

A study by Italy's Ramazzini Institute has evaluated lifespan environmental exposure of rodents to RFR, as generated by 1.8 GHz GSM antennae of cell phone radio base stations. Although the exposures were 60 to 6,000 times lower than those in the NTP study, statistically significant increases in Schwannomas of the heart in male rodents exposed to the highest dose, and Schwann-cell hyperplasia in the heart in male and female rodents were observed (30). A non-statistically significant increase in malignant glial tumors in female rodents also was detected. These findings with far field exposure to RFR are consistent with and reinforce the results of the NTP study on near field exposure. Both reported an increase in the incidence of tumors of the brain and heart in RFR-exposed Sprague-Dawley rats, which are tumors of the same histological type as those observed in some epidemiological studies on cell phone users.

Further, in a 2015 animal carcinogenicity study, tumor promotion by exposure of mice to RFR at levels below exposure limits for humans was demonstrated (31). Co-carcinogenicity of RFR was also demonstrated by Soffritti and Giuliani (32) who examined both power-line frequency magnetic fields as well as 1.8 GHz modulated RFR. They found that exposure to Sinusoidal-50 Hz Magnetic Field (S-50 Hz MF) combined with acute exposure to gamma radiation or to chronic administration of formaldehyde in drinking water induced a significantly increased incidence of malignant tumors in male and female Sprague Dawley rats. In the same report, preliminary results indicate higher incidence of malignant Schwannoma of the heart after exposure to RFR in male rats. Given the ubiquity of many of these co-carcinogens, this provides further evidence to support the recommendation to reduce the public's exposure to RFR to as low as is reasonably achievable.

Finally, a case series highlights potential cancer risk from cell phones carried close to the body. West et al. (33) reported four "extraordinary" multifocal breast cancers that arose directly under the antennae of the cell phones habitually carried within the bra, on the sternal side of the breast (the opposite of the norm). We note that case reports can point to major unrecognized hazards and avenues for further investigation, although they do not usually provide direct causal evidence.

In a study of four groups of men, of which one group did not use mobile phones, it was found that DNA damage indicators in hair follicle cells in the ear canal were higher in the RFR exposure groups than in the control subjects. In addition, DNA damage increased with the daily duration of exposure (34).

Many profess that RFR cannot be carcinogenic as it has insuÿ cient energy to cause direct DNA damage. In a review, Vijayalaxmi and Prihoda (35) found some studies suggested significantly increased damage in cells exposed to RF energy compared to unexposed and/or sham-exposed control cells, others did not. Unfortunately, however, in grading the evidence, these authors failed to consider baseline DNA status or the fact that genotoxicity has been poorly predicted using tissue culture studies (36). As well funding, a strong source of bias in this field of enquiry, was not considered (37).

CHILDREN AND REPRODUCTION

As a result of rapid growth rates and the greater vulnerability of developing nervous systems, the long-term risks to children from RFR exposure from cell phones and other WTDs are expected to be greater than those to adults (38). By analogy with other carcinogens, longer opportunities for exposure due to earlier use of cell phones and other WTDs could be associated with greater cancer risks in later life.

Modeling of energy absorption can be an indicator of potential exposure to RFR. A study modeling the exposure of children 3–14 years of age to RFR has indicated that a cell phone held against the head of a child exposes deeper brain structures to roughly double the radiation doses (including fluctuating electrical and magnetic fields) per unit volume than in adults, and also that the marrow in the young, thin skull absorbs a roughly 10-fold higher local dose than in the skull of an adult male (39). Thus, pediatric populations are among the most vulnerable to RFR exposure.

The increasing use of cell phones in children, which can be regarded as a form of addictive behavior (40), has been shown to be associated with emotional and behavioral disorders. Divan et al. (41) studied 13,000 mothers and children and found that prenatal exposure to cell phones was associated with behavioral problems and hyperactivity in children. A subsequent Danish study of 24,499 children found a 23% increased odds of emotional and behavioral diÿ culties at age 11 years among children whose mothers reported any cell phone use at age 7 years, compared to children whose mothers reported no use at age 7 years (42). A cross-sectional study of 4,524 US children aged 8–11 years from 20 study sites indicated that shorter screen time and longer sleep periods independently improved child cognition, with maximum benefits achieved with low screen time and age-appropriate sleep times (43). Similarly, a cohort study of Swiss adolescents suggested a potential adverse effect of RFR on cognitive functions that involve brain regions mostly exposed during mobile phone use (44). Sage and Burgio et al. (45) posit that epigenetic drivers and DNA damage underlie adverse effects of wireless devices on childhood development.

RFR exposure occurs in the context of other exposures, both beneficial (e.g., nutrition) and adverse (e.g., toxicants or stress). Two studies identified that RFR potentiated adverse effects of lead on neurodevelopment, with higher maternal use of mobile phones during pregnancy [1,198 mother-child pairs, (46)] and

Attention Deficit Hyper-activity Disorder (ADHD) with higher cell phone use and higher blood lead levels, in 2,422 elementary school children (47).

A study of Mobile Phone Base Station Tower settings adjacent to school buildings has found that high exposure of male students to RFR from these towers was associated with delayed fine and gross motor skills, spatial working memory, and attention in adolescent students, compared with students who were exposed to low RFR (48). A recent prospective cohort study showed a potential adverse effect of RFR brain dose on adolescents' cognitive functions including spatial memory that involve brain regions exposed during cell phone use (44).

In a review, Pall (49) concluded that various non-thermal microwave EMF exposures produce diverse neuropsychiatric effects. Both animal research (50–52) and human studies of brain imaging research (53–56) indicate potential roles of RFR in these outcomes.

Male fertility has been addressed in cross-sectional studies in men. Associations between keeping cell phones in trouser pockets and lower sperm quantity and quality have been reported (57). Both *in vivo* and *in vitro* studies with human sperm confirm adverse effects of RFR on the testicular proteome and other indicators of male reproductive health (57, 58), including infertility (59). Rago et al. (60) found significantly altered sperm DNA fragmentation in subjects who use mobile phones for more than 4 h/day and in particular those who place the device in the trousers pocket. In a cohort study, Zhang et al. (61) found that cell phone use may negatively affect sperm quality in men by decreasing the semen volume, sperm concentration, or sperm count, thus impairing male fertility. Gautam et al. (62) studied the effect of 3G (1.8–2.5 GHz) mobile phone radiation on the reproductive system of male Wistar rats. They found that exposure to mobile phone radiation induces oxidative stress in the rats which may lead to alteration in sperm parameters affecting their fertility.

RELATED OBSERVATIONS, IMPLICATIONS AND STRENGTHS OF CURRENT EVIDENCE

An extensive review of numerous published studies confirms non-thermally induced biological effects or damage (e.g., oxidative stress, damaged DNA, gene and protein expression, breakdown of the blood-brain barrier) from exposure to RFR (63), as well as adverse (chronic) health effects from long-term exposure (64). Biological effects of typical population exposures to RFR are largely attributed to fluctuating electrical and magnetic fields (65–67).

Indeed, an increasing number of people have developed constellations of symptoms attributed to exposure to RFR (e.g., headaches, fatigue, appetite loss, insomnia), a syndrome termed *Microwave Sickness* or *Electro-Hyper-Sensitivity* (EHS) (68–70).

Causal inference is supported by consistency between epidemiological studies of the effects of RFR on induction of human cancer, especially glioma and vestibular Schwannomas, and evidence from animal studies (8). The combined weight of the evidence linking RFR to public health risks includes a broad array of findings: experimental biological evidence of non-thermal effects of RFR; concordance of evidence regarding carcinogenicity of RFR; human evidence of male reproductive damage; human and animal evidence of developmental harms; and limited human and animal evidence of potentiation of effects from chemical toxicants. Thus, diverse, independent evidence of a potentially troubling and escalating problem warrants policy intervention.

CHALLENGES TO RESEARCH, FROM RAPID TECHNOLOGICAL ADVANCES

Advances in RFR-related technologies have been and continue to be rapid. Changes in carrier frequencies and the growing complexity of modulation technologies can quickly render "yesterdays" technologies obsolete. This rapid obsolescence restricts the amount of data on human RFR exposure to particular frequencies, modulations and related health outcomes that can be collected during the lifespan of the technology in question.

Epidemiological studies with adequate statistical power must be based upon large numbers of participants with suÿ cient latency and intensity of exposure to specific technologies. Therefore, a lack of epidemiological evidence does not necessarily indicate an absence of effect, but rather an inability to study an exposure for the length of time necessary, with an adequate sample size and unexposed comparators, to draw clear conclusions. For example, no case-control study has been published on fourth generation (4G; 2–8 GHz) Long-term Evolution (LTE) modulation, even though the modulation was introduced in 2010 and achieved a 39% market share worldwide by 2018 (71).

With this absence of human evidence, governments must require large-scale animal studies (or other appropriate studies of indicators of carcinogenicity and other adverse health effects) to determine whether the newest modulation technologies incur risks, prior to release into the marketplace. Governments should also investigate short-term impacts such as insomnia, memory, reaction time, hearing and vision, especially those that can occur in children and adolescents, whose use of wireless devices has grown exponentially within the past few years.

The Telecom industry's fifth generation (5G) wireless service will require the placement of many times more small antennae/cell towers close to all recipients of the service, because solid structures, rain and foliage block the associated millimeter wave RFR (72). Frequency bands for 5G are separated into two different frequency ranges. Frequency Range 1 (FR1) includes sub-6 GHz frequency bands, some of which are bands traditionally used by previous standards, but has been extended to cover potential new spectrum offerings from 410 to 7,125 MHz. Frequency Range 2 (FR2) includes higher frequency bands from 24.25 to 52.6 GHz. Bands in FR2 are largely of millimeter wave length, these have a shorter range but a higher available bandwidth than bands in the FR1. 5G technology is being developed as it is also being deployed, with large arrays of directional, steerable, beam-forming antennae, operating at higher power than previous technologies. 5G is not stand-alone—it will operate and interface with other (including 3G and 4G) frequencies and modulations to enable diverse devices under continual development for the "internet of things," driverless vehicles and more (72).

Novel 5G technology is being rolled out in several densely populated cities, although potential chronic health or environmental impacts have not been evaluated and are not being followed. Higher frequency (shorter wavelength) radiation associated with 5G does not penetrate the body as deeply as frequencies from older technologies although its effects may be systemic (73, 74). The range and magnitude of potential impacts of 5G technologies are under-researched, although important biological outcomes have been reported with millimeter wavelength exposure. These include oxidative stress and altered gene expression, effects on skin and systemic effects such as on immune function (74). *In vivo* studies reporting resonance with human sweat ducts (73), acceleration of bacterial and viral replication, and other endpoints indicate the potential for novel as well as more commonly recognized biological impacts from this range of frequencies, and highlight the need for research before population-wide continuous exposures.

GAPS IN APPLYING CURRENT EVIDENCE

Current exposure limits are based on an assumption that the only adverse health effect from RFR is heating from short-term (acute), time-averaged exposures (75). Unfortunately, in some countries, notably the US, scientific evidence of the potential hazards of RFR has been largely dismissed (76). Findings of carcinogenicity, infertility and cell damage occurring at daily exposure levels—within current limits—indicate that existing exposure standards are not suÿ ciently protective of public health. Evidence of carcinogenicity alone, such as that from the NTP study, should be suÿ cient to recognize that current exposure limits are inadequate.

Public health authorities in many jurisdictions have not yet incorporated the latest science from the U.S. NTP or other groups. Many cite 28-year old guidelines by the *Institute of Electrical and Electronic Engineers* which claimed that "Research on the effects of chronic exposure and speculations on the biological significance of non-thermal interactions have not yet resulted in any meaningful basis for alteration of the standard" (77)[2].

Conversely, some authorities have taken specific actions to reduce exposure to their citizens (78), including testing and recalling phones that exceed current exposure limits.

While we do not know how risks to individuals from using cell phones may be offset by the benefits to public health of being able to summon timely health, fire and police emergency services, the findings reported above underscore the importance of evaluating potential adverse health effects from RFR exposure, and taking pragmatic, practical actions to minimize exposure.

We propose the following considerations to address gaps in the current body of evidence:

- As many claim that we should by now be seeing an increase in the incidence of brain tumors if RFR causes them, ignoring the increases in brain tumors summarized above, a detailed evaluation of age-specific, location-specific trends in the incidence of gliomas in many countries is warranted.
- Studies should be designed to yield the strongest evidence, most eÿ ciently:
  - ➢ Population-based case-control designs can be more statistically powerful to determine relationships with rare outcomes such as glioma, than cohort studies. Such studies should explore the relationship between energy absorption (SAR[3]), duration of exposure, and adverse outcomes, especially brain cancer, cardiomyopathies and abnormal cardiac rythms, hematologic malignancies, thyroid cancer.
  - ➢ Cohort studies are ineÿ cient in the study of rare outcomes with long latencies, such as glioma, because of cost-considerations relating to the follow-up required of very large cohorts needed for the study of rare outcomes. In addition, without continual resource-consuming follow-up at frequent intervals, it is not possible to ascertain ongoing information about changing technologies, uses (e.g., phoning vs. texting or accessing the Internet) and/or exposures.
  - ➢ Cross-sectional studies comparing high-, medium-, and low-exposure persons may yield hypothesis-generating information about a range of outcomes relating to memory, vision, hearing, reaction-time, pain, fertility, and sleep patterns.
- Exposure assessment is poor in this field, with very little fine-grained detail as to frequencies and modulations, doses and dose rates, and peak exposures, particularly over the long-term. Solutions such as wearable meters and phone apps have not yet been incorporated in large-scale research.
- Systematic reviews on the topic could use existing databases of research reports, such as the one created by *Oceania Radiofrequency Science Advisory Association* (79) or EMF Portal (80), to facilitate literature searches.
- Studies should be conducted to determine appropriate locations for installation of antennae and other broadcasting systems; these studies should include examination of biomarkers of inflammation, genotoxicity, and other health indicators in persons who live at different radiuses around these installations. This is diÿ cult to study in the general population because many people's greatest exposure arises from their personal devices.
- Further work should be undertaken to determine the distance that wireless technology antennae should be kept away from humans to ensure acceptable levels of safety, distinguishing among a broad range of sources (e.g., from commercial transmitters to Bluetooth devices), recognizing that exposures fall with the inverse of the square of the distance

[2]The FCC adopted the IEEE C95.1 1991 standard in 1996.

[3]When necessary, SAR values should be adjusted for age of child in W/kg.

(The inverse-square law specifies that intensity is inversely proportional to the square of the distance from the source of radiation). The effective radiated power from cell towers needs to be regularly measured and monitored.

POLICY RECOMMENDATIONS BASED ON THE EVIDENCE TO DATE

At the time of writing, a total of 32 countries or governmental bodies within these countries[4] have issued policies and health recommendations concerning exposure to RFR (78). Three U.S. states have issued advisories to limit exposure to RFR (81–83) and the *Worcester Massachusetts Public Schools* (84) voted to post precautionary guidelines on Wi-Fi radiation on its website. In France, Wi-Fi has been removed from pre-schools and ordered to be shut off in elementary schools when not in use, and children aged 16 years or under are banned from bringing cell phones to school (85). Because the national test agency found 9 out of 10 phones exceeded permissible radiation limits, France is also recalling several million phones.

We therefore recommend the following:

1. Governmental and institutional support of data collection and analysis to monitor potential links between RFR associated with wireless technology and cancers, sperm, the heart, the nervous system, sleep, vision and hearing, and effects on children.
2. Further dissemination of information regarding potential health risk information that is in wireless devices and manuals is necessary to respect users' *Right To Know*. Cautionary statements and protective measures should be posted on packaging and at points of sale. Governments should follow the practice of France, Israel and Belgium and mandate labeling, as for tobacco and alcohol.
3. Regulations should require that any WTD that could be used or carried directly against the skin (e.g., a cell phone) or in close proximity (e.g., a device being used on the lap of a small child) be tested appropriately as used, and that this information be prominently displayed at point of sale, on packaging, and both on the exterior and within the device.
4. IARC should convene a new working group to update the categorization of RFR, including current scientific findings that highlight, in particular, risks to youngsters of subsequent cancers. We note that an IARC Advisory Group has recently recommended that RFR should be re-evaluated by the IARC Monographs program with high priority.
5. The World Health Organization (WHO) should complete its long-standing RFR systematic review project, using strong modern scientific methods. National and regional public health authorities similarly need to update their understanding and to provide adequate precautionary guidance for the public to minimize potential health risks.
6. Emerging human evidence is confirming animal evidence of developmental problems with RFR exposure during pregnancy. RFR sources should be avoided and distanced from expectant mothers, as recommended by physicians and scientists (babysafeproject.org).
7. Other countries should follow France, limiting RFR exposure in children under 16 years of age.
8. Cell towers should be distanced from homes, daycare centers, schools, and places frequented by pregnant women, men who wish to father healthy children, and the young.

Specific examples of how the health policy recommendations above, invoking the Precautionary Principle, might be practically applied to protect public health, are provided in the **Annex**.

[4]Argentina, Australia, Austria, Belgium, Canada, Chile, Cyprus, Denmark, European Environmental Agency, European Parliament, Finland, France, French Polynesia, Germany, Greece, Italy, India, Ireland, Israel, Namibia, New Zealand, Poland, Romania, Russia, Singapore, Spain, Switzerland, Taiwan, Tanzania, Turkey, United Kingdom, United States.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

ACKNOWLEDGMENTS

The authors acknowledge the contributions of Mr. Ali Siddiqui in drafting the Policy Recommendations, and those from members of the Board of the *International Network for Epidemiology in Policy* (INEP) into previous iterations of this manuscript. We are grateful to external reviewers for their thoughtful critiques that have served to improve both accuracy and presentation.This manuscript was initially developed by the authors as a draft of a Position Statement of INEP. The opportunity was then provided to INEP's 23 member organizations to endorse what the INEP Board had recommended, but 12 of those member organizations elected not to vote. Of the 11 that did vote, three endorsed the statement, two voted against it, and six abstained. Ultimately, the Board voted to abandon its involvement with what it determined to be a divisive topic. The authors then decided that, in the public interest, the document should be published independent of INEP.

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Conflict of Interest Statement: The authors declare that this manuscript was drafted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest, although subsequent to its preparation, DD became a consultant to legal counsel representing persons with glioma attributed to radiation from cell phones.

ANNEX: EXAMPLES OF ACTIONS FOR REDUCING RFR EXPOSURE

1. Focus actions for reducing exposure to RFR on pregnant women, infants, children and adolescents, as well as males who might wish to become fathers.
2. Reduce, as much as possible, the extent to which infants and young children are exposed to RFR from Wi-Fi-enabled devices such as baby monitors, wearable devices, cell phones, tablets, etc.
3. Avoid placing cell towers and small cell antennae close to schools and homes pending further research and revision of the existing exposure limits. In schools, homes and the workplace, cable or optical fiber connections to the Internet are preferred. Wi-Fi routers in schools and daycares/kindergartens should be strongly discouraged and programs instituted to provide Internet access via cable or fiber.
4. Ensure that WTDs minimize radiation by transmitting only when necessary, and as infrequently as is feasible. Examples include transmitting only in response to a signal (e.g., accessing a router or querying a device, a cordless phone handset being turned on, or voice or motion activation). Prominent, visible power switches are needed to ensure that WTDs can be easily turned on only when needed, and off when not required (e.g., Wi-Fi when sleeping).
5. Lower permitted power densities in close proximity to fixed-site antennae, from "occupational" limits to exposure limits for the general public.
6. Update current exposure limits to be protective against the non-thermal effects of RFR. Such action should be taken by all heath ministries and public health agencies, as well as industry regulatory bodies. Exposure limits should be based on measurements of RFR levels related to biological effects (2).
7. Ensure that advisories relating to cell phone use are placed in such a way that purchasers can find them easily, similar to the Berkeley Cell Phone "Right to Know" Ordinance (86).
8. Advise the public that texting and speaker mode are preferable to holding cell phones to the ear. Alternatively, use hands-free accessories for cell phones, including air tube headsets that interrupt the transmission of RFR.
9. When possible, keep cell phones away from the body (e.g., on a nearby desk, in a purse or bag, or on a mounted hands-free accessory in motor vehicles).
10. Delay the widespread implementation of 5G (and any other new technology) until studies can be conducted to assess safety. This includes a wide range of household and community-wide infrastructure WTDs and self-driving vehicles, as well as the building of 5G minicells.
11. Fiber-optic connections for the Internet should be made available to every home, oÿ ce, school, warehouse and factory, when and where possible.

GLOSSARY

ALARA	As Low a level As Reasonably Achievable
CBTRUS	Central Brain Tumor Registry of the United States
CI	Confidence Interval
EMR	Electro Magnetic Radiation
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
INEP	International Network for Epidemiology in Policy
LTE	Long-Term Evolution modulation
NTP	U.S. National Toxicology Program
OR	Odds Ratio
RFR	Radio-Frequency Radiation
SAR	Specific Absorption Rate
WTD	Wireless Transmitting Device

Statements to the FDA by Alfonso Balmori, BSc, Lennart Hardell MD, Paul Heroux PhD, Devra Davis PhD, Elihu D. Richter MD, MPH, Alvaro de Salles, PhD, Dr. Marc Arazi, Marko S. Markov PhD, Martin L. Pall, PhD, Hiie Hinrikus, PhD, DSc, David O. Carpenter MD, Suleyman Dasdag PhD.

Statement by Wildlife Biologist Alfonso Balmori, BSc on the FDA Review of Cell Phone Radiation and Cancer

The FDA review omits an evaluation of the science on wireless radiation impacts to trees and wildlife. Electromagnetic radiation is a form of environmental pollution which may hurt wildlife. I am providing examples of my published research below as examples of this scientific evidence.

I have co-published research entitled "Radiofrequency radiation injures trees around mobile phone base stations" finding harm to trees near base stations (cell antennas) in a long term field monitoring study in two cities. We measured the radiofrequency radiation levels and found significant differences between the damaged side facing the cell phone mast and the opposite side. Our statistical analysis demonstrated that electromagnetic radiation from mobile phone masts was harmful to the trees. The damage usually starts on one side of the tree, then extends to the whole tree over time. https://www.ncbi.nlm.nih.gov/pubmed/27552133

I have also published an experimental study where we exposed eggs and tadpoles of the common frog (Rana temporaria) to the electromagnetic radiation from mobile (cell) phone antennas located at a distance of 140 meters. The experiment lasted two months, from the egg phase until an advanced phase of tadpole prior to metamorphosis. In this study, we found the exposed group had altered development and a higher mortality rate in comparison to the unexposed frogs. https://www.ncbi.nlm.nih.gov/pubmed/20560769

In addition, my research has documented anthropogenic radiofrequency electromagnetic fields as an emerging threat to wildlife orientation. For example, exposure at levels that are found in the environment (in urban areas and near base stations) may particularly alter the receptor organs to orient in the magnetic field of the earth. These results could have important implications for migratory birds and insects, especially in urban areas, but could also apply to birds and insects in natural and protected areas where there are powerful base station emitters of radio frequencies. Therefore, more research on the effects of electromagnetic radiation in nature is urgently needed to investigate this emerging threat. At the present time, there are reasonable grounds based on scientific evidence for believing that microwave radiation constitutes an environmental and health hazard. Existing guidelines are not protective. The paper "Anthropogenic radiofrequency electromagnetic fields as an emerging threat to wildlife orientation" is online at https://www.ncbi.nlm.nih.gov/pubmed/25747364

Another research study I co-published in the journal Electromagnetic Biology and Medicine is entitled "The urban decline of the house sparrow (Passer domesticus): a possible link with

electromagnetic radiation." Between October 2002 and May 2006, point transect sampling was performed at 30 points during 40 visits in Valladolid, Spain. At each point, we carried out counts of sparrows and measured the mean electric field strength (radio frequencies and microwaves: 1 MHz–3 GHz range). Significant declines (P = 0.0037) were observed in the mean bird density over time, and significantly low bird density was observed in areas with high electric field strength. The logarithmic regression of the mean bird density vs. field strength groups (considering field strength in 0.1 V/m increments) was R = −0.87 (P = 0.0001). The results of this article support the hypothesis that electromagnetic signals are associated with the observed decline in the sparrow population. We conclude that electromagnetic pollution may be responsible, either by itself or in combination with other factors, for the observed decline of the species in European cities during recent years. The apparently strong dependence between bird density and field strength according to this work could be used for a more controlled study to test the hypothesis. https://www.ncbi.nlm.nih.gov/pubmed/17613041
In another study, monitoring of a white stork population in the vicinity of Cellular Phone Base Stations was carried out, with the objective of detecting possible effects. The total productivity, in the nests located within 200 meters of antennae, was 0_86 ± 0_16. For those located further than 300m, the result was practically doubled, with an average of 1_6 ± 0_14. Very significant differences among the total productivity were found (U = 240_ p = 0_001, Mann-Whitney test). Twelve nests (40%) located within than 200m of antennae never had chicks, while only one (3.3%) located further than 300m had no chicks. The electric field intensity was higher on nests within 200m (2_36 ± 0_82V/m) than on nests further than 300m (0_53 ± 0_82V/m). The study concludes that, "these results are compatible with the possibility that microwaves are interfering with the reproduction of white storks and would corroborate the results of laboratory research by other authors". https://www.tandfonline.com/doi/abs/10.1080/15368370500205472

A review on the impact of radiofrequency radiation from wireless telecommunications on wildlife is presented in "Electromagnetic pollution from phone masts. Effects on wildlife" published in the journal Pathophysiology. Electromagnetic radiation is a form of environmental pollution which may hurt wildlife. Phone masts located in their living areas are irradiating continuously some species that could suffer long-term effects, like reduction of their natural defenses, deterioration of their health, problems in reproduction and reduction of their useful territory through habitat deterioration. Electromagnetic radiation can exert an aversive behavioral response in rats, bats and birds such as sparrows. Therefore microwave and radiofrequency pollution constitutes a potential cause for the decline of animal populations and deterioration of health of plants living near phone masts. To measure these effects urgent specific studies are necessary.
https://www.ncbi.nlm.nih.gov/pubmed/?term=Electromagnetic+pollution+from+phone+masts.+Effects+on+wildlife

Despite the widespread use of wireless telephone networks around the world, authorities and researchers have paid little attention to the potential harmful effects of mobile phone radiation on wildlife. This paper briefly reviews the available scientific information on this topic and recommends further studies and specific lines of research to confirm or refute the experimental

results to date. Controls must be introduced and technology rendered safe for the environment, particularly, threatened species. https://www.ncbi.nlm.nih.gov/pubmed/25089692
Atmospheric electrical discharges during thunderstorms, and the related electromagnetic fields (EMFs)/waves called sferics, can be sensed by humans at long distances through a variety of symptoms, mainly headache, fatigue, etc. Up to today there is no explanation for this association. Sferics consist of partially polarized electromagnetic pulses with an oscillating carrier signal in the very low frequency (VLF) band and a pulse repetition frequency in the extremely low frequency (ELF) band. Their ELF intensity may reach ~5 mV/m at global ranges, and ~0.5 V/m at ~1000 km from the lightning. The health symptoms associated with sferics are also associated with antennas of mobile telephony base stations and handsets, which emit radio frequency (RF) radiation pulsed on ELF, and expose humans at similar or stronger electric field intensities with sferics. According to the Ion Forced-Oscillation mechanism, polarized ELF EMFs of intensities down to 0.1–1 mV/m are able to disrupt any living cell's electrochemical balance and function by irregular gating of electro-sensitive ion channels on the cell membranes, and thus initiate a variety of health symptoms, while VLF EMFs need to be thousands of times stronger in order to be able to initiate health effects. We examine EMFs from sferics in terms of their bioactivity on the basis of this mechanism. We introduce the hypothesis that stronger atmospheric discharges may reasonably be considered to be ~70% along a straight line, and thus the associated EMFs (sferics) ~70% polarized. We find that sferics mainly in the ELF band have adequate intensity and polarization to cause biological/health effects.

We provide explanation for the effects of sferics on human/animal health on the basis of this mechanism. https://www.ncbi.nlm.nih.gov/pubmed/28558424
It is documented that a few days or weeks before major Earthquakes (EQs) there are changes in animal behavior within distances up to 500 km from the seismic epicenter. At the same time Seismic Electric Signals (SES), geomagnetic and ionospheric perturbations, are detected within similar distances. SES consist of single unipolar pulses, and/or groups of such pulses called "SES activities" with an average frequency between successive pulses on the order of ~0.01 Hz and electric field intensity on the order of ~10-5-10-4 V/m (Frazer-Smith et al., 1990; Rikitake, 1998; Varotsos et al., 1993, 2011, 2019; Hayakawa et al., 2013; Grant et al., 2015). We show that the SES activities can be sensed by living organisms through the "Ion Forced-Oscillation Mechanism" for the action of Electromagnetic Fields (EMFs) on cells, according to which polarized EMFs can cause irregular gating of electro-sensitive ion channels on the cell membranes with consequent disruption of the cell electrochemical balance (Panagopoulos et al., 2000, 2002, 2015). This can be sensed by sensitive animals as discomfort in cases of weak and transient exposures, and may even lead to DNA damage and serious health implications in cases of intense exposure conditions (as in certain cases of man-made EMF exposures). Moreover, we show that the geomagnetic and ionospheric perturbations cannot be sensed through this mechanism. The same mechanism has explained meteoropathy, the sensing of upcoming thunderstorms by sensitive individuals, through the action of the EMFs of lightning discharges (Panagopoulos and Balmori, 2017). The present study shows that centuries-long anecdotal rumors of animals sensing intense upcoming EQs and displaying unusual behavior, lately documented by systematic studies, are now explained for the first time on the basis of the

electromagnetic nature of all living organisms, and the electromagnetic signals emitted prior to EQs. https://www.ncbi.nlm.nih.gov/pubmed/28558424

Signed, Alfonso Balmori, BSc Biologist. Spain
Alfonso Balmori on researchgate.

Paul Heroux PhD Statement in Response to the FDA Report on Cell Phone Radiation

The FDA Report stated," We do not know if there is a causal effect or if these results are due to weakening of the immune response due to animal stress from cyclic heating and thermoregulation decline in aging animals leading to whole-body temperature increase, possible sleep disruption due to the cyclic heating, or due to an RF-specific effect that has not been identified and has an adverse effect before heating becomes the dominant safety issue."

Response by Paul Heroux PhD
"FDA is pushing red herrings to avoid the inevitable conclusion that electromagnetic fields have important carcinogenic effects on animals below thermal levels.

This is an apparent attempt to confuse the discussion by invoking an "immune" mechanism driven by heat and sleep disturbances, and other ghost mechanisms that would inevitably turn out to be dead ends.

These surprising comments should not distract us from (1) at least four previous spectacular animal experiments linking fields to cancer, from (2) the drastic action of fields on human cancer cells at field intensities nowhere near the thermal limit, as well as (3) the literature linking fields to reactive oxygen species and mutations.

An institution (FDA) displaying such a fundamental reluctance to acknowledge evidence should abstain from commenting on the NTP study.

The FDA Report stated," It is possible that any form (ambient, IR, ultrasound) of cyclic whole-body heating of this magnitude may cause similar findings, but no such studies have been conducted to date."

Response by Paul Heroux PhD
"This is a way to extend the lie about health impacts of electromagnetic fields by directing attention to some form of further investigation that would allow industry to proceed with increases in human exposures, while we await the results of yet another waste of time."

Paul Héroux, PhD
Professor of Toxicology and Health Effects of Electromagnetism
McGill University Medicine

Department of Surgery, McGill University Health Center

Statement by Christos D. Georgiou, Ph.D.

The issued by FDA "literature review" conclusion that there are no connections between cell phones and cancer is not valid, as it is contradicted, at least, by the classification, by IARC-WHO, of cell phone-emitted EMF as possibly carcinogenic to humans (Group 2B). The numerous research studies IARC reviewed to base the Group 2B classification also included a study of mine (cited in the IARC-WHO 2013 report; https://www.ncbi.nlm.nih.gov/books/NBK304630/pdf/Bookshelf_NBK304630.pdf, pages 101,103,121), which advances the free radical pair mechanism of non thermal induction of carcinogenic oxidative stress by exposure to low-intensity RF radiation.

Christos D. Georgiou, Ph.D.
Professor Emeritus of Biochemistry
Biology Department
University of Patras, Greece

Statement by Anthony B. Miller MD

“Radiofrequency is an established carcinogen. Cell phones held close to the head will substantially increase the risk of a type of brain cancer—glioblastoma,” stated Dr. Anthony B. Miller, Professor Emeritus at the Dalla Lana School of Public Health, University of Toronto and former Director of the Epidemiology Unit of the National Cancer Institute of Canada. Miller also served as a Senior Epidemiologist, International Agency for Research on Cancer and published a major research review in 2018, concluding that “based on the evidence reviewed it is our opinion that IARC's current categorization of RFR as a Possible Human Carcinogen (Group 2B) should be upgraded to Carcinogenic to Humans (Group 1). Miller recommends people use safer wired technology rather than wireless technology, “We should do all we can to reduce exposure.”

Statement by Devra Davis PhD

“This astonishing report from an agency charged with protecting public health should be retracted. It does not meet minimum standards of scientific reporting or review, as it takes a skewed look at science, lists neither authors nor reviewers. It ignores the recent Yale study supported by the American Cancer Society linking cell phone use to thyroid cancer. It does not consider that antiquated phone test methods do not protect anyone from microwave radiation emitted by phones or other devices. It ignores repeated calls from the American Academy of Pediatrics and numerous experts in the field of child health to take into account the unique vulnerability of children, pregnant women and young adults. No reference is made to a growing body of research showing brain damage and headache and replicated research showing memory damage in teens after just one year of cell phone use," stated Devra Davis PhD, MPH, President of the Environmental Health Trust.

Prof. Suleyman Dasdag, Department of Biophysics, Medical School of Istanbul Medeniyet University, Istanbul,Turkey, also noted: "Mobile phones are not as innocent as they seem. In my studies to date, I have found that wireless radiofrequency (RF) does not affect every organ in the same way and very different parameters are important in the emergence of effects. In our two studies on RF and the brain in 2015 and our study published this year, we found that RFs may affect key molecules. In addition, we observed in our brain study that RF radiation can affect the death of brain cells. I also want cell phones not to cause brain tumors, but our studies and the published studies we have reviewed are in the direction that the risk will increase even more after 5G."

Martin L. Pall, PhD, Professor Emeritus of Biochemistry and Basic Medical Sciences, Washington State University who has published extensively on how EMFS activate Voltage-Gated Calcium Channels which can lead to tumor promotion, disputed the report's conclusions that cellphones are safe, noting that, "EMFs produce double strand DNA breaks which cause cancer via chromosomal rearrangements, copy number mutations and gene-amplification. EMFs also cause oxidized bases including 8-OHdG, which produce transition and transversion mutations such that when these occur in oncogenes or tumor suppressor genes, these mutations have important roles in causing cancer."

"This report is pure nonsense! It is as though the author didn't read any of the literature they cite," stated David O. Carpenter MD, Director, Institute for Health and the Environment, University at Albany who has repeatedly documented adverse effects over 4 decades of published research.

"Radiofrequency radiation should be regarded as a human carcinogen causing glioma, "stated Lennart Hardell MD, an advisor to the World Health Organization's International Agency for Research on Cancer, who has published several studies finding associations between cancer and people who use cell phones regularly. He referred to one of his published research reviews concluding that radiofrequency is a carcinogen.

"The latest report by the National Toxicology Program is a game changer. We also should not ignore case series reports on cancer in military workers with whole body exposure to RF/MW, stated Professor Elihu D. Richter MD, MPH at the Occupational and Environmental Medicine Department at the Hebrew University-Hadassah School of Public Health and Community Medicine.

"Due to the recent results described in many peer reviewed scientific papers published in the international literature showing significant human health risks (including cancer) at levels of EMF exposures well below the available recommended limits (e.g., ICNIRP, FCC/IEEE/ANSI). We believe that the Precautionary Principle should be urgently adopted and the population should be fully informed on the best ways to reduce their exposure and health impacts, " stated Alvaro de Salles, Ph. D. Professor at Federal University of Rio Grande do Sul, Porto Alegre, Brazil whose research studies have found children are more exposed to RF from cell phones.

"The FDA's position is totally incomprehensible especially since the findings of the Phonegate scandal have revealed the deception by cell phone manufacturers who have knowingly overexposed all cell phone users to excessive radiation for decades," stated Dr. Marc Arazi of Phonegate Association.

"Mankind is being forced to participate in a giant "experiment" without protocol, without collection of data and without adequate evaluation of the cocktail of EMF humankind is exposed to every day. The engineering community needs to recognize the fact that there is a difference between experimental exposure and continuous exposure to multiple frequencies and modulations. The FDA as well as ICNIRP have failed to investigate this to assure public safety, " stated Marko S. Markov PhD, author of major medical textbooks in bioelectromagnetics.

"Tissue heating is certainly not the only effect caused by radiofrequency radiation.," stated Hiie Hinrikus, PhD, DSc, Professor Emeritus Centre for Biomedical Engineering at the Tallinn University of Technology who has published several research studies on microwave radiation. "Hundreds of studies performed by independent researchers have convincingly approved biological effects caused by low-level radiofrequency radiation in animals and humans at constant temperature. The reason is coherent nature of radiofrequency radiation. During billions years, living nature has been adapted to natural solar radiation, radiofrequency radiation is in principle different from solar radiation. Sun emits irregular incoherent radiation in wide frequency spectrum whereas technical radiofrequency sources emit regular coherent single-frequency radiation. The impact of irregular random and regular coherent electromagnetic radiation on living systems is different. Irregular radiation causes random forces and movement in tissues and can create only tissue heating. Coherent radiation causes regular forces and synchronous movement affecting simultaneously large amounts of molecules and cells in tissues. Therefore, the impact of radiofrequency radiation is much stronger than the heating effect only. This is convincingly approved also in microwave chemistry."

BMJ Open

Subjective symptoms related to GSM radiation from mobile phone base stations: a cross-sectional study

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To cite: Gómez-Perretta C, Navarro EA, Segura J, *et al*. Subjective symptoms related to GSM radiation from mobile phone base stations: a cross-sectional study. *BMJ Open* 2013;**3**:e003836. doi:10.1136/bmjopen-2013-003836

▸ Prepublication history for this paper is available online. To view these files please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2013-003836).

Received 16 August 2013
Revised 16 November 2013
Accepted 20 November 2013

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ABSTRACT

Objectives: We performed a re-analysis of the data from Navarro *et al* (2003) in which health symptoms related to microwave exposure from mobile phone base stations (BSs) were explored, including data obtained in a retrospective inquiry about fear of exposure from BSs.

Design: Cross-sectional study.

Setting: La Ñora (Murcia), Spain.

Participants: Participants with known illness in 2003 were subsequently disregarded: 88 participants instead of 101 (in 2003) were analysed. Since weather circumstances can influence exposure, we restricted data to measurements made under similar weather conditions.

Outcomes and methods: A statistical method indifferent to the assumption of normality was employed: namely, binary logistic regression for modelling a binary response (eg, suffering fatigue (1) or not (0)), and so exposure was introduced as a predictor variable. This analysis was carried out on a regular basis and bootstrapping (95% percentile method) was used to provide more accurate CIs.

Results: The symptoms most related to exposure were lack of appetite (OR=1.58, 95% CI 1.23 to 2.03); lack of concentration (OR=1.54, 95% CI 1.25 to 1.89); irritability (OR=1.51, 95% CI 1.23 to 1.85); and trouble sleeping (OR=1.49, 95% CI 1.20 to 1.84). Changes in −2 log likelihood showed similar results. Concerns about the BSs were strongly related with trouble sleeping (OR =3.12, 95% CI 1.10 to 8.86). The exposure variable remained statistically significant in the multivariate analysis. The bootstrapped values were similar to asymptotic CIs.

Conclusions: This study confirms our preliminary results. We observed that the incidence of most of the symptoms was related to exposure levels—independently of the demographic variables and some possible risk factors. Concerns about adverse effects from exposure, despite being strongly related with sleep disturbances, do not influence the direct association between exposure and sleep.

Strengths and limitations of this study

- We used a robust statistical analysis with a highly homogeneous sample in a homogeneous environment.
- A participation bias cannot be ruled out. The late query about concerns (as a possible confounder) may render the results less valid.
- We observed that the incidence of most of the symptoms was related to exposure levels.

The health risk due to exposure to radiofrequency electromagnetic fields (RF EMFs) continues to be discussed today. The study that led to this debate was initiated after verification that the US embassy in Moscow was being subjected to such radiation from 1953 to May 1975.[1] Recently, a review of that episode[2] reopened the debate about the potential harmfulness of RF EMFs. The increasing number of base stations (BSs) on masts and buildings has increased public awareness. This issue has prompted scientific research to establish to what extent low-intensity EMFs may affect the health of humans and other organisms.[3 4] Furthermore, the term electromagnetic hypersensitivity has been recently introduced in discussions attributing symptoms to exposure to EMFs.[5–8] A review of this topic[9] in 2010 found that 8 of the 10 studies evaluated through PubMed had reported increased prevalence of adverse neurobehavioral symptoms or cancer in populations living at distances <500 m from BSs.

None of the studies reported exposure above accepted international guidelines, suggesting that current guidelines may be inadequate in protecting health. Thus, the need emerges to revaluate our pioneering work in this field in order to add new procedures and data. Few articles have addressed the possible association between microwave sickness and microwave exposure from Global System for Mobile Communications (GSM) BSs since the publication of our first study.[10] Chronologically, Santini *et al*[11] and Gadzicka *et al*[12] reported differences in the distance-dependent prevalence of symptoms such as headache, impaired concentration and irritability. A later Austrian study[13] showed a positive association between the measured electrical field (GSM 900/1800) in bedrooms and headaches, cold hands and feet and difficulties in concentration. An Egyptian study[14] showed a prevalence of neurological symptoms, such as headache, memory changes, dizziness, tremors, depressive symptoms and sleep disturbances among participants directly exposed to GSM signals from BSs.

The symptoms reported by all the above cited authors belong to those attributed to the microwave syndrome.[15] However, one article[16] using personal monitored data from GSM-UMTS frequency bands found no statistical association in adults. More recently, the same authors observed no association in children,[17] contradictory results in children and adolescents,[18] and concluded that the *few observed significant associations were not causal but rather occurred by chance*. Blettner *et al*[19] reported in phase 1 of their study more health problems closer to BSs, but in phase 2[20] they concluded that measured EMF emissions were not related to adverse health effects.

Other researchers focused their work on the possible existence of participants with sensitivity to GSM or UMTS signals according to psychological, cognitive or autonomic assessment. These researchers used short-term exposure (only 30–50 min) under laboratory conditions[21–23] and revealed a large disparity between participants. Recently, a study measuring several biological stress markers[24] found that RF EMF emitted by mobile phone BSs from 5.2 to 2126.8 $\mu W/m^2$ increased cortisol and salivary α-amylase, while IgA concentration was not significantly modified.

The Selbitz study[25] in 2010 described a significant dose–response relationship in symptoms related with sleep, mood, joints, infections, skin condition, as well as neurological, cardiovascular, visual and auditory systems and the gastrointestinal tract.

The existence of short-term physiological effects of EMF on sleep quality was not evident in the work of Danker-Hopfe *et al*[26]; however, it was stated that the presence of BSs per se (not the EMF) may have a negative impact on sleep quality.

A Polish study in 2012 did not show a correlation between electrical field strength and frequency of subjective symptoms; however, it showed a correlation between subjective symptoms and the distance to BSs.[27] A study carried out in Egypt[28] revealed that exposure to EMF emitted either from mobile phones or BSs had significant effects on the pituitary–adrenal axis. More recently, work developed in Iran[29] indicated that symptoms such as nausea, headache, dizziness, irritability, discomfort, nervousness, depression, sleep disturbance, memory loss and lowering of libido were statistically significant in people living near BSs (<300 m distances) compared with those living far from the BSs (>300 m).

In our cross-sectional analysis,[10] 11 of 16 symptoms showed statistically significant higher scores in the group with the maximum exposure level. The symptoms are included in the microwave syndrome. We also reported statistically significant correlation coefficients between the measured electrical field and 14 of 16 symptoms.

A review[30] recently established several conditions for epidemiological studies to be eligible for introduction in general analysis: *eligible studies must quantify exposure using objective measures (such as distance to the nearest BS, spot or personal exposure measurements in a specific frequency range); possible confounders must be considered and the selection of the study population must be clearly free of bias in terms of exposure and outcomes*.

Accordingly, in this reanalysis of our previous study,[10] possible confounders were included in addition to the specific RF EMF measurements made in 2001 (covering the specific range between 900 and 1800 MHz). Therefore, we coanalysed the effects of other variables such as sociodemographic data and the use of electronic devices. Concern about being damaged by radiation from antennas was also analysed.

The new statistical approach tested the possible influences of other variables, such as demographic data and the use of electronic devices. Moreover, since some concerns have been raised about possible health consequences caused by the emitted microwaves, we analysed whether these symptoms might be related to fear of exposure. As some participants refused to allow measurements in their homes, we analysed whether symptom status or subjective distance to the BS could be a bias of participation in the study. Interestingly, this period was free of other sources of RF such as WIFI or UMTS or the massive use of mobile phones, enabling a specific study of GSM technology. Finally, the suitability of the size of the sample was analysed.

METHODS

Study design

We chose a small urban area with mixed rural characteristics: low levels of environmental pollution (more agricultural than industrial); no major differences in socioeconomic characteristics throughout the region (excluding large cities); similar ethnicity (white Caucasian) and language (Spanish) and with mobile phone communication operative for at least 2 years. La Ñora was chosen because it had the features of a small city, and was located near the capital (Murcia) in a rural environment without any particular health or environmental problems. Consequently, La Ñora was representative of small urban areas in eastern Spain with fewer than 20 000 inhabitants—such rural areas accounting for 19.8% of the population and 35.9% of the territory in Spain.

Two BS masts, each about 30 m height, were sited at different positions to provide GSM-900-1800 coverage. The GSM 900 BS was positioned not before 1997 while the GSM 1800 BS was built in December 1999.

Data regarding the main demographic characteristics of the sample and their use of electronic devices was collected through a Spanish-language questionnaire.[11] All of the participants were of the same ethnic origin, shared similar family income levels and general standard of living, and were born in La Ñora or nearby. All the residents in the study were living in the village before the erection of both BSs. All of the residents were at home for more than 8 h a day for at least 6 days a week and normally slept at home.

The core of the questionnaire was a symptom checklist for estimating the frequency of 15 health-related symptoms attributed to microwave sickness. These symptoms were fatigue, irritability, headaches, nausea, loss of appetite, sleep disorders, depressive tendency, dizziness, concentration difficulties, memory loss, skin lesions, visual and hearing deficiencies, walking difficulties and cardiovascular problems. The frequency was quantified as never suffer = 0, sometimes = 1, often = 2 and very often =3.

The percentage of residents who reported electrical transformers less than 10 m from their home was 21.6%, while 42% reported high-voltage power lines less than 100 m from home. Finally, 40% of residents reported a TV transmitter within a radius of around 4 km.

The questionnaire included a statement that its purpose was health research and that the data gathered would be confidential.

Some 215 questionnaires were randomly distributed through 17 streets representing practically the entire village. The houses were selected using a street map of the village. In total, 150 questionnaires were collected with the remainder being uncollected because nobody was at home (31) or there was a refusal by the householder to complete the questionnaire (34).

During 2001, 101 RF EMF measurements in bedrooms were made. The other (49) residents who refused admittance for taking the measurements (16) were not at home for the scheduled measurement appointment (10) or had serious health problems (23).

However, some changes are now being introduced in this reanalysis. Thirteen of the participants included in the original study have now been eliminated: 2 participants were eliminated (one regarding alcohol abuse and another regarding pregnancy) to increase the requirement on health criteria and 11 participants were eliminated to increase the homogeneity of the RF EMFs measurements because there was a change (it was raining) in the usual dry weather conditions when the respective broadband measurements were registered.

The reanalysis of the dataset, which is the main focus of this paper, was finally performed with 88 participants (45 women and 43 men) instead of the 101 analysed in 2001.

Concerns about microwave exposure

Sixty-six of the 88 participants were reached by telephone in February 2012 and asked two questions:

A. Were you worried about the masts (BSs) when they were erected?
B. Did you believe their radiation (BSs) could damage your health?

In all cases, those who were worried about the masts were concerned about health consequences. Twenty-seven participants (40.9%) responded ‘no’ and 39 (59.1%) responded ‘yes’. Responses were analysed relative to age (analysis of variance (ANOVA) test), sex (λ statistic) and subjective distance to BS (Somers’ D statistic).

Exposure assessment

Broadband measurements were made on two Saturdays in February and March 2001 from 11:00 to 19:00 with a portable electrical field (400 MHz–3 GHz) detector (Nuova Elettronica Model LX-1435). This meter was calibrated with an HP-8510C network analyser inside an anechoic chamber at the University of Valencia. During the bedroom exposure assessment, the electric field probe was held for approximately 5 min about 1 m from the walls and 1.2 m above the ground—and moved around a circle of 0.25 m radius, orientating the antenna in different directions to obtain the maximum electrical field strength above the bed.

To check the intensity of TV and radio channels, as well as the intensity of working channels and broadcast channels for the GSM-900-1800 BSs, measurements of the spectral power density were carried out with a probe antenna and a portable spectrum analyser.

The probe was mounted on a linen phenolic tripod 1.2 m above the ground. The position of the probe was the same on both days—on a hill next to the village and 20 m from the BS. With the spectrum analyser we scanned the frequency bands and the levels were averaged for 6 min. The measurement of the spectrum was similar on both days—with a difference in the peak estimation (channel carriers) of about 1 dB.

The measured broadband exposure was almost invariable during the time interval of the measurements. Exposure changed with the position or place but it did not change over time, and this could be related with a low intensity of traffic (few phone calls) and the high and constant intensity of the broadcast channel.[10]

Statistical analysis

Demographic data were analysed using the Mann-Whitney one-way ANOVA and χ^2 test. Differences between groups were performed through variance (ANOVA) and covariance analysis.

The main statistical analysis was made using binary logistic regression (mode enter) carried out on a regular basis with subsequent bootstrapping (1000 bootstrap replications, 95% percentile method and simple sampling)[31] to provide more accurate SE and CIs. After producing (1000) bootstrap replicates θb of an estimator θ, the bootstrap SE was the SD of the bootstrap replicates.

$$\mathrm{SE}(\theta) = \sqrt{\left[\sum (\theta b - \theta)^2/(r-1)\right]}$$

$$b = 1 \rightarrow r$$

where θ is the mean of the θb. Owing to our small sample size, a non-parametric CI for the estimate (mean) was constructed from the quartiles of the bootstrap sampling distribution of θ. The 95% percentile interval (θ (lower) <θ<θ (upper)) is shown, where θb are the r-ordered bootstrap replicates: lower=0.025×r (sample 25) and upper=0.975×r (sample 975).

The dependent variables (health-related symptoms) given in four ordinal categories (0=never, 1=sometimes, 2=often and 3=very often) were dichotomised (0, 1=0 vs 2, 3=1).

The 15 health-related symptoms described above constituted the dichotomous dependent variables. Univariate analysis was then performed for each symptom and for each of the predictor variables: exposure to BS ($\mu W/m^2$ as a natural logarithmic) and age were used as continuous variables, while gender, computer use >2 h/day, mobile phone use >20 min/day and worry about the antennae were used as dichotomous variables. The covariates with predictive value were considered for the multivariate analysis. Thus possible confounder effects were evaluated.

In all cases, changes in −2 log likelihood, OR, 95% CIs and the p value were calculated. For all tests, a p value below 0.05 was considered statistically significant.

We used the GSM exposure (the measurement of RF EMF in the bedroom) as a continuous variable because it is recognised that categorisation of continuous variables introduces major problems in the analysis and interpretation of models derived in a data-dependent fashion.[32–34]

We chose exposure values in the logarithmic form because these values are well grouped around their median, while the raw values showed a high dispersion of values, with 2 outliers and 10 extreme values (data not shown).

Confounding was assessed by adding the potentially confounding variable to the model and making a subjective decision as to whether or not the coefficient of the variable of interest, ORs of GSM exposure, had changed substantially. A 10% variation was accepted as a considerable change.

Possible interactions between covariates were also evaluated.

The maximum number of covariates included in each multivariate analysis was calculated following this formula.[35] Let π be the smallest of the proportions of negative or positive cases in the population and k the number of covariates, then the minimum number of cases to include is:

$$N = 10\,k/\pi$$

Goodness-of-fit tests such as the classification table, the Hosmer-Lemeshow statistic, receiver operating characteristic (ROC) curves, Cox and Snell's and Nagelkerke's Pseudo R^2 measures were used. The Wald statistic was also evaluated to test the significance of individual independent variables. Moreover, possible multicollinearity was also tested.

With the predicted probability scores derived from the regression analysis, ROC curves were constructed for all symptoms or modalities in order to analyse sensitivity and specificity levels. For each curve, the best cut-offs for GSM exposure that maximises (sensitivity+specificity) were also calculated.

For statistical analysis, we used the Statistical Package for Social Sciences, V.21.0 (IBM SPSS Inc, Chicago, Illinois, USA) for Windows.

Owing to an exposure assessment for transformers, high-voltage power lines and radio or TV transmitters based on self-estimated distances would not produce a reliable exposure estimate, it was decided to omit these covariates in the analysis.

RESULTS

Demographic data and the percentage of users of personal computers and mobile phones were analysed. The mean age was 42 and 17 years (SD±17. 61, interval 15–81). Women totalled 51.1% (mean age=45.08 years, SD=17.98; interval=15–81) and 48.9% were men (mean age = 39.12 years, SD=16.88; interval=15–75). A total of 13.6% participants regularly used computers and 23.9% used mobile phones.

No differences related with age and use of mobile phones or computers were found between the sexes.

The univariate logistic regression indicated that age was inversely associated with irritability (OR=0.97, 95% CI 0.95 to 0.99) and that the oldest had the greatest difficulties hearing (OR=1.03, 95% CI 1.01 to 1.06) and walking (OR=1.04, 95% CI 1.01 to 1.07). However, gender clearly did not influence the outcome of any dependent variable. Use of mobile phones was linked with lack of appetite and vertigo, while worry about the radiation from BSs was associated with trouble sleeping (table 1). However, concern about radiation from BSs was unrelated to age (ANOVA test), sex (λ statistic) or subjective distance to BS (Somers' D statistic).

Most of the symptoms were related with GSM exposure, especially fatigue, irritability, lack of appetite, trouble sleeping, depression and lack of concentration. Change in −2 log likelihood showed similar results (table 2). Figure 1 shows the distribution of EMF measurements throughout the sample.

ROC curves for each of the logistic regression models (GSM exposure vs each symptom) oscillated between 0.65 and 0.87 (table 3). Headaches (0.84), nausea (0.86), appetite (0.87) and vascular problems (0.85) showed the highest values, while memory (0.67), skin (0.67) and visual disturbances (0.65) showed the lowest values. The Hosmer and Lemeshow test indicated that most analyses showed no significant p values. The exceptions were fatigue (0.003), depression (0.003) and vertigo (0.03). In the majority of the cases, the models predicted better specificity than sensitivity. Only in the

Table 1 Univariate ORs and 95% CIs of all clinical symptoms related with various possible confounders

Symptom/variable	Worry about BSs (1) OR (95% CI)		Computer use (2) OR (95% CI)		Mobile use (3) OR (95% CI)	
Fatigue	0.67	0.23 to 1.90	2.62	0.76 to 9.04	1.56	0.56 to 4.35
Irritability	1.13	0.43 to 3.03	1.56	0.45 to 5.34	2.62	0.94 to 7.33
Headaches	1.75	0.62 to 4.94	1.39	0.34 to 5.58	1.56	0.51 to 4.83
Nausea	0.68	0.18 to 2.24	0.34	0.04 to 2.84	1.43	0.44 to 4.67
Lack of appetite	1.05	0.33 to 3.40	3.16	0.87 to 11.44	4.28**	1.43 to 12.78
Trouble sleeping	3.12*	1.10 to 8.86	0.55	0.16 to 1.88	0.74	0.27 to 2.02
Depression	1.06	0.39 to 2.93	0.81	0.22 to 2.93	1.03	0.38 to 2.84
Lack of concentration	0.92	0.35 to 2.47	1.11	0.33 to 3.76	2.79	0.99 to 7.80
Memory loss	1.71	0.62 to 4.75	0.41	0.10 to 1.64	1.35	0.50 to 3.61
Skin alterations	0.74	0.23 to 2.35	ϕ	ϕ	0.63	0.16 to 2.45
Visual disturbances	1.31	0.48 to 3.60	0.77	0.21 to 2.77	1.63	0.60 to 4.39
Vertigo	0.61	0.20 to 1.91	0.77	0.19 to 3.10	2.90*	1.04 to 8.07
Vascular alteration	0.96	0.27 to 3.43	1.48	0.35 to 6.17	2.04	0.65 to 6.41
Hearing problems	0.59	0.20 to 1.70	0.77	0.19 to 3.10	0.48	0.15 to 1.60
Walking difficulty	0.60	0.20 to 1.79	ϕ	ϕ	0.42	0.11 to 1.60

*p<0.05; **p<0.01.
(1) Not worried, as reference codes. (2) and (3) no device use, as reference code, ϕ any participant affected using computer.
BS, base station.

case of headaches and sleep disorder, did sensitivity prevail over specificity (table 3—classification table). In the extreme case, skin and vascular problems showed null or minimum sensitivity and 100% specificity. Nagelkerke pseudo R^2 showed acceptable coefficients with the exception of the symptoms related with vertigo and skin problems (table 3).

Threshold cut-off values of GSM for sleep, attention, irritability and memory are also shown (table 3). The remaining cut-off values were not considered since sensitivity or specificity was reported at below 0.50%.

The influence of other covariates on the GSM ORs coefficients, such as age, cellular use and concern about the BS, was always less than 10% (table 2).

There was no observed multicollinearity among variables. The κ values according to factor analysis were always lower than 2 and well below the critical value of 30.

Finally, no interactions between covariates were observed.

SEs and CIs obtained by resampling were similar to those calculated from the asymptotic approximation (table 4). There was a small bias or difference between

Table 2 ORs and 95% CIs for GSM exposure: increase in risk per increase in log GSM (μW/m^2)

Symptom	OR (95% CI)	Change in −2 log likelihood	OR (95% CI)
Fatigue	1.39*** (1.14 to 1.70)	11.74***	2.13*** (1.34 to 3.83)
Irritability	1.51*** (1.23 to 1.85)	19.36***	2.58*** (1.61 to 4.12)
Irritability (adjusted with age)	1.47*** (1.20 to 1.81)	–	2.44*** (1.52 to 3.94)
Headaches	1.43** (1.15 to 1.78)	12.32***	2.28** (1.37 to 3.78)
Nausea	1.38** (1.09 to 1.73)	8.3**	2.09** (1.23 to 3.55)
Lack of appetite	1.58** (1.23 to 2.03)	16.31***	2.86*** (1.60 to 5.09)
Lack of appetite (adjusted to cellular use)	1.53** (1.19 to 1.99)	–	2.68*** (1.48 to 4.84)
Trouble sleeping	1.49*** (1.20 to 1.84)	16.38***	2.49*** (1.52 to 4.08)
Trouble sleeping (adjusted to worry to BSs)	1.64*** (1.22 to 2.19)	–	3.11*** (1.59 to 6.09)
Depression	1.41*** (1.16 to 1.72)	13.99***	2.22*** (1.42 to 3.48)
Concentration	1.54*** (1.25 to 1.89)	20.75***	2.68*** (1.67 to 4.32)
Memory	1.27** (1.06 to 1.52)	7.29**	1.73** (1.14 to 2.60)
Skin	1.24* (1.001 to 1.54)	4.08*	1.65* (1.01 to 2.71)
Visual	1.23 * (1.03 to 1.46)	5.30*	1.59* (1.06 to 2.40)
Vertigo	1.36** (1.11 to 1.66)	10.14***	2.02** (1.28 to 3.20)
Vertigo (adjusted to cellular use)	1.32** (1.08 to 1.62)	–	1.91** (1.20 to 3.04)
Vascular	1.32* (1.05 to 1.64)	6.30*	1.88* (1.12 to 3.14)
Hearing	0.96 (0.80 to 1.15)		0.90 (0.59 to 1.37)
Walking	0.95 (0.78 to 1.15)		0.88 (0.57 to 1.37)

Changes in −2 log likelihood are also shown. The third column represents the ORs for a 10-fold increase in GSM (log_{10} GSM).
*p<0.05; **p<0.01; ***p<0.001.
BS, base station; GSM, Global System for Mobile Communication.

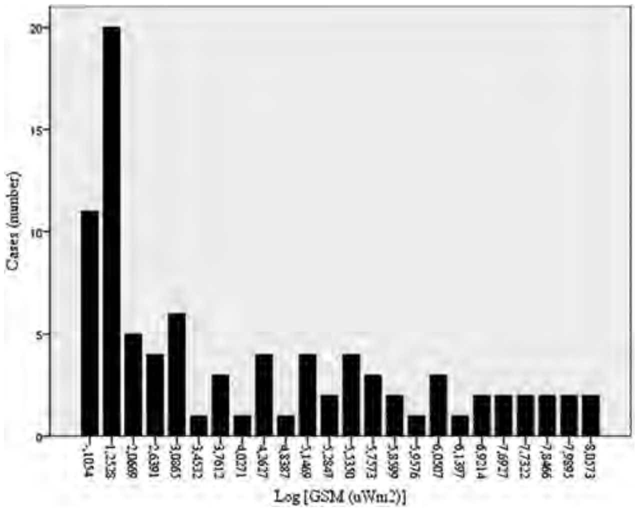

Figure 1 Distribution of electromagnetic field (EMF) measurement throughout the sample.

the average bootstrap coefficients (not shown) and the respective estimates obtained from the original sample.

There were no global health differences between those who permitted a bedroom exposure measurement (88 in our previous model) and those who refused RF measurements (26), and these results were unaltered when using age as a covariate. Square partial eta measured a 0% contribution of the willing participation variable to symptoms, such as irritability, headaches, walking difficulties and hearing loss that correlated with age. There was no relationship between subjective distance to the BS and willingness to participate (Pearson χ^2=2.80, df=1; p=0.094).

However, ANOVA showed that the group with recorded RF EMF levels was more prone to symptoms of memory loss (F=5.07; p=0.027), while participants without EMF measures showed more skin problems (F=10.66; p=0.001).

DISCUSSION

In the present reanalysis, a more robust statistical method was employed that was indifferent to the assumption of normality. To reduce the limitation of the sample size effect and extrapolate our results to the entire population from which the sample was obtained, a resample method or bootstrapping was used.

This new study partially confirms our preliminary results—namely, that most of the symptoms are related to GSM levels independent of the demographical variables and some possible risk factors. Related to microwave radiation, the spectral power density analysis maintained that the most important contribution to broadband measurements was from GSM 900/1800, and the main variability of the measurements between different places was due to a different coverage of the GSM 900/1800 signals, that is, spatial variability. This was further supported by the fact that the antenna used was fairly insensitive to frequencies below 400 MHz. Therefore, the radio channels 80–110 MHz were not a significant part of the broadband measurements. Moreover, the narrow band measurements showed TV channels with substantially lower intensities than the GSM 900/1800 signals. The effects from these exposures will therefore not confound the effects of BSs. Moreover, some authors[13] found that the only relevant contribution to the variance of the high microwave exposure was from BSs—up to 93% of variance. Moreover, at the time of our study, the GSM signal was almost invariable in time because there were very few calls. The main contribution was made from the broadcast channels working almost constantly throughout the day. Short-range evaluations of exposure could be acceptable for describing a 24 h period and the measurements were made in bedrooms—a location where the participants were assumed to spend significant periods of time.

However, some participants were mobile phone users at the time of this study and exposure to a mobile

Table 3 Goodness-of-fit of the outcome binary response variable related to GSM exposure (log=ln)

Symptom	ROC curves area	Classification table SSV	SPF	AV	Pseudo-R**2 (1)	Cut-off (2) (log GSM)	Cut-off (2) GSM (μW/m²)
Headaches	0.84***	0.90	0.23	0.72	0.41	–	1.77
Sleep	0.78***	0.82	0.66	0.76	0.28	1.66	5.26
Attention	0.78***	0.67	0.72	0.69	0.28	3.61	36.97
Irritability	0.76***	0.67	0.73	0.71	0.26	3.61	36.97
Memory	0.67**	0.54	0.77	0.67	0.11	4.99	146.94
Depression	0.75***	0.46	0.76	0.65	0.20	–	184.93
Visual	0.65*	0.24	0.83	0.60	0.08	–	368.71
Fatigue	0.73***	0.22	0.90	0.69	0.18	–	685.4
Vertigo	0.74***	0.16	0.87	0.67	0.19	–	685.4
Appetite	0.87***	0.40	0.94	0.85	0.43	–	1495.18
Nausea	0.86***	0.46	0.93	0.87	0.38	–	1495.18
Vascular	0.85***	0.20	1.0	0.90	0.34	–	3041.18
Skin	0.67*	0.00	1.00	0.81	0.072	–	8604.15

Cut-off values of exposure to microwaves according to ROC analysis. The data are presented in the ascending order.
*p<0.05; **p<0.01; ***p<0.001 (1) Nagelkerke (2) cut-off (ROC curve): only values showing SSV and SPF above 0.5 are reported.
AV, average; GSM, Global System for Mobile Communication; ROC, receiver operating characteristic; SPF, specificity; SSV, sensitivity.

Table 4 Statistics for r=1000 bootstrapped binary logistic regression (GSM exposure coefficients: increase in risk per increase in log GSM (μW/m^2)

		Bootstrap				Normal		
				95% percentile intervals			95% CI	
Symptom	B*	Bias	SE	Lower	Upper	SE	Lower	Upper
Fatigue	0.329	0.012	0.097	0.155	0.539	0.102	0.128	0.529
Irritability	0.411	0.016	0.110	0.241	0.670	0.104	0.207	0.615
Headache	0.358	0.022	0.139	0.149	0.688	0.113	0.137	0.578
Nausea	0.319	0.013	0.124	0.099	0.590	0.118	0.088	0.550
Appetite	0.456	0.026	0.134	0.264	0.784	0.128	0.205	0.707
Sleep	0.396	0.022	0.124	0.193	0.690	0.109	0.181	0.610
Depression	0.346	0.012	0.102	0.174	0.583	0.100	0.151	0.541
Attention	0.429	0.020	0.118	0.254	0.711	0.106	0.222	0.636
Memory	0.237	0.009	0.098	0.057	0.448	0.091	0.058	0.415
Skin	0.217	0.008	0.110	0.011	0.451	0.110	0.001	0.433
Visual	0.203	0.004	0.093	0.037	0.398	0.090	0.026	0.379
Hearing	−0.05	−0.002	0.089	−0.219	0.143	0.093	−0.228	0.135
Vertigo	0.306	0.010	0.101	0.127	0.530	0.102	0.107	0.505
Walking	−0.05	−0.006	0.098	−0.265	0.120	0.098	−0.246	0.138
Vascular	0.274	0.010	0.109	0.084	0.520	0.114	0.051	0.497

Asymptotic SEs and 95% CIs are also shown for comparison.
*β coefficient (log OR).
GSM, Global System for Mobile Communication.

phone during a phone call is much higher than that received from BSs. Nevertheless, some authors[13] stated about that *there is no* a priori *argument why these lower levels should have no effect on the presence of a widespread use of mobile telephones*. Exposure to a BS will be at a low but almost constant level for many hours of the day and especially at night.

While GSM exposure was associated with most of the symptoms, walking difficulties and hearing loss were correlated only with age. Age also remained slightly inversely associated with irritability. Users of cellular phones were more prone to symptoms of loss of appetite and vertigo, while those who expressed worry about the BSs were associated with sleep problems. This later finding was in concordance with two other articles.[13 20 26] However, worry about the BSs was unrelated with age, gender or subjective distance to BSs. This agrees with an article[36] claiming that there was no statistically significant association between symptom occurrence associated with perceived proximity to BSs, psychological components, sociodemographic characteristics and distance to BSs or power lines.

Some authors indicated that opponents of mobile phone towers generally do not express anxieties about EMF exposure, indicating that the risk rating is comparable with other commonly perceived hazards in the modern world.[37]

None of the analysed covariates behaved as confounders. The relationship of GSM exposure with irritability, sleep troubles, lack of appetite and vertigo remained statistically significant despite the introduction of the above covariates.

When the conventional multivariate analysis was tested using bootstrapping it was observed that the SE and CIs obtained by resampling were similar to those calculated from asymptotic approximation and this supports the adequacy of our conventional analysis. Our sample, chosen at random, represents the population from which it came.

The model appeared generally well adjusted while the cut-off values could constitute good guidance for predicting the threshold of symptom appearance.

We cannot truly state that residents were more worried, equally worried or less worried than elsewhere in this region, since we cannot provide the percentage of those worried about the BS masts in La Ñora compared with other nearby places. However, information about this issue was widespread in this region at the time, and the circumstances at La Ñora were shared with most other small urban and rural areas. The sample was randomly selected but a participation bias cannot be ruled out since most of our participants expressed fear regarding BSs and this could contribute to their participation in the study. It is also possible to speculate that the percentage of participants who refused to participate did so for the opposite reasons (indifference about BSs). In this regard, neither health status nor subjective distance to the BS explained a willingness to participate in the study.

Concerns about radiation from BSs were not related to age, sex or subjective distance to BSs. This agrees with statements from several authors[13] that living near a BS does not make people generally fearful, but people who generally worry about fields express stronger fears when they live close to a station.

Nevertheless, irrespective of these explanations, there seems to be effects of exposure that occur independently of the fear felt by the participants, since controlling for fear did not change the association between exposure and symptoms. However, the late query about concerns (as a possible confounder) may render the results less valid. In contrast to our findings, note that biological grounds explaining non-thermal effects have not been clearly established. Recently, it has been stated that voltage-gated calcium channels are essential to the beneficial or adverse responses to microwave EMFs, nanosecond EMF pulses and static electrical and magnetic fields.[38]

In summary, the results of this study indicate that effects of very low but long-lasting exposure to emissions from mobile telephone BSs on well-being cannot be ruled out. The effects almost completely matched the symptoms described within the microwave syndrome. Finally, unravelling the causal pathways would be best performed with an experimental study design.

CONCLUSIONS

This new study partially confirms our preliminary results about microwave sickness resulting from exposure to emissions from GSM mobile phone BSs. Fatigue, irritability, lack of appetite, sleep troubles, depression and lack of concentration were especially related with GSM exposure.

These results were independent of the main sociodemographic variables, other EMF exposures and anxiety about being irradiated. Nevertheless, we confirm that apprehension about modern technology could predict some symptoms, especially those related with sleep problems.

Our results agree with those who claimed that *by distorting perceptions of risk, disproportionate precaution might paradoxically lead to illness that would not otherwise occur*.[39] However, health changes related with GSM exposure seem to occur in a manner unrelated with those fears. Finally, exposure was very low during the period and also very low in comparison with Spanish recommendations[40] and international guidelines.[41]

Recommendations

We subscribe to the guidelines observed by other authors[42] in following the principle of prevention while the non-thermal effects are not considered in any official standard. This includes exposure minimisation within the limits of technical feasibility to guarantee a significant reduction in long-term radiation exposure to cellular phone towers in residential areas. Epidemiological and clinical studies should continue to observe possible health changes in the population. Finally, clear information about the correct use of newer electronic devices should be implemented.

Acknowledgements The authors would like to express their gratitude to Angeles Martinez Gomez for her assistance during the fieldwork in La Ñora as well as to the Spanish Ministry of Science and Technology.

Contributors CG-P was mainly responsible for designing and writing the manuscript and also made the main statistical contribution. EAN was one of the researchers responsible for the design and acquisition of radiofrequency electromagnetic field (RF EMF) data, as well as writing and reviewing the manuscript. JS contributed mainly in processing the RF EMF data, while MP was responsible for the design and final review of the manuscript.

Funding This work was funded by the Spanish Ministry of Science and Technology for grant FIT number 070000-2002-58.

Competing interests None.

Patient consent Obtained.

Ethics approval Ethical Committee of the University of Valencia in accordance with the Declaration of Helsinki (http://www.wma.net/e/policy/b3.htm).

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement The data used in this statistical analysis can be obtained from Dr CG-P on request by email (gomez_cla@gva.es).

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BMJ Open

Subjective symptoms related to GSM radiation from mobile phone base stations: a cross-sectional study

Claudio Gómez-Perretta, Enrique A Navarro, Jaume Segura, et al.

BMJ Open 2013 3:
doi: 10.1136/bmjopen-2013-003836

The Miseducation of America on 5G: The New York Times Gets It Spectacularly Wrong

Devra Davis Follow
Jul 22 · 12 min read ★

When William J. Broad, a Pulitzer-Prize winning *New York Times* science writer, strangely mangles information on the dangers of 5G, this plays right into the hands of those determined to advance this never-tested technology without serious examination of its long-term impact on human health and the environment.

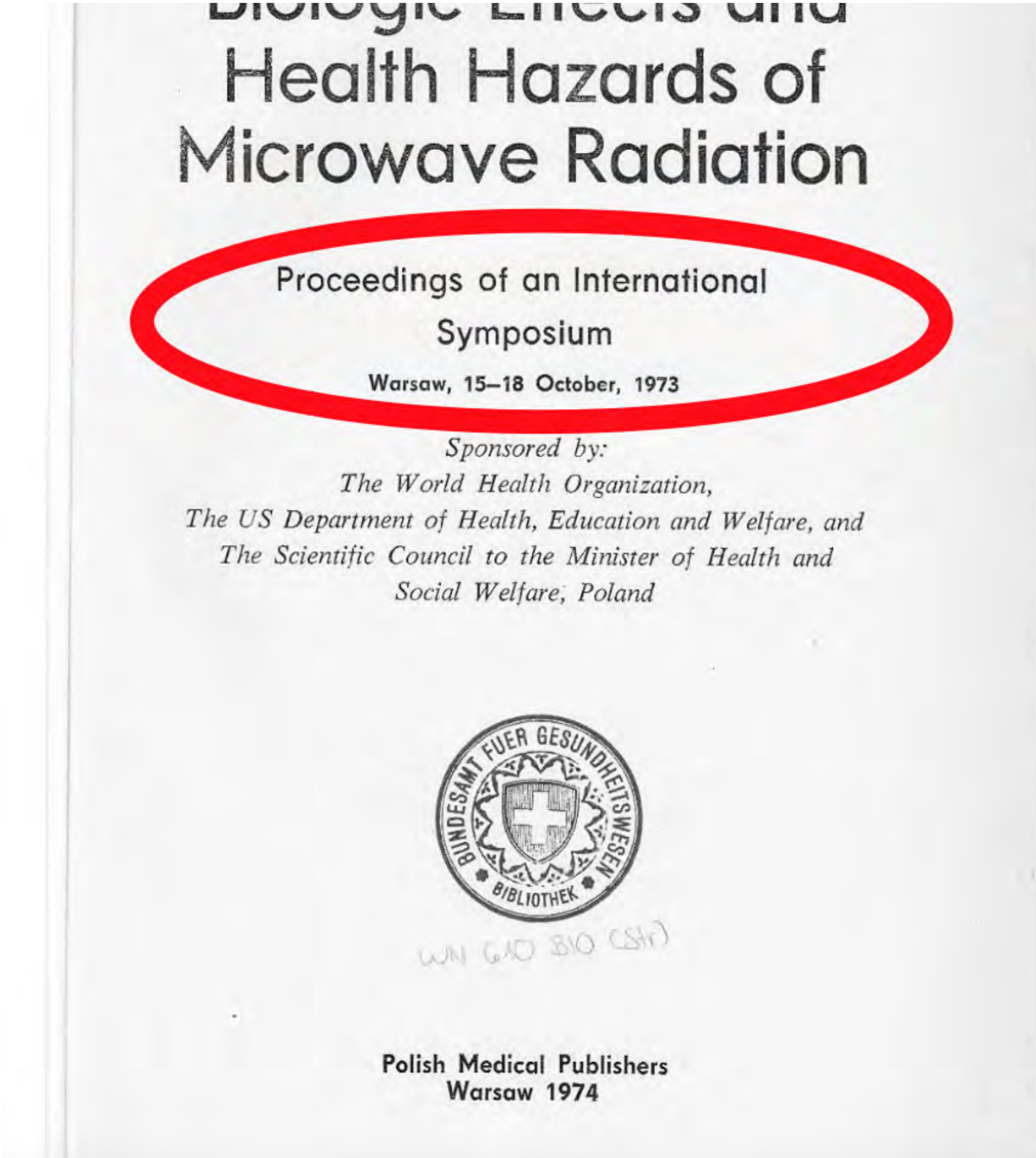
The recent headline of the NYTimes trumpeted 5G as the "health hazard that isn't." Not so fast. A close examination of claims in that article indicates that it is time for a reset on the march to the latest wireless technology as the consequences could not be more monumental.

Ten Corrections to William J. Broad's
"The 5G Health Hazard That Isn't" New York Times July 16, 2019

Issued by Devra Davis, PhD, MPH, President, Theodora Scarato, MSW, Executive Director, Environmental Health Trust.

1. **First of all, contrary to Broad's claim, Dr. Curry's report and graph on wireless radiation risks to children in schools in 2000 were not the central foundation for scientific concerns regarding wireless radiation.**


Biologic Effects and



Biologic Effects and Health Hazards of Microwave Radiation

Proceedings of an International Symposium

Warsaw, 15–18 October, 1973

Sponsored by:
The World Health Organization,
The US Department of Health, Education and Welfare, and
The Scientific Council to the Minister of Health and Social Welfare, Poland

Polish Medical Publishers
Warsaw 1974

WHO 1973 Conference Proceedings

- Long before 2000, scientists had investigated and confirmed numerous biological health impacts of electromagnetic (EMF) radiation.
- For over two decades, the US EPA had a robust research program on electromagnetic fields (EMF) that was expressly defunded by Congress in 1995, shortly after the EPA briefed the FCC about plans for developing EMF safety standards.
- As a result, no federal agency has responsibility for setting standards for public safety from exposures to EMF that include radiofrequency radiation (RF), also known as microwave or wireless radiation.

2. In fact, in contradiction to Broad's assertion, Curry's graph showing greater absorption with higher frequency of wireless radiation up to 3G was correct and directly applicable to schools.

- Curry's graph showing brain tissue absorption of RF came directly from laboratory research commissioned by the U.S. Air Force and was not a manipulation of data — as Broad claims.
- Broad alleges that Curry's graph was "wrong" because higher and faster 5G millimeter waves don't penetrate the skin. In fact, Curry's chart had nothing to do with the frequencies of 5G, but solely with the lower and slower wireless frequencies in use at that time about which there is no debate that Wi-Fi penetrates the body and brain as does Wi-Max.
- Wireless radiation frequencies get faster and higher, the depth of penetration goes down but the rate of absorption goes up.

- A graph from Curry's second report to the school district (also cited by Broad) references "absorption into a slab of grey matter" — otherwise known as the brain. Broad incorrectly captioned Curry's graph in the NYT story as showing "tissue damage," rather than "absorption" the word used in this graph shown below.

3. The NYTimes graph on 5G frequencies is wrong, because it

incorrectly indicates that 5G devices will start at 3000 MHz (3 GHz), when in fact companies have stated that 5G will use the same frequencies as current cell phones — as low as 600MHz, *in addition to* higher frequencies.

- The Wireless industry is clear that for 5G phones, routers, and systems to work, they must use a full range of frequencies, from low to middle to high, as well as higher millimeter-wave frequencies never used in mass-scale before (from 600 MHz up to around 50,000 MHz and higher into Terahertz for 6G). T-Mobile, for example, will use 600 MHz while AT&T is using 39 GHz in it's 5G test cities.
- New 5G phones will have multiple antennas emitting multiple frequencies and modulations all at the same time. Think Bluetooth,Wi-Fi, Mobile hotspot and LTE on top of the multiple 5G antennas in just one phone.
- As the American Academy of Pediatrics has noted in their letters to Congress, *lower* frequencies are absorbed deeply into brains and bodies, especially in children, because the skull of the young child is thinner than that of the adult, the neurons of their developing brains not fully myelinated, and their brains contain more fluid. As a consequence, the children will absorb proportionally more wireless radiation per exposure into the brain than adults, a point that Curry also makes in his reports.
- Broad's misrepresentation of 5G as not including these lower

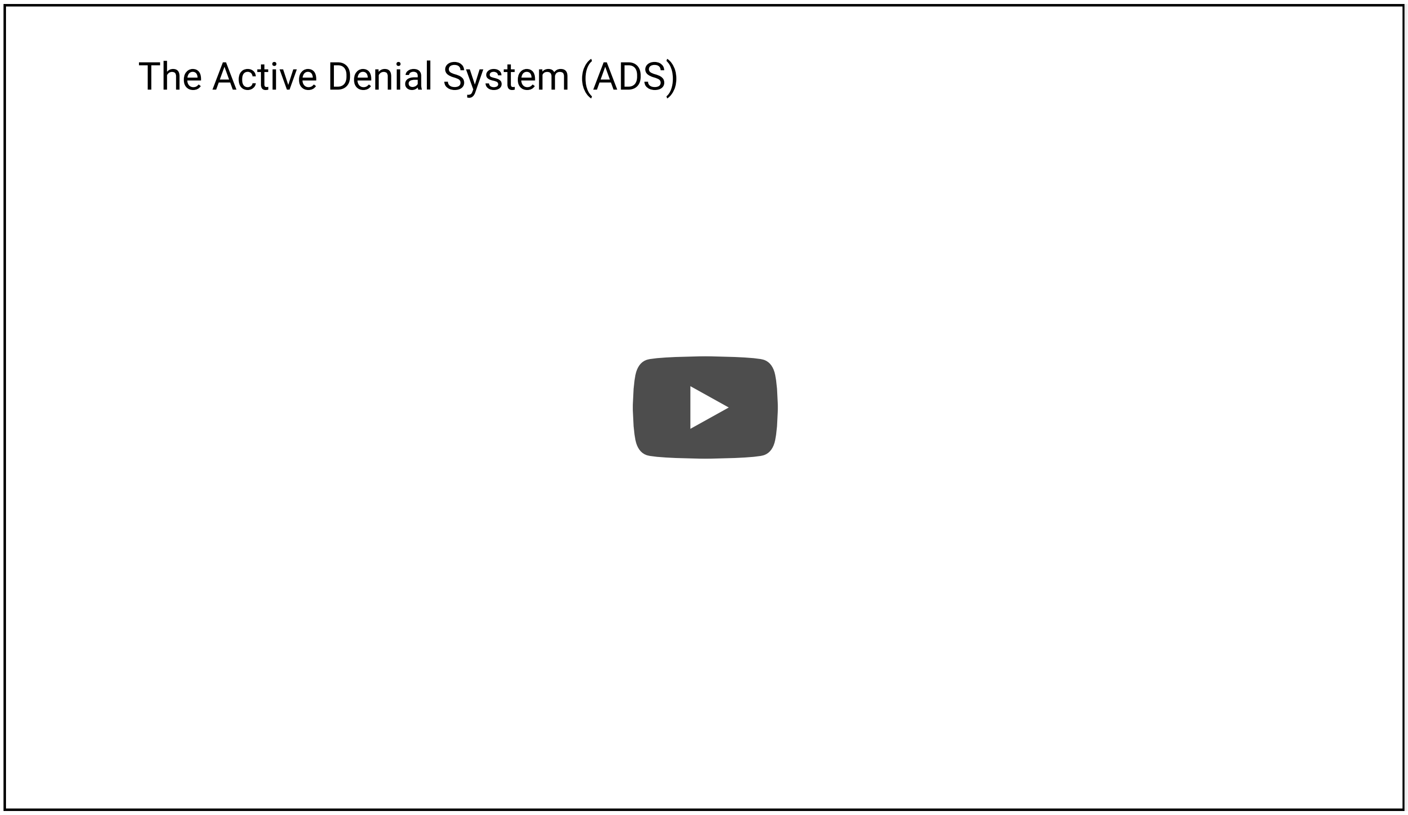
frequencies is the foundation for his erroneous conclusion that the skin is "a barrier" to 5G. We wrote Broad, but he refused to correct.

- By email, Marvin Ziskin clarified that his statement quoted by Broad that "5G emissions, if anything, should be safer" applied **solely** to the higher frequencies to be used in 5G as they did not penetrate into the body as deeply. Apparently, his statement did not apply to the slower and lower frequencies that are well known to be absorbed past the skin.

4. Broad errs in reporting the assertion of radiation physicists that radio waves become "safer" at higher frequencies because human skin purportedly "acts as a barrier." The skin does not just act as a mirror deflecting the radiation.

- 5G's faster mmWave frequencies between 30 and 300 GHz are **absorbed into** and just below the surface of the skin, and such exposure is biologically impactful. That is why the U.S. Defense Department developed weapons with high-powered millimeter waves as seen here. The Active Denial System (ADS), also known as the Pain-Ray, was deployed to Afghanistan, tested in prisons and considered as a pirate deterrent in Somalia.
- The military grounds for concluding that the Pain-Ray does not cause cancer after long-term exposure rests on a single three-month-long animal study involving two exposures per week. Further, the expert review alleges that blinking would spare eyes from harm. "The eyes would have to be held open to achieve damage“ and in a 2009 review

”Researchers learned that the human eye reflexively blinks within a quarter of a second of detecting millimeter waves, quickly protecting the eyes.” So do we stream movies superfast with our eyes closed? What about children’s developing eyes glued to 5G Virtual Reality streaming into classrooms?



- Wireless 5G networks will use beams of radiation like the Pain-Ray, and include Massive MIMO (multiplex in and multiplex out) and phased arrays meaning each installation could consist of numerous antennas simultaneously sending and receiving beaming waves into neighborhoods.
- A 2019 European Parliament Report notes, “The 5G radio emission

fields are quite different to those of previous generations because of their complex beamformed transmissions in both directions — from base station to handset and for the return. Although fields are highly focused by beams, they vary rapidly with time and movement and so are unpredictable." Because of this, that report concludes, "It is not possible to accurately simulate or measure 5G emissions in the real world."

- As our largest organ (~20 square feet), the skin is not a "barrier" but a filter that interacts with chemicals and EMF, that can produce systemic effects on the immune system and specific organs. Poison Ivy and peanuts need only touch the surface of the skin to set off an occasionally fatal reaction. A number of medicines are delivered through skin patches absorbed throughout the body. Babies born with jaundice are treated with intense light that penetrates through the skin to their blood that becomes transformed in their livers.
- As with all drugs in medicine or chemicals in the environment, biological impact depends on who gets exposed to how much under what specific conditions. For instance, a fair-skinned baby and her darker-skinned mother can have the same exposure to the sun with profoundly different results.

5. Contrary to what the NYTimes article asserts, studies find that as RF frequency increases past 10 GHz, the intensity of the rate of absorption does increase, despite the shallow penetration.

- Researchers investigating the impact to the skin from 5G's higher millimeter frequencies are "raising the warning flag" on the safety of 5G after finding that human sweat ducts absorb these frequencies at much higher rates than in surrounding skin structures — acting as tiny helical EMF antennas to magnify these signals.
- The video below shows one of those researchers, Paul Ben-Ishai, PhD, lecturer in the Department of Physics, Ariel University, Israel explaining how 5G millimeter waves interact with the skin. Ben-Ishai also wrote a letter to California Governor Brown on 5G.

Swiss government and private sector researchers caution that 5G frequencies can cause big increases in temperature that "may lead to permanent tissue damage after even short exposures."

- For insects, a new simulation study finds that their bodies can absorb up to three times more power from 5G that could lead to major changes in how they behave and function, affecting the capacity of bees and other insects to pollinate crops.
- Published reviews on 5G, millimeter waves and wireless (even from decades ago) have cataloged a host of harmful impacts including increased temperature, altered gene expression, faster cell growth, inflammatory and metabolic processes, damage to the eyes and cellular stress, memory problems, sperm damage, genetic damage, behavior issues and brain damage.

6. Contrary to the NYTimes statement, "mainstream scientists continue to see no evidence of harm from cellphone radio waves," more than 244 experts in the field of bioelectromagnetics have asked the United Nations to call for a moratorium on 5G.

- They note that while exposures have risen many fold, so have studies showing damage to human health and the environment.
- Astonishingly, Broad omitted any mention of the fact that an independent panel in 2011 advised the World Health Organization's International Agency for Research on Cancer (WHO/IARC) that cellphone and other wireless RF radiation should be classified as a "possible human carcinogen," based on evidence from studies carried

out up to that date.

- Nor does Broad report more recent analyses from scientists who have been senior advisors to the WHO and the NIH on bioelectromagnetics concluding that the FDA is downplaying clear evidence of cancer in the National Toxicology Program study, later corroborated by the Ramazzini Study, or that a growing number of scientists say RF is a "human carcinogen."
- In light of this mounting research, the WHO/IARC advisory group released 2019 "high priority" recommendations to reevaluate the cancer hazard from wireless radiation.

7. Broad neglected to mention industry connections of several of his sources.

- Several of the experts quoted in this article have in fact published research directly funded by the wireless industry or by NYU Wireless, "an R&D arm" of NYU's industry affiliates, which include AT&T, Sprint and Crown Castle — the very companies spearheading the rollout of 5G.
- The word "safe" means different things depending who you talk to. Industry reports define 'safe" as compliance with outdated FCC government limits despite the fact that these limits are based on thirty year old science. "Safe" is also conflated with "less penetration" into the body- another erroneous assumption based on no scientific research.

When independent scientists state electromagnetic fields are not "safe" because biological effects are replicated and proven (a fact), the industry connected scientist response is often that these biological effects "are not the same as *health* effects." This is no better exemplified in this presentation where "consistent evidence" of physiological changes during sleep are found, yet "these effects do not translate into any measure we can use to describe disturbances." When brain tumors, tumor promotion, genetic damage, memory problems, oxidative stress,brain wave changes, behavior issues in children, miscarriage, sperm damage, efflux of calcium ions and blood brain barrier permeability studies *are replicated,* the response is that it is "unclear," "difficult to draw conclusions," "the functional significance cannot be determined" and "more studies need to be done." When asked why authorities do not issue clear protections for children, they say the exposure is "low" and "society as a whole should decide" and it's difficult to prove safety."

- Unfortunately, the field of EMF research has been plagued with industry loyal experts, that have influenced federal agencies and research sponsorship bias, where works underwritten by industry tend to find no effect, while those few that are independently funded do report impacts.
- When Broad was questioned as to why he omitted industry affiliations in his March 2019 article claiming Russia was fomenting 5G health concerns, Broad responded in an email to EHT Executive Director Scarato that "*We do point out industry financial support when it seems*

appropriate. It's a judgment call."

8. Broad cites the lack of a marked uptick in brain cancer rates as proof of RF safety. This misunderstands the long latencies for brain cancer and also fails to consider that several other cancers plausibly tied with cellphone use are increasing in young adults.

- Cancers do not occur immediately after exposure to a causative agent and usually take years to several decades to be diagnosed. Widespread rises are not expected to be evident in today's statistics.
- New analysis by the U.S. Centers for Disease Control and others show that non-Hodgkin lymphomas, central nervous system tumors (CNST) (including brain cancers), renal, hepatic and thyroid tumors have increased recently among Americans under 20 years old.
- Perhaps more importantly, cancer is not the sole indicator of a problem. The Cleveland Clinic advises men who wish to father healthy children to remove phones from their pockets, because there is growing evidence that exposures can damage sperm. Sterility and infertility continue to rise in many countries. While factors accounting for this are complex, exposures to wireless radiation are relevant.

9. Broad's article fails to report on a number of major policy efforts to restrict 5G due to concerns about the lack of safety data, including the following developments:

- The European Environmental Authority ranked the impact of 5G as "high" due to "the possibility of unintended biological consequences."
- Swiss Re and Lloyd's have compared 5G and wireless to asbestos as "high" risk and most companies will not underwrite coverage for health damages.
- The State of New Hampshire passed HB522 establishing a commission on the health and environmental effects of 5G. One of the tasks of the Commission is to answer the question," Why have more than 220 of the worlds leading scientists signed an appeal to the WHO and the United Nations to protect public health from wireless radiation and nothing has been done?"
- The State of Louisiana passed HR 145 requesting authorities to study the environmental and health effects of 5G.
- Over a dozen municipalities in Italy have issued resolutions for precaution on 5G, as have several other localities in the world.
- Several US members of Congress have written the FCC asking for proof of safety of 5G and result was "unsatisfactary." Read the letters and responses here.
- The Ninth Circuit Court of Appeals, over industry objections, upheld the City of Berkeley's cell phone right to know ordinance requiring retailers to inform consumers that cellphones emit radiation and that "if you carry or use your phone in a pants or shirt pocket or tucked into a bra when the phone is ON and connected to a wireless network, you

may exceed the federal guidelines for exposure to RF radiation."

- A published analysis of cell phone radiation tests completed by the government of France shows when phones are touching the skin, they can exceed US FCC radiation limits up to 11 times, depending on the model.
- Oregon passed SB 283, a Bill that directs the Health Authority to review independently-funded scientific studies of the health effects of wireless, especially for school exposures.

- Cyprus just launched a major public educational campaign to reduce children's wireless exposures (as have several countries) and has removed wireless from the pediatric intensive care units of Archbıshop Makarıos III Hospital.
- The first major US medical conference for doctors on the health effects of electromagnetic radiation will be held this September in California.

10. Broad refuses to correct the inaccuracies of his articles and the

Times persists in demeaning critics and concerned citizens.

Despite ample documentation of the need for corrections, the NYT refuses to correct their misleading and deceptive articles about 5G and cellphone radiation.

Broad's 5G articles have been picked up by medical platforms and media nationwide, and are invoked as proof of safety by the former FCC Chairman Tom Wheeler who is also former Head of the CTIA-The Wireless Association. A 2015 Harvard Report documents how the heavy Congressional lobbying of the multibillion-dollar wireless industry coupled with the revolving door between industry and government has resulted in undue industry influence into the science and policy of wireless radiation.

The NYT article included a belittling graphic showing people fleeing in fear from a cell tower, mocking those who are working for safe neighborhoods and schools and the many nations that reduce children's exposure and do not permit towers near schools and hospitals, but did not reference a major investigative journalism analysis indicating serious grounds for concern.

Broad tweeted the story with "He was a very bright guy."

William J. Broad
@WilliamJBroad

"He was a very bright guy" nyti.ms/2XLqkVb

The 5G Health Hazard That Isn't

How one scientist and his inaccurate chart led to unwarranted fears of wireless technology.

nytimes.com

11 5:22 AM - Jul 16, 2019

38 people are talking about this

As Senator Patrick Moynihan stated, "Everyone is entitled to his own opinion, but not his own facts." We call upon the New York Times to correct the misinformation.

This was penned by Devra Davis, PhD, MPH, President and Theodora Scarato, MSW, Executive Director of Environmental Health Trust (EHT).EHT maintains scientific resources on 5G.

Note: Louis Slesin of Microwave News also reported on the inaccuracies in the New York Times article at "A Fact-Free Hit on a 5G Critic: Fabricating History on the New York Times Science Desk".

The 5G mass-experiment: Big promises, unknown risks

"The 5G Health Hazard That Isn't" New York Times 7/16/19 July 16, 2019

Curry PhD, Report on Wi-Fi in Schools, February 24, 2000

Curry PhD, Report on Wi-Fi in Schools, September 29, 2000

Health 5g Wireless Radiatin New York Times Cell Phone

Environmental Pollution 242 (2018) 643–658

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Thermal and non-thermal health effects of low intensity non-ionizing radiation: An international perspective☆

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A R T I C L E I N F O

Article history:
Received 6 April 2018
Received in revised form
31 May 2018
Accepted 4 July 2018
Available online 6 July 2018

A B S T R A C T

Exposure to low frequency and radiofrequency electromagnetic fields at low intensities poses a significant health hazard that has not been adequately addressed by national and international organizations such as the World Health Organization. There is strong evidence that excessive exposure to mobile phone-frequencies over long periods of time increases the risk of brain cancer both in humans and animals. The mechanism(s) responsible include induction of reactive oxygen species, gene expression alteration and DNA damage through both epigenetic and genetic processes. *In vivo* and *in vitro* studies demonstrate adverse effects on male and female reproduction, almost certainly due to generation of reactive oxygen species. There is increasing evidence the exposures can result in neurobehavioral decrements and that some individuals develop a syndrome of "electro-hypersensitivity" or "microwave illness", which is one of several syndromes commonly categorized as "idiopathic environmental intolerance". While the symptoms are non-specific, new biochemical indicators and imaging techniques allow diagnosis that excludes the symptoms as being only psychosomatic. Unfortunately standards set by most national and international bodies are not protective of human health. This is a particular concern in children, given the rapid expansion of use of wireless technologies, the greater susceptibility of the developing nervous system, the hyperconductivity of their brain tissue, the greater penetration of radiofrequency radiation relative to head size and their potential for a longer lifetime exposure.

1. Introduction

Electromagnetic fields (EMFs) are packets of energy that have no mass. They vary in frequency and wavelength. At the high end of the electromagnetic spectrum there are cosmic and X-rays that have enough energy to cause ionization, and therefore are known as ionizing EMFs. Below in frequency and energy are ultraviolet, visible light and infrared EMFs. Excessive exposure to ultraviolet EMFs poses clear danger to human health, but life on earth would not be possible without visible light and infrared EMFs. Below these forms of EMF are those used for communications (radiofrequency or RF-EMFs, 30 kHz-300 GHz) and those generated by electricity (extremely low-frequency or ELF-EMFs, 3 Hz-3 kHz). These EMFs do not have sufficient energy to directly cause ionization, and are therefore known as non-ionizing radiation. RF-EMFs at sufficient intensity cause tissue heating, which is the basis of operation of the microwave oven. However the question to be addressed here is human health effects secondary to exposures to non-ionizing EMFs at low intensities that do not cause measureable heating.

☆ This paper has been recommended for acceptance by Payam Dadvand.

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https://doi.org/10.1016/j.envpol.2018.07.019
0269-7491/

In spite of a large body of evidence for human health hazards from non-ionizing EMFs at intensities that do not cause measureable tissue heating, summarized in an encyclopedic fashion in the Bioinitiative Report (www.bioinitiative.org), the World Health Organization (WHO) and governmental agencies in many countries have not taken steps to warn of the health hazards resulting from exposures to EMFs at low, non-thermal intensities, nor have they set exposure standards that are adequately health protective. In 2001 the International Agency for Research on Cancer (IARC, 2002), part of the WHO, declared ELF-EMFs to be "possibly carcinogenic to humans", and in 2011 they made a similar declaration for RF-EMFs (Baan et al., 2011; IARC, 2013). The classification of RF-EMFs as a "possible" human carcinogen was based primarily on evidence that long-term users of mobile phones held to the head resulted in an elevated risk of developing brain cancer. One major reason that the rating was not at "probable" or "known" was the lack of clear evidence from animal studies for exposure leading to cancer. The US National Toxicology Program has released preliminary results of a study of long term exposure of rats to cell phone radiation which resulted in a statistically significant increase in brain gliomas, the same cancer found in people after long-term cell phone use, and schwannomas, a tumor similar to the acoustic neuroma also seen after intensive mobile phone use (Wyde et al., 2016). Similar results in rats have been reported in an independent study at the Ramazzini Institute with exposures similar to those from a mobile phone base station (Falcioni et al., 2018). This evidence, in conjunction with the human studies, demonstrates conclusively that excessive exposure to RF-EMF results in an increased risk of cancer. In light of this new evidence for cancer in rodents in response to prolonged exposure to mobile phone frequencies, the IARC rating should be raised at least to "probable" (Group 2A) if not "known" (Group 1).

Unfortunately the International EMF Project of the WHO, which is part of the Department of Public Health, Environment and Social Determinants of Health in Geneva, has consistently minimized health concerns from non-ionizing EMFs at intensities that do not cause tissue heating (WHO, 2014). In this regard WHO has failed to provide an accurate and human health-protective analysis of the dangers posed to health, especially to the health of children, resulting from exposure to non-thermal levels of electromagnetic fields. The Department of Public Health, Environment and Social Determinates of Disease takes its advice on the issues related to human health effects of non-ionizing EMFs from the International Commission on Non-ionizing Radiation Protection (ICNIRP). Almost all members of the core group preparing the new Environmental Health Criteria (EHC) document for the WHO are members of ICNIRP (Starkey, 2016; Hardell, 2017), a non-goverment organization (NGO) whose members are appointed by other members. In spite of recent efforts to control for conflicts of interest, ICNIRP has a long record of close associations with industry (Maisch, 2006). When queried as to why the WHO would take recommendations from such a group, WHO staff replied that ICNIRP is an official NGO which works closely with the WHO. Why this should exclude other scientific research groups and public health professionals is unclear, particularly since most members of ICNIRP are not active researchers in this field. We are particularly concerned that a new WHO EHC document on RF-EMFs is scheduled to be released soon, and that the members of the EHC Core Group and the individuals whose assistance has been acknowledged are known to be in denial of serious non-thermal effects of RF-EMFs in spite of overwhelming scientific evidence to the contrary (Starkey, 2016; Hardell, 2017).

Others have dismissed the strong evidence for harm from ELF- and RF-EMFs by arguing that we do not know the mechanism whereby such low energetic EMFs might cause cancer and other diseases. We have definitive evidence that use of a mobile phone results in changes in brain metabolism (Volkow et al., 2011). We know that low-intensity ELF- and RF-EMFs generate reactive oxygen species (ROS), alter calcium metabolism and change gene expression through epigenetic mechanims, any of which may result in development of cancer and/or other diseases or physiological changes (see www.bioinitiative.org for many references). We do not know the mechanisms behind many known human carcinogens, dioxins and arsenic being two examples. Given the strength of the evidence for harm to humans it is imperative to reduce human exposure to EMFs. This is the essence of the "precautionary principle".

There are a number of reasons for our concern. In the past the major exposure of the general population to RF-EMFs came from radio and television signals. Now there are almost as many mobile phones as there are people in the world, all of them being exposed to RF-EMFs. There are mobile phone towers everywhere, and in many developing countries there are no land-lines that allow communication without exposure to RF-EMFs. There is rapid movement in many developed countries to place small cell transmitting devices (5G) operating at higher frequencies (24–70 GHz) every approximately 300 m along sidewalks in residential neighborhoods. There are other significant sources of exposure, coming from WiFi, smart meters and soon from automobiles operating without a human driver. Therefore human exposure has increased dramatically in recent years, and continues to increase rapidly. While we already are seeing harm from these exposures, the degree of harm will only increase with time because of the latency that is known to occur between exposure and development of diseases such as cancer.

Standards for protection of human health from EMFs vary greatly around the world. Many countries set standards based on the false assumption that there are no adverse health effects of RF-EMFs other than those that are caused by tissue heating. This is the case in North America, Australia and some European countries. Many countries from the former Soviet Union have much more restrictive standards. However information from cellular and human studies show biological effects that constitute hazards to human health at exposure levels that are often exceeded during daily life.

This report follows a recent non-official meeting in Geneva with WHO representives, where the authors urged WHO to acknowlege low intensity effects of ELF-EMFs and non-thermal health effects of RF-EMFs. This report does not attempt to present a complete overview of the subject [see the Bioinitiative Report (www.bioinitiative.org) for that] but rather to provide a holistic picture of the processes explaining most or all of the adverse effects of EMF exposures. It summarizes the evidence for cancer resulting from exposure to EMFs, and identifies other diseases or pathological conditions such as Alzheimer's disease and hypofertility that have been shown to be associated with excesive exposure to low-intensity EMFs. We also focus on electrohypersensitivity (EHS) in both children and adults and cognitive and behavioural problems in children resulting from the increasing exposure. Finally we discuss what is known about the mechanisms whereby non-thermal EMF radiation can cause disease with special reference to EMF-related free radical production and epigenetic and genetic mechanisms.

2. Mobile phone use and the risk for glioma, meningioma and acoustic neuroma

The brain is the main target for exposure to RF-EMF radiation during use of handheld wireless phones, both mobile and cordless phones (Cardis et al., 2008; Gandhi et al., 2012). An increased risk for brain tumors has been of concern for a long time. The results of the Swedish National Inpatient Register have documented an increasing incidence of brain tumors in recent years (Carlberg and Hardell, 2017). In May 2011 RF radiation in the frequency range 30 kHz–300 GHz was evaluated to be a Group 2B, i.e. a "possible" human carcinogen, by IARC (Baan et al., 2011; IARC, 2013). This was based on an increased risk for glioma and acoustic neuroma in human epidemiological studies. In the following an updated summary is given of case-control studies on brain and head tumors; glioma, meningioma and acoustic neuroma. The Danish cohort study on 'mobile phone users' (Johansen et al., 2001; Schüz et al., 2006) is not included due to serious methodological shortcomings in the study design, including misclassification of exposure (see Söderqvist et al., 2012a).

2.1. Glioma

Glioma is the most common malignant brain tumor and represents about 60% of all central nervous system (CNS) tumors. Most of these are astrocytic tumors that can be divided into low-grade (WHO grades I-II) and high-grade (WHO grades III-IV). The most common glioma type is glioblastoma multiforme (WHO grade IV) with peak incidence in the age group 45–75 years and median survival less than one year (Ohgaki and Kleihues, 2005). Three research groups have provided results in case-control studies on glioma (Interphone, 2010; Coureau et al., 2014; Hardell and Carlberg, 2015). Hardell and colleagues have published results from case-control studies on use of wireless phones and brain tumor risk since the end of the 1990s (Hardell et al., 1990; for more discussion see Carlberg and Hardell, 2017).

A random effects model was used for meta-analyses of published studies, based on test for heterogeneity in the overall group ("all mobile"). Note that only the Hardell group also assessed use of cordless phones. Thus their reference category included cases and controls with no use of wireless phones in contrast to the other studies investigating only mobile phone use. In Table 1 results for highest cumulative use in hours of mobile phones is given. All studies reported statistically significant increased risk for glioma and the meta-analysis yielded an odds ratio (OR) = 1.90 [95% confidence interval (CI) = 1.31–2.76]. For ipsilateral mobile phone use the risk increased further to OR = 2.54 (95% CI = 1.83–3.52) in the meta-analysis based on 247 exposed cases and 202 controls.

Carlberg and Hardell (2014) found shorter survival in patients with glioblastoma multiforme associated with use of wireless phones compared with patients with no use. Interestingly mutation of the p53 gene involved in disease progression has been reported in glioblastoma multiforme in patients with mobile phone use ≥3 h per day. The mutation was statistically significantly correlated with shorter overall survival time (Akhavan-Sigari et al., 2014). Further support for the increased risk of glioma associated with mobile phone use has been obtained in additional analyses of parts of the Interphone study (Cardis et al., 2011; Grell et al., 2016; Momoli et al., 2017).

2.2. Meningioma

Meningioma is an encapsulated, well-demarked and rarely malignant tumor. It is the most common benign tumor and accounts for about 30% of intracranial neoplasms. It develops from the pia and arachnoid membranes that cover the CNS. It is slowly growing and gives neurological symptoms by compression of adjacent structures. The most common symptoms are headaches and seizures. The incidence is about two times higher in women than in men. Meningioma develops mostly among middle aged and older persons (Cea-Soriano et al., 2012). Carlberg and Hardell (2015) included meningioma in their case-control studies. The results of the meta-analysis for cumulative exposure in the highest category are given in Table 2. In total there was an increased (but not statistically significant) risk for cumulative exposure but the increased risk was statistically significant for ipsilateral use of mobile phones (OR = 1.49, 95% CI = 1.08–2.06).

2.3. Acoustic neuroma

Acoustic neuroma, also called vestibular schwannoma, is a benign tumor located on the eighth cranial nerve from the inner ear to the brain. It is usually encapsulated and grows in relation to the auditory and vestibular portions of the nerve. It grows slowly and due to the narrow anatomical space may give compression of vital brain stem structures. First symptoms of acoustic neuroma are usually tinnitus and hearing problems. Results for use of mobile phones in Interphone (2011) and Hardell et al. (2013) are given in Table 3. Statistically significant increased risk was found for cumulative ipsilateral use ≥1640 h yielding OR = 2.71 (95% CI = 1.72–4.28).

The study by Moon et al. (2014) was not included in the meta-analysis because data on cumulative mobile phone use with numbers of cases and controls were not given. Support of an increased risk was seen in the case-case part of the study (Moon et al., 2014) and also in the report by Sato et al. (2011). Pettersson et al. (2014) made a case-control study on acoustic neuroma in Sweden not overlapping the Hardell et al. (2013) study. An increased risk for the highest category of cumulative use of both mobile phone (≥680 h OR = 1.46, 95% CI = 0.98–2.17) and cordless phone (≥900 h OR = 1.67, 95% CI = 1.13–2.49) was found.Pettersson et al. (2014) was not included in the meta-analysis due to the many scientific shortcomings in the study, e.g. laterality analysis was not made for cordless phone, the numbers in the laterality analysis for mobile phone are not consistent in text and tables and the 'unexposed' reference category included subjects using either mobile and cordless phone, which is clearly not correct (Hardell and Carlberg, 2014).

Table 1
Numbers of exposed cases (Ca) and controls (Co) and odds ratio (OR) with 95% confidence interval (CI) for glioma in case-control studies in the highest category of cumulative hours of mobile phone use.

	All			Ipsilateral		
	Ca/Co	OR	95% CI	Ca/Co	OR	95% CI
Interphone 2010						
Cumulative use ≥1640 h	210/154	1.40	1.03–1.89	100/62	1.96	1.22–3.16
Coureau et al., 2014						
Cumulative use ≥896 h	24/22	2.89	1.41–5.93	9/7	2.11	0.73–6.08
Carlberg and Hardell, 2015						
Cumulative use ≥1640 h	211/301	2.13	1.61–2.82	138/133	3.11	2.18–4.44
Meta-analysis						
Longest cumulative use	445/477	1.90	1.31–2.76	247/202	2.54	1.83–3.52

Table 2
Numbers of exposed cases (Ca) and controls (Co) and odds ratio (OR) with 95% confidence interval (CI) for meningioma in case-control studies in the highest category of cumulative hours of mobile phone use.

	All			Ipsilateral		
	Ca/Co	OR	95% CI	Ca/Co	OR	95% CI
Interphone 2010						
Cumulative use ≥1640 h	130/107	1.15	0.81–1.62	46/35	1.45	0.80–2.61
Coureau et al., 2014						
Cumulative use ≥896 h	13/9	2.57	1.02–6.44	6/4	2.29	0.58–8.97
Carlberg and Hardell 2015						
Cumulative use ≥1640 h	141/301	1.24	0.93–1.66	67/133	1.46	0.98–2.17
Meta-analysis						
Longest cumulative use	284/417	1.27	0.98–1.66	119/172	1.49	1.08–2.06

Table 3
Numbers of exposed cases (Ca) and controls (Co) and odds ratio (OR) with 95% confidence interval (CI) for acoustic neuroma in case-control studies in the highest category of cumulative hours of mobile phone use.

	All			Ipsilateral		
	Ca/Co	OR	95% CI	Ca/Co	OR	95% CI
Interphone 2011						
Cumulative use ≥1640 h	77/107	1.32	0.88–1.97	47/46	2.33	1.23–4.40
Hardell et al., 2013						
Cumulative use ≥1640 h	27/301	2.40	1.39–4.16	19/133	3.18	1.65–6.12
Meta-analysis						
Cumulative use ≥1640 h	104/408	1.73	0.96–3.09	66/179	2.71	1.72–4.28

2.4. *In summary*

Based on case-control studies there was a consistent finding of increased risk for glioma and acoustic neuroma associated with use of mobile phones. Similar results were found for cordless phones in the Hardell group studies, although such use was not reported by the other study groups. The findings are less consistent for meningioma although somewhat increased risk was seen in the meta-analysis of ipsilateral mobile phone use. A longer follow-up time is necessary for this type of slow growing tumor.

The results on glioma and acoustic neuroma are supported by results from animal studies showing co-carcinogenic and tumor promoting effects from RF-EMF (Tillmann et al., 2010; Lerchl et al., 2015). Recent results from the National Toxicology Program (NTP) study showed genotoxicity of RF radiation in rats and mice exposed to RF-EMF (Smith-Roe et al., 2017). That result supports previous findings of DNA strand breaks in rat brain cells exposed to RF-EMF (Lai and Singh, 1997).

Of importance also is that the results in the NTP and Ramazzini studies both demonstrated an increased incidence of tumors of the same type, glioma and malignant schwannoma, as has been seen in humans with mobile phone use (Wyde et al., 2016; Falcioni et al., 2018). Acoustic neuroma (vestibular schwannoma) is a similar type of tumor as malignant schwannoma, although benign. In fact, rates of brain tumors are increasing in Sweden and use of wireless phones has been suggested to be the cause (Hardell and Carlberg. 2017).

3. Other diseases and pathological conditions attributed to exposure to low-intensity EMFs

The evidence for harm from RF-EMF is strongest for cancer as a consequence of intensive mobile phone use, especially gliomas, glioblastomas and acoustic neuromas. But there is other evidence for elevation in risk of leukemia among children living near to very high intensity radio transmission towers (Michelozzi et al., 2002; Ha et al., 2007). This is particularly interesting because leukemia is the cancer most associated with elevated exposure to ELF-EMFs arising from power lines (Ahlbom et al., 2000; Greenland et al., 2000). There is some evidence for elevations in breast cancer risk among women who wear their mobile phones in their bra (West et al., 2013). Heavy use of a mobile phone was associated with significantly elevated rates of ipsilateral parotid tumors in studies from both Israel (Sadetzki et al., 2007) and China (Duan et al., 2011). No increased risk was found in a Swedish study, but the results were limited by low number of participants and lack of data on heavy and long-term use of wireless phones (Söderqvist et al., 2012b).

There are other significant human health hazards of concern. There is strong animal and human evidence that exposure to RF-EMFs as well as ELF-EMFs reduces fertility in both males (reviewed by McGill and Agarwal, 2014) and females (Roshangar et al., 2014). An association between spontaneous abortion and non-thermal EMF exposure including ELF-EMFs was reported in several case-control studies (Dodge, 1970; Juutilainen et al., 1993; Li et al., 2017). The increased use of mobile phones and increased exposure coming from WiFi, smart meters and other wireless devices has been paralled in time with male hypofertility and sperm abnormalities in semen (Rolland et al., 2013). These effects may be related to holding an active wireless laptop in a man's lap or having an active mobile phone on their belt, but more study is needed. There is evidence that isolated human sperm exposed to RF-EMFs are damaged by generation of reactive oxygen species (Agarwal et al., 2009).

There are other diseases or physiologic alterations which have been reported to be associated with exposure to non-thermal EMFs in humans and in animals (Belyaev et al., 2016). Alzheimer disease has been shown to be significantly associated with chronic ELF-EMF occupational exposure in prospective epidemiological studies (García et al., 2008; Davanipour and Sobel, 2009). Exposure to RF-EMFs has been reported to increase neuropsychiatric and behavioural disorders (Johansson et al., 2010; Divan et al., 2012), trigger cardiac rhythm alteration and peripheral arterial pressure instability (Havas, 2013; Saili et al., 2015), induce changes in immune system function (Lyle et al., 1983; Grigoriev et al., 2010; Sannino et al., 2011, 2014) and alter salivary (Augner et al., 2010) and thyroid (Koyu et al., 2005; Mortavazi et al., 2009; Pawlak et al., 2014) function. There is an urgent need for more study of these diseases or biological alterations in relation to exposure to both ELF- and RF-EMFs.

4. An emerging concern: cognitive and neurobehavioral problems in children

Children, and especially fetuses, are more vulnerable than adults for most environmental exposures (Sly and Carpenter, 2012). This is because their cells are rapidly dividing and their organ systems are not mature. As a result, events that perturb cellular function early in life can result is abnormalities that last. There is a building body of evidence indicating that exposure to RF-EMFs has adverse effects on cognition and neurobehavior, especially in children and adolescents. Concern about the particular sensitivity of children to RF-EMFs emitted from mobile phone was first raised in 2000 by a British independent expert group (IEG, 2000) that noted that the increased sensitivity to EMFs of children could be due not only to the natural vulnerability of the developing nervous system, but also to the smaller head size and thickness of the skull. These factors, plus the higher conductivity of the young nervous system, result in greater penetration of RF-EMFs into the brain (Gandhi et al., 1996). Of concern is the fact that any adverse effects during development may have life-long consequences and that young people, because they will have a longer life span, will receive a greater cumulative exposure than adults (Kheifets et al., 2005; Hansson Mild et al., 2006).

There are several reasons to be concerned. Animal studies have shown that *in utero* RF-EMF exposure from mobile phones affects fetal programming and leads to alteration in neurodevelopment and behavior of offsprings (Aldad et al., 2012; Zhang et al., 2015). Exposure of young rats to non-thermal intensities impairs learning and spatial memory secondary to a deleterious impact of EMFs on hippocampal, pyramidal or cortical neurons. Similar detrimental cognitive and behavioural defects were also observed in adult animals exposed to low-intensity.

EMFs (Bas et al., 2009; Deshmukh et al., 2015; Kumari et al., 2017; Shahin et al., 2017). The exposure induces markers of oxidative stress and inflammation in the brain (Dasdag et al., 2012; Megha et al., 2015).

There are human data consistent with these animal studies. Divan et al. (2008) reported that prenatal and to a lesser degree postnatal exposure to cell phones is associated with emotional and hyperactivity problems in 7-year old children. This finding was confirmed in a second replicative study involving different participants (Divan et al., 2012). Birks et al. (2017) used data from studies in five cohorts from five different countries (83,884 children) and concluded that maternal mobile phone use during pregnancy increased the risk that the child will show hyperactivity and inattention problems. A meta-analysis involving 125,198 children (mean age 14.5 years) reported statistically significant associations between access to and use of portable screen-based media devices (e.g. mobile phones and tablets) and inadequate sleep quality and quantity and excessive daytime sleepiness (Carter et al., 2016). Early life exposure to lead has long been known to cause a reduction in cognitive function and shortened attention span (Needleman et al., 1979). Two studies have shown that prenatal (Choi et al., 2017) or postnatal (Byun et al., 2017) mobile phone exposure results in greater neurobehavioral effects in children with elevated lead levels than those seen with elevated lead alone. These results raise concern that EMFs may have synergistic actions with other environmental contaminants known to cause a reduction in intelligence quotient (IQ) and attention, such as polychlorinated biphenyls, methyl mercury, environmental tobacco smoke and probably others (Carpenter, 2006).

Finally the problem should be considered at the societal, worldwide level. Many adolescents (Lenhart, 2015) and even very young children and infants (Kabali et al., 2015) use cordless devices immoderately, to such a point that the common intensive use of devices in children and adolescents has been ascribed as an addiction (Paz de la Puente and Balmori, 2007; Roberts et al., 2014).

The specific absorption rate (SAR)-based ICNIRP safety limits were established on the basis of simulation of EMF energy absorption using standardized adult male phantoms, and designed to protect people only from the thermal effects of EMFs. These assumptions are not valid for two reasons. Not only do they fail to consider the specific morphological and bioclinical vulnerabilities of children, but also they ignore the effects known to occur at non-thermal intensities. The same criticisms apply to other so called "independent" advisory groups or agencies, such as the Advisory Group of Non-Ionizing Radiation in the UK (AGNIR, 2012), the French Agency for Food, Environmental and Occupational Health & Safety in France (ANSES, 2013), and the Scientific Committee on Emerging Newly Identified Health Risk (SCENIHR, 2009), all of whom deny the detrimental health effects of low intensity, non thermal EMF exposure and make recommendations based only on thermal SAR considerations.

Although several scientific authorities, such as the US American Academy of Pediatrics (AAP, 2013), and the Russian National Committee on Non-Ionizing Radiation Protection (RNCNIRP, 2011) have made specific recommendations to not allow the use of mobile phones by children and to limit their use by adolescents, unfortunately these age categories remain a target for marketing of mobile phone devices [http://www.who.int/peh-emf/project/mapnatreps/RUSSIA%20report%202008.pdf]. The RNCNIRP has warned that if no rational, health-based safety limits are adopted for children and adolescents and no measures are taken to limit the use of cordless devices, we can expect disruption of memory, decreases in learning and cognitive capabilities, increases in irritability, sleep disturbance, and loss of stress adaptation in this population. There will also be long-term effects, including an increase in brain cancer, infertility, EHS, Alzheimer disease and other neurodegenerative diseases (RNCNIRP, 2011; Markov and Grigoriev, 2015). National and international bodies, particularly the WHO, will bear major responsiblity for failing to provide specific science-based guidance and recommendations so as to avoid such global health threats.

5. Electrohypersensitivity, microwave illness or idiopathic environmental intolerance attributed to electromagnetic fields

There is a segment of the human population that is unusually intolerant to EMFs. The term "electromagnetic hypersensitivity" or "electrohypersensitivity (EHS)" to describe the clinical conditions in these patients was first used in a report prepared by a European group of experts for the European Commission (Bergqvist et al., 1997). Santini et al. (2001, 2003) reported similar symptoms occurring in users of digital cellular phones and among people living near mobile phone base stations.

In 2004, because of the seemingly increasing worldwide prevalence, WHO organized an international scientific workshop in Prague in order to define and characterize EHS. Although not acknowledging EHS as being caused by EMF exposure, the Prague working group report clearly defined EHS as "a phenomenon where individuals experience adverse health effects while using or being in the vicinity of devices emanating electric, magnetic or electromagnetic fields" (www.who.int/pehemf/EHS_Proceedings_June2006.pdf). Following this meeting, WHO acknowledged EHS as an adverse health condition (WHO, 2005).

According to the Prague Workshop recommendations, it was proposed to use the term “idiopathic environmental intolerance (IEI) attributed to electromagnetic fields” (IEI-EMF) because of the lack of a proven causal link with EMF exposure (Hansson Mild et al., 2006). This pathological disorder is identical to what has been previously described under the term “microwave illness” (Carpenter, 2015).

This syndrome is characterized by fatigue, chronic pain and impaired cognitive function (see the Paris appeal, http://appel-de-paris.com/?lang=en). The precise mechanism(s) whereby environmental exposure to either ELF- or RF-EMFs can cause the development of this syndrome are still uncertain. However several lines of experimental and clinical data are sufficiently strong so as to indicate that ELF-EMFs and RF-EMFs exposure is associated with adverse biological and clinical health effects in humans as well as animals (Rea et al., 1991; McCarty et al., 2011; Belpomme et al., 2015; Hedendahl et al., 2015; Irigaray et al., 2018a). The prevalence of EHS has been estimated to range 1–10% in developed countries (Hallberg and Oberfeld, 2006) but appears today to be around 3% (Huang et al., 2018).

Since WHO official reports on mobile phone exposure and public health (WHO, 2014) and more particularly on EHS (WHO, 2005), much clinical and biological progress has been made to identify and objectively characterize EHS, as was summarized during the international scientific consensus meeting of the 5th Paris Appeal Congress that took place in May 2015 in Brussels at the Royal Belgium Academy of Medicine (ISD, 2015). EHS has many characteristics in common with other IEI pathological disorders, including chronic fatigue syndrome, fibromyalgia, Gulf War Illness and especially the syndrome of multiple chemical senssitvity (MCS), which Belpomme et al. (2015) have shown to be associated with EHS in many patients who report being electrohypersensitive.

5.1. Bioclinical identification and characterisation of electrohypersensitivity

In a prospective study involving systematic face-to-face questionnaire-based interviews and clinical physical examinations of nearly two thousand patients who self-reported having EHS or EHS and MCS, Belpomme and colleagues reported that EHS is a well-defined clinico-biological entity, characterized by the progressive occurrence of neurologic symptoms, including headache, tinnitus, hyperacusis, superficial and/or deep sensibility abnormalities, fibromyalgia, vegetative nerve dysfunction and reduced cognitive capability. These symptoms are repeatedly reported by the patients to occur each time they are exposed to EMFs, even of weak intensity. They result in chronic insomnia, fatigue, emotional lability and depressive tendency (Belpomme et al., 2015; Irigaray et al., 2018b).

Table 4 presents the detailed symptomatic picture which was obtained during face-to-face interviews with subjects with EHS in comparison to those with both EHS and MCS and to a series of apparently healthy control subjects that showed no evidence of EHS and/or MCS. As shown in the Table, the symptoms reported are consistent with those in other published questionnaire-based studies of EHS patients (Dodge, 1970; Johansson et al., 2010; Nordin et al., 2014; Medeiros and Sanchez, 2016; Röösli, 2008). The clinical symptoms observed in EHS or EHS/MCS patients are statistically significantly much more frequent that those in apparently normal controls. Although many of these symptoms are non-specific, the general clinical picture resulting from their association and frequency strongly suggests that EHS can be recognized and identified as a specific neurological disorder.

Because of the multiple and relatively common symptoms and the lack of recognized objective diagnosis criteria, studies on EHS were left with only the patient's self-reported interpretation for many years. As a result, EHS has unfortunately been considered to be a psychiatric disease of unknown origin. This helps explain why most mainstream public health and societal bodies claim there is not sufficient data proving that the clinical symptoms experienced and reported by EHS patients are caused by EMF exposure. Therefore they refuse to acknowledge EHS as a true neuropathological disorder. This negative point of view was supported by some blind or double blind studies showing that most individuals who report they suffer from EHS were not able to identify when they were exposed to either EMFs or sham controls (Rubin et al., 2011; Eltiti et al., 2015). However other studies have found that EHS subjects can identify EMF exposure in a statistically significant manner when they are blinded to whether or not the exposure was on (Rea et al., 1991; McCarty et al., 2011).

To account for these seemingly negative results a nocebo effect was suggested (ANSES, 2017). However there is presently no consensus on a biological mechanism through which a nocebo effect could occur (Medeiros and Sanchez, 2016; Chrousos and Gold, 1992; Jakovljevic, 2014). Moreover, results obtained in a carefully designed psycho-clinical study in self-reporting EHS patients are not consistent with an initial nocebo response to perceived EMF exposure, even though it is plausible that after the onset of the disease such phenomena may intervene secondarily through an acquired learning and conditioning process (Dieudonné, 2016). In addition, a meta-analysis of cross sectional studies has documented a 38% greater risk of development of headaches among mobile phone users than non-users, and an increasing risk of headache with longer daily call duration (Wang et al., 2017).

Belpomme, Irigaray and colleagues recently identified several biomarkers in EHS and/or MCS patients which allow physicians to identify and objectively characterize EHS as a true somatic pathological disorder, discounting the hypothesis of a causal psychosomatic or nocebo-related process. These came in part from a prospective clinical and biological analysis of a series of several hundred consecutive cases of individuals who self-reported that they suffered from EHS or both EHS and MCS (Belpomme et al., 2015) and more recently from the prospective anlaysis of an additional series of EHS patients (Irigaray et al., 2018a). Table 5 summarizes the different biomarkers that have been measured in the peripheral blood of these patients and the results which have been obtained based on the EHS and EHS/MCS patient groups. Note that among the different markers, the 6-hydroxymelatonin sulfate/creatinine ratio in urine appears to be the best marker to be used in medical practice since it has been found to be decreased in all cases evaluated to date (Belpomme et al., 2015).

By measuring different major oxidative stress-related biomarkers, such as thiobarbituric acid reactive substances (TBARS), oxided glutathione (GSSG) and nitrotyrosine (NTT) in EHS patients, Irigaray et al. (2018b) have recently shown that near 80% of the EHS patients present with detectable oxidative stress biomarkers (Fig. 1). More than 40% of EHS patients present with at least one positive biomarker, 20% with two and 15% will all three of the biomarkers investigated. This indicates that in addition to the inflammation-related biomarkers previously associated with EHS, EHS patients are also characterized by exhibiting biomarkers of oxidative stress (Belpomme et al., 2015; Irigaray et al., 2018a,b).

The significance of the different biomarkers measured in the peripheral blood of EHS and EHS/MCS patients is that these results imply that these patients present with some degree of oxidative/nitrosative stress, inflammation and autoimmune response. Increased levels of several of these markers (notably protein S100B and NTT) may reflect hypoxia-associated oxidative stress-induced blood brain barrier (BBB) opening. It has been previously hypothesized that opening of the BBB can be caused by environmental

Table 4
Clinical symptom occurrence in EHS and EHS/MCS patients in comparaison with normal controls[a].

	EHS	EHS/MCS	p[b]	Normal controls	p[c]	p[d]
Headache	88%	96%	0.065	0%	<0.0001	<0.0001
Dysesthesia	82%	96%	0.002	0%	<0.0001	<0.0001
Myalgia	48%	76%	<0.0001	6%	<0.0001	<0.0001
Arthralgia	30%	56%	<0.001	18%	0.067	<0.0001
Ear heat/otalgia	70%	90%	<0.001	0%	<0.0001	<0.0001
Tinnitus	60%	88%	<0.0001	6%	<0.0001	<0.0001
Hyperacousis	40%	52%	0.118	6%	<0.0001	<0.0001
Dizziness	70%	68%	0.878	0%	<0.0001	<0.0001
Balance disorder	42%	52%	0.202	0%	<0.0001	<0.0001
Concentration/Attention deficiency	76%	88%	0.041	0%	<0.0001	<0.0001
Loss of immediate memory	70%	84%	0.028	6%	<0.0001	<0.0001
Confusion	8%	20%	0.023	0%	0.007	<0.0001
Fatigue	88%	94%	0.216	12%	<0.0001	<0.0001
Insomnia	74%	92%	0.001	6%	<0.0001	<0.0001
Depression tendency	60%	76%	0.022	0%	<0.0001	<0.0001
Suicidal ideation	20%	40%	0.003	0%	<0.0001	<0.0001
Transitory cardiovascular abnormalities	50%	56%	0.479	0%	<0.0001	<0.0001
Occular deficiency	48%	56%	0.322	0%	<0.0001	<0.0001
Anxiety/Panic	38%	28%	0.176	0%	<0.0001	<0.0001
Emotivity	20%	20%	1	12%	0.176	0.176
Irritability	24%	24%	1	6%	<0.001	<0.001
Skin lesions	16%	45%	<0.0001	0%	<0.0001	<0.0001
Global body dysthermia	14%	8%	0.258	0%	<0.0001	<0.007

[a] This data results from the clinical analysis of the 100 first clinically evaluated cases issued from the already published series of EHS and/or MCS patients who have been investigated for biological markers [Belpomme et al., 2015]. It has been compared symptomatically with data obtained from a series of 50 apparently normal subjects matched for age and sex, used as controls.
[b] Significance levels (p values) obtained for compararison between the EHS and EHS/MCS groups.
[c] Significance levels (p values) obtained for compararison between the EHS and normal control groups.
[d] Significance levels (p values) obtained for compararison between the EHS/MCS and normal control groups.

Table 5
Patient mean values and standard deviations of biomarker levels in comparison with normal reference values as well as the percentage of patients with abnormal values in the peripheral blood in subjects with EHS or both EHS and MCS (Belpomme et al., 2015).

Biomarker and Normal reference values	Patients groups			
	EHS Mean ± SD	% Above normal	EHS/MCS Mean ± SD	% Above Normal[a]
hs-CRP < 3 mg/l	10.3 ± 1.9	15%	6.9 +/1.7	14.3%
Vitamine D > 30 ng/ml	20.6 ± 0.5	69.3%	14.5 ± 1.3	70.1%
Histamine< 10 nmol/l	13.6 ± 0.2	37%	13.6 ± 0.4	41.5%
IgE< 100 UI/ml	329.5 ± 43.9	22%	385 ± 70	24.7%
S100B < 0.105 μg/l	0.20 ± 0.03	14.7%	0.17 ± 0.03	19.7%
Hsp 70 < 5 ng/ml	8.2 ± 0.2	18.7%	8 ± 0.3	25.4%
Hsp 27< 5 ng/ml	7.3 ± 0.2	25.8%	7.2 ± 0.3	31.8%
Anti-O-myelin auto-antibodies[b]	Positive	22.9%	Positive	23.6%
24-h urine 6-OHMS/creatinine ratio >0.8[c]	0.042 ± 0.003	100%	0.048 ± 0.006	100%

hs-CRP, high-sensitivity C-reactive protein; IgE, Immunoglobulin E; S100B, S 100 calcium binding protein B; Hsp 27, heat shock protein 27; Hsp 70, heat shock protein 70; anti-O-myelin auto-antibodies, auto-antibodies against O-myelin; 6-OHMS, 6-hydroxymelatonin sulfate.
[a] There is no statistically significant difference between the two groups of patients for the different biomarkers analyzed, suggesting that EHS and MCS share a common pathological mechanism for genesis.
[b] Qualitative test.
[c] Data restricted to those not on neuroleptic medication as the simultaneous use of several psychotherapeutic drugs may also be associated with a decrease of this 24-h urine ratio by modifying melatonine metabolism.

stressors, be they chemicals or EMFs. This may have occurred in these patients, as has been shown to occur in several (but not all) animal experiments involving EMF exposure (Oscar and Hawkins, 1977; Persson et al., 1997; Eberhardt et al., 2008; Sirav and Seyhan, 2009). Comparable data using metabolic and genetic biomarkers were also obtained in another large series of EHS patients (De Luca et al., 2014). Overall these data indicate that the clinical use of biomarkers allows the objective characterisation and identification of EHS and MCS as two etiopathologic facets of a unique pathological disorder, and also allows insight into the genesis of these two diseases.

The development of new imaging techniques has also greatly increased our ability to objectively characterize EHS and MCS. Using ultrasonic cerebral tomosphygmography (UCTS) (Parini et al., 1984), EHS- and EHS/MCS-patients were found to have a statistically significant decrease in mean pulsometric index in several middle cerebral artery-dependant portions of the temporal lobes, especially in the capsulo-thalamic area, which is part of the limbic

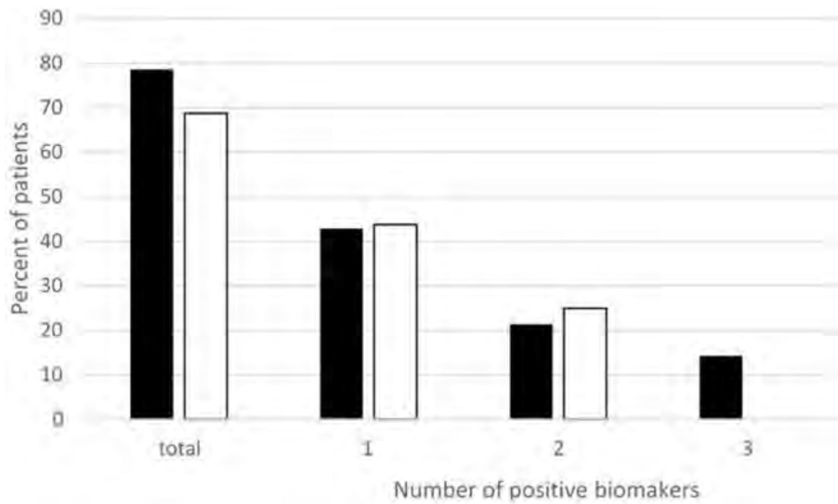

Fig. 1. Percentage of EHS self-reporting patients having positive TBARs, GSSG and/or NTT oxidative stress biomarkers measured in the peripheral blood. "Positive" biomarkers correspond to marker levels above the upper normal limit; "total" corresponds to the patients with one or more positive biomarker levels. Black bars show the percentage of patients with one, two or all three of the biomarkers for TBARS, GSSG and NTT. The white bars show the percentage of patients with either TBARs or GSSG or both oxidative stress markers.

system and the thalamus. This suggests that EHS and EHS/MCS may be associated with a brain blood flow (BBF) deficiency and/or neuronal dysfunction in these brain structures (Belpomme et al., 2015; Irigaray et al., 2018a,b). Irigaray et al. (2018c) have recently confirmed that UCTS is the best imaging technique to diagnose EHS and to follow patients treated for EHS and/or MCS.

In addition, using positron emission tomography (PET) it has been shown that short term exposure to pulse-modulated RF-EMF causally affects regional BBF in normal subjects using a mobile phone (Aalto et al., 2006; Huber et al., 2005), a finding that may account for the modifications observed in the sleep and waking EEG (Huber et al., 2002). By use of functional MRI (fMRI) in EHS patients exposed chronically to ELF-EMFs, regional BBF changes have been reported in the frontal lobes, such as abnormal default mode network and more particularly a decrease in BBF and cerebral metabolism. These observations indicate that fMRI may also be a tool for diagnosis of EHS and clinical follow up of patients (Heuser and Heuser, 2017). A decreased BBF-associated pulsometric index decrease in both hemispheres was also recently observed by the Belpomme group by using transcranial Doppler ultrasound (TDU) (Purlauastja and Sorond, 2012) applied to the middle cerebral artery in a study involving 120 EHS and/or MCS patients. This study revealed a decrease in pulsatility index and an increase in diastolic flow velocity in 70% of the 120 cases investigated to date.

In summary it is the strong opinion of the authors that there is presently sufficient clinical, biological and radiological data emanating from different independent international scientific research groups for EHS, whatever its causal origin, to be acknowledged as a well-defined, objectively characterized pathological disorder. As a result, patients who self-report that they suffer from EHS should be diagnosed and treated utilizing presently available objective biological tests, among which are the concentration of peripheral blood biomarkers and the use of imaging techniques such as PET, fMRI and TDU and, when available, UCTS. Whatever its etiological origin and mechanism of action, EHS should be acknowledge by the WHO as a real and distinct neurological and pathological disorder (McCarty et al., 2011; Hedendahl et al., 2015) and thus be included in the International Classification of Diseases.

5.2. Possible etiopathogenic processes involved in genesis of electrohypersensitivity

EMFs, both RF-EMFs at non-thermal intensities and ELF-EMFs, have been found to cause persistent adverse biological effects in microorganisms (Fojt et al., 2004), plants (Roux et al., 2008; Maffei, 2014), birds (Balmori, 2005; Balmori and Hallberg, 2007; Frey, 1993), and mammals. Therefore the effects observed in humans cannot be due to only a nocebo or psychosomatic effect. These biological effects may be due both to the pulsed and polarised characteristics of man-made EMFs emitted by electric or wireless technologies as opposed to the terrestrial non-polarised and continuously emitted natural EMFs (Blackman, 2009; Belyaev, 2015; Panagopoulos et al., 2015).

The inflammatory and oxidative/nitrosative states that have been documented in EHS patients are remarkable since they confirm the data obtained experimentally in animals exposed to non-thermal EMFs (Esmekaya et al., 2011; Burlaka et al., 2013), and especially in the brain (Megha et al., 2015; Kesari et al., 2011). The limbic system–associated capsulo-thalamic abnormalities that the Belpomme group has observed by using UCTS in EHS and/or MCS patients (Belpomme et al., 2015; Irigaray et al., 2018a,c) may likely correspond to the hippocampal neuronal alterations caused by EMF exposure in the rats (Bas et al., 2009; Furtado-Filho et al., 2015; Deshmukh et al., 2013). Fig. 2 summarizes our hypothesis regarding the inflammation and oxidative stress-related mechanisms which may account for EMF- and/or chemically-related health effects in the brain and consequently for EHS genesis.

6. Mechanisms whereby low intensity electromagnetic fields cause biological effects and harm

Arguments used in the past to attempt to discount the evidence showing deleterious health effects of ELF-EMFs and RF-EMF exposure at non-thermal SAR levels were based on the difficulties encountered in understanding the underlying biological effects and the lack of recognized basic molecular mechanisms accounting for these effects. This is no longer the case. There are a number of well-documented effects of low intensity EMFs that are the mechanistic basis behind the biological effects documented above (www.

bioinitiative.org). These include induction of oxidative stress, DNA damage, epigenetic changes, altered gene expression and induction including inhibition of DNA repair and changes in intracelluar calcium metabolism. Both low-intensity ELF-EMF and non-thermal RF-EMF effects depend on a number of physical parameters and biological variables and physical parameters, which account for the variation in health outcomes (Belyaev, 2015; Belyaev et al., 1999). Importantly, the most severe health effects are observed with prolonged chronic exposures even when intensities are very low (Belyaev, 2017). The physics of non-equilibrium and non-linear systems and quantum mechanics are at least in part the basis of the physical mechanisms responsible for the non-thermal molecular and biological effects of non-thermal EMF radiation (Belyaev, 2015), although a detailed report on these actions is beyond the scope of this review.

Lower RF-EMF intensity is not necessarily less bioactive or less harmful. Non-thermal EMF effects can be observed at intensities which are very close to ordinary background levels and quite similar to intensities emitted by mobile phone base stations. There are time windows for observation of non-thermal EMF effects which may be dependent upon the endpoint measured, the cell type and the duration and power density of exposure. Non-thermal RF-EMF effects are affected by static magnetic fields and electromagnetic stray fields, which result in the variation of non-thermal EMF effects from mobile phones because of adjacent electrical appliances, power lines and other sources of ELF and static magnetic fields, including changes in the geomagnetic field (Gapeev et al., 1999a and b).

Cell-to-cell interactions potentiate the response to non-thermal EMFs (Belyaev et al., 1996). Biological responses to EMFs have been shown to be influenced by sex and age (Zhang et al., 2015; Sirav and Seyhan, 2016). Physiological parameters such as the stage of cell growth, oxygen, divalent ions and temperature are important

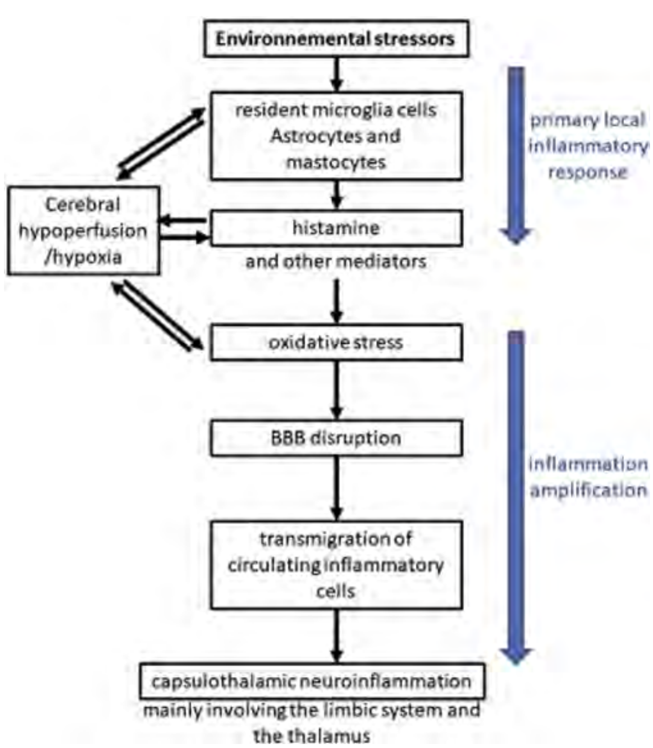

Fig. 2. Hypothetical EHS/MCS common etiopathogenic model based on neuro-inflammation and oxidative/nitrosative stress-induced blood brain barrier disruption (Belpomme et al., 2015).

variables affecting cellular responses to EMFs (Liburdy and Vanek, 1987; Sannino et al., 2011).

6.1. Combined exposures

EMFs at non-thermal intensities may interfere with other environmental stressors, showing an interplay of molecular pathways and resulting in either beneficial or detrimental health effects, depending on the nature and conditions of co-exposures (Novoselova et al., 2017; Ji et al., 2016). One example is the demonstration that RF-EMF exposure modulates the DNA damage and repair induced by ionizing radiation (Belyaev et al., 1993). Another example is the synergistic of exposure to lead and EMFs on cognitive function in children described above (Choi et al., 2017; Byun et al., 2017). These co-exposure factors should be considered when assessment of detrimental effects, including carcinogenicity, is performed.

Not all of the effects of EMFs on the nervous system and other organs are necessarily harmful. The best example of a positive effect is the well-documented and clinically useful benefit of applied magnetic fields to promote bone healing (Bassett, 1994). Both ELF-EMF (Zhang et al., 2015) and RF-EMF (Arendash et al., 2010) have been reported to slow cognitive decline in rodent models of Alzheimer's disease. Some human studies report a facilitating effects of cognitive performance (Lee et al., 2001) while Koivisto et al. (2000) reported an increase in response time and vigilance tasks but a decrease in mental arithmetic tasks. These studies clearly show that EMFs have biological effects at non-thermal intensities, but suggest that not all biological effects are necessarily harmful.

6.2. Duration of exposure and dose intensity

Such parameters as power density, dose, and duration of exposure have been analyzed for development of reliable safety standards, which would protect against the detrimental health effects of chronic exposure to RF-EMFs at non-thermal intensities. Some studies show no effect under fixed short-term exposures, but this does not imply that there are no effects from longer-term exposures (Choi et al., 2014). Exposure in studies showing RF-EMF effects was on average twice the duration as those with no significant effects (Cucurachi et al., 2013). The response to non-thermal EMFs depends on both power density and duration of exposure. Importantly, the same response is observed with lower power density but prolonged exposure as at higher power density and shorter exposure (Nordenson et al., 1994). While SAR is a good surrogate for thermal RF effects from acute exposures, many studies have shown that SAR should be either replaced by “dose-specific absorption” or power density complimented by duration of exposure for description of non-thermal RF effects (Belyaev, 2015). Recent studies have provided more evidence for the greater importance of dose and duration of exposure than SAR alone for biological and health effects from long-term exposures to non-thermal RF-EMFs (Furtado-Filho et al., 2015).

6.3. Oxidative stress

Non-ionizing radiation does not have sufficient energy to directly break chemical bonds, and therefore the DNA damage that occurs with non-ionizing EMF exposures is primarily a consequence of generation of reactive oxygen species (ROS), resulting in oxidative stress. There are numerous animal experiments which clearly demonstrate that non thermal EMFs can cause oxidative stress (Esmekaya et al., 2011; Burlaka et al., 2013), particularly in the brain (Shahin et al., 2017; Dasdag et al., 2012; Megha et al., 2015; Furtado-Filho et al., 2015). Oxidative stress is known to play a central role in development of cancer and aging and serves as a signaling agent in the inflammatory response (Holmstrom and Finkel, 2014).

The brain is a particularly important organ for sensitivity to EMFs. Brain cancer resulting from EMF exposures is a serious concern, and EHS is a disease of the central nervous system. Several mechanisms at the cellular and molecular levels have been reported that may be the basis of these non-thermal RF-EMF effects on brain function. ELF- and/or RF-EMF exposure at embryonic or early postnatal stages can alter *in vivo* synaptic efficacy and plasticity of neurons (Balassa et al., 2014), a finding which was further supported by *in vitro* studies showing a significant decrease in the differentiation of neural stem cells into neurons (Eghlidospour et al., 2017), the alteration of transcript levels of neuronal differentiation-related genes and impairment of neurite outgrowth of embryonic neural stem cells exposed to ELF- or RF-EMFs (Ma et al., 2014). These observations support the conclusion that low-intensity but prolonged exposure to non-thermal EMFs may have adverse effects on neurogenesis during development and indicate how important it is to protect the fetus and young child from excessive exposure to all mobile devices.

Animal studies have documented that 900 MHz or 2.45 GHz non thermal RF-EMF exposure in rats, either short term or chronic, can trigger neuronal dysfunction and even apoptosis of hippocampal pyramidal cells (Bas et al., 2009; Shahin et al., 2017) and cerebellum Purkinje cells (Sonmez et al., 2010) through induction of oxidative stress. Exposure of pregnant dams elicited EMF oxidative stress-induced neuronal pathologic changes in offspring (Odaci et al., 2016). Such pathological changes could be due to ROS-induced opening of the BBB (Nordal and Wong, 2005) and/or to ROS-associated brain hypoxia caused by a decrease in EMF-induced BBF and/or EMF-induced hemoglobin deoxygenation (Mousavy et al., 2009; Muehsam et al., 2013). The resulting hypoxia may induce metabolic neuronal dysfunction as in the case of EHS patients (Belpomme et al., 2015) but also neuronal cell death by either apoptosis or necrosis as in the case of Alzheimer's disease and other forms of dementia (Bell and Zlokovic, 2009).

While some consider the laboratory data on EMFs as being inconsistent, showing either detrimental or no effects and on occasion even beneficial effects, the vast majority still show detrimental effects. For example Henry Lai in the Bioinitiative Report Research Summaries Update of November 2017, Chapter 6 on Genotoxic Effects, reported that i) of 46 studies on ELF genotoxicity with the comet assay as the end point, 34 studies (74%) showed detrimental effects, ii). Of 189 total studies on ELF and oxidative stress, 162 (87%) showed a positive correlation, and iii) of 200 studies on RF and free radicals, 180 (90%) showed detrimental effects. One reason for variability between laboratory studies is the strong dependence on low-threshold EMF effects on a number of physical and biological variables (Belyaev, 2010).

6.4. Genetic and epigenetic mechanisms

Genetic effects are the most direct cause for carcinogenicity. This is true both for genotoxic changes caused by exposure to EMFs and existing polymorphic genetic differences within a population that increase susceptibility to cancer. DNA can no longer be considered to be unaffected by environmental EMF levels, as many studies have shown that DNA can be activated and damaged by EMFs at levels that have been considered to be safe (Blank and Goodman, 1999).

The primary mechanism through which low-intensity EMFs can alter DNA is through ROS production. Lai and Singh (2004) first reported that a 2 h exposure of rats to 60 Hz EMFs at 0.1–0.5 mT resulted in DNA strand breaks in neurons, and provided evidence that this effect was mediated by free radical formation and blocked by free radical scavengers. Vijayalaxmi and Prihoda (2009) in a meta-analysis of 87 publications found a biologically small but statistically significant difference between DNA damage in ELF-EMF-exposed somatic cells as compared to controls, and reported evidence for epigenetic changes for some outcomes. For ELF-EMFs this breakage effect was stronger when exposure was intermittent rather than continuous (Nordenson et al., 1994).

Yang et al. (2008) have reported an $OR = 4.31$ (95% CI $=$ 1.54–12.08) for leukemia in children living within 100 m of a high voltage powerline if they had a certain polymorphism of a DNA repair gene.

Exposure to RF-EMFs can also induce DNA damage under specific conditions (Markova et al., 2005). Tice et al. (2002) and Vijayalaxmi et al. (2013) reported DNA damage and micronuclei formation in cultured human leukocytes and lymphocytes upon exposure to RF-EMF signals of at least 5 W/kg. Not all cell types showed similar responses. Schwartz et al. (2008) reported micronucleus changes in fibroblasts but not lymphocytes exposed to 1950 MHz EMFs. Kesari et al. (2014) also demonstrated DNA strand breaks in the brains of rats exposed for 2 h per day for 60 days to a 3G mobile phone. Changes in DNA secondary structure (Semin, 1995; Diem et al., 2005) and chromosome instability (Mashevich, 2003) have been observed upon exposure to RF-EMFs emitted by mobile phones.

Epigenetic changes, rather than genetic changes in DNA, may underlie many or even most of the biological effects of non-thermal EMFs (Sage and Burgio, 2017). Non-thermal EMFs are epigenetic stressors which can alter gene expression by acting through physical or biochemical processes and be reflected as chromatin remodeling (Belyaev et al., 1997), histone modification (Wei et al., 1990) or altered microRNA (Dasdag et al., 2015) at intensities far below those that cause measureable tissue heating.

Chromatin plays a key regulatory role in controlling gene expression and, more particularly, the access of transcription factors to DNA. It has been shown that extremely low intensity RF-EMF exposure, i.e. at intensities comparable to that of mobile phone and towers, results in changes in chromatin conformation and gene expression (Belyaev et al., 1997; Belyaev and Kravchenko, 1994; Belyaev et al., 2006; Belyaev et al., 2009). In a large number of cells and tissues, compaction of chromatin in specific loci may lead to gene silencing, loss of histone regulatory effects and DNA repair capacity (Wei et al., 1990). Belyaev and collaborators (Markova et al., 2005; Belyaev et al., 2009) have shown that exposure to RF-EMFs emitted by GSM mobile phone alters chromatin conformation in human lymphocytes and inhibits formation of p53-binding protein 1 (53BP1) and phosphorylated histone H2AX (γ-H2AX) DNA repair foci.

EMFs in both the ELF and RF ranges may epigenetically affect DNA by inducing the expression of stress response genes and consequently the synthesis of chaperone stress proteins (Blank and Goodman, 2011a and b). A specific gene sequence has been identified that acts as a sort of antenna, specifically sensitive and responsive to EMFs (Blank and Goodman, 2011b). This is a gene sequence coding for HSP70, a protein belonging to a family of conserved, ubiquitously expressed "heat shock proteins" that sense danger signals and protect cells from the most disparate stress conditions. This is an unambiguous demonstration that EMF exposure even at non-tissue heating intensities has the potential to be harmful to cells and organisms. The HSP70 promotor contains different DNA regions that are specifically sensitive to diverse stressors, thermal and non-thermal. The EMFs are specifically perceived by the sequences sensitive to non-thermal stimuli. During the process of HSP70-response induction, EMFs can activate directly the HSP70 gene promoter (Rodrequez-De la Fuente et al.,

2010) which contains a magnetic field-responsive domain (Lin et al., 1999, 2001).

EMF-related HSP70 and HSP27 stress responses have been detected in the hippocampus of rats exposed to non-thermal EMFs (Yang et al., 2012). Shahin et al. (2017) reported that mice exposed to 2G mobile phones continuously for four months showed elevated ROS, lipid peroxidation, total nitrate and nitrite concentrations and malondialdehyde levels in homogenates of different tissues, and decreased levels of several antioxidant enzymes. These observations justify the use of these markers to characterize EHS in patients who report that they are sensitive to EMFs.

The EMF effects have been suggested to be mediated by the mitogen-activated protein kinase (MAPk) cascades, which is a central signaling transduction pathway which governs all stress-related cellular processes occurring in response to extracellular stimuli (Friedman et al., 2007). It has been shown that long term exposure of cells to mobile phone frequencies or to ELF-EMFs (Goodman et al., 2009) activates the extracellular-signal regulated kinase (ERK), which is one of the four MAPk cascades so far identified.

Non-thermal RF-EMFs may also alter expression of other genes. As long ago as Byus et al., 1988 showed that 450 MHz RF increased ornithine decarboxylase activity in hepatoma cells. Markova et al. (2005) exposed human fibroblasts and mesenchymal stem cells to mobile phone RF-EMFs with analysis of tumor suppressor p53 binding protein 1. Formation of 53BP1 foci was inhibited in both cells types, but the stem cells always showed a greater response. Fragopoulou et al. (2011) exposed mice to either a typical mobile phone or a wireless DECT base station and analyzed the brain proteome. They found significant alteration in 143 specific proteins (ranging from a 0.003 fold downregulation to up to a 114-fold overexpression.) Luo et al. (2013) exposed pregnant women undergoing a first trimester abortion to a mobile phone applied to the abdomen and performed a proteomic analysist of placental villous tissue. They report 15 proteins which were significantly altered by at least 2- to 2.5-fold in exposed women as compared to control women. Twelve of these proteins were identified. Yan et al. (2008) exposed rats to mobile phones 6 h per day for 126 days, and found upregulation of specific mRNAs that regulated several proteins, including calcium ATPase, neural cell adhesion molecule, neural growth factor and vascular endothelial growth factor. EMFs at non thermal levels may not only alter the expression of many proteins but also may directly affect protein conformation (Fragopoulou et al., 2011; Bohr and Bohr, 2013; Beyer et al., 2013) and modify enzyme activity (Vojisavljevic et al., 2010), so altering the regulating capacity of the epigenome. These are epigenetic, not genetic, effects (Sage and Burgio, 2017).

Non-thermal EMF exposure can epigenetically interfere with the differentiation and proliferation programs of stem cells in fetal and adult tissues through ROS production (Wolf et al., 2007; Falone et al., 2007; Ayşe et al., 2010; Park et al., 2014). Stem cells are the most sensitive cells to EMF exposure (Eghlidospour et al., 2017; Markova et al., 2010) and this is particularly the case for neural stem cells of the hippocampus (Leone et al., 2014).

The endogenous natural ionic currents and electrical fields in the human body (Jaffe and Nuccitelli, 1977) are vulnerable to the oscillary properties of non-thermal EMFs. These consequently may cause detrimental effect on cell differentiation and proliferation in adult tissues (Levin, 2003) in addition to the effects on cell differentiation, proliferation and migration in the fetus (Wolf et al., 2007; Ayşe et al., 2010; Leone et al., 2014). Fetal programming cannot be reduced to only genetic programs. Developmental processes are essentially epigenetic (Leone et al., 2014), and exposure to epigenetic stressors such as non-thermal EMFs are much more dangerous for the fetus than for the adults.

6.5. Calcium regulation

There has long been evidence that EMFs alter several aspects of calcium function. This is important because calcium regulates many different aspects of cell function. Bawin and Adey (1976) reported that very weak ELF-EMFs trigger efflux of calcium from isolated chick brain, although the implications of this observation were not clear. Later they reported a similar action of RF-EMFs (Adey et al., 1982). Pulsed low-frequency EMFs promote bone healing and promote calcium uptake into bone (Spadaro and Bergstrom, 2002) and osteoblasts (Zhang et al., 2010). 50 Hz EMFs increase the number of voltage-gated calcium channels in neuroendocrine cells (Grasso et al., 2004) and presynaptic nerve cell terminals (Sun et al., 2016). Wei et al. (2015) found that ELF-EMFs also altered the frequency of calcium transients in cardiomyocytes and decreased calcium concentrations in sarcoplasmic reticulum. These changes in calcium in heart muscle may be the basis for the cardiovascular effects reported in humans on exposure to EMFs (Havas, 2013). In spite of numerous studies reporting altered calcium metabolism upon exposure to both ELF- and RF-EMFs, the overall implications of these effects are still not clear. However, some have suggested (Ledoigt and Belpomme, 2013) that calcium activation of proteins could be the initial event that results in altered protein configuration, leading to generation of ROS and ultimately activating the molecular pathways to cancer.

7. Public Health Implications of Human Exposure to EMFs

The incidence of brain cancer in children and adolescents has increased between 2000 and 2010 (Ostrom et al., 2015). Gliomas are increasing in the Netherlands (Ho et al., 2014), glioblastomas are increasing in Australia (Dobes et al., 2011) and England (Philips et al., 2018) and all brain cancers are increasing in Spain (Etxeberrua et al., 2015) and Sweden (Hardell and Carlberg, 2017). The latency period between initial exposure and clinical occurrence of brain cancer is not known but is estimated to be long. While not all reports of brain cancer rates show an increase, some do. The continually increasing exposure to EMFs from all sources may contribute to these increases. The prevalence of EHS is unknown, but various reports suggest that it is between 1 and 10% of the population (Hallberg and Oberfeld, 2006; Huang et al., 2018). Male fertility has been declining (Geoffroy-Siraudin et al., 2012; Levine et al., 2017). EMFs increase the risk of each of these diseases and others. Alzheimer's disease is increasing in many countries worldwide and its association with ELF-EMF occupational exposure has been clearly demonstrated through several independent epidemiological studies (Davanipour and Sobel, 2009; Sobel et al., 1996; Qiu et al., 2004) and a meta-analysis of these studies (García et al., 2008). A recent meta-analysis (Huss et al., 2018) has reported an increased risk of amyotrophic lateral sclerosis in workers occupationally exposure to ELF-EMFs.

Safety limits for RF exposure have been based (until today) on the thermal effects of EMFs. But these standards do not protect people, particularly children, from the deleterious health effects of non-thermal EMFs (Nazıroğlu et al., 2013; Mahmoudabadi et al., 2015). Each of these diseases is associated with decrements in health and quality of life. Brain cancer patients often die is spite of some improvement in treatment, while EHS patients present with increased levels of distress, inability to work, and progressive social withdrawal. The ability for humans to reproduce is fundamental for the maintenance of our species.

The scientific evidence for harm from EMFs is increasingly strong. We do not advocate going back to the age before electricity or wireless communication, but we deplore the present failure of public health international bodies to recognize the scientific data showing the adverse effects of EMFs on human health. It is encouraging that some governments are taking action. France has removed WiFi from pre-schools and ordered Wi-Fi to be shut off in elementary schools when not in use (http://www.telegraph.co.uk.news/2017/12/11/france-ipose-total-ban-mobile-phones-schools/). The State of California Department of Public Health has issued a warning on use of mobile phones and offered advice on how to reduce exposure (State of California, 2017). There are many steps that are neither difficult nor expensive that can be taken to use modern technology but in a manner that significally reduces threats to human health.

It is urgent that national and international bodies, particularly the WHO, take this significant public health hazard seriously and make appropriate recommendations for protective measures to reduce exposures. This is especially urgently needed for children and adolescents. It is also important that all parts of society, especially the medical community, educators, and the general public, become informed about the hazards associated with exposure to EMFs and of the steps that can be easily taken to reduce exposure and risk of associated disease.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.envpol.2018.07.019.

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Sonderbeilage in Ausgabe 3-2020 / ISSN 1437-2606 / 33. Jahrgang

umwelt · medizin · gesellschaft

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Review

Biological effects of electromagnetic fields on insects

Alain Thill

Abstract

Worldwide, the number of insects is decreasing at an alarming rate. It is known that among other causes, the use of pesticides and modern agricultural practices play a particularly important role. The cumulative effects of multiple low-dose toxins and the spread of toxins in nature have not yet been methodically researched, or only in the early stages.

Existing research indicates another factor of anthropogenic origin, which might cause subtle adverse effects: the increasingly frequent use of artificial electromagnetic fields (EMF) such as high voltage, mobile telephony and Wi-Fi. The infrastructure of the next generation of mobile communications technologies, 5G, is being deployed without having been previously tested for possible toxic effects. With mankind's aspirations for omnipresence of technology, even modest effects of electromagnetic fields on organisms might eventually reach a saturation level that can no longer be ignored.

This systematic review evaluates the state of knowledge regarding the toxic effects of electromagnetic fields (EMF) on insects. Also included is a general review of reported effects and mechanisms of EMF exposure, which addresses new findings in cell biology. 72 of 83 analyzed studies found an effect. Negative effects that were described in studies include: disturbance of the sense of orientation, reduced reproductive ability and fertility, lethargy, changes in flight dynamics, failure to find food, reduced reaction speeds, escape behavior, disturbance of the circadian rhythm, blocking of the respiratory chain and damage to the mitochondria, misactivation of the immune system, increased number of DNA strand breaks.

Some mechanisms of action leading to these damages are identified. EMFs affect the metabolism, among other things affecting voltage-gated calcium channels, e.g. in neurotransmission and in muscle tissue, which can lead to an overactivation of signal transduction and of the respiratory chain with production of free oxygen radicals and consequently leading to oxidative cell stress.

The results show that EMF could have a serious impact on the vitality of insect populations. In some experiments it was found that despite low levels of exposure to transmitters, harmful effects occurred after several months. Field strengths 100 times below the ICNIRP limits could already have effects. Against the background of the rapid decline of insects and the further expansion of high-frequency electromagnetic field sources, there is not only an urgent need for further research, but also in particular on the interactions with other harmful noxious agents, such as pesticides. When planning the expansion of mobile networks, insect habitats should be protected from high-intensity EMF exposure already now.

1. Biological effects of electromagnetic fields (EMF)

The recently publicly announced insect decline, the beginnings of which go back several decades, seems to be caused by a multitude of factors with cumulative effects (Hallmann et al. 2017; Sánchez-Bayo and Wyckhuys 2019, Fig. 1). Although it is assumed that the main causes are to be found in the use of pesticides and in the restructuring or destruction of natural habitats, additional negative effects of other kinds cannot be excluded – e.g. the effects of hormone-like substances, heavy metals and electromagnetic fields, all factors whose occurrence in nature has drastically increased in recent decades (Sharma et al. 2016; Rhind 2009; Bandara and Carpenter 2018).

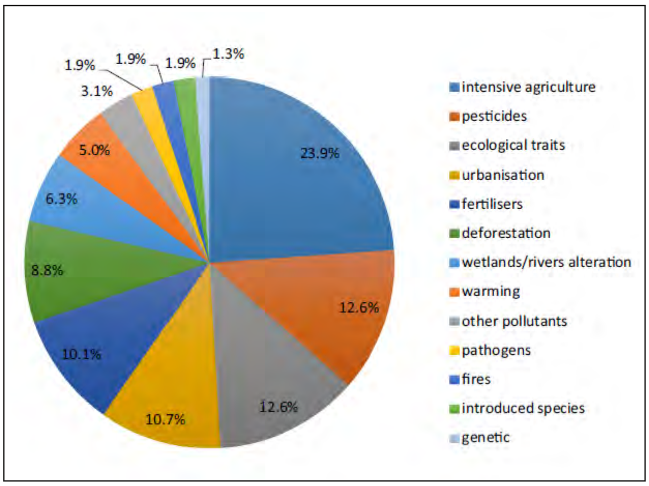

Figure 1: Main causes of recent insect decline.
Source: Sánchez-Bayo and Wyckhuys 2019

This review deals primarily with the effects of low- and high-frequency electromagnetic fields on insects. The effects of low-frequency magnetic fields (and EMF) from power lines (at 50 Hz power frequency) have been relatively well studied already, e.g., in terms of incidence of leukemia in humans (ARIMMORA final report 2015), or toxicity to insects (Wyszkowska et al. 2016; Maliszewska et al. 2018; Shepherd et al. 2018).

High voltage and mains electricity became standard in Europe from 1950 onward. Less well researched are the newer, high-frequency electromagnetic fields (HF-EMF) in the microwave range, as used for mobile phone networks, but also Wi-Fi and similar applications (from 1990 on). In the case of low-frequency EMF, adequate experimental devices to apply the characteristic EMF to organisms in the laboratory, so-called Helmholtz coils, have existed for decades. Hereby the field strength can also be adjusted. In comparison, there are no adequate emulations for high-frequency EMF, such as those emitted by mobile phone towers or Wi-Fi routers – or they are very expensive and/or require a permit (mobile phone repeaters). The most realistic approach at the moment is to use mobile phones as emulation of mobile phone masts for laboratory tests, and actual Wi-Fi routers.

Since we are about to develop the next generation of mobile phones (5G), whose infrastructure could include a further increase of radiated energy in the urban sector, the safety of this technology should be demonstrated in advance - as is inevitable when marketing new drugs (Bandara and Carpenter 2018).

In general, a distinction is made between thermal and non-thermal biological effects of electromagnetic fields. The thermal effect is based on direct heating of tissue (as in a microwave oven). Below the intensities where tissue heating can be measured, several additional non-thermal effects have been described, e.g. microwave hearing (in humans), also known as the Frey effect, whose mechanism has been known for several decades (electroelastic transformation of microwaves into sound waves in the skull, see Chou, Guy, and Galambos 1982; Belyaev and Markov 2015).

Furthermore, parametric resonance, which is accompanied by a change of the human and animal electroencephalogram, is regarded as scientifically proven (Hinrikus et al. 2017; Mohammed et al. 2013). There is increasing evidence that parametric resonance is a by-product of the activation of voltage-gated ion channels and is associated with calcium release (Agnati et al. 2018; Pall 2016; Sun et al. 2016; Belyaev and Markov 2015) – and thus affects all animal and plant organisms.

In summary, it could be said that biological effects of chronic EMF exposure follow this general pattern: EMF act (directly or indirectly) on voltage-gated calcium channels (VGCC), opening them and leading to calcium release.

More precisely, voltage-gated ion channels (Na^+, K^+), as well as the NMDA receptor, seem to be sensitive to non-thermal (i.e. very low) EMF levels and this is probably related to useful functions of the perception of endogenous EMF ("ephaptic coupling"), which are produced by the activity of neurons and astrocytes (Martinez-Banaclocha 2020; Chiang et al. 2019; Hales and Pockett 2014). Thus, the mechanism of ephaptic coupling seems to play an active role in the synchronous activity of heart cells (Weinberg 2017), as well as in the olfactory processing of odorant mixtures (antennas or olfactory nerve) (Zhang et al. 2019; Bokil et al. 2001), and also in the coordination of movement in the cerebellum (Han et al. 2018).

In these cases, however, voltage-gated sodium channels (Weinberg 2017; Han et al. 2018), potassium channels (Fogle et al. 2015) or NMDA receptors (Chiang et al. 2019) – which are voltage-sensitive and channel sodium and calcium ions – have been shown to be the macromolecules directly affected by EMF. In addition, it is assumed that astrocytic calcium waves, through ephaptic coupling, influence and regulate neuronal activity over wide areas and to a large extent (Agnati et al. 2018; Martinez-Banaclocha 2020).

The EMF-induced activation of voltage-gated sodium and potassium channels or NMDA receptors leads indirectly, by triggering or amplifying action potentials, to increased activation of synaptic VGCC and release of calcium (Pilla 2012); neurotransmission based on action potentials via chemical synapses requires activation of VGCC (Atlas 2013).

Calcium is one of the most common secondary messengers in all organisms, and elevated levels of calcium have an activating effect, e. g. on the respiratory chain and muscle (Kim et al. 2019). Calcium in turn releases nitric oxide (NO) via calmodulin. An overactivation of calcium-dependent neurotransmission (and possibly metabolic pathways) leads to the production of free oxygen radicals (reactive oxygen species, ROS) such as peroxynitrite, i. e. to oxidative stress.

Chronically increased oxidative stress has a toxic effect on organisms in many different ways, e. g. by blocking the respiratory chain, causing damage to mitochondria, misactivation of the immune system and an increase in the genetic mutation rate (Valko et al. 2007; Saliev et al. 2019).

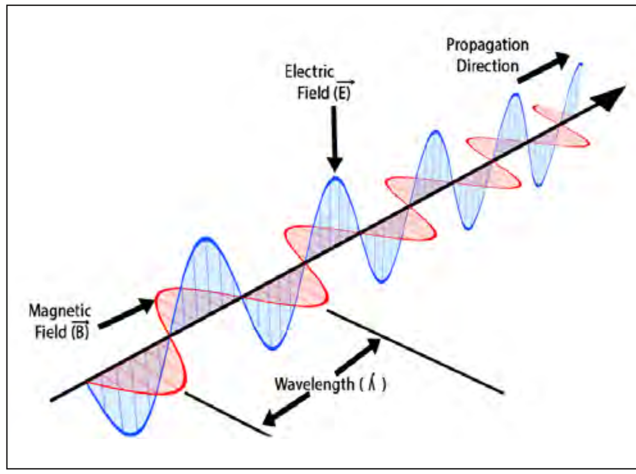

Figure 3: Electromagnetic wave. Electric field strength in blue, magnetic field strength in red. The radiation intensity or power density of an EMF can be derived from both field strengths (see appendix).
Source : https://byjus.com/physics/characteristics-of-em-waves/

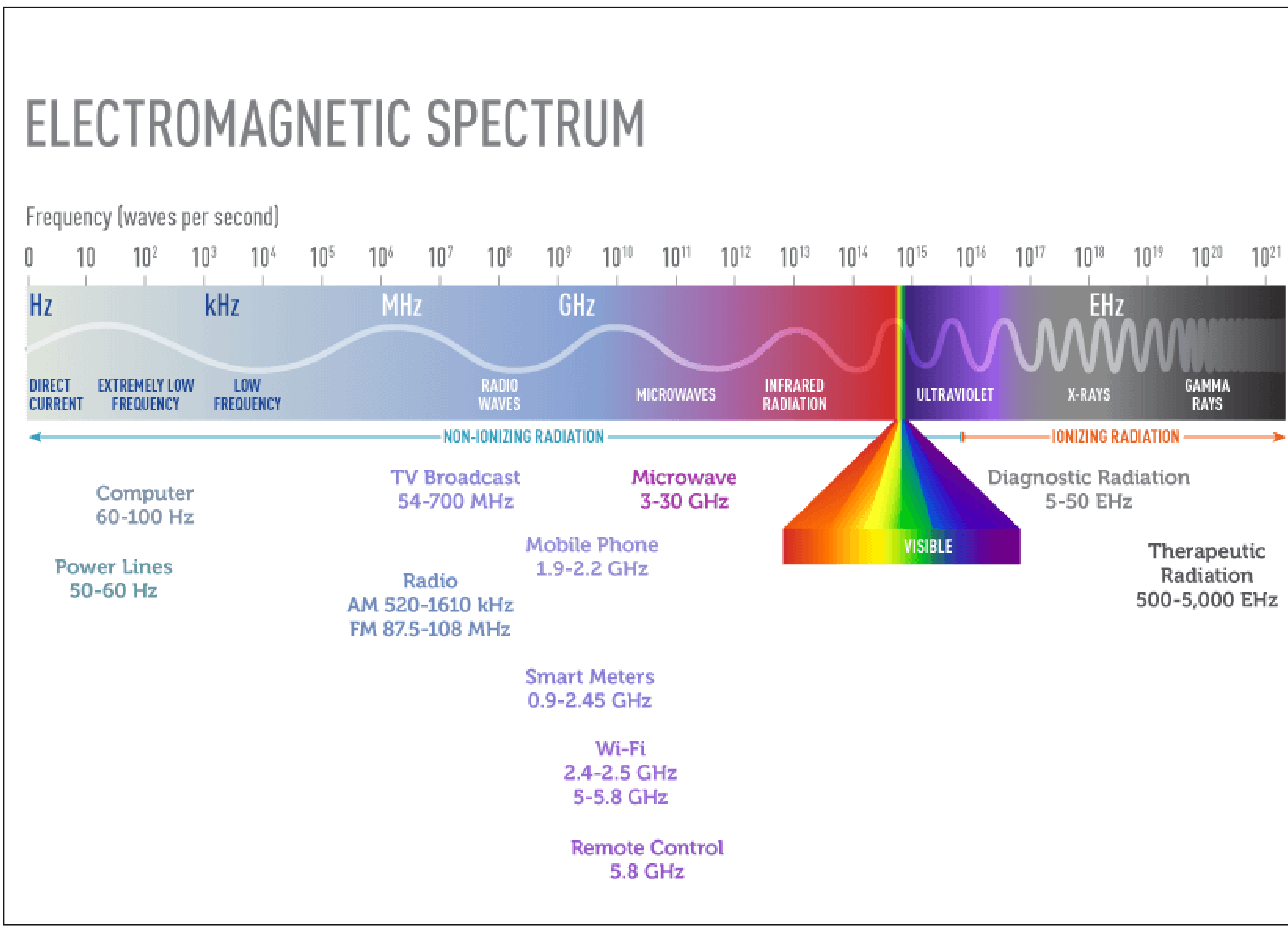

Figure 2: Electromagnetic spectrum. Source: https://thinktankgreen.com/emf-testing/facts-education/electromagnetic-spectrum/

1.1 Magnetic sense

Natural variations in the Earth's magnetic field ("geomagnetic field", GMF), e.g. due to solar flares, have been shown to cause stress in animals. The effect is well documented by the research group around Krylov in fish and daphnia (Krylov 2017). A strong correlation was also found for honeybees (Ferrari and Tautz 2015).

Guijun Wan et al. 2019 have provided experimental evidence that in the absence of the natural geomagnetic field the feeding behavior and development of locusts is disturbed. Quote: *"These results support the hypothesis that strong changes in GMF intensity may influence the feeding behavior of insects and the underlying regulatory processes. Our results provide further evidence that magnetoreception and regulatory responses to changes in GMF can influence a variety of biological processes."*

The existence of a magnetic sense is described in most insect orders: for example, in butterflies, beetles, flies, ants and bees (Hymenoptera) as well as termites and cockroaches (Guerra, Gegear, and Reppert 2014; Gegear et al. 2008; Oliveira et al. 2010; Lambinet et al. 2017; Vacha, Puzova, and Kvicalova 2009).

However, the question of the magnetic sense is quite complex and not yet conclusively elucidated, since different organisms use different mechanisms (Clites and Pierce 2017; Nordmann, Hochstoeger, and Keays 2017). At the molecular level, two typical but different magnetoreception systems have been discovered: cryptochrome and magnetite.

1.2 Cryptochrome

Cryptochrome (CRY) is a molecule from the blue light receptor family that regulates the circadian rhythm in insects. In addition, cryptochrome is magnetosensitive (Georgiou 2010) once it has been activated by high-energy light (via the radical pair mechanism). CRY is found both in the eyes of most insects and vertebrates and in their brains (i.e. ventro-lateral neurons of insects or in the suprachiasmatic nucleus – SCN of vertebrates), where it is part of the circadian rhythm (molecular clock, see Solov'yov and Schulten 2014).

Fedele et al. 2014 showed by means of cryptochrome mutant Drosophila fruit flies, that cryptochrome is necessary for light- and EMF-induced delay of circadian rhythms, and that these effects actually occur in the brain of Drosophila but not in the SCN of mice. Furthermore, they could show that the actual magnetoreceptor does not have to be cryptochrome itself. Qin et al. 2016 have shown that cryptochrome is associated with the protein CG8198 (MagR – the putative magnetoreceptor), both located in the eye.

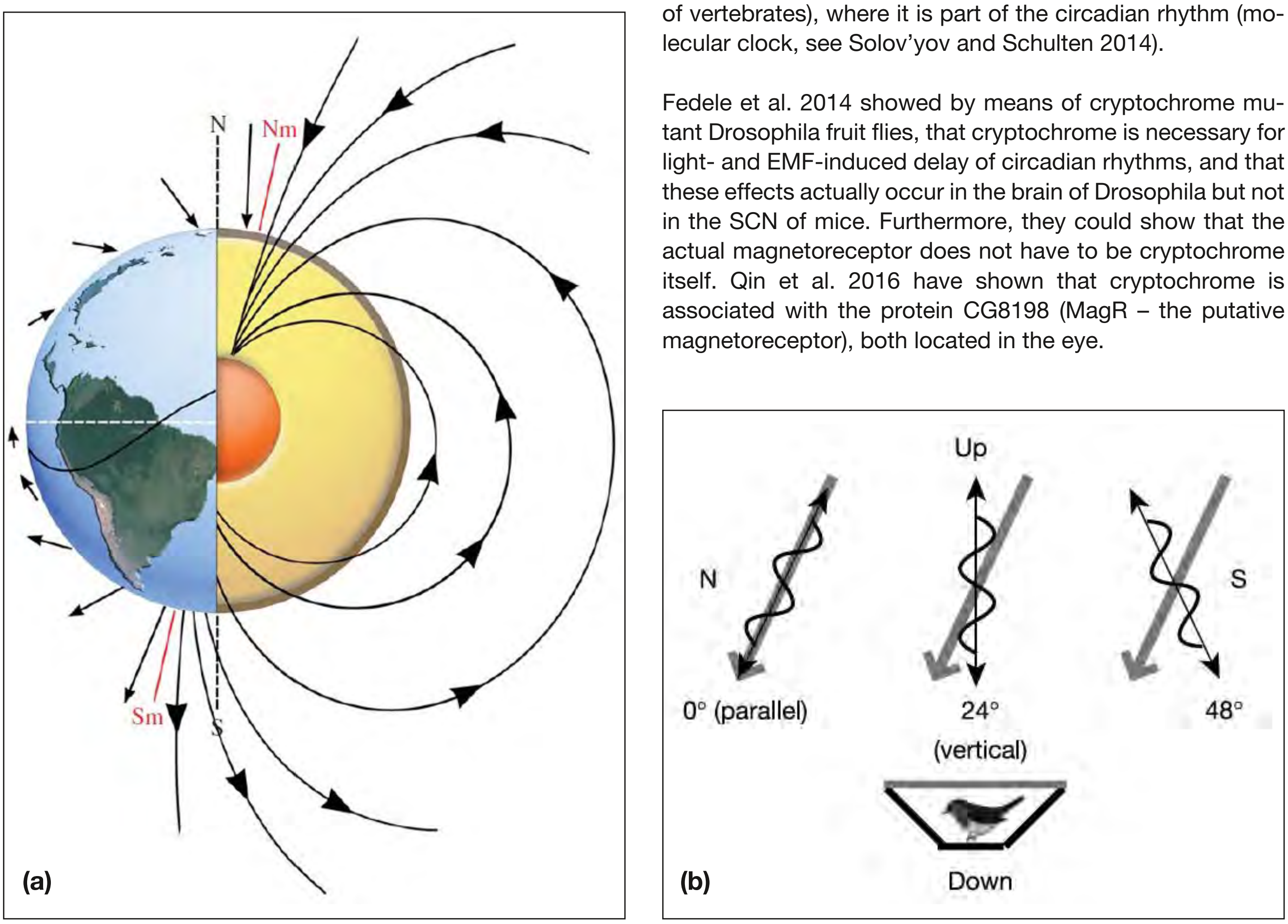

Figure 4a + b: (a) Earth's magnetic field. Source: Shaw et al. 2015. (b) Effect of the angle of the incoming EM field on the birds' magnetic sense. Grey arrow: Inclination of the Earth's magnetic field. From Ritz et al. 2004.

Fogle et al. 2015 showed that CRY activates the voltage sensor (or redox sensor) of the voltage-controlled potassium channel Kvß (in the brain of Drosophila), which leads to an increased firing rate of action potentials, whereby free radicals formed by CRY in an intermediate step, which has not yet been clarified, are transferred to "hyperkinetic" (Hk).

Sherrard et al. 2018 investigated the production of free radicals in Drosophila. PEMF devices ("pulsed electomagnetic field") are Helmholtz coils with predefined characteristics, which e.g. cause faster healing of bone fractures or wounds (Pilla 2012). Wild type Drosophila showed an aversion reaction and a formation of free radicals (ROS) after irradiation with a medical PEMF device with non-thermal power (2 mT). This was not the case with mutant Drosophila, whose cryptochrome had been removed. An effect in the wild type was found only when blue (or white) light was additionally present, since insect cryptochrome requires high-energy blue photons to activate (no effect was observed under red light). Although not postulated by the authors, this allows the conclusion that the toxicity of EMF in Drosophila cumulates with the presence of (blue light-intensive) artificial light.

Sherrard et al. 2018 were able to show in cell cultures of the Owl Butterfly (Spodoptera frugiperda) that cryptochrome is necessary for the formation of free radicals when treated with PEMF coils – and this probably concerns all low-frequency EMF sources. Whether cryptochrome is also necessary for oxidative cell stress (in insects) when irradiated with radiofrequency EMF has not yet been investigated.

Bartos et al. 2019's experiment with German cockroaches (Blatella germanica) proves that additional complex interactions between the local geomagnetic field (or artificial magnetic fields) and EMF are crucial in the quantum mechanical processes (radical pair mechanism) that activate cryptochrome, as previously shown for birds (Ritz et al. 2004, Fig. 4) and theoretically analyzed in detail by Warnke (Warnke 2009).

In contrast to the VGCC activation hypothesis, the activation of cryptochrome by EMF has been clearly proven, in birds and insects, and has been largely elucidated, and leads to the activation of VGCCs in a further step, at least in Drosophila. The VGCC hypothesis is based on numerous observations, that EMF cause a release of calcium ions, and that calcium channel blockers protect from negative effects (Pall 2013) – however, calcium and VGCCs are involved in many processes of neurotransmission – e.g., at excitatory synapses (Caddick et al. 1999; Atlas 2013). In principle, however, there is nothing to be said against the assumption that VGCCs can be activated (opened) by EMF, both directly and indirectly via cryptochrome (and other macromolecules) (Damulewicz and Mazzotta 2020; Catterall 2010; Littleton and Ganetzky 2000). However, only the pathway of light-dependent activation of cryptochrome (by EMF) in the clock neurons of Drosophila, which leads to an increased action potential firing rate, and produces described, but not yet fully understood adverse effects, presumably by increased calcium release at the synapses, has so far been experimentally proven.

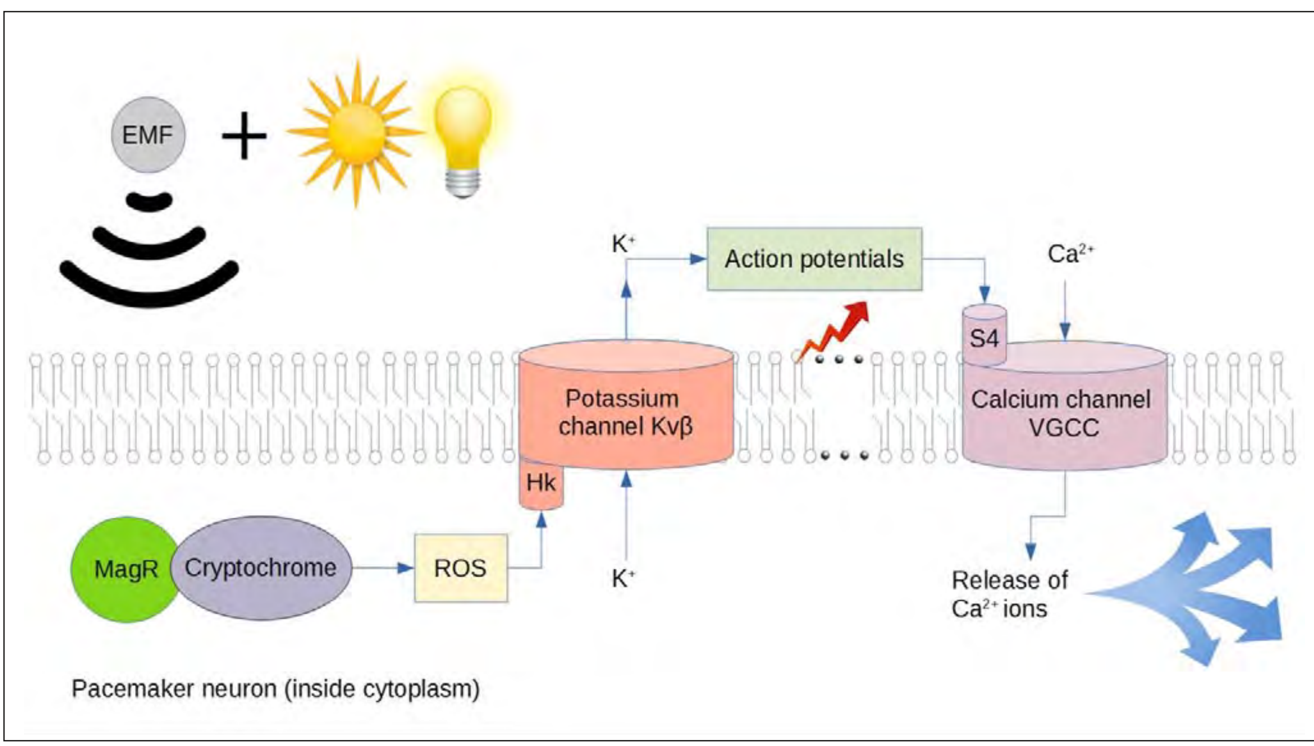

Figure 5: Mechanism of cryptochrome activation in Drosophila. In the presence of blue (or white) light and EMF, cryptochrome is activated and produces free radicals (ROS). ROS lead to the opening of potassium channels and the triggering of action potentials, which in turn activate synaptic VGCC. This leads to an increase in intracellular calcium content and release of neurotransmitters.

1.3 Magnetite

All insects possess cryptochromes in the retina and brain. However, the retinal cryptochromes only function as magnetosensors when blue light is present. Insects that are (also) active in the dark seem to use a magnetite-based magnetic sense instead; this has been experimentally confirmed in bees, ants and termites (Lambinet et al. 2017; Liang et al. 2016; Shaw et al. 2015). In organisms whose magnetic sense is not based on cryptochrome but on magnetite (mouse, bee, turtle, human), changes in the size of the magnetite crystals, which are mechanically (and possibly piezoelectrically) transferred to VGCC by the cytoskeleton, cause a release of calcium (Hsu et al. 2007).

Hsu et al. 2007 report: “While we confirmed the presence of superparamagnetic magnetite in the iron granules, we observed changes in the size of the magnetic granules in the trophycytes upon applying additional magnetic field to the cells. A concomitant release of calcium ions was observed by confocal microscope. This size fluctuation triggered the increase of intracellular Ca^{2+}, which was inhibited by colchicines and latrunculin B, known to be blockers for microtubule and microfilament syntheses, respectively. The associated cytoskeleton may thus relay the magnetosignal, initiating a neural response. A model for the mechanism of magnetoreception in honeybees is proposed, which may be applicable to most, if not all, magnetotactic organisms.” However, both mechanisms could equally well occur simultaneously but largely independently in the organism.

2 Overview of the research situation on the topic

2.1 Previous reviews

2.1.1 Cucurachis Review

Quoting Cucurachi et al. 2013: “Insects are a useful target system for the study of RF-EMF due to their limited size, short life cycle and the possibility to easily detect developmental errors (Schwartz et al., 1985).“ Of 25 studies investigating EMF effects on insects, 22 were evaluated as “effect”, and 3 as “no effect”.

2.1.2 Balmoris Review

Balmori 2014 reports on five studies that prove or suggest effects in insects – for example, the hypothesis that flower recognition, which is demonstrably partly due to the perception of electric fields, could be disturbed (Clarke et al. 2013).

2.1.3 Friesens Report

Friesen 2014 lists around 64 studies concerning EMF effects in insects.

2.1.4 Redlarskis Review

Redlarski et al. 2015 reports 15 studies on Drosophila (all forms of EMF and also static magnetic fields) between 1985 and 2004, 13 of which found an effect.

2.1.5 Eklipse Report

In the framework of the European EKLIPSE initiative, a detailed report was written at the request of the british NGO “Bug-Life” (Malkemper et al. 2018; Goudeseune, Balian, and Ventocilla 2018). 39 studies were identified and evaluated according to ecological aspects, 26 of which were additionally evaluated according to technical aspects.

2.1.6 Vanbergen et al. Review

Vanbergen et al. 2019 is based on the Eklipse report (and comes from the same researchers). The report emphasizes the proven toxicity of artificial light at night, and the suspected but so far insufficiently proven toxicity of anthropogenic radiofrequency (HF) electromagnetic radiation. In addition to the Eklipse Report, whose literature search was completed in July 2017, a few more recent studies are included here (described further below), e. g. Shepherd et al. 2018; R. Odemer and F. Odemer 2019. In addition, according to the authors, the only clearly proven effect of electromagnetic radiation so far is the disturbance of orientation (Wan, Zhao, and J. Xu 2014; Sutton et al. 2016; Bae et al. 2016).

2.2 Further procedure

The bibliographies of these reviews were extracted and integrated into a collected Bibtex bibliography, using the open source program JabRef. This resulted in a total of 159 studies, 101 of which, after closer examination, dealt with the topic of insects and EMF.

Since the reviews only included an exhaustive overview of the literature until 2017 (and in detail only until 2014), a Google Scholar and Pubmed Central Search of the years 2015-2020 was additionally made, using the following search terms: one of each: “insect; invertebrate; animal; wildlife; biodiversity; bee; drosophila; pollinator” AND all the following terms (with “or”): “EMR; EMF; electrosmog; electromagnetic field; electromagnetic radiation; electromagnetic”.

These two collections of literature were combined and more studies from the author’s collection were added, resulting in a total of 190 studies. 44 studies were solely concerned with the magnetic sense of insects, and were already discussed in the chapter on magnetic sense. 39 other studies were reviews, or purely theoretical treatises.

There remained 107 studies, which concerned experiments with EMF in insects. 15 studies were excluded because of qualitative deficiencies (poor), or because they dealt solely with static magnetic or electric fields, or technical methods for studying insects using EMF (such as RFID or radar tracking), or thermal effects (heating insects with microwaves). 6 studies were double-publications, i.e. the same experiments were published twice; these studies were classified as irrelevant. 83 studies that specifically concerned experiments with EMF in insects were now all individually evaluated and recorded in a summary table. 2 HF-EMF studies, which are pure computer simulations (Thielens 2020, Thielens 2018), were treated separately. These studies are prospective but not empirical in nature and therefore did not provide data points for the graphs - but did provide statements on the effects to be expected in the future.

Number according to EMF used:

Low-frequency: 29 studies

High-frequency: 55 studies (encompassing 63 experiments)

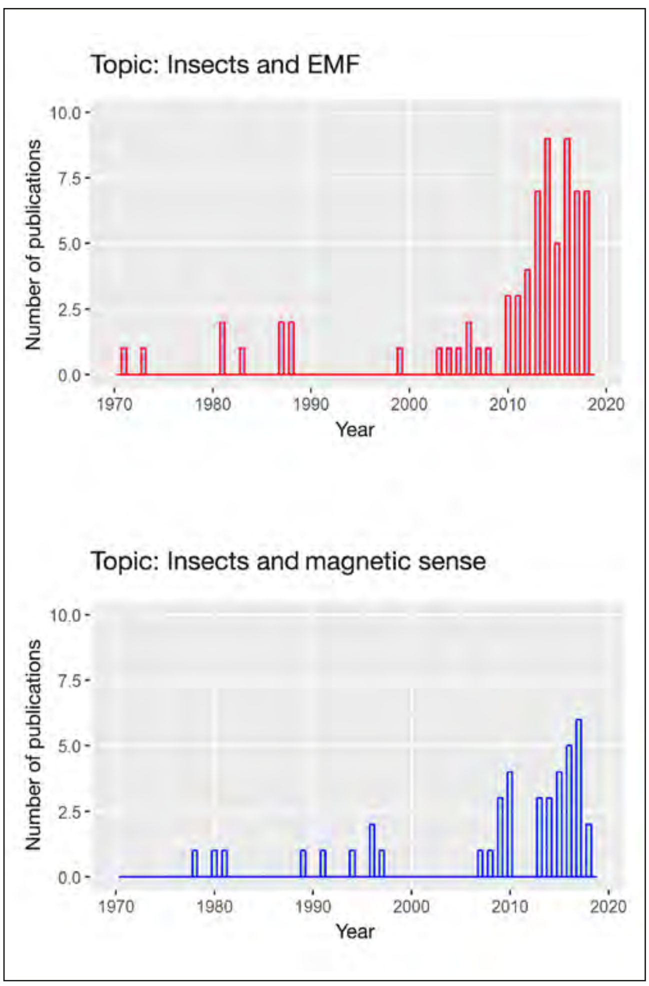

Figure 6: Number of publications per year

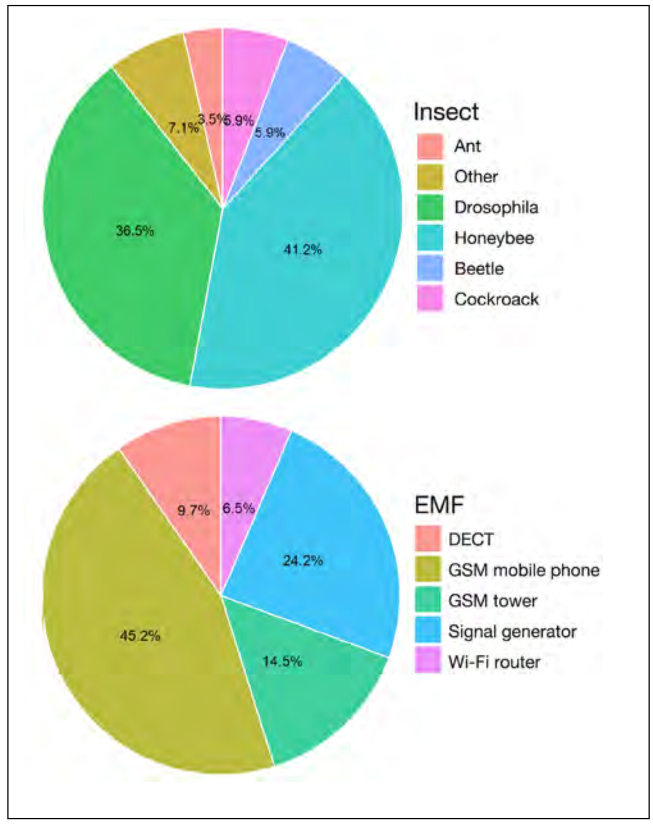

Figure 7: Publications by insect species and high-frequency EMF sources.

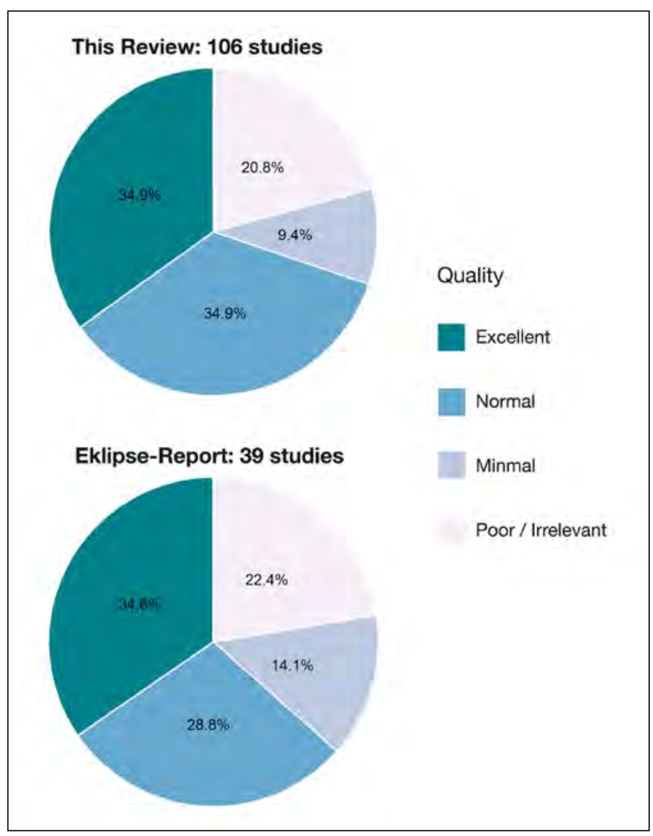

Figure 8: Quality of the studies. EKLIPSE report compared to this review. For the Eklipse Report: average score from evaluations according to biological and technical aspects.

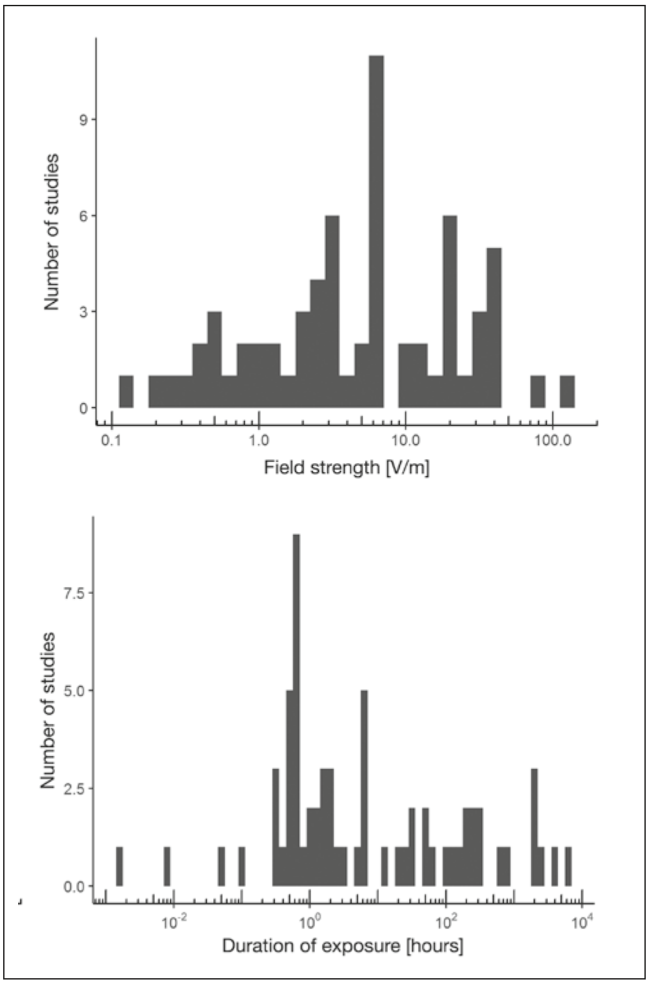

Figure 9: Publications by field strength and exposure duration (data points from 55 HF-EMF studies).

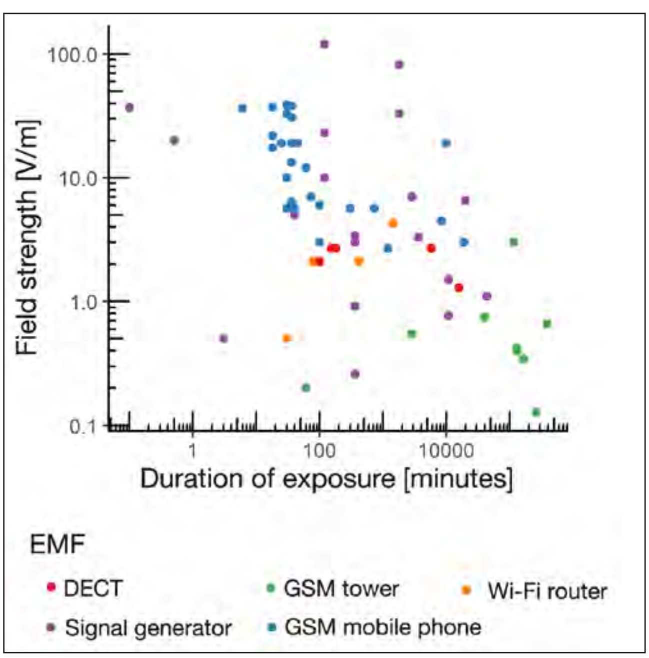

Figure 10: EMF field strength in relation to the duration of exposure (data points from 55 HF-EMF studies).

In the 55 HF studies, radiation intensities (i.e. electric field strengths) ranged from 0.04 to 38200 mW/m2, respectively 0.13 to 120 V/m. The duration of EMF-exposure of insects ranged from 6 seconds to 9 months. The radiation dose (field strength x time) can be calculated from the quantities field strength and exposure duration. Statistical data necessary for a meta-analysis were only available in a handful of studies, although many studies showed significant findings ($p < 0.05$) and it would probably have been only a minor effort for the authors to provide additional information such as confidence intervals (CI) or standard deviations (SD). Thus, no "state-of-the-art" analysis with consideration of the publication bias was made.

Instead, adverse effects described in studies were estimated in detail and the general toxicity (of the EMF) was estimated with a 4 point scale (0 = none, 1 = minor, 2 = moderate, 3 = strong effect), according to the same system used by IPBES (Potts et al. 2016) and the EKLIPSE report (Malkemper et al. 2018; Goudeseune, Balian, and Ventocilla 2018). The cut-off values were set at a rate of change of 10 %, 25 % and 50 % of a variable respectively. The categories for observed effects (variables): general toxicity, memory, sensory function, reproduction/genes, orientation, preference, oxidative stress.

The general toxicity was determined by considering the variable with the highest degree of (significant) percentage change as the decisive one (e.g. assigning a 3 if DNA damage increases by 50 % or more, even if all other measured variables show less than 50 % deviation from control). The quality of each study was similarly estimated using a 4 point scale (Potts et al. 2016).

As the name implies, the estimated toxicity values are not exact and definitive findings, as they are based on studies which in the majority of cases have not been carried out according to the prevalent criteria of care (e.g. in toxicology) and in most cases have not been replicated. In addition, they are only based on a 4-point scale, which does not allow for precise information, but at least a rough estimate.

Looking back on the history of science, however, it can be said that adverse effects have often been identified and described early on, but have been ignored – e.g. concerning asbestos, lead and cigarettes – and it took decades to understand the mechanisms and for the official position to change. The European Environment Agency EEA has produced several reports on this specifically under the title 'Late lessons from early warnings' (Gee et al. 2013).

Regarding the suspected harmfulness of various EMF sources (Fig. 11): the signal generator seems to be less harmful than the actual commercial EMF types at the same field strength. Most signal generators do not produce the characteristic strong and random fluctuations that are emitted, for example, by a mobile phone in talk mode or active Wi-Fi.

Similarly, mobile phone towers are apparently less harmful than GSM mobile phones, although both have the same signal characteristics. The field strength of the signal of mobile phone towers was in the range of 1.7 V/m on average (median value 0.66 V/m), whereas the field strength at exposure with GSM mobile phones was 10.8 V/m on average (median value 6.5 V/m), cf. Fig. 10. Converted into power densities, the quantitative difference is easier to comprehend (median values): mobile phone tower 1.15 mW/m^2, GSM mobile phone 112 mW/m^2.

This indicates that the currently typical field strengths of mobile phone towers are relatively much less toxic than GSM mobile phones, DECT and Wi-Fi. Probably the currently typical field strengths of mobile phone towers are still too weak to cause strong biological effects quickly (within days or hours), although some experiments found harmful effects after several months. Estimated toxicity values were also calculated in a normalized way, i.e. by dividing with the radiation dose. In this consideration, the LF-EMF of power lines or Helmholtz coils are relatively much less toxic than all tested RF-EMF (see also Fig. 12).

3. Commented listing of individual studies

3.1 Low-frequency electromagnetic fields (LF-EMF)

As early as 1976, Altmann and U. Warnke 1976 reported: "Bees in the 50-Hz high voltage field show an increased metabolism as a result of increased motor activity. At low field strengths (below about 10 kV/m), the metabolic increase is not uniform among different caged bee groups. At medium field strengths (approx. 20 kV/m – 40 kV/m), the metabolic increase correlates with the field strength. At high field strengths (above approx. 50 kV/m) mutual stinging occurs." Other researchers have confirmed these effects, as well as a disturbance of orientation: Wellenstein 1973; Greenberg et al. 1981; Bindokas, Gauger, and Bernard Greenberg 1988; Korall, Leucht and Martin 1988.

Ramirez et al. 1983 conducted the following experiment: A magnetic field of 100 µT strength at 50 Hz power frequency was applied to egg-laying Drosophila. This resulted in a significantly reduced egg deposition in the magnetic field group compared to the control.

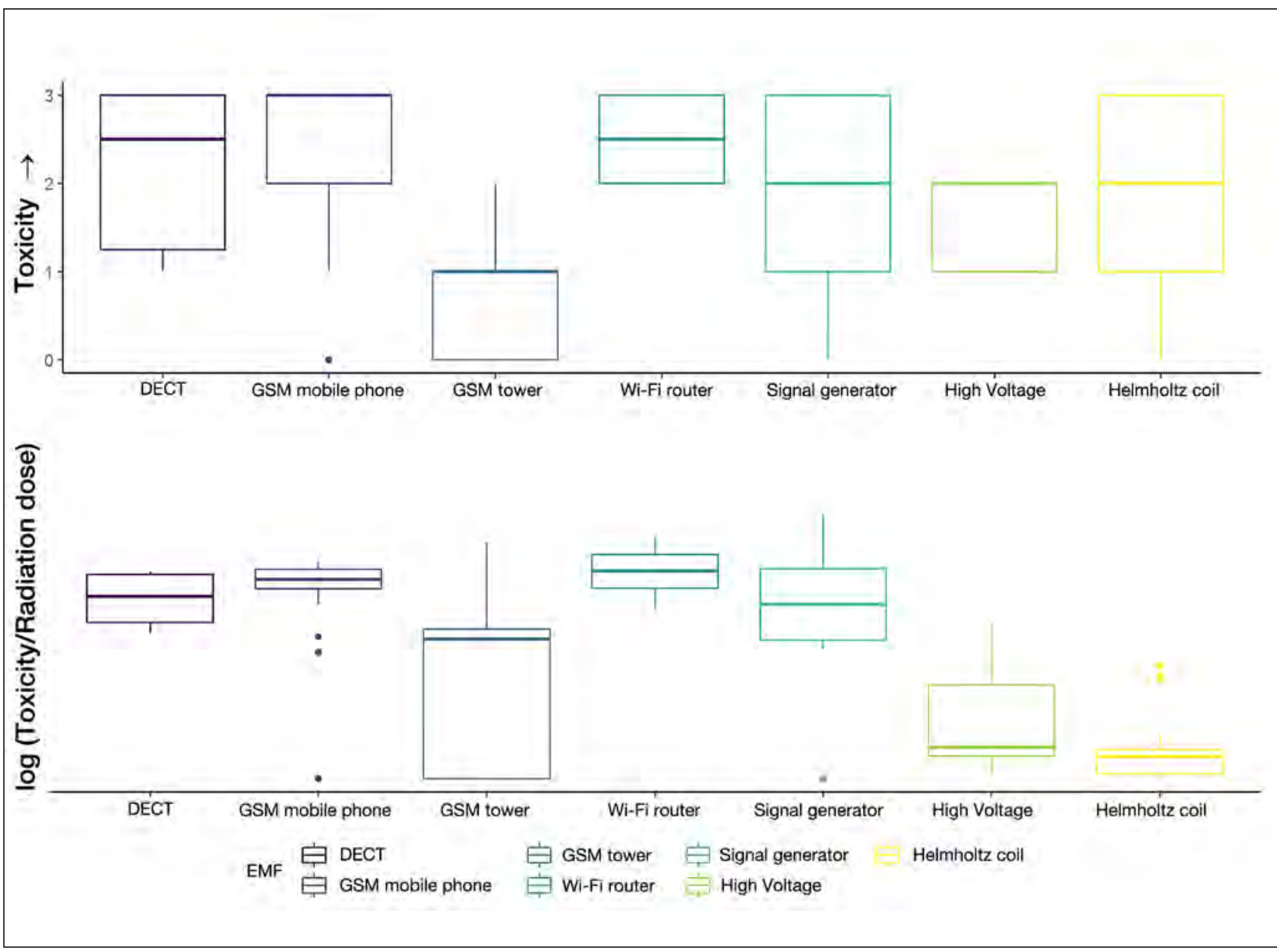

Figure 11: Above: Suspected toxicity to insects by EMF type (estimated value). Lower graph: relative toxicity by EMF type (estimated value), normalized to the radiation dose, i.e. divided by the product of field strength and exposure duration [V/m × min], displayed on a $\log_2$ scale. To compare the HF-EMF with the LF-EMF, all values of magnetic field strength [T] were converted to electric field strength [V/m] (see appendix).

3.1.1 Shepherd 2018, 2019

Shepherd et al. 2018 and Shepherd et al. 2019 investigated the effects of EMF from power lines (50 Hz power frequency) on honeybees (Apis mellifera). Specially designed coils were used to generate a magnetic field of 20 – 7000 µT, with the same characteristics as power lines. Low-frequency EMF significantly interfere with the parameters food intake, flight behaviour, learning (proboscis extension reflex) and memory formation at field strengths of 100 µT and above. At 7000 µT the wing beat frequency is also significantly increased.

Quote: *"ELF-EMF exposure was found to reduce learning, alter flight dynamics, reduce the success of foraging flights towards food sources, and feeding. The results suggest that 50 Hz ELF-EMFs emitted from powerlines may represent a prominent environmental stressor for honey bees, with the potential to impact on their cognitive and motor abilities, which could in turn reduce their ability to pollinate crops."*

Shepherd et al. 2019 also found increased aggression (by 60 %) in bees exposed to 100 µT compared to control, and confirmed the negative effects on short-term memory observed in their previous study. "These results indicate that short-term exposure to ELF EMFs, at levels that could be encountered in bee hives placed under power lines, reduced aversive learning and increased aggression levels."

In his doctoral thesis (Shepherd 2018), Shepherd also tested the combined effect of EMF with the neonicotinoid clothianidin, finding a reduced toxicity of EMF compared to the control. Quote: "These results provide a first indication that ELF-EMFs that may occur in the environment may influence critical behaviors and biological processes in important insects, supporting the need for larger field studies to determine the environmental effects of ELF-EMFs and suggesting further investigation to elucidate the mechanisms of biological effects of ELF-EMFs".

3.1.2 Erdoğan 2019

In the first experiment of Erdoğan 2019, 36 beehives were set up in 4 rows, and an electric fence was installed in front of the beehives. Part of the hives were screened from the low frequency EMF of the electric fence with earthed flyscreen. Number of workers, honey yields, and brood area were significantly lower in the exposed colonies compared to shielded controls.

In their second experiment, Erdoğan and Cengiz 2019 investigated the preference of food sources, with magnetic coils of 0, 50, 100, 150, and 200 µT placed together with food sources. This resulted in a strong preference for food sources with low field strength as well as longer residence times at these food sources.

3.1.3 Todorović 2019

Todorović et al. 2019 used 50 Hz power frequency (10 mT) on larvae of Argentine cockroaches (Blaptica dubia), during 5 months, and found significantly reduced digestive tract mass, GST activity, and significantly increased CAT and SOD activity, indicating increased oxidative stress.

3.1.4 Maliszewska 2018

Maliszewska et al. 2018 used 50 Hz power frequency (7 mT) on American cockroaches (Periplaneta americana) and found significantly increased malondialdehyde levels – an indicator of oxidative stress (after 24 h), as well as significantly reduced glutathione levels (GSH) after 7 days of irradiation. In addition, the reaction speed to noxious heat decreased considerably.

3.1.5 Wyszkowska 2016

Wyszkowska et al. 2016 placed desert locusts in an alternating magnetic field (4 mT, 50 Hz) and found reduced activity. In the cell assay at 7 mT, significantly increased heat shock protein HSP70 was measured, similarly high values as in a heated sample. Observation of the extensor tibiae (jumping muscle) and its ganglion revealed altered action potentials (longer and stronger at 7 mT compared to control), as well as reduced muscle strength.

3.1.6 Zhang 2016

Zhang et al. 2016 showed that thermal stress (35 °C) and EMF exposure (50 Hz, 3 mT) produce a synergistic effect that enhances the negative effect of EMF on lifespan, locomotion and oxidative stress in Drosophila melanogaster.

3.2 High-frequeny electromagnetic fields (HF-EMF): Recent publications

3.2.1 Panagopoulos 2019, [...] 2006

Panagopoulos has made a series of experiments with Drosophila, here in the following only an excerpt, since a detailed description of the entirety of the experiments would go beyond the scope of this article (Panagopoulos 2019; Panagopoulos 2017; Panagopoulos, Cammaerts et al. 2016; Panagopoulos, Johansson and Carlo 2015b; Panagopoulos, Johansson and Carlo 2015a; Panagopoulos, Karabarbounis and Liolioulsis 2013; Panagopoulos 2012; Panagopoulos, Chavdoula and Margaritis 2010; Panagopoulos and Margaritis 2010; Panagopoulos, Chavdoula, Karabarbounis et al. 2007; Panagopoulos, Chavdoula, Nezis et al. 2007; Panagopoulos, Karabarbounis and Margaritis 2004; Panagopoulos, Karabarbounis and Margaritis 2002).

Panagopoulos has recently summarized his own results from many experiments and over 10 years of research (Panagopoulos 2017). Dimitris Panagopoulos 2019 investigated the effect of a GSM transmitting mobile phone on development of Drosophila ovaries and found a significantly increased number of DNA strand breaks compared to the non-irradiated control. In addition, 36 minutes of GSM exposure (at 19 V/m = 380 mW/m^2) were shown to be significantly more harmful than 120 hours of exposure to a 2 mT low frequency magnetic field (Fig. 12. Helmholtz coil, similar to the LF-EMF experiments described above).

Quoting from Saliev et al. 2019 regarding Panagopoulos 2011: "The difference of effects on reproductive capacity of insects from modulated and non-modulated EMF was examined by Panagopoulos. Experimental data showed that exposure to non-modulated GSM 900 MHz signal led to a decrease in the insect's reproduction ability, while the modulated GSM 900 MHz signal caused a decrease in reproduction. It was clearly demonstrated that the modulated GSM signal ('speaking' mode) had a more significant impact on oogenesis of insects. In addition, the bio-effects from GSM-900 MHz and GSM-1800 MHz signals were studied and compared using the same biological model. A fall in reproductive capacity was detected for both types of GSM radiation. The work of Panagopoulos concurs with other reports on the influence of radiation from mobile phone on reproductive functions and embryogenesis."

Worth mentioning are the experiments in Panagopoulos, Chavdoula and Margaritis 2010, where maximum toxicity was found at a distance of 0 cm and 30 cm from a GSM mobile phone (and significantly lower toxicity in the area in between). Panagopoulos and Margaritis 2010 attribute this to an "intensity window", as earlier researchers have done (Salford et al. 2008). In Drosophila, this bioactive window appears to be at an intensity of about 100 mW/m2 (6 V/m), which corresponds to a distance of about 30 meters from a GSM mobile phone mast.

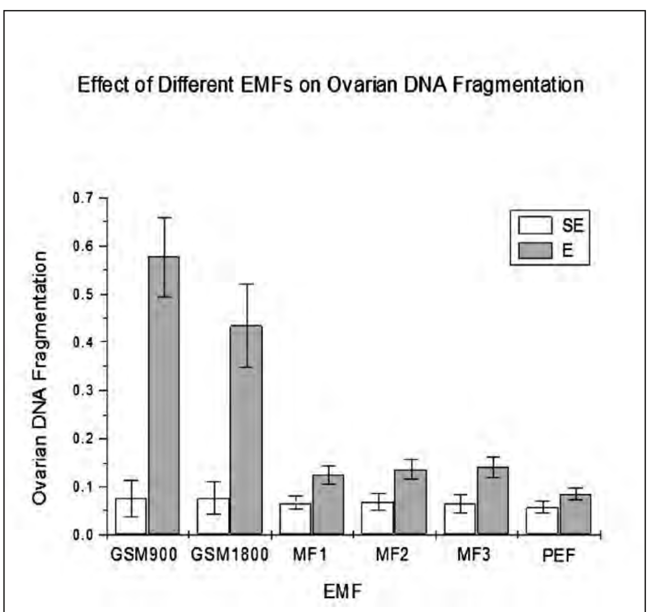

Figure 12: Impact of GSM and low-frequency electromagnetic fields on the DNA strand break rate in Drosophila ovaries (MF1 = 0.1 mT, MF2 = 1 mT, MF3 = 2 mT). Controls (SE) compared to exposed ovaries (E).
Source: Dimitris J Panagopoulos 2019.

3.2.2 Manta 2017, 2014

A study conducted by Margaritis and Manta (Margaritis et al. 2014), the result of 280 experiments, shows an increase in reactive oxygen species (ROS) in the ovaries of Drosophila after exposure to radiofrequency fields. Included were GSM mobile phone, DECT base and handset, Wi-Fi router, Bluetooth, baby phone, microwave oven, 900 MHz unmodulated (oscilloscope) and FM radio. The GSM mobile phone and DECT proved to be particularly harmful, but all other artificial EMFs tested were also slightly harmful in the sense that they led to reduced fertility and increased cell death in the ovaries.

Manta et al. 2017 builds on the 2014 study and has specifically studied free radical production and the genetic profile (gene induction). 168 genes were differentially expressed after irradiation by GSM mobile phone (270 mW/m^2 = 10 V/m during 30 min), 15 of which were down-regulated, including the cryptochrome gene. A number of genes of the antioxidative cycle and genes associated with repair mechanisms were expressed more strongly.

3.2.3 Singh 2020

Singh et al. 2020 irradiated Drosophila during 5 days with a 2400 MHz horn antenna, and found significant differences in brain morphology. Computer-assisted automatic classification of microscopic images of the brain achieved an accuracy of 94.66 % in correctly assigning the images (irradiated or control), although no clear differences were visible to the naked eye (under the microscope).

3.2.4 Lopatina 2019

Lopatina et al. 2019 studied the sensory and memory function of honeybees under irradiation with a Wi-Fi router. Five groups of 18 bees were used, two of which were exposed to a Wi-Fi router (estimated at 50 mW/m^2, for 24 h) and three of which served as controls. The response of the fixed bees to the presentation of a flavored sugar solution was recorded, as well as the formation of a conditioned reflex (proboscis extension reflex) and the retention of this reflex in long-term memory. Significant differences were observed between irradiated and non-irradiated groups in terms of response to presented food (disturbed), short-term memory (significantly deteriorated) and long-term memory (slightly improved). The whole experiment was repeated one year later, with the same results.

3.2.5 Odemer 2019

Odemer and Odemer 2019 studied the development of honey bee queens in the presence of a transmitting GSM mobile phone in the hive (about 2.2 V/m or 13 mW/m^2). The development of larvae to queens was significantly impaired (40% decrease after 14 days of exposure) compared to control. However, other development parameters remained the same between irradiated and non-irradiated queens and their colonies.

3.2.6 Vilić 2017

In Vilić et al. 2017 honey bee larvae were exposed to 900 MHz radiation for 2 hours, unmodulated (4 field strengths) and modulated (80 % 1 kHz, 217 Hz). DNA damage was significantly increased with modulated but not with unmodulated radiation. However, TBARS ("thiobarbituric acid reactive substance"), an indicator of lipid peroxidation and oxidative stress, was significantly reduced in all irradiated groups – indicating reduced oxidative stress. The authors summarize the results of other, similar studies, with about one third showing an increase, one third a decrease and the remaining studies finding constant or variable oxidation parameters. The conclusion is that the effects of radiofrequency EMF are complex and depend on the type of animal studied (e.g. insect, earthworm, rat), the developmental stage (e.g. egg, larva, adult) and the duration of exposure.

3.2.7 Taye 2017

Taye et al. 2017 used a total of 20 beehives placed at 5 different distances from a mobile phone tower (100, 200, 300, 500 and 1000 meters), observed during 6 months, at very low radiation intensities (20–80 µW/m^2). Quoting Taye: "The flight activity and returning ability of worker honey bees were maximum in colonies placed at 500 m and minimum at 100 m from the tower."

3.2.8 Favre 2017, 2011

In Favre 2017 the weak local GSM signal (1 µW/m^2) was detected, amplified and then projected onto a nearby beehive, using a directional antenna. The amplified signal had a power intensity in the range of 80–100 µW/m^2 (0.17 to 0.19 V/m) directly in front of the transmitting antenna and about 1 to 2.5 µW/m^2 (0.02 to 0.03 V/m) in the front of the hive (inside). Favre's bees responded with the (acoustically recorded) whistle sound – a signal associated with danger or displacement of the hive – within 1 hour after the start of GSM irradiation and this was tested 5 times.

In the pilot study Favre 2011, a GSM mobile phone was placed directly in the beehive instead of the GSM repeater – here too the whistle sound was the reaction of the bees. This experiment was repeated twelve times, each time with different beehives.

3.3 High-frequency electromagnetic fields: Older Studies

3.3.1 Lázaro 2016

Lázaro et al. 2016 used pan traps at certain distances (50, 100, 200, 400 m) around five mobile phone masts on the Greek island Limnos and five towers on Lesvos. From 17000 collected insects, 3700 wild bees, 800 wasps and 7000 beetles the following tendencies were observed: Avoidance of high EMF levels for beetles and wasps, but attraction to wild bees (more wild bees trapped near antennas) – with a clearer tendency of attraction for ground-nesting wild bees as opposed to above-ground nesting wild bees. Power densities ranged from 0.1 V/m = 26 µW/m2 to 0.7 V/m = 1300 µW/m^2.

3.3.2 Geronikolou 2014

Geronikolou et al. 2014 compared the effect of 900 MHz (mobile phone) and 1900 MHz (DECT handset) irradiation on Drosophila eggs (100 minutes in the near field). A significant decrease in fertility (i.e. number of laid eggs) was observed.

3.3.3 Chavdoula 2010

Drosophila were subjected to a GSM mobile phone in call mode for 6 minutes per day. Quoting Panagopoulos, Chavdoula and Margaritis 2010: "Intermittent exposures with 10-min intervals between exposure sessions proved to be almost equally effective as continuous exposure of the same total duration, whereas longer intervals between the exposures seemed to allow the organism the time required to recover and partly overcome the above-mentioned effects of the GSM exposure."

3.3.4 Cammaerts 2014, 2013, 2012

Cammaerts, De Doncker, et al. 2012; Cammaerts, Rachidi, et al. 2013 and Cammaerts and Johansson 2014 describe three experiments on ants in the laboratory that reveal avoidance of EMF, disturbance of memory, orientation and movement. Cammaerts recommends repeating a similar setup with bees.

3.3.5 Kumar 2011–2013

Kumar, Sangwan, and Badotra 2011 investigated the effect of mobile phone exposure on different biomolecules in adult worker honeybees. Ten honeybees were taken from each comb and irradiated in a small cage with two mobile phones in talk mode. The exposure duration was 10, 20 or 40 minutes. The concentration of different biomolecules increased significantly.

Kumar 2012 and Kumar, Rana and Kalia 2013 investigated the effect of mobile phone exposure on different biomolecules in the seminal fluid (2012) and hemolymph (2013) of honeybee drones (same setup as the previous experiment, exposure duration 30 minutes). Seminal fluid: the concentration of carbohydrates, proteins and lipids increased compared to the control and the activity of various enzymes was reduced. Hemolymph: the concentration of various biomolecules increased under the influence of EMF, e.g. from 1.65 mg/ml to 2.75 mg/ml for carbohydrates, 3.74 mg/ml to 4.85 mg/ml for proteins and from 0.325 mg/ml to 1.33 mg/ml for lipids.

3.3.6 Stever & Kuhn 2006, 2005

In the pilot study Stever, Kuhn et al. 2006, Stever and Kuhn investigated the effects of DECT base stations (at 2.5 mW average power, or about 1.4 mW/m^2) on the sense of orientation of individual honey bees and the development of bee colonies. Eight out of sixteen hives were exposed to DECT base stations for 11 days. The sense of orientation was significantly worse in the irradiated group, as well as the development of the hives. Stever, Kimmel et al. 2006 repeated the experiment and studied again the sense of orientation (duration until return, number of returners) with the same setup and could confirm the disturbing effect of DECT.

3.4 No-effect studies

3.4.1 Miyan 2014

Miyan 2014 used 35 beehives, in 5 exposure groups, in 0–800 m distance from a mobile phone mast. No differences between the exposure groups were found for all measured parameters, e.g. honey production, pollen collection, reproduction, hive size, etc. A power density of 0.423 V/m was measured directly at the mobile phone tower (475 µW/m^2), all other values were below 0.01 V/m (25 µW/m^2), which are very low values that are hardly found in Europe. The maximum value at 0 m was also below the threshold value where experts suspect a harmful effect, i.e. 1000–100000 µW/m^2 (Cucurachi et al. 2013; Panagopoulos and Margaritis 2010).

3.4.2 Hoofwijk 2013

In 2011, an experiment of the group around Tjeerd Blacquiere (Hoofwijk and Blacquiere 2013) investigated indicators for the toxicity of mobile phone masts to honey bees. The experimental set-up consisted of 20 hives housed in two separate enclosures. 10 hives were shielded with metal mesh, 10 were exposed to the radiation of the nearby mobile phone mast. All experiments were performed double-blind. The test site with the two dwellings is located 230 m away from a mobile phone mast, in direct view. The GSM 900 MHz intensity on site, outside the dwellings, was on average 0.5 V/m or about 660 µW/m^2.

The authors summarize the results of the experiment as such: "Our investigations show that colonies from the exposed and the control group had a comparable developmental success from the egg via the larva to the adult bee, comparable orientation skills, a comparable performance in their adult phase, comparable morphometric and physiological parameters at hatching, a comparable longevity, a comparable development at colony level (production or bread and young bees), but differed in winter survival in the sense that more non-exposed than exposed colonies survived."

Winter survival rate: 3 out of 10 for exposed hives, 9 out of 10 for non-exposed (shielded). According to the authors, the nested setup of shielded and exposed hives being housed in two separate "houses" of 10 colonies does not permit for a clear statistical description of the outcome, and this experiment should be repeated with at least 30 exposed and 30 shielded hives, housed separately each or in small groups, to reduce the possibility of a parasite infecting an entire house, as the exposed hives in the above experiment had high infection rates with Varroa mites.

4. Overview of research and state of knowledge at the beginning of 2020

Overview of the study situation:

High-frequency EMF: effect found in 56 of 64 experiments in 46 of 55 studies

Low-frequency EMF: effect found in 26 of 29 studies

The effect found was in most cases harmful, in rare cases neutral. In one study (Makarov and Khmelinskii 2016) it could be shown that both negative and positive effects can be achieved by changing the parameters of a 3D LF-EMF.

General considerations and recommendations for the future:
One experimental finding supporting the hypothesis of activation of VGCC – or other voltage-gated channels – is that damage from EMF occurs only after prolonged exposure to radiation from one direction. A randomly rotating ("chaotic") magnetic field can be used to neutralize the toxicity of simultaneous irradiation with EMF (Lai and Singh 2005; Litovitz et al. 1994). In practice, one would therefore expect a stronger harmfulness of EMF in plants than in moving animals, which has also been generally confirmed experimentally (Halgamuge, Yak and Eberhardt 2015; Halgamuge 2016). In insects, the harmful influence should be stronger in the early stages of development (egg, larva, pupa) than in adults - signs of this were found e.g. by Odemer and Odemer 2019.

There is considerable evidence of many medical applications of EMFs waiting to be used (Markov 2007; Pilla 2013). Even if current wireless EMF technologies are generally – dose-dependently – toxic, existing research suggests that it should be easy to significantly improve the biocompatibility of wireless technologies (Lai 2004; Pilla 2006). Since, at least as far as the largely elucidated mechanism of cryptochrome activation is concerned, the presence of blue (or white) light seems necessary for adverse effects of EMF in insects, the massive use of artificial street lighting should be reconsidered – and if necessary, light sources with less blue content should be used (e.g., LEDs with a "warm" instead of "cold" spectrum). For all insects that use magnetite for their magnetic sense, e.g. all hymenopterans – bees, wasps, ants – harmful effects of EMF are to be expected even in the absence of (artificial) light.

Starting at which field strengths are toxic effects expected to occur in insects, or have been proven to occur in experiments? Panagopoulos, Chavdoula and Margaritis 2010 has detected a bioactive window at a distance of 20–30 cm from GSM mobile phones, which corresponds to a power density of 100 mW/m^2, or about 6 V/m – where significant toxic effects have been observed in Drosophila already after short-term exposure (10 minutes), and these results have meanwhile been replicated several times (Chavdoula 2010, Margaritis 2014, Geronikolou 2014). If this is generally true for insects, the limit for toxic effects would be 100 times below the current ICNIRP limits (10 W/m^2 or 61 V/m, see Non-Ionizing Radiation Protection et al. 2020), which only protect against thermal effects. For chronic exposure, negative effects might be expected at a power density 10 times lower – i.e. 10 mW/m^2 – but here the state of knowledge is still uncertain.

At the moment (anno 2020), power densities in the environment are generally still far below 10 or 100 mW/m^2 (i.e. 2 or 6 V/m). A recent study has measured values of 0.17–0.53 V/m RMS in the field (0.1–0.8 mW/m^2 – Thielens, Greco et al. 2020). The author of this review has measured values up to a maximum of 10 mW/m^2 RMS (2.5 V/m) in his master's thesis, but only in the immediate vicinity (30–50 m) of LTE/GSM masts. Measurements in urban hotspots (UK, Ofcom 2020) found a maximum of 150 mW/m^2 (1.5 % of the ICNIRP limit) and an average of 25 mW/m^2 (as sum of all RF emissions in the frequency range 0.3–6 GHz).

In Belgium, Italy, Switzerland, Russia, and China, the maximum permissible exposures (installation limits) for the general population are 6 V/m (100 mW/m^2) or less (3 V/m in Luxembourg) in the mobile telephony/Wi-Fi range, while Germany, the USA, and many other countries adhere to the ICNIRP limits, which are set at 41 V/m (4000 mW/m^2) for 900 MHz, or at 61 V/m (10 W/m^2) for 2 GHz and above (funkstrahlung.ch 2017; Woelfle 2003; Non-Ionizing Radiation Protection et al. 2020).

Thirty-six (36) of the 64 radiofrequency experiments in this review used a field strength of less than 6 V/m (100 mW/m^2), and 30 experiments (83 %) nevertheless found clear indications of or statistically significant adverse effects, roughly starting from 3 V/m, i.e. even below the particularly low installation limits found only in some countries. The installation limit is measured where people can stay for long periods of time, i.e. streets, city squares, homes, etc.

According to Thielens, Bell, et al. 2018, the absorption of artificial EMFs in insects remains relatively constant, even at much higher frequencies than those generally used today (e.g. 60 GHz). The wavelengths of 5G are very close to the body length of various insects, which leads to resonant absorption (see Fig. 13). 5G will be gradually expanded, into progressively higher frequencies. As the power loss due to scattering, reflection, and the lower penetration force of higher frequencies becomes increasingly greater, the radiated power of base stations would also have to be increased to ensure that wireless connections in homes and vehicles function comfortably. According to Xu et al. 2017, the power of a single 5G station (in the 15 GHz band) should be about 10 W/m^2 at 1 m distance, or 100 mW/m^2 at 10 m distance.

After Thors et al. 2017 calculations, 5G antennas would, in the worst case, only emit 15 % of their theoretical maximum power and would have the advantage – compared to the current infrastructure (1G–4G) – that the radiation intensity would be reduced to virtually zero in the absence of users (e.g. at night).

According to measurements by Ofcom, 5G base stations (in the UK) currently only have power levels of up to 3.8 mW/m^2, and on average only 0.59 mW/m^2, in urban hotspots (Ofcom 2020). However, since the infrastructure is still very rudimentary and the number of users small, these figures may be many times higher in the future, especially since with 5G, the antenna power is directly dependent on the number of channels used, i.e. the end users. Recent measurements at 5G pilot projects in France found higher values, e.g. about 6 V/m (100 mW/m^2) at a distance of 150 meters, at maximum antenna power, and about 3.5 V/m (32 mW/m^2) at the end device in case of a 10 gigabyte download (Anfr 2020). However, this is only a rough estimate, since the new "beam-forming" technique precisely focuses the radiation from typically 64 individual antennas per 5G station onto devices (small aperture, i.e. beam angle) and at the same time each base station transmits toward many devices separately ("massive MIMO").

It is planned to install one base station every 250 meters (or less) in the urban sector, with a distinction being made between so-called "small cells" and ordinary base stations. If this were to be implemented, a considerable portion of the air region typical for insects, in urban areas, would possibly be saturated with power levels around 100 mW/m^2 at some point. Switzerland, Italy and a few Eastern European countries are probably within the safe range with a 6 V/m installation limit – but elsewhere in Europe the 5G expansion threatens to lead to a significant increase in EMF emissions.

In view of the current research situation, the author of this review must warn against such an approach, as harmful effects on insects would be unavoidable. In addition, 5G-radiation is probably – at least for insects – more bioactive than e.g. 4G-emissions of the same field strength, because of the very "dense" signal characteristics (Panagopoulos 2011).

However, the currently available information and assessments on 5G are quite controversial and contradictory, ranging from “completely unproblematic”, with reference to a significantly reduced radiation exposure compared to current technology (Chiaraviglio et al. 2018; Matalatala et al. 2018) – although recent measurements do not or only to a limited extent confirm this (Anfr 2020; Ofcom 2020) – up to apocalyptic warnings of serious effects (Kostoff et al. 2020; Hardell and Nydberg 2017). Until the truth emerges, the development of the expansion should be closely monitored and toxicological tests should be started immediately to quickly identify and quantify any harmful effects so that realistic protective guidelines can be issued. Toxic effects to insects might occur at radiation levels that are safe for humans, particularly in the higher frequency bands (see Figure 13). This author refers to the so-called precautionary principle, which is detailed in Article 191 of the Treaty on the Functioning of the European Union.

Conclusions: Research indicates that EMF could have a serious impact on the vitality of insect populations. 72 of the 83 studies analysed found an effect. Negative effects that were described in studies include: disturbance of the sense of orientation, reduced reproductive capacity and fertility, lethargy, changes in flight dynamics, in the success of foraging, in reaction speeds, escape behaviour, disturbance of circadian rhythms, blocking of the respiratory chain and damage to mitochondria, misactivation of the immune system, increased number of DNA strand breaks.

Some mechanisms of action leading to these damages are identified. EMF affect the metabolism, among other things affecting voltage-controlled calcium channels, e.g. in neurotransmission and in muscle tissue, which can lead to an overactivation of signal transduction and of the respiratory chain with production of free oxygen radicals and consequently to oxidative cell stress.

In some experiments, it was found that despite low levels of exposure to transmitters, harmful effects occurred after several months. Field strengths 100 times below the ICNIRP limits could already have effects. Harmful effects for insects might occur at radiation intensities that are harmless to humans – especially in the higher frequency bands (see Fig. 13). Until the truth is known, the development of the expansion should be closely monitored and toxicological tests should be started immediately to quickly identify and quantify any harmful effects so that realistic protective guidelines can be established. Against the background of the rapid decline of insects and the further expansion of high-frequency electromagnetic field sources, there is not only an urgent need for further research, but also in particular, on interactions with other harmful noxious agents such as pesticides. When planning the expansion of mobile networks, insect habitats should be protected from high-intensity EMF exposure already now. This author refers here to the so-called precautionary principle, which is anchored in Article 191 of the Treaty on the Functioning of the European Union.

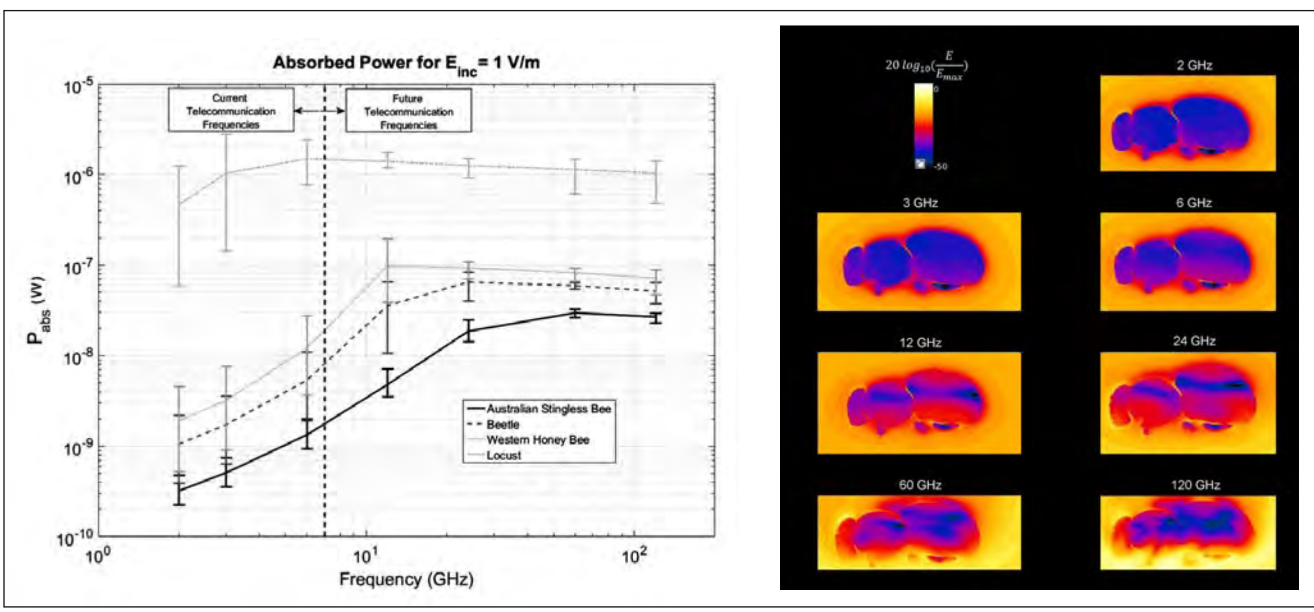

Figure 13: Energy absorption by insects at increasing microwave frequencies. Source: Thielens, Bell, et al. 2018.

5. Appendix

5.1 List of abbreviations

5G .... The fifth generation of mobile communications technology

EEG .... Electroencephalogram

EMF .... Electromagnetic fields

GHz .... Gigahertz (1 GHz corresponds to 1.000 MHz)

ICNIRP ..... The International Commission on Non-Ionizing Radiation Protection

NMDA ...... N-methyl-D-aspartate receptor, an ionotropic glutamate receptor

MIMO ...... "Multiple input multiple output"

RMS .... "root mean square", the square mean

ROS .... "reactive oxygen species", free radicals

VGCC .... "voltage-gated calcium channel", voltage-gated calcium channel

W/m² .... watts per square meter, a measure of radiated power density

5.2 Calculations

The SI unit for expressing the strength of an electromagnetic field is volts per meter [V/m], and this is also the general unit of measurement for electric fields. It can be used to calculate the average (RMS) power density or radiation intensity in watts per square meter [W/m^2] in the case of electromagnetic fields, which is also used in solar cell technology. For all radiofrequency studies included here, all given values of field strength were converted into V/m if they were described in a different unit.

The following formulas were used (Woelfle 2003; Poynting-Vector):

$$S = \frac{E^2}{Z_0} \quad \text{oder auch:} \quad E = \sqrt{S \times Z_0}$$

where E is the electric field strength [V/m]

S the power density [W/m^2]

Z_0 the wave impedance [377 Ohm]

For electromagnetic waves, electric field strength is linked to magnetic field strength, according to:

$$B = E/c$$

with B the magnetic field in Tesla,

E the electric field in volts per meter and

c the speed of light (3×10^8 m/s)

(derived from the Ampère-Faraday law, or directly from the Poynting-Vector)

In the near-field, i.e. below one wavelength (e. g. < 30 cm for GSM900), the electric and magnetic fields are present as a vortex field. Averaged over many measurements, however, the proportionality of electric and magnetic field strength is maintained here as well.

The SAR value, short for "Specific Absorption Rate", expresses how much energy is actually absorbed by irradiated tissue, and therefore depends on the tissue type (or generally on the material), and was estimated here to be

$$SAR = \frac{(E \times 1{,}19)^2}{1.000}\ \text{W/kg}$$

according to Panagopoulos, Johansson, and Carlo 2013; Sagioglou et al. 2014.

The author has no conflict of interest to declare.

Author: Alain Thill, M.Sc.

client: Aktionsgruppe für Umwelttoxikologie Akut Luxemburg | Co-Finanzierung: Diagnose-Funk e.V, NaBu Baden-Württemberg

quote: Thill A (2020). Biologische Wirkungen elektromagnetischer Felder auf Insekten. Beilage in umwelt · medizin · gesellschaft | 33 | 3/2020

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Tables

V/m	mW/m^2	nT	SAR [W/kg]
0.00	0.00	0.00	0.00
0.10	0.03	0.33	0.00
0.20	0.11	0.67	0.00
0.30	0.24	1.00	0.00
0.40	0.42	1.33	0.00
0.50	0.66	1.67	0.00
0.60	0.95	2.00	0.00
0.70	1.30	2.33	0.00
0.80	1.70	2.67	0.00
0.90	2.15	3.00	0.00
1.00	2.65	3.34	0.00
1.20	3.82	4.00	0.00
1.40	5.20	4.67	0.00
1.60	6.79	5.34	0.00
1.80	8.59	6.00	0.00
2.00	10.61	6.67	0.01
2.20	12.84	7.34	0.01
2.40	15.28	8.01	0.01
2.70	19.34	9.01	0.01
3.00	23.87	10.01	0.01
4.00	42.44	13.34	0.02
5.00	66.31	16.68	0.04
6.00	95.49	20.01	0.05
7.00	129.97	23.35	0.07
8.00	169.76	26.68	0.09
9.00	214.85	30.02	0.11
10.00	265.25	33.36	0.14
15.00	596.82	50.03	0.32
20.00	1061.01	66.71	0.57
25.00	1657.82	83.39	0.89
30.00	2387.27	100.07	1.27
35.00	3249.34	116.74	1.73
40.00	4244.03	133.42	2.27
45.00	5371.35	150.10	2.87
50.00	6631.30	166.78	3.54
55.00	8023.87	183.46	4.28
60.00	9549.07	200.13	5.10
70.00	12997.35	233.49	6.94
80.00	16976.13	266.84	9.06
90.00	21485.41	300.20	11.47
100.00	26525.20	333.56	14.16

Table 1: Conversion of high-frequency EMF field strengths

Author	Year	Insect	EMF	Title
Wyszkowska	2019	Honeybee	Helmholtz coil	Electromagnetic fields and colony collapse disorder of the honeybee.
Todorovic	2019	Cockroach	Helmholtz coil	Long-term exposure of cockroach Blaptica dubia (Insecta: Blaberidae) nymphs ...
Shepherd	2019	Honeybee	Helmholtz coil	Increased aggression and reduced aversive learning in honey bees exposed to ...
Panagopoulos	2019	Drosophila	Helmholtz coil	Comparing DNA damage induced by mobile telephony and other types of man-...
Erdoğan	2019	Honeybee	Electric fence	Determination of the effect of electric fence system on productivity and behav...
Erdoğan	2019	Honeybee	Helmholtz coil	Effect of Electromagnetic Field (EMF) and Electric Field (EF) on Some Behavio...
Sherrard	2018	Drosophila	PEMF	Low-intensity electromagnetic fields induce human cryptochrome to modulate in...
Shepherd	2018	Honeybee	Helmholtz coil	Extremely low frequency electromagnetic fields impair the cognitive and motor...
Shepherd	2018	Honeybee	Helmholtz coil	The effects of extremely low frequency electromagnetic fields on insects...
Maliszewska	2018	Cockroach	Helmholtz coil	Electromagnetic field exposure (50 Hz) impairs response to noxious heat in ...
Zmejkoski	2016	Drosophila	Helmholtz coil	Different responses of Drosophila subobscura isofemale lines to extremely low...
Zhang	2016	Drosophila	Helmholtz coil	Coupling mechanism of electromagnetic field and thermal stress on Drosophila ...
Zagirnyak	2016	Drosophila	Electric motor	Experimental research of electromechanical and biological systems compatibility...
Wyszkowska	2016	Locust	Helmholtz coil	Exposure to extremely low frequency electromagnetic fields alters the behavio...
Makarov	2016	Drosophila	3d-LF EMF cell	External control of the Drosophila melanogaster egg to imago development peri...
Todorovic	2015	Beetle	Helmholtz coil	Effects of two different waveforms of ELF MF on bioelectrical activity of ant...
Patenkovic	2015	Drosophila	Helmholtz coil	The impact of extremely low frequency electromagnetic field (50 Hz, 0.25 mT) ...
Jankowska	2015	Cockroach	Helmholtz coil	Exposure to 50 Hz electromagnetic field changes the efficiency of the scorpion...
Fedele	2014	Drosophila	Helmholtz coil	Genetic analysis of circadian responses to low frequency electromagnetic field...
Li	2013	Drosophila	Helmholtz coil	Gene expression and reproductive abilities of male Drosophila melanogaster ...
Dimitrijevic	2013	Drosophila	Helmholtz coil	Temporal pattern of Drosophila subobscura locomotor activity after exposure ...
Tipping	1999	Drosophila	Helmholtz coil	Observations on the effects of low frequency electromagnetic fields on cellul...
Korall	1988	Honeybee	Helmholtz coil	Bursts of magnetic fields induce jumps of misdirection in bees by a mechanism...
Bindokas	1988	Honeybee	765 kV	Mechanism of biological effects observed in honey bees (Apis mellifera, L.) h...
Walters	1987	Drosophila	Helmholtz coil	Test for the effects of 60-Hz magnetic fields on fecundity and development in...
Altmann	1987	Honeybee	2 kV-line	Thermographie der Honigbienen-Wintertraube unter Einfluss von Hochspannung...
Ramirez	1983	Drosophila	Helmholtz coil	Oviposition and development of Drosophila modified by magnetic fields...
Greenberg	1981	Honeybee	765 kV	Response of honey bees, Apis mellifera L, to high-voltage transmission lines...
Wellenstein	1973	Honeybee	220 kV	Der Einfluss von Hochspannungsleitungen auf Bienenvölker (Apis mellifica L...

Table 2: List of low-frequency studies (LF)

Author	Year	Insect	EMF	Title
Thielens	2020	Honeybee	Simulation	Radio-Frequency Electromagnetic Field Exposure of Western Honey Bees...
Singh	2020	Drosophila	Signal generator	A novel pilot study of automatic identification of EMF radiation effect on ...
Panagopoulos	2019	Drosophila	cell phone	Comparing DNA damage induced by mobile telephony and other types of man-...
Odemer	2019	Honeybee	cell phone	Effects of radiofrequency electromagnetic radiation (RF-EMF) on honey bee ...
Lopatina	2019	Honeybee	Wi-Fi router	Effect of Non-Ionizing Electromagnetic Radiation on Behavior of the Honeybee ...
Jungwirth	2019	Honeybee	Signal generator	The Effect of Electromagnetic Fields Produced by Wi-Fi Routers on the Magnetite ...
Bartos	2019	Cockroach	Signal generator	Weak radiofrequency fields affect the insect circadian clock...
Zubrzak	2018	Honeybee	Signal generator	Thermal and acoustic changes in bee colony due to exposure to microwave ...
Thielens	2018	various	Simulation	Exposure of Insects to Radio-Frequency Electromagnetic Fields from 2 to 120 GHz...
Mikhaylova	2018	Flies	Signal generator	Determining the electromagnetic field parameters to kill flies at livestock ...
Vilic	2017	Honeybee	Signal generator	Effects of short-term exposure to mobile phone radiofrequency (900 MHz) on ...
Vargova	2017	Tick	Signal generator	Ticks and radio-frequency signals: behavioural response of ticks ...

Taye	2017	Honeybee	GSM tower	Effect of electromagnetic radiation of cell phone tower on foraging behaviour...
Syalima	2017	Cockroach	cell phone	Mobile phone radiation induces sedation in Periplaneta americana...
Poh	2017	Mosquito	Signal generator	Effects of low-powered RF sweep between 0.01-20 GHz on female Aedes Aegypti ...
Manta	2017	Drosophila	cell phone	Mobile-phone radiation-induced perturbation of gene-expression profiling, ...
Favre	2017	Honeybee	GSM tower	Disturbing Honeybees' Behavior with Electromagnetic Waves: a Methodology...
Lazaro	2016	various	GSM tower	Electromagnetic radiation of mobile telecommunication antennas affects the ...
Fauzi	2016	Drosophila	cell phone	The Effect of EMF Radiation Emitted by Mobile Phone to Insect Population ...
Dyka	2016	Drosophila	Signal generator	Effects of 36.6 GHz and static magnetic field on degree of endoreduplication ...
Darney	2016	Honeybee	Signal generator	Effect of high-frequency radiations on survival of the honeybee (Apis mellifera ...
Patel	2015	Honeybee	GSM tower	Impact of electromagnetic radiations on biology and behaviour of Apis mellifera ...
Dalio	2015	Honeybee	cell phone	Effect of Electromagnetic (cell phone) radiations on Apis mellifera ...
Sagioglou	2014	Drosophila	Signal generator	Apoptotic cell death during Drosophila oogenesis is differentially increased ...
Miyan	2014	Honeybee	GSM tower	Effect of electromagnetic waves on the performance of Apis mellifera ...
Margaritis	2014	Drosophila	Wi-Fi router	Drosophila oogenesis as a bio-marker responding to EMF sources...
Manta	2014	Drosophila	DECT	Reactive oxygen species elevation and recovery in Drosophila bodies and ovaries...
Mall	2014	Honeybee	GSM tower	Effect of electromagnetic radiations on brooding, honey production and foraging...
Geronikolou	2014	Drosophila	DECT	Diverse radiofrequency sensitivity and radiofrequency effects of mobile or ...
El Halabi	2014	Honeybee	GSM tower	The effect of cell phone antennas' radiations on the life cycle of honeybees.
Cammaerts	2014	Ant	Signal generator	Ants can be used as bio-indicators to reveal biological effects of electromag...
Cammaerts	2014	Ant	Signal generator	Effect of Short-Term GSM Radiation at Representative Levels in Society on a B...
Vijver	2013	various	GSM tower	Investigating short-term exposure to electromagnetic fields on reproductive ...
Kumar	2013	Honeybee	cell phone	Biochemical changes in haemolymph of Apis mellifera L. drone under the influence ...
Hoofwijk	2013	Honeybee	GSM tower	Mobiele telefonie en de ontwikkeling van honingbijen.
El Halabi	2013	Honeybee	cell phone	The effect of cell phone radiations on the life cycle of honeybees.
Cammaerts	2013	Ant	Wi-Fi router	Food collection and response to pheromones in an ant species exposed to electro-...
Panagopoulos	2012	Drosophila	cell phone	Effect of microwave exposure on the ovarian development of Drosophila ...
Kumar	2012	Honeybee	cell phone	Influence of cell phone radiations on Apis mellifera semen.
El Kholy	2012	Drosophila	cell phone	Effect of 60 minutes exposure to electromagnetic field on fecundity, learning...
Cammaerts	2012	Ant	Signal generator	GSM 900 MHz radiation inhibits ants association between food ...
Sahib	2011	Honeybee	cell phone	Impact of mobile phones on the density of honeybees.
Kumar	2011	Honeybee	cell phone	Exposure to cell phone radiations produces biochemical changes in worker honey ...
Favre	2011	Honeybee	cell phone	Mobile phone-induced honeybee worker piping.
Sharma	2010	Honeybee	cell phone	Changes in honeybee behaviour and biology under the influence of cellphone ...
Panagopoulos	2010	Drosophila	cell phone	Bioeffects of mobile telephony radiation in relation to its intensity or distance...
Chavdoula	2010	Drosophila	cell phone	Comparison of biological effects between continuous and intermittent exposure...
Lee	2008	Drosophila	Signal generator	Mobile phone electromagnetic radiation activates MAPK signaling and regulates...
Panagopoulos	2007	Drosophila	cell phone	Cell death induced by GSM 900-MHz and DCS 1800-MHz mobile telephony radiation...
Stever	2006	Honeybee	DECT	Verhaltensänderung der Honigbiene Apis mellifera unter elektromagnetischer ...
Atli	2006	Drosophila	Signal generator	The effects of microwave frequency electromagnetic fields on the development ...
Stever	2005	Honeybee	DECT	Verhaltensänderung unter elektromagnetischer Exposition–Pilotstudie 2005...
Panagopoulos	2004	Drosophila	cell phone	Effect of GSM 900-MHz mobile phone radiation on the reproductive capacity of ...
Weisbrot	2003	Drosophila	cell phone	Effects of mobile phone radiation on reproduction and development in Drosophila ...
Westerdahl	1981	Honeybee	Signal generator	Flight, orientation, and homing abilities of honeybees following exposure to ...
Westerdahl	1981	Honeybee	Signal generator	Longevity and food consumption of microwave-treated (2.45 GHz CW) honeybees ...
Carpenter	1971	Beetle	Signal generator	Evidence for nonthermal effects of microwave radiation: Abnormal development ...

Table 3: List of high-frequency studies (HF)

Author	Year	Title
Stoll	2019	Method and device for influencing insects.
Sadeghi	2019	Microwave Application for Controlling Oryzaephilus surinamensis Insects Infes...
Rosi	2019	Emigration Effects Induced by Radio Frequency Treatment to Dates Infested by ...
Souza	2018	Low-cost electronic tagging system for bee monitoring.
Benedetti	2017	Device and respective control method for controlling the activities of a colo...
Panagopoulos	2013	ELF alternating magnetic field decreases reproduction by DNA damage induction...
Schneider	2012	RFID tracking of sublethal effects of two neonicotinoid insecticides on the f...
Al Ghamdi	2012	The effect of static electric fields on Drosophila behaviour.
Tirkel	2011	Effects of Millimetre Wave Exposure on Termite Behavior.
Swedberg	2011	Rfid helps scientists study honeybees' homing behavior.
Schick-Borken	2011	Schülerstudie zur Einwirkung von Wlan Strahlung auf die Entwicklung von Mehl...
Pinpathomrat	2011	Inhibition of Culex quinquefasciatus (Diptera: Culicidae) viability by nanosec...
Hausmann	2011	Auswirkung von Mobilfunkstrahlung auf Hautflügler (Hymenoptera) und Käfer (...
Panagopoulos	2010	The identification of an intensity window on the bioeffects of mobile telephony...
Panagopoulos	2010	The effect of exposure duration on the biological activity of mobile telephony...
Panagopoulos	2008	Mobile telephony radiation effects on living organisms.
Kimmel	2007	Effects of electromagnetic exposition on the behavior of the honeybee (Apis m...
Harst	2007	Can Electromagnetic Exposure Cause a Change in Behaviour? Studying Possible N...
Pan	2004	Apparent biological effect of strong magnetic field on mosquito egg hatching...
Webber	1946	High-frequency electric fields as lethal agents for insects.
Headlee	1931	The differential between the effect of radio waves on insects and on plants...

Table 4: List of excluded studies (poor quality, irrelevant or double publications)

Author	Year	Title
Wan	2019	Geomagnetic field absence reduces adult body weight of a migratory insect by ...
Landler	2018	Cryptochrome: The magnetosensor with a sinister side?
Kong	2018	In-vivo biomagnetic characterisation of the American cockroach
Zhang	2017	Molecular Mechanisms for Electromagnetic Field Biosensing
Nordmann	2017	Unsolved mysteries: Magnetoreception – A sense without a receptor
Lambinet	2017	Honey bees possess a polarity-sensitive magnetoreceptor
Krylov	2017	Biological effects related to geomagnetic activity and possible mechanisms
Clites	2017	Identifying cellular and molecular mechanisms for magnetosensation
Clarke	2017	The bee, the flower, and the electric field: electric ecology and aerial elec...
Wu	2016	Magnetoreception Regulates Male Courtship Activity in Drosophila
Sutton	2016	Mechanosensory hairs in bumble bees (Bombus terrestris) detect weak electric ...
Qin	2016	A magnetic protein biocompass
Liang	2016	Magnetic sensing through the abdomen of the honey bee
Bae	2016	Positive geotactic behaviors induced by geomagnetic field in Drosophila
Wan	2015	Cryptochromes and Hormone Signal Transduction under Near-Zero Magnetic Fields...
Spasic	2015	Effects of the static and ELF magnetic fields on the neuronal population acti...
Shaw	2015	Magnetic particle-mediated magnetoreception
Ferrari	2015	Severe Honey Bee (Apis mellifera) Losses Correlate with Geomagnetic and Proto...
Wan	2014	Bio-effects of near-zero magnetic fields on the growth, development and repro...
Solovyov	2014	Cryptochrome and Magnetic Sensing
Guerra	2014	A magnetic compass aids monarch butterfly migration
Greggers	2013	Reception and learning of electric fields in bees
Clarke	2013	Detection and learning of floral electric fields by bumblebees
Begall	2013	Magnetic alignment in mammals and other animals
Winklhofer	2010	Magnetoreception
Wajnberg	2010	Magnetoreception in eusocial insects: an update
Oliveira	2010	Ant antennae: are they sites for magnetoreception?
Liedvogel	2010	Cryptochromes—a potential magnetoreceptor: what do we know and what do we w...
Yoshii	2009	Cryptochrome mediates light-dependent magnetosensitivity of Drosophila's circ...
Vacha	2009	Radio frequency magnetic fields disrupt magnetoreception in American cockroac...
Knight	2009	Cockroaches use radical pair mechanism to detect magnetism
Gegear	2008	Cryptochrome mediates light-dependent magnetosensitivity in Drosophila
Hsu	2007	Magnetoreception System in Honeybees (Apis mellifera)
Kirschvink	1997	Measurement of the threshold sensitivity of honeybees to weak, extremely low-...
Kirschvink	1996	Microwave absorption by magnetite
Frier	1996	Magnetic compass cues and visual pattern learning in honeybees
Hsu	1994	Magnetoreception in honeybees
Kirschvink	1991	Is geomagnetic sensitivity real? Replication of the Walker-Bitterman magnetic...
Walker	1989	Short Cummunication: Honeybees can be Trained to Respond to very Small Change...
Kirschvink	1981	The horizontal magnetic dance of the honeybee is compatible with a single-dom...
Gould	1980	Orientation of demagnetized bees
Gould	1978	Bees have magnetic remanence
Becker	1964	Reaktion von Insekten auf Magnetfelder, elektrische Felder und atmospherics
Schneider	1963	Systematische Variationen in der elektrischen, magnetischen und geographisch-...

Table 5: List of magnetic sense studies

FORUM MEDIZIN
Verlagsgesellschaft mbH

Tree damage caused by mobile phone base stations

An observation guide

By Helmut Breunig

Photos and RF measurements by Cornelia Waldmann-Selsam
Additional photos by Alfonso Balmori, Helmut Breunig, Örjan Hallberg, Volker Schorpp and Monika Schuberth-Brehm

March 2017

Why an observation guide?

Since the rollout of GSM mobile phone networks in the 1990s, scientists have criticized that the effects of radiofrequency or RF radiation (microwaves) on living organisms and the environment have not been sufficiently studied. In the setting of exposure limits for mobile phone base stations, RF radiation effects on plants have not been considered. In view of the explosive proliferation of the diverse wireless communication technologies across the entire environment and almost all areas of life, this represents an uncovered risk. This is why available studies and documentations on how RF radiation affects and damages trees engage our particular attention. They contain important evidence that justifies the urgent call for further thorough investigations. No research, however, has been initiated by the established science community and official radiation protection agencies to date.

The observation guide presented here is meant to encourage independent observations and documentations of trees and any damage they may sustain through exposure to radiofrequency radiation. It builds on the work and foundational findings of BERNATZKY, BALMORI, SCHORPP, HALLBERG, WALDMANN-SELSAM, and others.

In light of the increasingly visible consequences of climate change, the continuation of their work is an important step toward forming an independent judgment. This is all the more important since the observations described here will take extra efforts – especially in view of the massive climatic changes – to ensure that this issue is not denied the scientific recognition by the established research community it deserves.

This call for research is based on the reasonable suspicion suggesting an association between health symptoms in humans and damage in trees at locations in the line of sight of mobile phone base stations, which was pointed out by EGER and WALDMANN-SELSAM.

Why observe trees?

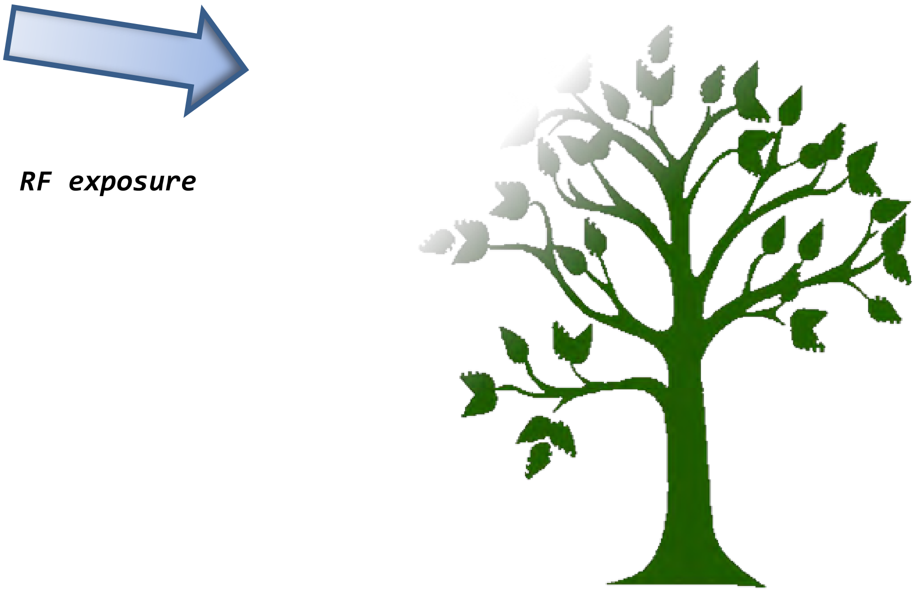
As stationary and perennial living organisms, trees are well suited for studying the question as to whether radiofrequency emissions from phone masts may cause damage in plants. The observation guide is designed to help *observers recognize visible crown damage in free-standing trees exposed to radiofrequency radiation. The photos show typical damage patterns and thus can sharpen the observer's eye. Based on this observation guide, scientists and laypersons alike can systematically observe trees in their immediate living environment or in other regions when they travel.*

In urban areas, it is not uncommon that trees are located within the exposure area of different phone masts from multiple directions. In crowns of free-standing (solitary) trees, which are exposed to RF radiation from one side only, it is rather easy to show the signs that may indicate a possible exposure to RF radiation. Advanced stages of sustained damage are best suited for describing the typical characteristics. This is also how the examples for this observation guide have been selected. The majority of the examples are deciduous trees.

Based on the analysis of advanced patterns of damage and their development, general characteristics for the crown damage in exposure areas of RF transmitters can be derived, which, in turn, can help recognize damage in trees with a less advanced stage and under conditions where the exposure occurs from multiple directions.

Observation of one-sided crown damage in trees in the line of sight of mobile phone base stations

Visual signs include irregular leaf coloration, leaf wilt, leaf loss, temporal and spatial irregularities in the seasonal leaf color change and leaf loss, fewer shoots, greatly elongated shoots with foliage at the tip and bare patches farther down the shoot, changes in branching patterns, and dead limbs and branches. The damage is most prominent at the edge on one side of the crown. This area is referred to as the starting point of damage. From there, the damage decreases in its intensity toward the opposite side of the crown that may be less affected or not at all. The crown volume, which is damaged within this geometric space, is referred to as the damage area. It will continue to develop further over the course of several growing seasons.



The geometry of the crown damage points to an abiotic, atmospheric, exposure-related factor of influence.

If, in the case of a free-standing tree, the starting point of damage is in line of sight of an RF transmitter, it is reasonable to suspect that the damage pattern may be caused by the exposure to the RF radiation of the RF transmitter.

The RF measurements, as stated for selected photos below, were taken by WALDMANN-SELSAM, using the EMF-broadband analyzer HF59B (27–3300 MHz) with the horizontal-isotrope antenna UBB27_G3 (Gigahertz Solutions), in some cases in conjunction with a 6 m (ca. 20 ft) long telescopic rod. It is not the intention of the RF measurements to provide a detailed RF radiation exposure analysis for a given location. This basic measurement method, however, is sufficient in demonstrating that a given crown may only be exposed from one side, that the worst damage occurs at the side of the tree with the highest RF exposure levels facing the RF transmitter, and that the damage patterns described in the observation guide occur at exposure levels well below currently valid exposure limits.

The presented agreement of the measurement results with the visual observations makes existing associations more transparent and thus demonstrates that the observation method described here is well suited to

generate meaningful documentations, even without measuring the actual RF exposure levels.
In conjunction with heat, cold, drought, soil composition, soil compaction and sealing, salting, air pollutants, soil contaminants, and pests, different types of crown damage can occur. By observing negative effects on the foliage, spatial orientation and crown damage development over time described here, specific characteristics of the exposure pattern due to radiofrequency radiation become apparent.

Linden tree, July 2015
Well-developed tree crown in the city
No RF transmitter in the line of sight

Norway maple tree, August 2012
Badly damaged tree crown on the side facing an RF transmitter

At both locations, soil sealing is a concomitant adverse factor. The difference in the crown pattern, therefore, is most likely not a result of soil sealing.

At the location of the red oak tree shown here, none of the known stress factors are obvious. Still, the crown is damaged in a way that corresponds to the above-shown graph. The tree is in the line of sight of a nearby mobile phone base station.

Exposure ->

Red oak tree,
August 2013

The direction of the RF emission source and the location of the starting point of damage on the side of the tree facing the mobile phone base station coincide with each other.

Red oak tree, August 2013

Red oak tree, August 2015

Section of red oak tree, August 2013

Section of red oak tree, August 2015

The damage area spreads across the crown over the course of the coming years. At the individual branches, the sight is similar to drought damage. The spatial and temporal development of the damage area as a whole, however, is not typical for drought damage that occurs as a result of a lack of water at the roots.

The loss and discoloration of the leaves is most prominent where the tree faces the RF transmitter. The spread of the damage area follows a pattern independent of the branch architecture of the tree.
The location of the damage area is independent of the natural environment and the sky direction.

Tree damage in the line of sight of RF transmitters has already been extensively documented. The damage in these documentations shows diverse patterns and developmental stages (see Documentations).

The photos presented here place a special emphasis on the unique damage pattern due to RF radiation exposure from one side.

Some of the photos also show the location of the tree crown in relation to the associated RF transmitter within sight. If the RF transmitter is not shown, the distance to the RF transmitter is given.

Examples of different spruce trees show that similar damage patterns can also be observed in conifers to various degrees.

Exposure from the right side,
260 m (ca. 850 ft)

Spruce, October 2010

Exposure from the right side,
190 m (ca. 620 ft)

Spruce, March 2012

Exposure from the left side,
200 m (ca. 660 ft)

Spruce, June 2003

Exposure from the left side,
310 m (ca. 1000 ft)

Spruce, October 2008

The damage decreases on the side of the crown facing away from the RF transmitter (damage gradient), which can be explained by the attenuation effect of the foliage. Due to the absorption and scattering of the RF radiation along its path through the foliage, the power flux density of the RF radiation decreases (used measurement unit: microwatt per square meter = $\mu W/m^2$). Comparison measurements between the side of the tree crown facing the RF transmitter and the side facing away from it confirm this.

Exposure from upper left ->

Norway maple tree, June 2015

Measurement:	Side facing the RF transmitter:	Opposite side:
14 July 2015	2,100 $\mu W/m^2$	290 $\mu W/m^2$

The agreement between the spatial orientation of the damage gradient and the gradient of the RF measurements suggests that the damage is associated with the RF radiation exposure from the RF transmitter.

According to the Twenty-sixth Ordinance Implementing the Federal Immission Control Act, *German exposure limits for mobile phone base stations range from 4,500,000 to 10,000,000 $\mu W/m^2$, depending on the respective mobile phone network.*

May 2013

July 2016

The damage increases over the years and spreads from the direction of the RF transmitter across the crown. No regeneration can be seen. This is a sign of chronic exposure to a damaging factor. The RF exposure from the mobile phone base station within sight began between 2006 and 2008.

Observing the development of the damage over the long term provides insight into the unique characteristics of the damage.

May 2013

June 2014

June 2015

The tree is located at a strip of greenery, running in a north-south direction. To the east (foreground), the root area is sealed by a traffic area. The damage area points toward south where the RF transmitter is located. Despite the less than favorable climate conditions at this side, the crown on the north side has expanded.

At the upper left – where the RF radiation hits the crown – the dieback at the edge is the most severe.

The annual increase in leaf loss most likely can be traced back to an impairment of the buds in the year before. The resulting decreased level of shoots for leaves and branches causes the closed crown to open at those points, whereby one quarter of the crown outline starts breaking up.

With increasing leaf dieback, the attenuation effect of the foliage decreases, starting at the edge of the crown.

Inside the crown, there are naturally less leaves because of shadow

July 2016

effects. This is why – after the more dense foliage at the crown edge has receded – it is easier for the RF radiation to cross over to the other side of the crown. As a result of the increasing RF exposure level, the crown then also starts to lose leaves in this opposite area and thus the tree’s inherent attenuation also decreases. In this way, the damage area spreads from the inside to the outside of the side of the crown edge facing away from the RF transmitter.

April 2015
In bloom

The more the branches and buds are protected by the attenuation inherent to the crown, the higher the density of the flowering shoots will be.

Due to the crown dieback at the side facing the RF transmitter, more light reached the inside of the crown, resulting in shorter shoots with buds on branches closer to the trunk compared to the right side.

February 2017

After renewal pruning

Because the right side of the crown had denser foliage, the inside of the crown experienced more shade. Consequently, the shoots are more elongated, trying to reach the edge with more light exposure, resulting in less branching along the way. After pruning, the crown then has less buds for renewal at this side.

The renewal of pruned crowns, which are exposed to radiofrequency radiation, should be included in observations.

If trees, which are lined up in a row, show all damage on the same side, this may also be a sign of RF radiation causing damage to the crowns.

June 2016

<-Exposure from upper right

Distance 730 m (ca. 2400 ft)

July 2008

Month not known 2010

Sycamore maple tree

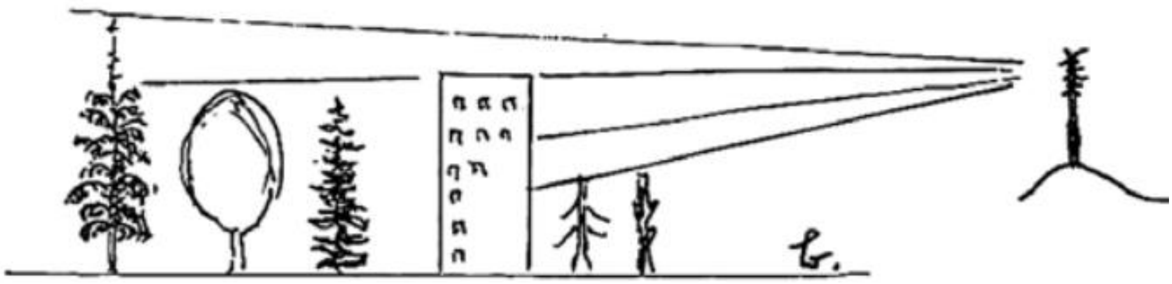
Starting point of damage and damage gradient coincide with the direction of the RF emission source. The damage increases over the years.

If the RF radiation exposure comes from above, the damage is particularly prominent at the top of the tree.

Gleditsia tree
September 2011

Beech trees,
June 2009

Crowns can show damage when a tree stands in front of a building that faces an RF transmitter and also when a tree stands behind such a building if the treetop reaches above the rooftop.



(Figure taken from BERNATZKY 1994)

The following example shows a situation similar to the tree in the above graphic in the upper left.

Exposure from the right
above the rooftop

Cherry tree, September 2012

Distance to multiple RF transmitters
150-500 m (ca. 500-1600 ft)

June 2015

Trees of the same species planted along a roadside are especially well suited for comparing RF radiation exposure patterns. The trees in the radio shadow of the building show a different pattern compared to those exposed directly to RF radiation.

RF radiation exposure ->

Tree-lined road
Turkish hazel trees,

June 2008

Tree-lined road
Turkish hazel trees,

August 2013

The Turkish hazel trees on the left are mostly in the radio shadow of the buildings. The line of trees on the right side of the road are more exposed; both directly and indirectly (reflection from buildings). The bare shoots and dead twig tips of the transparent crowns of the trees on the right side of the road reveal the level of stress caused by the RF radiation.

The shielding effect of buildings can be demonstrated with measurements of the RF exposure levels. In the radio shadow, the tree crowns are only marginally affected.

Distance to RF transmitter 130 m (ca. 430 ft)

Exposure and view from south — *Maple tree*, *Hornbeam tree*

View from north — *Hornbeam tree*, *Maple tree*

October 2009

In spring, dead branches were removed

July 2012

8,000

200

30

μW/m²

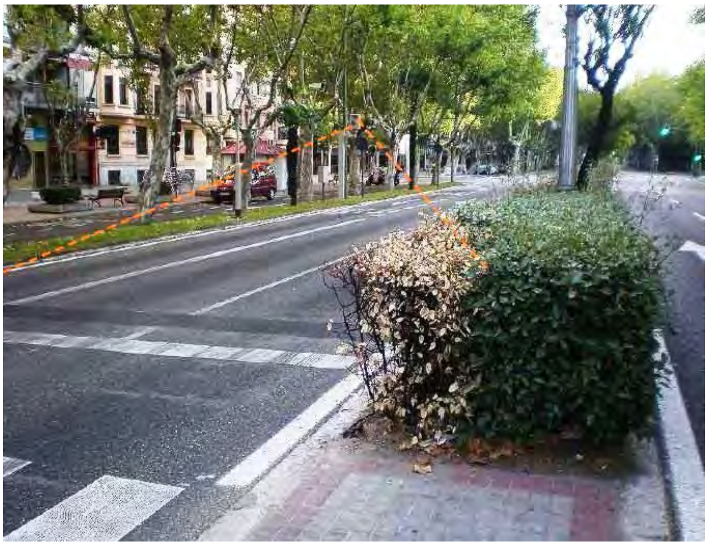
RF measurements, May 2012

Maple tree *Hornbeam tree*

October 2014

Hornbeam tree *Maple tree*

The upper part of the crown that reaches above the bridge structure is exposed by an RF transmitter. Despite excellent light conditions and a good water supply, leaf loss occurs at this location. The lower part of the foliage is dense and healthy because it is protected by the bridge structure.



Microwave exposure from a traffic radar <-

Viburnum hedge in a strip of greenery

The damage area in the foliage of the hedge clearly delineates the focused exposure area of the radar.

A disparate fall coloration inside the crown with regard to its timing can be conspicuous. The one-sided discoloration of the foliage occurs on the side facing the RF transmitter.

RF exposure from the upper left ->

Distance to RF transmitter 60 m (ca. 200 ft)

Hornbeam tree, October 2010

At the edge facing the RF transmitter, the leaf loss and the coloration differences within the crown show the damage gradient from the starting point of damage to the damage area.

Ash trees naturally lose their leaves in fall without major discoloration. If the leaves of one tree start falling in different areas of the crown at different times, this can be the result of a one-sided RF exposure. This characteristic requires observing the tree over several years. Thus it would be possible to distinguish the damage from the acute effects of frost, which can be caused by cold air that blows in from the side.

Ash tree, October 2016

Tree site at a slope

<- Exposure from the right from RF transmitter a the same height, distance 500 m (ca. 1600 ft)

In winter, bare crowns of deciduous trees will reveal differences in their sides, if applicable, which would indicate an exposure to RF radiation.

RF exposure from the left from a distance of 320 m (ca. 1050 ft)

->

Sycamore maple tree, February 2017

The branching differs between the left and the right side.
On the side of the crown facing the RF transmitter, less branching of branches and shoots occurs. The closed crown starts opening from the left and above.

*At the side **facing the RF transmitter,** the closed crown starts opening and areas of dieback become visible as a result of less branching.*

*At the side of the crown **facing away from the RF transmitter,** branching is clearly much denser. The edge of the crown looks smoother and closed.*

Characteristics of damage to the foliage of free-standing trees in the case of one-sided radiofrequency exposure from mobile phone base stations over a longer period:

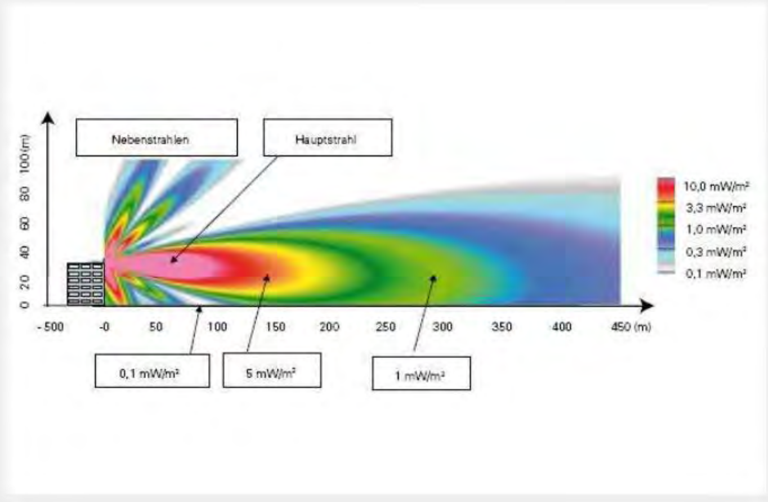
- ***The decrease in foliage starts at the edge of the crown (starting point of damage).***
- ***Over the following growing seasons, the process of receding foliage will spread from the starting point of damage across the crown to other areas (damage area).***
- ***The gradual spread of the damaged area follows the spatial pattern of decreasing attenuation provided by the foliage.***
- ***At all sites, the tree crown is in the line of sight of a RF transmitter.***
- ***This type of damage occurs at sites where conditions vary in their suitability for tree growth.***

The damage patterns described here, which are suspected of being caused by adverse effects of RF radiation, require observations over several years. It is possible then to follow the characteristic development of the damage area over time to distinguish it from the damaging effects of other factors.

You can sharpen your observational eye to detect the typical damage patterns by observing trees over longer periods that have mobile phone base stations installed nearby or have been newly planted next to RF transmitters. When older trees are cut or pruned, checking if the tree is in the line of sight of RF transmitters can be revealing.

Evaluation of observations

Conventional antennas of mobile phone base stations emit RF radiation either in all directions (omnidirectional antennas) or in a particular direction with main and side lobes, focused vertically and horizontally (directional or sector antennas). A sector antenna commonly covers a horizontal area of 120°.



The simulation shows how the transmit output of a sector antenna propagates through space. In addition to the main lobe, which covers the far-field area, there are also side lobes at certain angles.
Source: LfU

Haupstrahl = main lobe

Nebenstrahlen = side lobes

(Figure taken from Bayerisches Landesamt für Umwelt*)*

The incident RF radiation is reflected, scattered, and diffracted at buildings and the landscape. As a result, the spatial distribution and intensity of the RF electromagnetic field is rather inhomogeneous. In turn, the RF exposure levels at trees in the same location, which are standing in *the line of sight of an RF transmitter, can vary greatly. Even the area of the crown that sustains the highest exposure can be at different heights. For example, the pictures of the red oak tree (p. 5-6) clearly show how the opening up of the closed crown can occur midway up the crown.*

Both in general and in the vicinity of mobile phone base stations, damage to tree crowns can occur in different locations for various reasons.
If, in a line-of-sight exposure area of RF transmitters, there are trees with clear patterns of damage and trees with little or no obvious damage, the best practice approach in epidemiology (BRADFORD-HILL) does not allow for the conclusion that the existing damage could not have been caused by the exposure to the RF radiation from the RF transmitters as long as this has not been verified by an in-depth investigation of the matter.
Therefore, the exposure to RF radiation should always be considered by the environment and parks agencies when assessing damaged trees.

Typical city view with trees in the vicinity of mobile phone sites
July 2015

The linden trees to the left in the blind spot near the antennas (marked) don't seem to be adversely affected. Other trees in the background along the road and the newly planted tree in front of the building all are in the line of sight of the RF transmitters on the rooftop. Here we can recognize damage to the shape of the top of those trees and to the density of their foliage.

Due to the limited knowledge in this research area, it cannot be ruled out at this time that differences among trees in the line of sight of a given RF transmitter may also be traced back to characteristics of the tree species and their provenances.

The expectation that trees within the exposure area of a given mobile phone base station should respond in the same way is therefore unfounded as long as this matter has not been studied in depth.

Furthermore, crown damage can be caused by different factors that overlap with each other. In laboratory studies, it could be demonstrated that RF radiation is capable of triggering physiological stress responses in plants. This finding suggests that we should focus our observations on whether the damaging effect of a possible additional stress factor tends to be more prominent on the side of the crown exposed to RF radiation. For example, it should be noted if the point from which the damage spreads and the incidence and degree of infestations with e.g. fungi, viruses, worms, and insects are associated in any way with the side of the tree facing an RF transmitter.

The same basically also applies to other common natural and technical factors, which may only affect one side of the tree such as wind direction, solar exposure, traffic exhausts, road salt, root and trunk damage.

The initial stages of damage development caused by heat, drought due to a lack of water in the soil, root damage, damage to the water pathways in the tree, and limited frost damage may at first sight look like a crown damaged by the exposure to radiofrequency radiation.

The more the damage of the crown advances, as can be observed as the result of the chronic exposure to radiofrequency radiation over several growing seasons, the clearer the distinguishing characteristics become. "The damage follows a path along the direction of the RF radiation" (see the documentation by SCHORPP, 2007).

At any location without RF radiation exposure, it should be rather unlikely to find a damage pattern as shown here.

Maple tree, September 2006

SCHORPP points out that the inhomogeneous emissions of the antennas as well as the reflection, diffraction, and scattering effects at buildings may lead to well-defined, small-area differences in power density levels.
These types of crown dieback are new and only occur around built environments.
In this case, an explanation that only refers to known damaging factors does not cut it.

The above presentation regarding one-sided crown damage – describing the characteristics of temporal and spatial patterns in shape and color, while considering various site factors – demonstrates that no other damaging factor is known at this time that could regularly cause the above-described damage patterns in crowns of free-standing trees.

In this observation guide, the selection of damage patterns is limited to the ones presented for didactic reasons. There are many additional types and developmental stages of visible crown damage caused by radiofrequency radiation (see Documentations). We lack comprehensive documentations on the hazard assessment to date. To justify the lack of a systematic investigation into this type of crown damage with the notion that only a few such observations have been made so far bears the risk of overlooking a new threat to the environment and humanity.

In times of climate change, to what extent will efforts to maintain trees in urban areas for their balancing effect be challenged if we do not consider the consequences of chronic RF radiation exposure?

Tree crowns in a strip of greenery become damaged through the exposure to ***radiofrequency radiation***
July 2008

In an urban green space, healthy tree crowns in the radio shadow
August 2015

Scientific application of the observation method

Owing to the new and unique type of damage pattern, an in-depth investigation into its causes seems indicated and can be carried out with relatively little effort. The above-described observation method can serve as a guide for locating and assessing crown damage in trees. By applying the knowledge of the developmental characteristics of the above-described type of crown damage, it is possible to also include less advanced levels of damage.

For the study **Radiofrequency radiation injures trees around mobile phone base stations,** *60 trees with the above-described damage pattern were located in the cities of Bamberg and Hallstadt, some of which have been documented over the course of several years.*

The visual inspections at each location revealed that, in the case of one-sided crown damage, it was exclusively the damaged side facing an RF transmitter. The RF exposure level measurements on the damaged side were on average about 2,000 µW/m² and on the opposite side about 200 µW/m².

Another group of 30 trees was randomly selected. Thirteen trees of this group had crown damage. The visual inspections revealed that six of the trees had crown damage only on one side of the tree, which was facing an RF transmitter; five of the trees had damage on more than one side all of which were facing RF transmitters on the respective damaged sides. One tree (spruce) with a damaged top also was in the line of sight of an RF transmitter, as was another tree that had dead parts of the crown removed. The RF radiation exposure levels for the trees of this group were on average about 1,600 µW/m² on the side facing an RF transmitter and about 600 µW/m² on the opposite side.

The crown damage occurred regardless of different soil characteristics of the tree locations such as sealing, strips of greenery, gardens, parks, in the vicinity of water bodies, etc.

The RF radiation exposure levels for the 17 trees of the randomly selected group that were not in the line of sight of any RF transmitter ranged from about 8 to 50 µW/m², both on the side with the highest reading and the opposite side.

In addition, a third group of 30 trees was located in an area with lower RF background levels where the trees were not in the line of sight of any RF transmitter. In those areas, the RF radiation exposure levels ranged from 3 to 40 µW/m². The difference in the RF radiation exposure levels between the two sides of a given tree was negligibly small, max. 10 µW/m². All 30 tree crowns did not show any signs of damage.

At all locations of the 47 trees with no line-of-sight connection to an RF transmitter and an overall low RF background level, no crown impairments as described above were visible.

The assumption that the type of crown damage described in this guide is caused by the exposure to radiofrequency radiation proves to be justified because

- ***this particular crown damage occurs at exposed locations in the line of sight of mobile phone base stations, and***
- ***at unexposed locations outside the line-of-sight exposure areas of RF transmitters, however, this crown damage does not occur.***

Documentations *(selection)*

- *SCHORPP, V., http://www.puls-schlag.org/dr-volker-schorpp.htm*
  2007: Baumschäden durch chronische Hochfrequenz-Belastungen?
  (Tree damage from chronic radiofrequency radiation?)
  2011: Tree damage from chronic high frequency exposure, The effect of electromagnetic radiation on trees, First symposium February 18, 2011, Lecture, Baan, Netherlands
  http://www.puls-schlag.org/download/Schorpp-2011-02-18.pdf
- *WALDMANN-SELSAM, C., 2016: Trees in Bamberg*
  http://kompetenzinitiative.net/KIT/wp-content/uploads/2016/09/Trees-in-Bamberg-and-Hallstadt-Documentation-2006-2016.pdf

References *(with additional sources)*

BRADFORD-HILL, A., 1965: The Environment and Disease: Association or Causation? https://www.edwardtufte.com/tufte/hill

- *BERNATZKY, A., 1994: Baumkunde und Baumpflege (Dendrology and Tree care); Bernhard Thalacker Verlag Braunschweig*
- *BALMORI, A., 2004: ¿Pueden afectar las microondas pulsadas emitidas por las antenas de telefonía a los árboles y otros vegetales?* *http://tinyurl.com/j89d24w*
- *EGER, H., WALDMANN-SELSAM, C., 2013: Tree damages in the vicinity of mobile phone base stations* *http://kompetenzinitiative.net/KIT/wp-content/uploads/2016/06/Tree-damages-in-the-vicinity-of-mobile-phone-base-stations.pdf*
- *Waldmann-Selsam, C., Balmori-de la Puente, A., Breunig, H., Balmori, A., 2016: Radiofrequency radiation injures trees around mobile phone base stations* *https://www.researchgate.net/publication/306435017_Radiofrequency_radiation_injures_trees_around_mobile_phone_base_stations*

Contact:

This private manuscript was written by Diplom-Forstwirt Helmut Breunig (Diplom degree in forestry).

You can download the Observation Guide at:

Competence Initiative for the Protection of Humanity, the Environment and Democracy e.V.

http://kompetenzinitiative.net/KIT/KIT/new-observation-guide-tree-damage/

German version: http://kompetenzinitiative.net/KIT/KIT/beobachtungsleitfaden-baumschaeden-durch-mobilfunkstrahlung/

If citing this work, please provide the author's name and the Internet link of the document.

If you would like to contact the author regarding the contents of the Observation Guide, please send an e-mail to

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Feedback and suggestions are always welcome. If you wish to send me photos, please contact me by e-mail before sending any photos.

The WASHINGTON
SPECTATOR

JANUARY / FEBRUARY 2022

VOL. 48, NO. 1 ISSN 0887-428X

washingtonspectator.org

Federal Court Instructs FCC to Review Electromagnetic Radiation Standards

By Barbara Koeppel

For 25 years—through five Democratic and Republican administrations—the Federal Communications Commission has refused to revise the regulations it set in 1996 that address what level of radiation from cell phones should be considered safe. Labeled radio-frequency radiation (RFR), these emissions are discharged from all wireless devices, Wi-Fi networks, and the thousands of towers stretched across the United States that transmit and receive the signals.

The FCC's power is promethean. It is the sole U.S. agency that determines the acceptable RFR exposure from wireless devices for people of all ages, wildlife, and the environment. And it insists its original 1996 limits are fine.

However, scientists who've reviewed hundreds of studies published over the last two decades claim the FCC ignores critical findings that show a "statistically significant" link between heavy cell phone use (10 or more years) and brain and thyroid tumors, especially on the side of the head where people hold their phones. Professional groups such as the American Academy of Pediatrics and the California Medical Association have asked the FCC to update its numbers.

The scientists and physicians worry that the FCC simply repeats the industry's line that all is well—which is particularly troubling since millions more people around the world are exposed each year. In the United States, for example, only 44 million people had cell phones in 1996; today, the number has soared to about 300 million, and that doesn't include the tablets, watches, and other wireless products that increase RFR exposure exponentially.

Photo by BearFotos

ALSO INSIDE:

Thus, in 2019, the Environmental Health Trust (EHT), Consumers for Safe Cell Phones, Children's Health Defense, and 11 other petitioners sued the FCC. They argued that although the U.S. Government Accountability Office told the FCC in 2013 to review its 1996 limits in light of new research, six years later, the FCC was still repeating its all-is-safe mantra. In a 2019 press release, the FCC said that "after a thorough review of the record, we find it appropriate to maintain the existing radiofrequency limits, which are among the most stringent in the world for cell phones."

At the least, this assurance is doubtful. The lawsuit against the FCC argues precisely the opposite: that the Commission has *not* reviewed "the record." Also, researchers point out that countries such as Italy, Switzerland, France, Israel, China, India, and Russia have more stringent limits than the United States regarding the use of Wi-Fi in schools and day care centers, and on acceptable levels of radiation emissions from cell towers. In addition, some have banned all cell phone ads pitched to children.

The lawsuit notes that the FCC even ignored the landmark 10-year, $30 million National Toxicology Program study carried out under the National Institutes of Health—which produced unequivocal results in 2019. Having exposed rats and mice to cell phone radiation for two years, the NTP researchers reported "clear evidence of cancer in the male rats' heart cells, some evidence of increased brain gliomas (brain cancer), and adrenal gland tumors, DNA damage in the brains of male and female rats and mice, and lower birth weights of female rats' offspring."

Two years after the suit was filed, the U.S. Court of Appeals of the D.C. Circuit ruled in August 2021 that the FCC had to reexamine the research to determine if its regulations should be updated. Further, the court called the commission's behavior "arbitrary and capricious," since it had ignored evidence of the harm to children's brains (which are not fully developed) and to

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The Washington Spectator (ISSN 0887-428X) is published bi-monthly by the Public Concern Foundation Inc, 105 Hudson Street, Suite 407, New York, NY 10013. © 2022 in the U.S.

male and female reproductive systems. It also ruled that because the FCC never produced regulations about radiofrequency radiation's effects on wildlife, it had "completely failed" to address the evidence of potential environmental harm.

However, the court did not set a date for the FCC to comply—which meant the commission could retain its old regulations indefinitely. Also, the court did not address the issue of whether RFR exposures cause cancer; instead it said the FCC had passed the "minimum legal requirement" to assure it had evaluated the research on cancer and radiation exposure. Thus, scientists are concerned that the FCC will again find ways to defer serious examination of the voluminous literature on the subject.

How could this be, given the NTP findings and other research? To bolster its no-cancer claims, the FCC points to a letter the U.S. Food and Drug Administration wrote the commission, which claimed the NTP results weren't relevant to humans since the study was done on rats and mice (although 10 years earlier, the FDA itself had approved the animal study). Dr. Joel Moskowitz, director of the Center for Family and Community Health at the University of California, Berkeley and a leading authority on radiofrequency radiation, says, "The FDA wrote a biased review of the research regarding cancer risk from cell phone radiation."

[Dr. Joel Moskowitz:] "The FDA wrote a biased review of the research regarding cancer risk from cell phone radiation."

Also, the FCC cited reports from organizations that have undeclared conflicts of interest (ties to the wireless industry), which contest the cancer links. Dr. Ronald Melnick, the lead designer of the NTP study, has published two articles stating that the results from these groups' reports were "unfounded."

In fact, the FCC failed on several fronts. Besides ignoring the NTP study, the commission dismissed the American Academy of Pediatrics' request for regulations that reflect the special effects RFR have on children and pregnant women. It never explained why it ignored research that showed children's brains absorb higher levels of the radiation. Instead, it has insisted for 20-plus years that RFR is only harmful if it overheats the human body by at least one degree centigrade. This is a red herring, since wireless devices don't emit the kind of radiation that produces higher temperatures. Also, the FCC didn't consider the effects of long-term exposures.

Many researchers insist these links have been proven. As noted in an earlier article in this journal ("Wireless Hazards," *Washington Spectator*, December 2020), studies over the past 20 years have found strong evidence of brain tumors and leaks in the blood-brain barrier, acoustic neuromas (tumors on the nerves leading from the inner ear to the brain), thyroid tumors, and cognitive impairment. They also showed a link to male infertility: when men carried phones in their pants' pockets, their sperm were weakened and reduced. Also, physicians and scientists found that some individuals are particularly sensitive to RFR radiation, which can cause tinnitus, vertigo, headaches, fatigue, and loss of memory. Early this month, some experts studying the U.S. diplomats' and CIA agents' "Havana Syndrome" symptoms suggested they could be related to radiofrequency radiation.

The latest evidence

Theodora Scarato, the executive director of the Environmental Health Trust, says that since the FCC had not yet responded to the court's August ruling by last November, the EHT asked the commission to consider additional studies that were completed after 2019, when the suit was filed.

For example, in late 2019, the European Parliamentary Research Service said that electromagnetic fields (EMFs) emitted by 2G, 3G, and 4G cell phones (which operate at 450 to 6,000 megahertz) are "probably carcinogenic for humans," particularly in causing gliomas, acoustic neuromas, and meningiomas (slow-growing, mostly nonmalignant brain tumors).

In 2020, Yoon-Jung Choi and Joel Moskowitz (the lead authors) and three other scientists reviewed 46 "case-controlled studies" and published their findings in "Cellular Phone Use and Risk of Tumors: Systematic Review and Meta-Analysis," in the November *International Journal of Environmental Research and Public Health*. Moskowitz says, "This study updated our earlier analysis published in 2009." Evidence from the new study, he says, links cell phone use to increased tumor risk. The researchers' numbers are compelling: 1,000 or more hours of cell phone use, or about 17 minutes a day over 10 years, was associated with a statistically significant 60 percent increase in brain tumor risk.

Also in 2020, Devra Davis (an epidemiologist and co-founder of the Environmental Health Trust), Aaron Pilarcik (a biophysicist at the Worcester Polytechnic Institute), and Anthony Miller (an epidemiologist specializing in cancer etiology and an adviser to the World Health Organization) reviewed data on colon and rectal cancer from the U.S. Centers for Disease Control, the U.S. SEER Program at the National Cancer Institute, and the Iranian National Cancer Registry. They found that the colon cancer risk for adults born in the 1990s had doubled and the rectal cancer risk had increased fourfold by the time they were 24 years old—when compared to those born 60 years ago. They hypothesized that cell phone radiation could play a role in the increased risk and recommended the FCC set limits to reduce the exposure. Their study, "Increased Generational Risk of Colon and Rectal Cancer in Recent Birth Cohorts Under Age 40—the Hypothetical Role of Radiofrequency Radiation from Cell Phones," was published in the *Annals of Gastroenterology and Digestive Disorders.*

In 2020, Henry Lai (a retired University of Washington scientist) reviewed the research on genetic effects and found that exposure to RFR can break DNA strands and affect the central nervous system. The review, "Genetic Effects of Non-Ionizing Electromagnetic Fields" was published in the December 2020 issue of *Electromagnetic Biology and Medicine.*

In 2021, Henry Lai, with Albert Manville (a biologist formerly at the U.S. Fish and Wildlife Service) and Blake Levitt (an environmental journalist), studied the effects of cell phone towers in various countries, comparing data from the 1980s to the present. They found that the toxic effects of EMFs on cells and genes had altered "the wildlife's orientation and migration patterns, their ability to find food, mate, reproduce, build nests and dens, and maintain and defend their territory." Yet the FCC has still set no standards for long-term, low-level EMF exposure on wildlife. The scientists' three-part research was published in *Reviews on Environmental Health,* "Effects of Non-Ionizing Electromagnetic Fields (EMF) on Flora and Fauna."

Also in 2021, the journal *Andrologia* published a study by Iranian scientists who found DNA fragmentation in sperm and recommended that men keep cell phones "away from the pelvis as much as possible."

Further, from 2015 to the present, the French government has tested the radiation from cell phones when people hold them next to their bodies. Their findings are dramatic: They reported exposures to RFR up to 11 times higher than those approved in FCC guidelines. Thus, the government passed a ministerial order in 2019 urging the public to limit children's cell phone use and "keep the phones away from the belly of pregnant women and the lower abdomen of adolescents."

Moreover, the National Institutes of Health and the American Cancer Society funded a study in 2019 and 2020 at Yale University that found increased thyroid cancer among heavy cell phone users.

The accompanying table enumerates many of the ways that doctors and vigilant public jurisdictions have identified to help people reduce the health risks that could be associated with exposure to RFR and cell phone radiation emissions.

The EHT's Scarato reminds readers concerned about RFR emissions exposure to "contact their senators and representatives to raise the issues with the committees." In the Senate, the Committee on Commerce, Science, and Transportation, along with its Subcommittee on Communications, Media, and Broadband oversees the FCC. In the House, the FCC reports to the Energy and Commerce Committee and its Communications and Technology Subcommittee. Public pressure on the members of these committees will help to prod the FCC to review the research and respond to the ruling of the Court of Appeals. ■

Barbara Koeppel is a Washington, D.C.-based investigative reporter who covers social, economic, political, and foreign policy issues.

PROTECT YOURSELF FROM WIRELESS RADIATION

The California Department of Public Health recommends these precautions:

- Use headsets—not ear buds—but remove them when not talking, since even headsets release small amounts of radiation when not in use.
- Text instead of talk.
- Carry phones away from your body in backpacks, tote bags, handbags, and briefcases.
- Keep phones away from your head when streaming.
- Download movies instead of streaming them.
- Don't use cell phones when reception is poor and they show just one or two bars—in subways, cars, basements, or rural areas. Under such circumstances cell phones often need vastly more energy to communicate with cell towers and other phones, and radiation levels intensify.
- Men should not carry phones in pants' pockets. Cleveland Clinic Center for Male Fertility researchers found this weakened and reduced sperm, which can cause infertility.

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PROTECT YOURSELF FROM WIRELESS RADIATION

Countries must adopt tough laws

- Belgium and France banned companies from designing phones to appeal to children.
- Israel and Cyprus banned Wi-Fi in day care centers and kindergartens, requiring connections be wired. Israel limited Wi-Fi use in first and second grades to three hours a week.
- France ordered cities to map the locations of antennae, measure their radiation levels, and tell the public. Also, it banned ads showing people holding phones next to their heads and ordered companies to list phones' exposure levels. If they don't, they can be fined up to 75,000 euros.
- India ordered companies to remove towers located near hospitals and schools.
- Israel ordered companies to list phones' radiation levels.
- Geneva (Switzerland) placed a moratorium on the rollout of 5G.

Scientists also recommend these steps:

- Use corded landlines at home, but put satellite or cordless handsets on speakerphone, since they emit even more radiation than cell phones.
- Push for laws to protect children.
- Get states to create expert commissions to study radiation emissions' effects. New Hampshire's commission recommended that towers and antennae be placed farther from schools and homes.

birds

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Electromagnetic Pollution as a Possible Explanation for the Decline of House Sparrows in Interaction with Other Factors

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Simple Summary: In recent decades, there has been a decline of the house sparrow (*Passer domesticus*), mainly in European cities, and several hypotheses have been proposed. The objective of this article is to delve into the reasons why an increase in electromagnetic radiation especially in cities, may be intervening in some way. Previous studies indicated that house sparrows were significantly negatively associated with increasing electromagnetic radiation and sparrows disappeared from areas most polluted. Electromagnetic radiation is the most plausible factor and is the only one that affects the other hypotheses proposed so far. Additionally, the recent sparrow decline matches the deployment of mobile telephony networks. For these reasons, electromagnetic radiation is not only a plausible but a probable hypothesis that must be seriously considered, probably in synergy with the other factors previously proposed.

Abstract: In recent decades, there has been a decline of the House Sparrow (*Passer domesticus*), mainly in European cities, and several hypotheses have been proposed that attempt to determine the causes of this rapid decline. Previous studies indicated that house sparrows were significantly negatively associated with increasing electromagnetic radiation and sparrows disappeared from areas most polluted. In addition, there are many studies on the impact of radiation on other bird and non-bird species, as well as numerous laboratory studies that demonstrated detrimental effects at electric field strength levels that can be found in cities today. Electromagnetic radiation is the most plausible factor for multiple reasons, including that this is the only one that affects the other hypotheses proposed so far. It is a type of pollution that affects productivity, fertility, decreases insects (chicken feed), causes loss of habitat, decreases immunity and can promote disease. Additionally, the recent sparrow decline matches the deployment of mobile telephony networks. Further, there are known mechanisms of action for non-thermal effects of electromagnetic radiation that may affect sparrows causing their decline. Thus, electromagnetic radiation must be seriously considered as a factor for house sparrows' decline, probably in synergy with the other factors previously proposed.

Keywords: immunity; food; *Passer domesticus*; phone masts; productivity

Citation: Balmori, A. Electromagnetic Pollution as a Possible Explanation for the Decline of House Sparrows in Interaction with Other Factors. *Birds* **2021**, *2*, 329–337. https://doi.org/10.3390/birds2030024

Academic Editor: Jukka Jokimäki

Received: 23 July 2021
Accepted: 17 September 2021
Published: 21 September 2021

1. Introduction

The House Sparrow (*Passer domesticus*) is a bird species that lives in urban or suburban habitats and has spread from its original areas in Eurasia to a large number of cities around the world [1]. In recent decades, there has been a decline of house sparrows in several European cities [2–4]. In the United Kingdom, a 71% decline from 1994–2002 occurred in London [5], and urban bird populations in southeast England appear to be declining more rapidly than suburban or rural populations [6]. The house sparrow has been added to the Red List of UK endangered species [7].

Outside of the United Kingdom, the decline of house sparrow populations appears as a global and widespread phenomenon throughout its native range in Europe [4]. In several European cities, such as Brussels, Ghent and Antwerp, many populations of sparrows have disappeared [7,8]; similar declines have been reported in Dublin [9]. A study on the abundance of house sparrows between September 1998 and November 2008, shows that the species has experienced a steep decline of about 70% in urban parks in Valencia (Spain), reflecting a declining population trend at the whole city scale [10]. In Hungary, the population of house sparrows has suffered a moderate declining trend for ten years [11]. Jokimäki et al. [12] studied population trends of the house sparrow and the Eurasian Tree Sparrow in Europe, and in more detail in Finland. The decrease of the house sparrow was quite clear in many European countries. The wintering populations of the house sparrow have decreased, whereas the Eurasian Tree Sparrows have both expanded their wintering range and increased their population size in Finland. The house sparrow has suffered from decreased winter feeding activities and increased human population size within human settlements in Finland.

The most complete and recent field study was conducted covering the urban diversity of Paris, analysing fine-scale habitat characteristics of house sparrow population sizes and trends, using a fifteen-year census (2003–2017) in nearly 200 census sites [4]. This study documented a dramatic decline (−89%) of the species over the study period, which was sharpest at sites with the highest numbers of house sparrows at the beginning of the study period. However, a study a few years previously mentioned that Paris was one of the few cities where house sparrow populations were preserved [3].

The decline of sparrows is also occurring outside of Europe. In India, the number of house sparrows has decreased dramatically in several parts of the country [13,14]. These worldwide declines are worrying, as house sparrows usually live in cities and suburban areas and are an important bioindicator of the health status of urban ecosystems, as an urban sentinel species [4].

Despite having carried out many studies to explain this, there is no solid theory concerning the underlying causes to solve the enigma, but several hypotheses have been proposed so far [3,7,15,16]. The objective of this article is to delve into the reasons why we consider there are strong arguments that the increase in electromagnetic radiation around the world and especially in cities may be intervening in some way, in combination with other proposed factors, in this house sparrow decline.

2. Hypotheses Raised to Explain the House Sparrow Decline

The most important explanatory hypotheses that have been raised so far are the following: lack of food in urban areas affecting both nestlings and adults, particularly insects, which adults feed to nestlings; cleaner streets resulting in reduced foraging opportunities; competition for food from other urban species; increased predation by domestic cats; an increase in predator pressure due to a possible recovery of urban Eurasian Sparrowhawk (*Accipiter nisus*) populations; loss of nesting sites as newly built houses often lack suitable nesting cavities; increased use of pesticides in parks and gardens, pollution, disease transmission, and reduction of colony size below some critical value, resulting in the disappearance of the colony as a breeding unit (the Allee effect) [6,7,11,17]. For many authors, this decline may be attributed to several interactive and cumulative effects [2].

Interestingly, in the most recent, broad and in-depth study carried out in Paris [4], house sparrows do not actually lack nesting sites in the urban areas. Furthermore, house sparrows declined at all sites and the local temporal trends in abundance were independent of habitat characteristics; even areas with extended green spaces did not provide sufficient quality to secure the maintenance of large populations. On the other hand, in Paris, Eurasian Sparrowhawk first bred in 2008, when house sparrows were already declining, and this cannot explain the decline of the species. The authors studied the evolution of 18 air pollutants in Paris over the study period and related these to house sparrow abundances and found that the highest numbers were counted at the beginning of the period, when air pollution was maximal, and air quality did not deteriorate during the fifteen-year study. They concluded that air pollution was not responsible for the observed decline, neither were weather fluctuations. Finally, the authors explained that their study did not assess the potential influence of other urban-specific disturbances that were proposed as proximate causes of the decline of urban house sparrows, such as the potential role of increasing noise, light and/or electromagnetic pollution, not assessing the influence of increasing domestic cat abundance (the other major predator of sparrows), neither the increasing inter-specific competition with other urban exploiters, nor the existence of diseases and parasites [4].

Another recent study showed that avian malaria (*Plasmodium relictum*) infection is found at a higher prevalence in sparrows in London and may be a factor contributing to the declining trend of this species [17]. On the other hand, pollution (air quality) may cause negative physiological effects, such as increased oxidative stress, and negatively affect the reproductive output through decreased chick body mass [2].

3. Electromagnetic Radiation as a Likely Factor

Four studies have been published on the possible effects of electromagnetic radiation on sparrows, two in Europe and two in India. The main characteristics, alternative hypotheses and results of these studies are shown in the Table 1.

A possible effect of long-term exposure to low-intensity electromagnetic radiation from mobile phone (GSM) base stations, on the number of house sparrows during the breeding season, was investigated in Flanders, Belgium [18]. The study was carried out by sampling 150-point locations within six areas to examine small-scale geographic variation in the number of house sparrow males, and the strength of electromagnetic radiation from base stations. Spatial variation in the number of house sparrow males was negative and highly significantly related to the strength of the electric fields from both the 900 and 1800 MHz frequency bands and the sum of both. The negative relationship was highly similar within each of the six study areas, despite the differences among the areas in both the number of birds and radiation levels. Thus, this study showed that the number of sparrows correlated with the electromagnetic pollution levels and supported the notion that long-term exposure to higher levels of radiation negatively affected the abundance or behaviour of house sparrows in the wild [18].

Another study was performed with 30-point transect sampling, visited every month for more than three years (n = 40) in Valladolid (Spain), counting the sparrows and measuring the mean electric field strength (radiofrequencies and microwaves between 1 MHz and 3 GHz range). A significantly low bird density was observed in areas with high electric field strength and a general population decline in bird density over time was detected [19].

Studies performed in India, showed that sparrows were disappearing from areas where mobile towers were installed and the electromagnetic contamination was highest [13,14]. A study performed by monthly monitoring of urban and rural areas, found that the population of house sparrows was declining in urban areas, where cellphone towers were more common compared to the rural areas, and sparrow populations were disappearing rapidly from areas contaminated with electromagnetic radiation [14]. Another study investigating the impact of electromagnetic radiation (mobile towers) was conducted over a period of two years. Rural sites with plentiful availability of nesting sites, food, water and roosting sites, and with minor competition for nesting sites, food and risk of predation were selected. In such places, the population should increase, however, the author found that the population decreased. Since the maximum decrease in nests was found in sites where the maximum number of mobile towers were operational, the author proposed that electromagnetic radiation from mobile towers could be the cause [13].

A lack of invertebrate prey during the reproductive period, used to feed chicks in the nest, has also been suggested as a possible explanation for the population decline of house sparrows in urban centres [7], since the availability of key insect prey such as Aphidoidea, Curculionidae, Orthoptera and Lepidoptera is very important for the growth and development of nestlings [6]. Numerous studies have shown that electromagnetic pollution might affect the number of insects that house sparrows feed to their chicks [20].

Table 1. House sparrows vs. radiation studies.

Ref	Study	City	Country	Habitat	Years	Study Type	Method	Number of Replicates	Main Results	Alternative Hypotheses
[18]	Everaert and Bauwens, 2007	Six residential areas in the region of Gent–Sint-Niklaas (East Flanders	Belgium	Urban areas	Spring of 2006	Descriptive	Point counts	No	Spatial variation in the number of house sparrow males was negatively and highly significantly related to the strength of the electric fields from both the 900 and 1800 MHz frequency bands. This negative relationship was highly similar within each of the six study areas	Not considered
[19]	Balmori and Hallberg, 2007	Valladolid	Spain	Urban areas	October 2002 to May 2006	Descriptive	Line Transect and Point Counts	40	Significantly low bird density was observed in areas with high electric field strength	-Air pollution -Food availability Electromagnetic pollution may be responsible, either by itself or in combination with other factors for the observed decline of the species in European cities during recent years
[13]	Singh et al., 2013	Jammu region	India	Urban and suburban areas	March 2009 to March 2013	Descriptive	Line Transect and Point Counts	2	In urban areas, the major cause of decline is the lack of nesting sites. In rural sites, the maximum decrease in nests found in Motorshed (30%) where maximum number of mobile towers were operational.	- Lack of nesting sites in modern houses - Increasing competition for nesting sites - Lack of roosting sites - Effect of mobile towers - Increase of predation - Shortage of food - Lack of water sites To study the impact of electromagnetic radiation (mobile towers), rural sites were selected where the availability of nesting sites, food, roosting sites, water is available in plenty. The competition for nesting sites, food and risk of predation is also less. So, in such places, the population should increase. But the population was found to decrease where maximum number of mobile towers were operational
[14]	Shende and Patil, 2015	Kalmeshwar region	India	urban suburban and rural areas	from July 2011 to June 2012	Descriptive	Line Transects Method	12	The correlation between population of Passer domesticus and number of RF towers shows that, the population of Passer domesticus is decreases with increase in number of RF towers. The authors found a relationship between dispersal of Population of Passer domesticus with distance (in Meter) from towers. The electromagnetic signals are directly or indirectly associated with the decline in the house sparrow population in Kalmeshwar and nearby areas	Decline in their number over the last decade because of: - Loss of nesting sites, - Food sources, - Pollution, - Diseases and - Increase in predators

The studies reviewed and discussed show that electromagnetic radiation is not only a plausible but a probable factor for multiple reasons, including that this is the only factor that interferes with all other hypothesised factors proposed so far. Electromagnetic radiation is a type of pollution that affects productivity [21–23], fertility [22], decreases insect chicken feed [24], causes habitat loss [25,26] and decreases immunity [27–29]. It is well known that a stressed immune system may increase the susceptibility of a bird to infectious diseases, bacteria, viruses and parasites [30].

4. Electromagnetic Radiation Effects on Other Species

There are interesting studies investigating the response of city birds according to the distance to phone masts, since the electric field strength is marked by that distance [31]. A study carried out in Spain showed that phone masts interfere with White Stork (*Ciconia ciconia*) reproduction. The total productivity in nests located farther than 300 m of antennae was practically double, compared with those located within 200 m. Furthermore, 40% of nests located within 200 m of antennae never had chicks, while only one (3.3%) located further than 300 m had no chicks. In sites located within 100 m of one or several phone masts with the main beam of radiation impacting directly on the nest, many young died from unknown causes [23].

A study in India noted the occurrence of changes for different bird species near cellphone towers. The occurrences were inversely linked with the power density and most birds were found at the lowest radiation areas. Avian nests were not detected near but were found at ≥80 m away from the towers, in the area with low radiation impacts. At different distances from the two different cellphone towers and for the four directions of space, the study clearly indicated that the occurrence of birds was closely negatively related to the electric field strength [32]. In another Indian study, the occurrence of birds in exposed and unexposed zones were 28.08% and 71.91%, respectively [33].

In another study, the number of individuals (birds) recorded within a 200 m radius of a mobile tower was comparatively less than that found outside the 200 m radius. Birds were highly affected by electromagnetic radiation produced from mobile towers and the electromagnetic radiation emitted from cellphone towers affected their physiology and behaviour [34].

A review highlighted the potential impact of electromagnetic field radiation on avian populations. An uncertainty exists on the effects of electromagnetic radiation exposure on birds due to the scarcity of studies on this matter, but most studies indicate the possibility of changes in behaviour and effects on physiology, breeding success and mortality [35]. A study on the airport radar effects on birds provided evidence that birds detected the radar presence, and slight differences in power density and pulse properties could potentially alter avian behaviour [36].

In addition, there are many other studies on the impact of radiation on non-bird animals [26,31,37–39]. Bat activity was significantly reduced in habitats exposed to an electromagnetic radiation (from a radar) that can exert an aversive behavioural response [40,41]. However, studies conducted in real field situations must be performed with a sufficient experimental exposure time, because results with a short exposure time are likely to be ambiguous (e.g., 48 h in [42]).

An experiment was conducted exposing the common frog (*Rana temporaria*) to electromagnetic radiation from several mobile (cell) phone antennae located at a distance of 140 m from the egg phase until an advanced tadpole phase prior to metamorphosis. The results indicated that radiation emitted by phone masts in a real situation may affect development and may cause an increase in mortality of exposed tadpoles [43].

A detailed long-term (2006–2015) field-monitoring study was performed in the cities of Bamberg and Hallstadt (Germany) [44]. Observations and photographic recordings of unusual or unexplainable tree damage were taken, alongside the measurement of electromagnetic radiation. Many trees showed damage patterns that were not attributable to harmful organisms, such as diseases (fungi, bacteria, viruses) and pests (insects, nematodes) or other environmental factors (water stress, heat, drought, frost, sun, compaction of the soil, air and soil pollutants). Statistical analysis demonstrated that electromagnetic radiation from mobile phone masts was harmful for trees [44].

In the laboratory setting, several authors have reported a significant increase of embryonic mortality of chickens exposed to radiation from mobile phones [25,45,46], that could affect wild birds living in areas polluted by electromagnetic radiation. Microwaves used in cellphones produce a non-thermal response in several types of neurons in birds [47]. Various outcomes of this radiation lead to neural damage, locomotory defects, threatening the reproductive capacities of birds [48]. For these reasons, electromagnetic radiation is not only a plausible but a probable hypothesis for the decline in sparrows.

5. Mechanisms by Which Non-Ionizing Electromagnetic Radiation Could Affect Birds

Some of the disruptive effects of radio frequency fields could be related to interference with voltage-gated calcium channels in cells [49–53]. It has been proposed that electromagnetic fields act similarly in animals and plants, with the probable activation of these calcium channels via their voltage sensor [54]. In their responses to low-intensity microwave electromagnetic fields, membrane calcium channel is activated, allowing calcium influx into the cell, and thus increasing the intracellular (Ca^{2+}) concentration. They undergo both oxidative stress and DNA strand breaks, with those strand breaks leading to the formation of micronuclei and to chromosomal rearrangements. Remote activation by electromagnetic fields significantly increases intracellular calcium concentrations in glass catfish (*Kryptopterus bicirrhis*), indicative of cellular excitability wireless control of cellular function by activation of a novel protein responsive to electromagnetic fields [55].

Current evidence indicates that exposure at levels found in the environment (in urban areas and near base stations) could particularly alter the receptor organs to orient in earth's magnetic field, although the species conservation implications are unknown. Radio frequency fields in the megahertz range disrupt the orientation of birds by interfering directly with the primary processes of magnetoreception and therefore disable the avian compass as long as they are present [56–58]; these authors, reported the sensitivity for orientation of European Robins (*Erithacus rubecula*) to radio frequency magnetic fields. The orientation of migratory birds is disrupted when very weak high-frequency fields (broadband field of 0.1–10 MHz of 85 nT or a 1.315 MHz field of 480 nT) are added to the static geomagnetic field of 46,000 nT [59]. Engels et al. [60] convincingly demonstrated that European Robins are unable to use their magnetic compass in the presence of urban electromagnetic radio frequency noise in the frequency range of 2 kHz to 5 MHz. Therefore, electrosmog scrambles a bird's magnetic sense.

6. Conclusions

The studies discussed above indicate that sparrows disappear from areas most contaminated by electromagnetic radiation. In addition, there are many other studies on the impact of radiation on other species of birds and non-bird animals, as well as laboratory studies that demonstrate its effects at electric field strength levels that can be found in cities. The results of all these studies considered jointly support the hypothesis that electromagnetic pollution may be responsible, by itself or in conjunction with other factors, for the reduced number of the sparrows in cities in recent years. Furthermore, the disappearance of sparrows and the introduction of phone mast towers are temporally correlated: sparrow decline matches chronologically with the deployment of mobile telephony networks, especially during recent decades. However, there are some weaknesses of this study; since it is based on only a few house sparrow's studies ($n = 4$), and low number of replicates. The correlation between electromagnetic radiation and sparrow abundance does not imply causality, although the possibility of this happening seems very likely considering the different number of places analysed. However, it is possible that other factors, such as habitat structure and vegetation, which may differ between the near surroundings of the towers (in addition to the radiation level) and areas further away could also interplay in house sparrow abundance. Interestingly, the study performed in Paris suggests that specific environmental changes have occurred in this city during the last 15 years and that the current conditions are unsuitable for the maintenance of dense local populations of house sparrows [4].

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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Article *in* Journal of Insect Conservation · April 2016

DOI: 10.1007/s10841-016-9868-8

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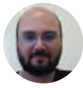

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DOI 10.1007/s10841-016-9868-8

ORIGINAL PAPER

Electromagnetic radiation of mobile telecommunication antennas affects the abundance and composition of wild pollinators

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Received: 9 October 2015 / Accepted: 17 April 2016

Abstract The exponential increase of mobile telephony has led to a pronounced increase in electromagnetic fields in the environment that may affect pollinator communities and threaten pollination as a key ecosystem service. Previous studies conducted on model species under laboratory conditions have shown negative effects of electromagnetic radiation (EMR) on reproductive success, development, and navigation of insects. However, the potential effects that widespread mobile telecommunication antennas have on wild pollinator communities outside the laboratory microcosm are still unknown. Here we studied the effects of EMR from telecommunication antennas on key wild pollinator groups (wild bees, hoverflies, bee flies, remaining flies, beetles, butterflies, and wasps). We measured EMR at 4 distances (50, 100, 200 and 400 m) from 10 antennas (5 on Limnos Island and 5 on Lesvos Island, eastern Mediterranean, Greece), and correlated EMR values with insect abundance and richness (the latter only for wild bees and hoverflies). All pollinator groups except butterflies were affected by EMR. In both islands, beetle, wasp, and hoverfly abundance decreased with EMR, whereas the abundance of underground-nesting wild bees and bee flies unexpectedly increased with EMR. The effect of EMR on the abundance of remaining flies differed between islands. With respect to species richness, EMR only tended to have a negative effect on hoverflies in Limnos. As EMR affected the abundance of several insect guilds negatively, and changed the composition of wild pollinators in natural habitats, it might also have additional ecological and economic impacts on the maintenance of wild plant diversity, crop production and human welfare.

Keywords Bee flies · Beetles · Butterflies · Distance to the antenna · Electromagnetic smog · EMR · Hoverflies · Species richness · Wasps · Wild bees

Introduction

Pollinators play an important functional role in most terrestrial ecosystems and provide a key ecosystem service that is vital to the maintenance of wild plant communities and agricultural productivity (Klein et al. 2007; Kremen et al. 2007; Potts et al. 2010). Over the past decade, several studies have warned about the decline in pollinators (Biesmeijer et al. 2006; Pauw 2007; Goulson et al. 2008; Burkle et al. 2013) and the serious consequences this may have (e.g. Ashman et al. 2004; Burkle et al. 2013). This pollinator loss has been related to anthropogenic disturbances such as alterations in land use, habitat loss and climate change (Kearns et al. 1998; Aguilar et al. 2006; Hegland et al. 2009; Potts et al. 2010). At the same time, the use of mobile telephony has grown exponentially during recent years, resulting in a pronounced increase in electromagnetic fields in the environment. Detrimental effects of electromagnetic exposure have been shown for a

Electronic supplementary material The online version of this article (doi:10.1007/s10841-016-9868-8) contains supplementary material, which is available to authorized users.

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Published online: 26 April 2016

variety of living organisms, from vertebrates to invertebrates, plants and bacteria (see reviews in Cucurachi et al. 2013; Balmori 2015).

The majority of studies on the effects of electromagnetic radiation on insects have been conducted on two model species: the fruit fly (*Drosophila melanogaster*) and the honeybee (*Apis mellifera*). The studies of electromagnetic radiation on the fruit fly have mostly shown developmental delays (Atli and Ünlü 2006) and negative effects on reproductive success (e.g. Panagopoulos et al. 2004; Atli and Ünlü 2006, 2007; Panagopoulos and Margaritis 2010; Panagopoulos et al. 2010; Chavdoula et al. 2010; but see Weisbrot et al. 2003 for a positive effect, and Vijver et al. 2013 for no effect) due to DNA fragmentation and reproductive cell death (Chavdoula et al. 2010; Panagopoulos et al. 2007, 2010). In honeybees, radiation decreases colony strength and oviposition rate (Sharma and Kumar 2010; Sahib 2011), and induces worker piping, a behaviour associated with swarming (Favre 2011). Electromagnetic radiation also interferes with honeybee navigation, as honeybees use compass mechanisms for orientation based on magnetite structures in their bodies (Kirschvink et al. 2001; Wajnberg et al. 2010; Válková and Vácha 2012; Balmori 2015). Due to electromagnetic smog, honeybees are often unable to return to their hives (Harst et al. 2006; Favre 2011; Sharma and Kumar 2010; Sahib 2011), and the resulting massive loss of workers then leads to a colony collapse (e.g. Harst et al. 2006; Sharma and Kumar 2010), which is why electromagnetic radiation has been suggested as one of the potential causes of the colony collapse disorder (CCD; e.g. Warnke 2009; Sahib 2011). Fewer studies exist in the literature regarding other insects, but it is known that radio frequency magnetic fields disrupt magnetoreception in the American cockroach (Vácha et al. 2009). In ants, electromagnetic radiation affects visual and olfactory memory, influencing their ability to associate cues to food (Cammaerts et al. 2012), as well as locomotion and orientation (Cammaerts et al. 2014; Cammaerts and Johansson 2014). Although most of these studies are conducted on model organisms and under laboratory conditions (Cucurachi et al. 2013), current evidence strongly indicates that insects in natural and protected areas may be negatively affected by the presence of base-station emitters of electromagnetic radiation (Balmori 2015). It still remains unknown, however, whether the presence of telecommunication antennas can modify wild pollinator communities by altering species abundance and/or species richness, thus threatening the maintenance of pollination as an ecosystem service.

In this study we investigate whether the electromagnetic radiation emitted by mobile telecommunication antennas affects the abundance and diversity of wild pollinators, as suggested by a preliminary study (Tscheulin et al. 2010) that indicated an effect of distance to the antenna on some pollinator groups. To do this, we measured the intensity of electromagnetic radiation at different distances from 10 telecommunication antennas in two Mediterranean islands, and correlated these measurements with the abundance and species richness of wild pollinators. Since the susceptibility of insects to radiation may differ, we hypothesized that electromagnetic radiation would modify the composition of the insect community and affect species richness negatively. Our specific questions were: (1) does electromagnetic radiation affect the abundance and richness of pollinating insects? And if so, (2) does the effect differ among taxonomic groups and nesting behaviours?

Materials and methods

Study sites

The study was conducted on two Mediterranean islands (Lesvos and Limnos) in the north-eastern Aegean (Greece), characterized by a variety of natural and managed habitats that support a great diversity of pollinators. In particular, the bee-friendly habitats the study was carried out in were phrygana (i.e. low scrub habitats with high pollinator diversity and abundance; Petanidou and Ellis 1993; Nielsen et al. 2011), which is dominant on Limnos and to a lesser degree on Lesvos; and olive groves (i.e. semi-natural habitats cultivated for centuries using non-intensive methods; Potts et al. 2006; Nielsen et al. 2011), which are co-dominant on Lesvos. Both these habitats have been shown to be equally rich in bee diversity and abundance (Potts et al. 2006; Nielsen et al. 2011).

In each island, we selected 5 mobile telecommunication antennas (antennas, hereafter; Fig. 1) as study sites, located in either phrygranic habitats or cultivated olive groves (Table 1). All study antennas were mobile telephony base stations, using frequency bands between 800 and 2,600 MHz, and were located at altitudes below 350 m in homogeneously flower-rich landscapes, and were separated by a minimum distance of 5 km. We have no reason to believe that antennas in the two islands differ in their emitted frequencies as all providers in Greece use similar frequency bands. Antennas located at high altitudes or in coniferous habitats were excluded in order to avoid pronounced differences in pollinator communities among antennas and sampling points (see below). Each of the study islands (and all the sites within them) is homogeneous in terms of climate and vegetation, and there are no apparent differences in land use management among sites (mostly light livestock grazing, beekeeping, and traditional ploughing of the olive groves).

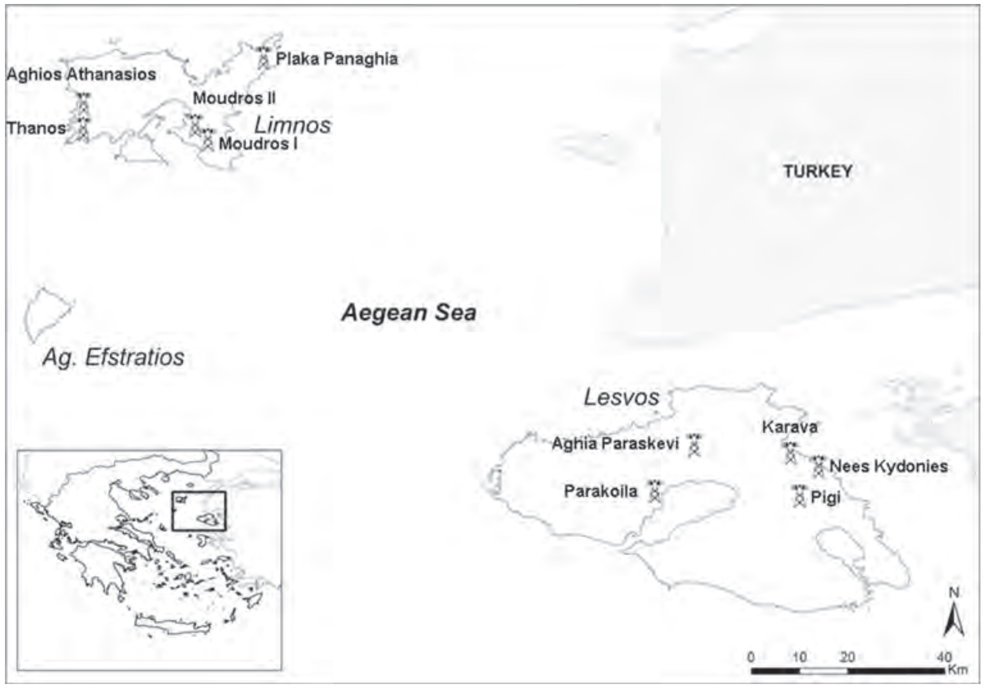

Fig. 1 Map of the study sites on Lesvos and Limnos Island (north-eastern Aegean, Greece)

Table 1 Study sites, respective habitat, coordinates, and mean EMR ± SD (V/m; see text for details)

Island	Site	Habitat	Latitude	Longitude	Mean EMR			
					50 m	100 m	200 m	400 m
Lesvos	Aghia Paraskevi	Olive groves	39°16′21.40″N	26°12′53.39″E	0.376 ± 0.042	0.313 ± 0.054	0.670 ± 0.015	0.271 ± 0.058
	Karava	Phrygrana	39°15′26.26″N	26°23′39.07″E	0.385 ± 0.012	0.341 ± 0.037	0.611 ± 0.030	0.632 ± 0.041
	Nees Kydonies	Phrygrana	39°13′56.74″N	26°26′46.09″E	0.516 ± 0.121	0.350 ± 0.049	0.069 ± 0.056	0.010 ± 0.004
	Parakoila	Phrygrana	39°11′11.95″N	26° 8′29.56″E	0.236 ± 0.112	0.149 ± 0.028	0.110 ± 0.184	0.118 ± 0.095
	Pigi	Olive groves	39°10′41.18″N	26°24′40.46″E	0.100 ± 0.054	0.077 ± 0.034	0.074 ± 0.028	0.061 ± 0.019
Limnos	Aghios Athanasios	Phrygrana	39°54′19.54″N	25° 4′44.66″E	0.512 ± 0.134	0.556 ± 0.057	0.169 ± 0.035	0.358 ± 0.085
	Moudros I	Phrygrana	39°50′20.06″N	25°18′36.30″E	0.083 ± 0.086	0.020 ± 0.055	0.084 ± 0.014	0.067 ± 0.012
	Moudros II	Phrygrana	39°51′52.57″N	25°17′11.64″E	0.139 ± 0.015	0.066 ± 0.043	0.010 ± 0.013	0.057 ± 0.030
	Plaka Panaghia	Phrygrana	39°59′25.80″N	25°24′49.30″E	0.278 ± 0.007	0.288 ± 0.014	0.386 ± 0.012	0.196 ± 0.023
	Thanos	Phrygrana	39°51′34.19″N	25° 4′41.59″E	0.327 ± 0.099	0.232 ± 0.247	0.132 ± 0.014	0.309 ± 0.078

Sampling points at 50 and 100 m were within the emission lobes of the antennas, except in Pigi (50 m + 100 m) and Moudros I (50 m)

Measurements of electromagnetic radiation

In April 2012, we measured the electrical field E component of electromagnetic radiation (EMR, hereafter) at 4 distances (50, 100, 200 and 400 m; sampling points, hereafter) from each of the 10 study antennas. These sampling points were selected in order to achieve a large range of EMR intensities at each study site, based on the inverse-square law, which states that an isotropic physical quantity or strength is inversely proportional to the square of the distance from the source of that physical quantity (Goldsmith 2005). However, the spatial structure of the electric field around the base station can be quite complex, and depend on factors such as topography, antenna vertical tilt and emission lobes (Balanis 2005; Goldsmith 2005). At each sampling point we also measured elevation with an altimeter, to account for differences in elevation with the distance to the antenna in the statistical analyses.

For the EMR measurements we used the device EMR-Narda (Narda EMR-300 Broadband RF Survey Meter; Flüge 2004) equipped with electric and magnetic probes. The electric field E probe has a wider frequency spectrum response than the magnetic field B probe, namely 100 kHz–3 GHz and 80 MHz–1 GHz, respectively. In these frequency ranges, the EMR wavelength is much smaller than the measurement distances from the antennas, so one can safely assume that we are measuring in the far-field and consequently either E or B measurements are sufficient. We therefore chose to measure the E field, due to its wider frequency spectrum. E measurements in units of V/m are hereafter referred to simply as EMR measurements. The aforementioned frequency ranges contain all frequencies used by mobile telephony services. They also include radio and television communications, which are not serviced by the antennas at the locations monitored. In order to record potential diurnal EMR patterns, EMR was measured continuously during 24 h at the sites Karava, Kydonies, and Pigi on Lesvos Island, and at Aghios Athanasios, on Limnos Island. Following these measurements of EMR, shorter-term measurements (2 h) were carried out in all the remaining study sites. In total, between 115 and 1,400 measurements were recorded at each site and sampling point, each of these measurements corresponding to a 6-min average of electrical field.

Insect abundance and richness

At each sampling point we collected insects three times during the main flowering period (April, May and June) in 2012, using the pan trapping method (Westphal et al. 2008; Nielsen et al. 2011). Samplings were carried out under good weather conditions, i.e. temperature >15 °C, sunshine, low wind speed and relative humidity lower than 65 %. We arranged the pan traps in triplet units, with each triplet comprising three pan traps of a different UV-bright colour: blue, yellow, and white. These colours account for different colour preferences of pollinating insects (Westphal et al. 2008). Five triplets were set up at each sampling point of an antenna complex, on the ground, with any two triplets being separated by ca. 10 m. During each sampling round, pan traps were filled with 400 ml of water containing 1 drop of aroma-free kitchen detergent to break the water surface tension, and left for 48 h covering the entire flight activity period of diurnal and nocturnal pollinators.

Collected insects were transferred to small plastic ziplock bags and refrigerated if they were to be processed within 24 h, otherwise deep frozen until pinning. After processing in the laboratory, bees and hoverflies were identified to species level (where necessary with the help of European specialists), while the remaining insects were assigned to one of the following taxonomic groups: beetles, butterflies, wasps, bee flies, and remaining flies that included all flies not belonging to hoverflies or bee flies (i.e. flies mainly belonging to the families Anthomyiidae, Muscidae, Calliphoridae, Nemestrinidae, Empididae, Tachinidae, Stratiomyidae, Asilidae, Rhagionidae, and Tabanidae). Honeybees were excluded from the analyses because they are managed, and their abundance is therefore biased by beekeepers' decisions. All identified insects are deposited in the Melissotheque of the Aegean (Petanidou et al. 2013).

Pollinator abundance at each sampling point for each group was estimated as the total number of individuals collected at that sampling point, pooling the data of the three sampling rounds together. Similarly, species richness was calculated as the total number of species collected at each sampling point during the three sampling rounds (e.g. Westphal et al. 2008; Nielsen et al. 2011; Lázaro et al. 2016).

Wild bees were categorized following their nesting behaviour, i.e. underground versus aboveground nesting, based on existing literature (Michener 2007; Müller 2015), and our own observations (see Table S1 for categories used).

Flower cover

Flower cover measurements were conducted in ten 1 m × 1 m squares selected at random at each sampling point and round, within the area where insects were collected. The total number of functional reproductive units, i.e., flowers or inflorescences depending on the species ('flowers' hereafter) for each plant species was counted within these squares. For each sampling point we calculated flower abundance as total number of flowers recorded in the ten squares, and flower richness as the total number of flowering species recorded. Plant specimens were deposited in the herbarium of the Laboratory of Biogeography and Ecology at the University of the Aegean.

Statistical analyses

All the statistical analyses were carried out using generalized linear mixed models (GLMM, library lme4) conducted in R 3.1.2 (R Development Core Team 2008), where site was included as a random variable to avoid pseudoreplication. To study how EMR varied with the distance to the antenna, the elevation and the island, we ran a model (Gamma distribution, log link function) with distance and elevation as continuous variables, and island as a categorical predictor variable. Full models on the abundance and species richness of insects were conducted separately for each taxonomic group and included EMR, distance, elevation (log transformed to improve model fitting), total flower abundance, and flower richness (to control for variations in the flowering community that could affect the response) as continuous predictor variables, island as a fixed predictor, and the interaction between EMR and island, to detect any difference between islands in the response to EMR. For wild bee abundance and richness, we ran additional models in which the nesting behaviour of wild bees was included as a fixed categorical factor (underground vs. aboveground nesting), to test whether this factor affected the response to EMR. Due to the loss of some pan traps during sampling, and to control for the potential effects of these small changes in sampling effort on the results, we included the number of pan traps (log-transformed) as an offset in the models (Zuur et al. 2009). Due to the nature of the data, we used Poisson distributions and log link functions in these analyses. In some Poisson models we included an observation-level random intercept to cope with overdispersion (Zuur et al. 2013). Prior to analyses, we ran variation inflation factor (VIF) analyses to identify collinear predictor variables that should be removed from further analyses (Zuur et al. 2009). VIF values were smaller than 3 for all variables, thus none of the predictors needed to be removed (Zuur et al. 2009). Before the analyses, we also used Moran's I (library ncf; Bjørnstad and Falck 2001) to check for any spatial correlation in the data or in the residuals of the models (without random factor). Neither the data nor the residuals showed any spatial correlation, indicating that our mixed model approach was appropriate. Model selection was conducted using the 'dredge' function (package MuMIn; Barton 2014), including EMR in each model, and setting the maximum number of variables to 4 to avoid over-parametrization. Means and estimates are accompanied by their standard error throughout the text.

Results

EMR measurements

We found some diurnal-nocturnal patterns in EMR values in the sites measured continuously for 24 h (see Figure S1 in Electronic Supplementary Material). However, the patterns differed among sites, the effect of time was small compared to differences among distances and sites (Table 1; Figure S2 in Electronic Supplementary Material), and EMR values did not differ significantly when measured for only two or for 24 h ($\chi^2_1 = 2.53$, $p = 0.112$). Consequently, in our models we used the average EMR values measured per site and sampling point.

Overall, EMR values did not significantly differ between islands (Lesvos: 0.27 ± 0.05 V/m; Limnos: 0.21 ± 0.04 V/m; $\chi^2_3 = 0.08$, $p = 0.779$) and did not decrease with the distance to the antenna ($\chi^2_1 = 0.71$, $p = 0.398$), supporting the results of other studies (e.g. Vijver et al. 2013), possibly because some of the sampling points located close to the antenna may have been outside or at the edge of the emission lobes of the antenna. The interaction between island and distance was also non-significant ($\chi^2_1 = 0.95$, $p = 0.329$). Mean values (±SD) recorded at each sampling point are shown in Table 1.

EMR effects on insects

On Lesvos, we collected 11,547 insects in total: 1,334 wild bees (133 species), 41 hoverflies (9 species), 426 wasps, 75 bee flies, 2,857 other remaining flies, 6,758 beetles, and 84 butterflies. On Limnos, the total number of insects collected amounted to 5,544: 2,467 wild bees (108 species), 155 hoverflies (6 species), 357 wasps, 11 bee flies, 2,263 other remaining flies, 252 beetles, and 131 butterflies. Table S1 in the Supplementary Material shows the number of different wild bee and hoverfly species found at each study site.

EMR effects on the abundance of the different insect guilds

EMR had contrasting effects on the abundance of different pollinator groups, affecting some positively, while others negatively. In addition, for most pollinator groups the effects found were consistent in both islands.

Overall wild bee abundance increased significantly with EMR in both islands (Fig. 2a); however, the increase was steeper on Limnos than on Lesvos (Table 2A; Fig. 2a). When including the nesting behaviour of wild bees in the analysis, the triple interaction Island × Nesting behaviour × EMR was also significant ($\chi^2_1 = 7.47$, $p = 0.006$), showing that only underground-nesting wild bees were positively related to EMR, while aboveground-nesting wild bees were not affected on the study islands (Fig. 3). Again, the response was steeper in the case of Limnos.

Beetle abundance decreased significantly with EMR in both islands (Fig. 2b). However, as for wild bees, the relationship was more pronounced on Limnos than on Lesvos (Table 2B; Fig. 2b). There were significantly more beetles on Lesvos than on Limnos (Lesvos: 337.9 ± 62.8 cumulated insects per sampling point; Limnos: 12.6 ± 6.3; Table 2B).

The abundance of bee flies increased with EMR (Table 2C; Fig. 2c), while EMR was negatively related to the abundance of wasps (marginally non-significant relationship; Table 2D; Fig. 2d).

Wasp abundance also increased with flower richness (estimate: 0.140 ± 0.051; Table 2D) and decreased with flower abundance (estimate: −0.008 ± 0.004; Table 2D).

Hoverfly abundance was negatively related to EMR (Table 2E; Fig. 2e) and tended to increase with flower abundance (estimate: 0.009 ± 0.006; Table 2E).

The effect of EMR on the abundance of the broad group 'remaining flies' differed drastically between islands. Thus,

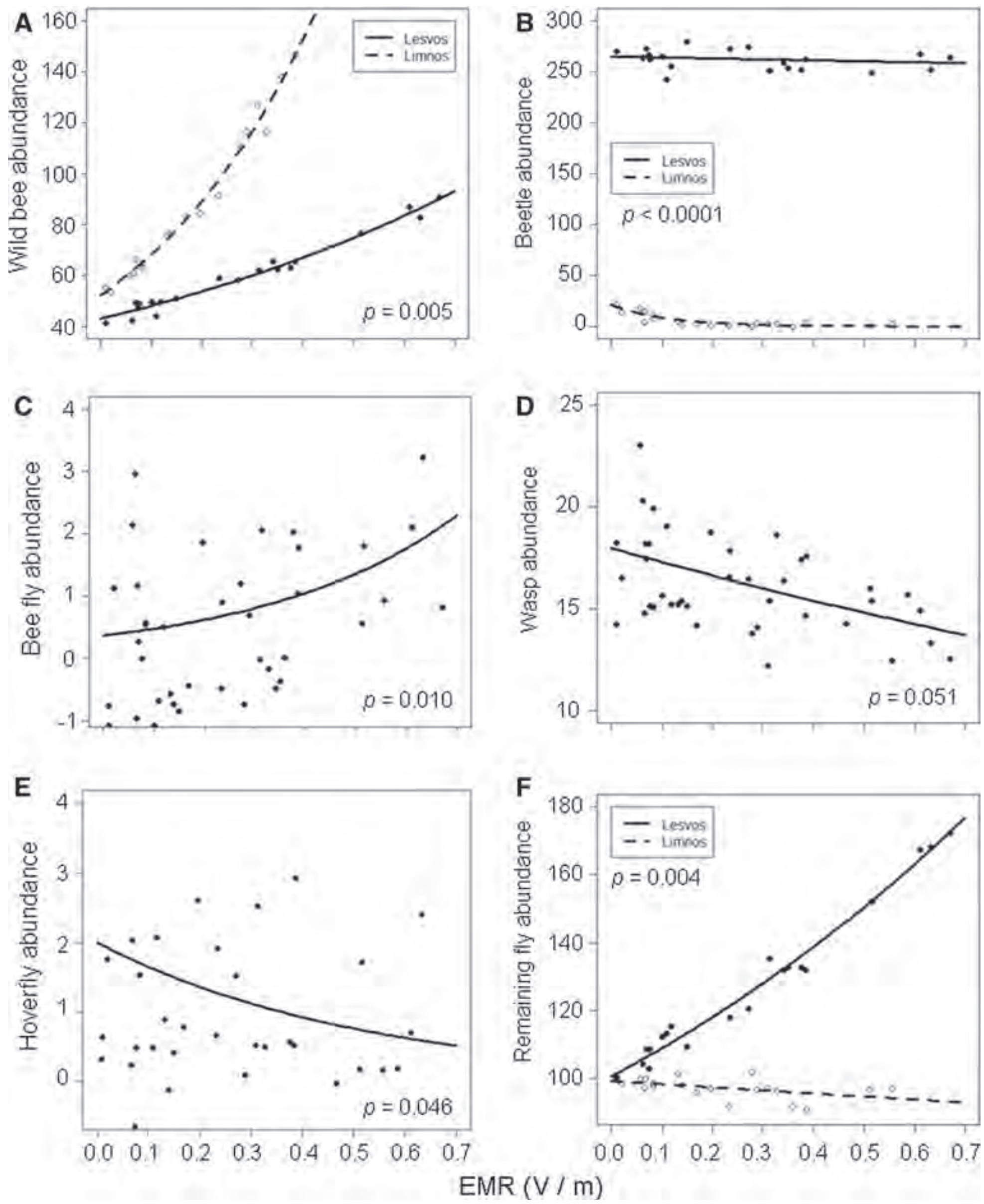

Fig. 2 Partial residual plots showing the significant relationships between EMR and the abundance of pollinating insects. When the interaction between EMR and island was significant, the relationships are depicted separately for each island. The *lines* represent the estimate of the best model and the *circles* represent partial residuals. Note that different graphs vary in y-axis scale

while EMR was positively related to the abundance of remaining flies in Lesvos, it was negatively related in Limnos (Table 2F; Fig. 2f).

Butterfly abundance (Table 2G) was not related to EMR, but was significantly higher in Limnos than in Lesvos (Limnos: 6.6 ± 1.0 cumulated insects per sampling point; Lesvos: 4.2 ± 0.8; Table 2G).

EMR effects on species richness of wild bees and hoverflies

EMR was not related to overall wild bee species richness (Table 2H), even when nesting behaviour was included in the model (Best model: EMR: $\chi^2_1 = 0.14$, $p = 0.71$; Nesting behaviour: $\chi^2_1 = 705.95$, $p < 0.0001$; 2.10 ± 1.24 vs. 1.88 ± 0.22 mean species/sampling point for underground- and aboveground-nesting wild bees respectively).

The interaction between EMR and island had a marginally non-significant effect on hoverfly richness (Table 2I). EMR tended to negatively affect hoverfly species richness but only in Limnos, whereas in Lesvos there was no significant relationship between these two variables (Fig. 4).

Discussion

For the first time to our knowledge, we have shown that electromagnetic radiation as typically emitted by telecommunication antennas affects the abundance and

Table 2 Results of the best models relating EMR to the abundance and richness of insects

Model	Variables tested	χ^2	*df*	*p*	Estimate for relationship with EMR
(A) Wild bee abundance	Island	1.79	1	0.181	
	EMR*Island	7.86	1	0.005	Lim (+), Les (+)
	Flower richness	12.97	1	0.0003	
(B) Beetle abundance	Island	5.49	1	0.019	
	EMR*Island	85.88	1	<0.0001	Lim (−); Les (−)
(C) Bee fly abundance	EMR	6.63	1	0.010	(+)
(D) Wasp abundance	EMR	3.78	1	0.051	(−)
	Flower richness	7.61	1	0.006	
	Flower abundance	5.05	1	0.025	
(E) Hoverfly abundance	EMR	3.98	1	0.046	(−)
	Flower abundance	2.86	1	0.091	
(F) Remaining flies abundance	Island	0.52	1	0.469	
	EMR*Island	8.33	1	0.004	Lim (−); Les (+)
(G) Butterfly abundance	Island	5.59	1	0.018	
	EMR	0.003	1	0.953	ns
(H) Wild bee richness	EMR	0.10	1	0.753	ns
(I) Hoverfly richness	Island	1.74	1	0.189	
	EMR*Island	3.13	1	0.077	Lim (−); Les (ns)

'+' a positive, '−' a negative, and ns: a non-significant relationship. When there was a significant interaction between island and EMR the sign of the estimate is given separately for Limnos (Lim) and Lesvos (Les)

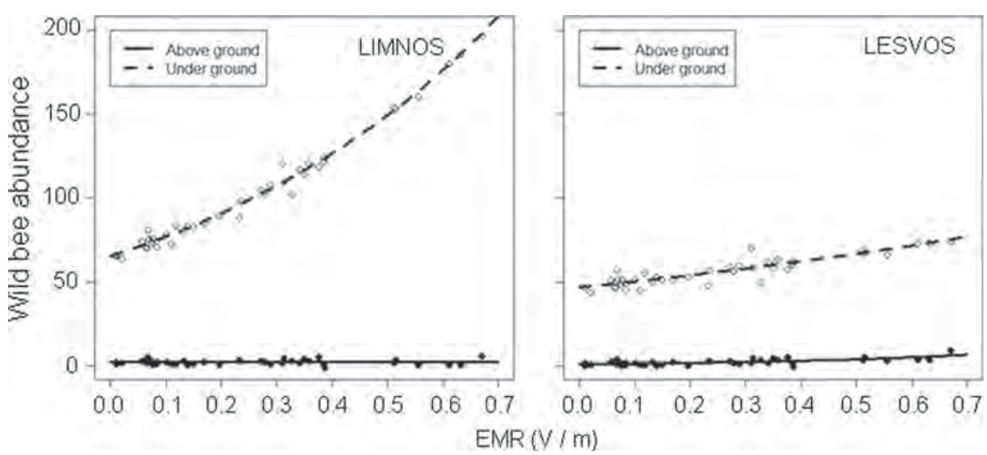

Fig. 3 Partial residual plots showing the relationship between EMR and the abundance of underground- and aboveground-nesting wild bees. As the triple interaction EMR × Island × Nesting behaviour was significant ($p = 0.006$), the relationships are depicted separately for each island. The *lines* represent the estimate of the best model and the *circles* represent partial residuals

composition of wild pollinators in natural habitats. In both study islands, beetle, wasp and hoverfly abundance decreased with EMR, whereas, to our surprise, wild bee and bee fly abundance increased with EMR. The effect of EMR on the abundance of remaining flies differed between islands. These differences in the response of insect guilds are likely due to differences in their susceptibility to radiation.

We expected telecommunication antennas to affect the abundance of wild pollinators because these animals rely on their cognitive and orientation abilities to forage and navigate (Chittka and Thomson 2001), and electromagnetic smog is known to affect cognition and orientation in insects (e.g. Cammaerts et al. 2012, 2014; Sharma and Kumar 2010; Sahib 2011). Our communities were similar in terms of habitat and human activities, and in our analyses we controlled for the variations in flower abundance and diversity among study sites (as these variables might directly affect the pollinator community); therefore, although we cannot totally discard the potential effect of an unmeasured variable, we are confident that our results reflect the effect of radiation on wild pollinator

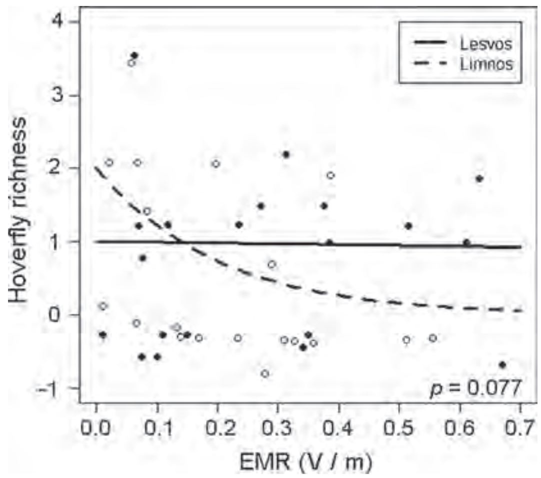

Fig. 4 Partial residual plots showing the significant relationships between EMR and the hoverfly richness. Since the interaction between EMR and island was marginally non-significant, the relationship is depicted separately for each island. The *lines* represent the estimate of the best model and the *circles* represent partial residuals

communities, either directly or indirectly. As expected, EMR modified the abundance of all the studied pollinator groups, with the only exception of butterflies; however, pan traps are not efficient tools for collecting butterflies (they accounted for only 1.3 % of the total specimens collected), and maybe a more adequate sampling method would have led to a different result. Interestingly, the effects of EMR on the abundance of pollinators were not always negative. More specifically, we found that overall wild bee abundance and bee fly abundance increased significantly with EMR, while hoverfly, beetle, and wasp abundance decreased with EMR in both islands. When looking closer at wild bees, we found that only the abundance of underground-nesting wild bees was positively related to EMR, whereas wild bees nesting aboveground were not affected by EMR. It is remarkable though, that the effects of EMR on insect abundance were consistent in both islands for all the pollinator groups except for the broad group 'remaining flies', which might have been due to differences in the composition of this group between the two islands. Previous studies have also shown that the effects of electromagnetic radiation vary for different animals. Within mammals, negative effects of radiation have been found in rats and mice (e.g. Maskey et al. 2010, 2012; Narayanan et al. 2015; Sahin et al. 2015), as well as in dogs, cats, and cows (Marks et al. 1995; Löscher and Käs 1998). Within insects, the effects on different species were also variable. For instance, negative effects of electromagnetic radiation have been reported on cognition, locomotion, and orientation in the ant *Myrmica sabuleti* (Cammaerts et al. 2012, 2014), and on worker piping and navigation in honeybees (e.g. Favre 2011; Sharma and Kumar 2010; Sahib 2011), and on development and reproductive success of the fruit fly (e.g. Panagopoulos et al. 2004; Atli and Ünlü 2007). Nevertheless, a field study on the effects of electromagnetic exposure on the reproductive capacity of several insects revealed no effects (Vijver et al. 2013). The authors suggest that this lack of effects could be at least partially attributed to short term exposures or to the length of waves in relation to the small size of the animals (Vijver et al. 2013). Our study, however, revealed alterations in the structure of the pollinator community. The negative relationship between EMR and the abundance of wasps, beetles and hoverflies might indicate a high sensitivity of these insects to electromagnetic radiation. In contrast, pollinators potentially more tolerant to EMR, such as underground-nesting wild bees and bee flies, may fill the vacant niches left by less tolerant species and thus result in an increase of their populations. One possible explanation for these results is that EMR may have particularly detrimental effects on the potentially more susceptible larval stages of these flower visitors. If so, larvae developing aboveground (many beetles, wasps, many hoverflies) may be more vulnerable than those developing underground (underground-nesting wild bees, i.e. the majority of Apoidea), because the former may be exposed to higher radiation levels. The fact that bee flies are mostly represented in our study by the genera *Phthiria* and *Cyllenia*, which are parasitoids of prepupal or pupal stages of moths and sawflies developing underground (Yeates and Greathead 1997), may also support our hypothesis. At any rate, these changes in the composition of pollinator communities may have important ecological consequences for the maintenance of pollination services and biodiversity, but also economic impacts in respect to potential effects on agricultural productivity (Gallai et al. 2009; Potts et al. 2010).

Reduced pollinator diversity in a community can reflect disturbances of the environment (Potts et al. 2010), and thus, we expected EMR to negatively affect overall pollinator species richness. However, our results on pollinator species richness were weak and not as conclusive as those on abundance, because we found no significant effect of EMR on wild bee species richness, and only a marginally non-significant negative effect on hoverfly species richness in Limnos, the study island where the overall effects of EMR were stronger. At any rate, the tendencies were always negative, and therefore, we cannot rule out that an increase in sampling effort in future research could reveal stronger effects of EMR on species richness.

Conclusions

Electromagnetic radiation from telecommunication antennas affected the abundance and composition of wild pollinators in natural habitats. EMR had contrasting effects on the abundance of different pollinator groups (negative on beetles, wasps, and hoverflies; positive on underground-nesting wild bees and bee flies), which may be due to different susceptibilities to radiation particularly of the larval stages. Pollinators and their host plants constitute pollination networks. Although the architecture of these mutualistic networks can increase the capacity of pollinator populations to persist under harsh conditions, once a tipping point in human-induced environmental change is reached, pollinator populations may collapse simultaneously (Lever et al. 2014). Therefore, these changes in the composition of pollinator communities associated with electromagnetic smog may have important ecological and economic impacts on the pollination service that could significantly affect the maintenance of wild plant diversity, crop production and human welfare.

Acknowledgments The research has been co-financed by the European Union (European Social Fund—ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF)—Research Funding Program: THALES: Investing in knowledge society through the European Social Fund. We would like to thank W. Arens, H. Dathe, J. Dils, A. Ebmer, M. Kuhlmann, V. Mizerakis, A. Mueller, A. Pauly, C. Praz, M. Quaranta, S. Risch, W. Schedl, E. Scheuchl, M. Schwarz, M. Terzo and A. Vujic for insect identification.

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