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ElektrosmogReport

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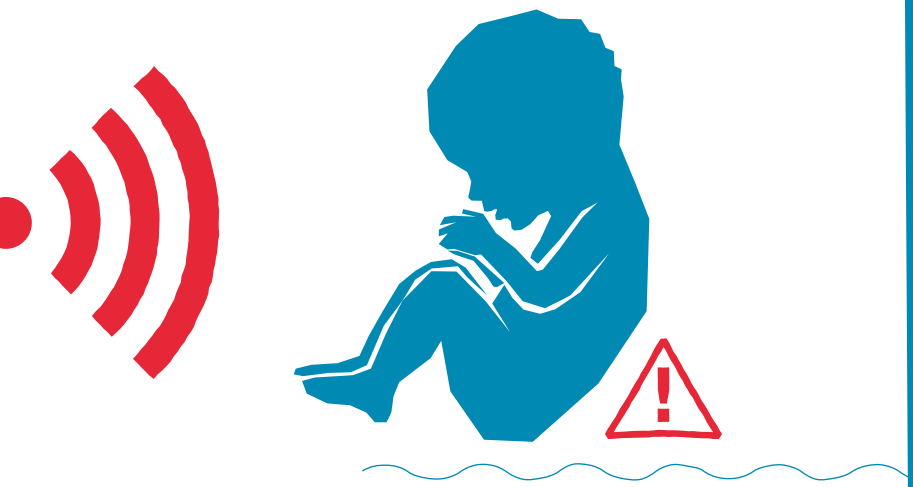

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RF radiation during pregnancy causes lasting damage

Male reproductive and cellular damage after prenatal 3.5 GHz radiation exposure: One-year postnatal effects

Gelenli Dolanbay E, Mert T, Caliskan Bender G, Bektas H, Uslu U, Fernandez-Rodriguez CE, Dasdag S (2025). Male reproductive and cellular damage after prenatal 3.5 GHz radiation exposure: One-year postnatal effects. *Annals of the New York Academy of Sciences*, 1554(1), 140–152. https://doi.org/10.1111/nyas.70116

Previous studies have indicated a link between exposure to radiofrequency (RF) radiation and reduced sperm quality and motility, as well as increased oxidative stress in testicular tissue [1]. The 2012 BioInitiative Report emphasized that RF radiation can trigger epigenetic changes, disrupt DNA repair mechanisms, and induce new mutations, all of which can impair male fertility. However, the extent to which RF radiation exposure affects the reproductive systems of male embryos remains largely unexplored. This study addresses a significant gap in the literature by examining possible persistent damage resulting from prenatal RF radiation exposure and its impact on spermatogenesis in adulthood.

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Study design and implementation:

Scientists exposed pregnant Wistar rats to 3.5 GHz GSM radiation for two hours per day, either throughout the entire pregnancy (3 weeks; 3T) or during the final two weeks (2T) of pregnancy. Measured field strengths inside the cage ranged from 24 to 28 V/m, power densities from 1.53 to 2 W/m², and the maximum averaged SAR over 10 g was 0.038 W/kg. The control group was sham-exposed. After birth, six male offspring were randomly selected and kept without further exposure until adulthood (12 months). Therefore, exposure occurred only in utero. Histological analyses of the testes were performed, including the Johnson score, seminiferous tubule diameter, and epithelial height, as well as immunohistochemical analyses using markers for DNA double-strand breaks, autophagy, and apoptosis. In addition, a semen analysis of the epididymides was performed. The histological and immunohistochemical evaluations were performed blinded. The statistical ANOVA test was corrected using Holm–Bonferroni method.

Results:

Histological examinations revealed significant morphological changes in both groups of offspring exposed intrauterine, compared to the control group that was not exposed. Specifically, the diameter of the seminiferous tubules, the height of the epithelium, and the Johnson score decreased. The percentage of sperm with physiological morphology in the sham-exposed group was within the expected range (74%), whereas the number of healthy sperm decreased in the exposed groups. Apoptosis markers (TUNEL and the apoptotic index) increased in a statistically significant manner in the testicular tissue. The marker for DNA double-strand breaks, γ-H2AX, also increased in a statistically significant manner. Beclin-1, an autophagy indicator, increased statistically significantly in the 3T group.

Conclusions:

Prenatal exposure to 3.5 GHz RF radiation below international limits can cause persistent structural and cellular changes in testicular tissue. These changes include impaired spermatogenesis, DNA damage, increased autophagy, and apoptosis that persist in offspring into adulthood. Despite being exposed only intrauterine, the tissue of the experimental animals does not recover from the damage. This suggests that mobile phone radiation during critical phases of embryonic development may pose a significant risk to male fertility. The authors point out that morphological changes in sperm are probably not artifacts because the physiological sperm morphology in the control group is within the expected range [2]. Furthermore, the authors compare their results with those of previous studies and note that nearly all of the observed adverse health effects have already been documented [3–6]. (Most of these studies have been reviewed in previous issues of the ElektrosmogReport; editor's note.)

Editor's note:

This study stands out for its clear design (prenatal exposure), high relevance (long-term effects), validated exposure measurement, multimodal endpoint analysis, and adherence to scientific standards such as blinding, randomization, and comprehensive statistical analysis. Of particular concern is the fact that the described long-term damage is caused by chronic exposure to low field strengths to which we are exposed in everyday life. Ideally, functional fertility data such as sperm motility and other molecular markers would have been included to draw conclusions about the underlying mechanisms. Oxidative stress markers are particularly noteworthy here, as the authors discuss oxidative stress as a potential cause of the sterilizing effect of RF radiation exposure. (RH)

1. Cordelli E, Ardoino L, Benassi B, Consales C, Eleuteri P, Marino C et al. (2024). Effects of radiofrequency electromagnetic field (RF-EMF) exposure on male fertility: A systematic review of experimental studies on non-human mammals and human sperm in vitro. *Environment International*, 185, 108509. https://doi.org/10.1016/j.envint.2024.108509

2. van der Horst G, Skosana B, Legendre A, Oyeyipo P, du Plessis SS (2018). Cut-off values for normal sperm morphology and toxicology for automated analysis of rat sperm morphology and morphometry. *Biotechnic & Histochemistry*, 93(1), 49–58. https://doi.org/10.1080/10520295.2017.1380842

3. Özgen M, Take G, Kaplanoğlu İ, Erdoğan D, Seymen C M (2023). Therapeutic effects of melatonin in long-term exposure to 2100 MHz radiofrequency radiation on rat sperm characteristics. *Revista Internacional de Andrologia*, 21(4), 100371. https://doi.org/10.1016/j.androl.2023.100371

4. Shahin NN, El-Nabarawy NA, Gouda AS, Mégarbane B (2019). The protective role of spermine against male reproductive aberrations induced by exposure to electromagnetic field – An experimental investigation in the rat. *Toxicology and Applied Pharmacology*, 370, 117–130. https://doi.org/10.1016/j.taap.2019.03.009

5. Li R, Ma M, Li L, Zhao L, Zhang T, Gao X et al. (2018). The protective effect of autophagy on DNA damage in mouse spermatocyte-derived cells exposed to 1800 MHz radiofrequency electromagnetic fields. *Cellular Physiology and Biochemistry*, 48(1), 29–41. https://doi.org/10.1159/000491660

6. Xing F, Zhan Q, He Y, Cui J, He S, Wang G (2016). 1800MHz microwave induces p53 and p53-mediated caspase-3 activation leading to cell apoptosis in vitro. *PLOS One*, 11(9), e0163935. https://doi.org/10.1371/journal.pone.0163935

RF radiation worsens prognosis after oxygen deprivation

Effects of prenatal mobile phone radiation exposure on MMP9 expression: Implications for inflammation, oxidative stress, and sensory-motor impairment after neonatal hypoxia-ischemia in rats

Khayat S, Fanaei H, Lakzaee N (2023). Effects of prenatal mobile phone radiation exposure on MMP9 expression: Implications for inflammation, oxidative stress, and sensory-motor impairment after neonatal hypoxia-ischemia in rats. *Toxicology Reports*, 11, 378–384. https://doi.org/10.1016/j.toxrep.2023.10.007

Due to the widespread use of mobile phones, the biological effects of their non-ionizing radiation are of great interest. Neonatal hypoxia-ischemia (HI), which is characterized by an insufficient supply of oxygen and blood to the brain, is the leading cause of death and brain damage in newborns. Depending on the severity, long-term disabilities such as cerebral palsy, intellectual disability, and cognitive and motor disorders may result. (However, in mild cases, the newborn can develop normally; editor's note.) A lack of oxygen and blood supply to the brain leads to a cascade of events, including inflammation, oxidative stress, and energy failure, which contribute to brain damage. Matrix metalloproteinases (MMPs) play a crucial role in the pathophysiology of neonatal HI. During these events, the upregulation of MMPs can lead to increased permeability of the blood–brain barrier. This allows inflammatory cells and molecules to enter the brain, thereby worsening the condition. This study investigates whether prenatal exposure to mobile phone radiation modulates MMP formation and influences the extent of brain damage.

Study design and implementation:

Twenty pregnant Wistar rats were randomly divided into two groups: a sham exposure group and an exposure group. The exposure source was a 900 MHz mobile phone frequency simulator with a nominal output power of 2 W/kg. The maximum measured power density was 0.45 mW/m² at a distance of 20 cm from the transmitting antenna. The test animals were exposed for 12 hours per day throughout their pregnancies. Immediately after birth, the male offspring were divided into four test groups (n = 20). The groups were labeled as follows: SHAM (surgery without injury to the right carotid artery), EXP (exposure plus surgery without injury to the carotid artery), HI (hypoxia induced by occlusion of the right carotid artery), and HI/EXP (exposure plus hypoxia induced by occlusion of the right carotid artery). Neurobehavioral tests (cliff avoidance and negative geotaxis) were performed 15 days after birth. Then, the brains of the rat pups were removed and analyzed. The scientists evaluated infarct volume, cerebral edema, and the expression of MMP-2 and MMP-9 mRNA (RT-qPCR), as well as TNF-α and the oxidative and antioxidant capacities (TOC/TAC). Statistical analysis was performed using Bonferroni-corrected ANOVA.

Results:

There were no significant differences in any of the molecular biological markers (MMPs, TNF-α, and TOC/TAC) between the sham and EXP groups. However, the HI and HI/EXP groups showed statistically significant differences for all markers except MMP-2. Combining HI with exposure was also associated with worse neurobehavioral test results, a larger infarct volume, and greater cerebral edema than HI alone. Infarct size and cerebral edema increased, and performance in behavioral and sensorimotor tests worsened. Animals exposed without HI showed no noticeable changes in this regard.

Conclusions:

The data in this publication suggest that prenatal exposure to mobile phone radiation is associated with a poorer prognosis for hypoxic-ischemic encephalopathy. The literature describes how an unphysiological change in MMP-9 expression, as observed here, can result in irreparable neuronal damage [1, 2]. Consistent with the present study's findings, an in vitro study found that mobile phone radiation can modulate MMP expression [3]. The authors hypothesize that exposure to mobile phone radiation in utero, in the context of hypoxic-ischemic encephalopathy, led to increased MMP-9 expression, which then damaged the integrity of the blood–brain barrier. This results in immune cell infiltration, oxidative stress, and pro-inflammatory cytokines, promoting ischemic damage and cerebral edema.

Editor's note:

The strengths of the work presented include its relevant design with appropriate sample size (prenatal exposure, investigation of the leading cause of neonatal death) and with the investigation of multiple biochemical and morphological endpoints as well as associated neurobehavioral tests. Limitations include an inability to quantify the absorbed dose in the embryo, low measured overall power density, and a lack of long-term data. (RH)

1. Reinhard S M, Razak K, Ethell IM (2015). A delicate balance: role of MMP-9 in brain development and pathophysiology of neurodevelopmental disorders. *Frontiers in Cellular Neuroscience*, 9, 280. https://doi.org/10.3389/fncel.2015.00280

2. Salah MM, Abdelmawla MA, Eid SR, Hasanin RM, Mostafa EA, Abdelhameed MW (2019). Role of Matrix Metalloproteinase-9 in Neonatal Hypoxic-Ischemic Encephalopathy. *Open Access Macedonian Journal of Medical Sciences*, 7(13), 2114–2118. https://doi.org/10.3889/oamjms.2019.618

3. Azimipour F, Zavareh S, Lashkarbolouki T (2020). The effect of radiation emitted by cell phone on the gelatinolytic activity of matrix metalloproteinase-2 and -9 of mouse pre-antral follicles during in vitro culture. *Cell Journal*, 22(1), 1–8. https://doi.org/10.22074/cellj.2020.6548

Protection against prenatal RF radiation damage

Maternal linalool treatment protects against radiofrequency wave-induced deteriorations in adolescent rats: A behavioral and electrophysiological study

Azimzadeh M, Noorbakhshnia M (2024). Maternal linalool treatment protects against radiofrequency wave-induced deteriorations in adolescent rats: A behavioral and electrophysiological study. *Scientific Reports*, 14(1), 17257. https://doi.org/10.1038/s41598-024-68103-5

The prenatal period is a critical phase of brain development. During this time, the brain is highly susceptible to stress factors, such as RF radiation from mobile phones. Numerous studies indicate that mobile phone radiation can cause anxiety, cognitive impairment, disturbances in calcium homeostasis, and increased permeability of the blood–brain barrier. The blood–cerebrospinal fluid barrier and the cerebrospinal fluid–brain barrier regulate trace element balance in the brain via complex mechanisms. Copper (Cu), manganese (Mn), iron (Fe), and zinc (Zn) are essential for physiological function and brain development. These elements, among other things, regulate gene expression, act as enzyme activators, and protect against the formation of reactive oxygen species (ROS). Disrupting the homeostasis of these trace elements can lead to neurodegenerative diseases such as Alzheimer's or Parkinson's disease. Linalool, a monoterpene found in essential oils, is used in naturopathy. It is said to have antioxidant, anti-inflammatory, and anxiolytic properties. This study investigates the effects of intrauterine mobile phone exposure on adolescent rats and the potential protective effects of linalool.

Study design and implementation:

Twenty pregnant female rats were randomly divided into four groups of five rats each (n = 5): 1. Control Group (saline); 2. Linalool Group (25 mg/kg linalool); 3. Exposed Group (RF radiation exposure + saline); and 4. Exposed + Linalool Group (RF radiation exposure + 25 mg/kg linalool). The exposure source was a commercial 900 MHz GSM mobile phone (Nokia 1616) with the following manufacturer specifications: SAR value 1.19 W/kg (head) and 0.32 W/kg (whole body). The daily exposure duration during the entire gestation period (21 days) was 1 hour and 40 minutes. Mobile phone radiation was generated by 100 missed calls per day, with the phone placed 20 cm from the cages. Three to five offspring per mother were placed in sex-separated cohorts (n = 10) for subsequent analysis. Behavioral tests (elevated plus maze, Morris water maze, and light-dark box) were performed on day 50 after birth. Electrophysiological tests were performed on brain neurons on day 60 after birth. We examined

the excitability of hippocampal neurons using an input/output protocol and long-term potentiation with 100 Hz stimulation of Schaffer collaterals. Next, we quantified the trace elements copper (Cu), manganese (Mn), iron (Fe), and zinc (Zn) in the hippocampus. Statistical analyses were performed using ANOVA with the appropriate post hoc tests. All examinations were performed on a gender-specific basis.

Results:

In neurobehavioral tests, offspring exposed prenatally (Group 3) exhibited statistically significant differences compared to the control group (Group 1). Both male and female animals exhibited anxiety-like behaviors, as well as impaired spatial learning and memory. The female animals were more severely affected than the males. Maternal linalool treatment greatly reduced the harmful effects of mobile phone radiation exposure, often bringing them down to the level of the unexposed control group. Electrophysiological examinations revealed significantly reduced excitability of hippocampal neurons, accompanied by impaired induction and maintenance of long-term potentiation, in Group 3 compared to Group 1. No sex-based differences were observed. Once again, maternal administration of linalool led to significant improvements in electrophysiological findings, bringing them to the level of the control group. The homeostasis of the examined trace elements in the hippocampus was disturbed in a statistically significant manner: Fe, Cu, and Mn increased significantly, while Zn decreased significantly. With the exception of Zn, maternal linalool treatment restored homeostasis. This also significantly improved the Cu/Zn ratio.

Conclusions:

In a rat model, prenatal exposure to a commercial mobile phone can cause substantial and persistent damage in both sexes. This damage includes impaired neuronal excitability and synaptic plasticity, both of which are associated with altered behavior and cognitive performance. The authors suggest that oxidative stress or increased blood–brain barrier permeability is responsible for altered trace element homeostasis. The Cu/Zn ratio is an indicator of inflammation and oxidative stress. According to the authors, the documented neuroprotective effect of linalool may be related to its antioxidant properties or its ability to increase synaptic plasticity.

Editor's note:

The multimodal design of the study, which includes neurobehavioral, electrophysiological, and biochemical analyses, as well as gender-specific data, yields robust results. Earlier studies in various species have confirmed the observed harmful effects of mobile phone radiation [1–3]. Although dosimetric verification of the RF radiation level was not performed because the RF radiation was generated by a commercial mobile phone that falls below international limits, this is a realistic exposure scenario. Due to the simplicity of the exposure parameters, the study can be easily reproduced. (RH)

1 Deniz ÖG, Kaplan S (2022). The effects of different herbals on the rat hippocampus exposed to electromagnetic field for one hour during the prenatal period. *Journal of Chemical Neuroanatomy*, 119, 102043. https://doi.org/10.1016/j.jchemneu.2021.102043

2 Qin TZ, Wang X, Du JZ, Lin JJ, Xue YZ, Guo L et al. (2024). Effects of radiofrequency field from 5G communications on the spatial memory and emotionality in mice. *International Journal of Environmental Health Research*, 34(1), 316–327. https://doi.org/10.1080/09603123.2022.2149708

3 Dasgupta S, Wang G, Simonich MT, Zhang T, Truong L, Liu H et al. (2020). Impacts of high dose 3.5 GHz cellphone radiofrequency on zebrafish embryonic development. *PLOS One*, 15(7), e0235869. https://doi.org/10.1371/journal.pone.0235869

Q10 protects against RF-induced fertility damage

Ameliorative role of coenzyme Q10 in RF radiation-associated testicular and oxidative impairments in a 3.5-GHz exposure model

Bektas H, Yildirim S, Cakir S, Dogu S, Altindag F (2026). Ameliorative role of coenzyme Q10 in RF radiation-associated testicular and oxidative impairments in a 3.5-GHz exposure model. *Bioelectromagnetics*, 47(1), e70043. https://doi.org/10.1002/bem.70043

Numerous studies have shown that radiofrequency electromagnetic fields (RF-EMFs), such as those emitted by mobile devices, can trigger oxidative stress reactions at the cellular level. RF-EMFs may interact with ion channels and receptors on cell membranes, leading to increased production of reactive oxygen species (ROS) and inhibited antioxidant defenses. Coenzyme Q10 plays a vital role in electron transport in mitochondria and is crucial for adenosine triphosphate (ATP) production. It also acts as a powerful antioxidant, protecting cell membranes and DNA from oxidative damage. This study examined the impact of 3.5 GHz GSM radiation on the male reproductive system and the possible protective effects of CoQ10 in a rat model.

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Study design and implementation:

Twenty-eight adult male Wistar rats were randomly divided into four groups of seven (n = 7): 1) Sham-exposed, 2) RF-exposed, 3) Sham-exposed + Q10, 4) RF-exposed + Q10. All groups were exposed to 3.5 GHz GSM radiation for two hours daily over a period of 30 days. The numerical model used to calculate the specific absorption rate (SAR) was validated by comparing simulated and measured field strengths. The whole-body SAR was 0.17 W/kg, while the testis-specific SAR was 0.027 W/kg. Temperature monitoring was performed. The scientists determined the following parameters: hormonal (testosterone, LH (luteinizing hormone), and FSH (follicle-stimulating hormone)), oxidative (MDA (malondialdehyde), GSH (glutathione), TAS (total antioxidant status), and TOS (total oxidative status)), and histopathological. Statistical analysis was performed using ANOVA with an appropriate post hoc test.

Results:

Exposure to GSM radiation resulted in significant reductions in testosterone, LH, and FSH levels. Administering Q10 significantly mitigated the RF effect on LH and testosterone levels; however, no effect was observed for FSH. Statistically significant differences in oxidative stress markers were observed between 3.5 GHz exposure and sham exposure. MDA and TOS increased, while TAS decreased. GSH was not significantly affected. In this case, the administration of coenzyme Q10 also had a mitigating effect. Histologically, disorganization of the seminiferous tubules, degeneration of the germ epithelium, and a statistically significant decrease in the Johnsen score (an assessment of spermatogenesis) were observed. Although administering Q10 reduced histological damage, it did not reverse it completely to the level of the control group.

Conclusions:

The results suggest that chronic exposure to 3.5 GHz GSM radiation may induce oxidative stress in testicular tissue and disrupt the hypothalamic-pituitary-gonadal axis in a rat model. Consequently, changes in important reproductive characteristics were observed. The exposure parameters were selected to rule out thermal effects. Coenzyme Q10 exerts partial protection by acting as an antioxidant to maintain testosterone levels and redox balance. Overall, the results underscore the vulnerability of the male reproductive system to non-thermal effects of mobile phones. However, the authors emphasize that no conclusions should be drawn about the effects of real 5G signals due to the GSM modulation used in this study.

Editor's note:

Thanks to its integrative design, which combines hormonal, biochemical, and histological analyses, the study is convincing. The clear documentation of non-thermal exposure conditions and transparent classification of results within the context of signal modulation (GSM vs. 5G) are also notable strengths. The use of a 5G carrier frequency of 3.5 GHz in conjunction with GSM modulation may be due to the prohibition of transmitting genuine 5G signals without authorization, as this could cause interference. In any case, this study contributes to the growing body of scientific evidence showing that radiofrequency electromagnetic fields (RF-EMFs) of various frequencies are harmful to the male reproductive system [1–3]. (RH)

1 Yu G, Tang Z, Chen H, Chen Z, Wang L, Cao H et al. (2020). 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. *The Science of the Total Environment*, 698, 133860. https://doi.org/10.1016/j.scitotenv.2019.133860

2 Cordelli E, Ardoino L, Benassi B, Consales C, Eleuteri P, Marino C et al. (2024). Effects of radiofrequency electromagnetic field (RF-EMF) exposure on male fertility: A systematic review of experimental studies on non-human mammals and human sperm in vitro. *Environment International*, 185, 108509. https://doi.org/10.1016/j.envint.2024.108509

3 Kaur P, Rai U, Singh R (2023). Genotoxic risks to male reproductive health from radiofrequency radiation. *Cells*, 12(4), 594. https://doi.org/10.3390/cells12040594

Wi-Fi causes transgenerational damage

From adults to offspring: Wi-Fi RF-EMR exposure in adult zebrafish impairs reproduction and transgenerationally effects development and behavior of progeny

Mehta J, Khira R, Fumakiya S, Sharma P, Punekar A, Jain C et al. (2025). From adults to offspring: Wi-Fi RF-EMR exposure in adult zebrafish impairs reproduction and transgenerationally effects development and behavior of progeny. *The Science of the Total Environment*, 1008, 180982. https://doi.org/10.1016/j.scitotenv.2025.180982

The biological effects of radiofrequency electromagnetic fields (RF-EMFs), especially those from Wi-Fi, are complex and sometimes contradictory. This makes it difficult to draw clear conclusions. Nevertheless, an increasing number of studies describe oxidative stress resulting from Wi-Fi exposure. Model organisms, such as fish, amphibians, and insects, have antioxidant protection systems comparable to those of mammals, albeit weaker, as well as limited repair mechanisms. These systems are especially important in early developmental stages and in germ cells, which are more sensitive to external stressors. Due to the ongoing scientific debate about the effects of RF-EMFs and increased sensitivity, model organisms such as zebrafish (*Danio rerio*) are valuable for evaluating the impact of stress factors on development. Despite significant differences between amniotic and freshwater environments, the highly conserved nature of vertebrate developmental pathways establishes zebrafish as a valid model for evaluating EMF-induced effects on development and germ cells. This includes applying these results to human health. This study analyzes the effects of EMF exposure on the reproductive systems of adult zebrafish and on the development and behavior of their offspring.

Study design and implementation:

Adult zebrafish were exposed to the Wi-Fi field of a commercial router for up to 30 days, four hours per day, in a controlled laboratory setting. The router's duty cycle was based on the Wi-Fi duty cycle measured during a 1080p video stream at 6 Mbps (e.g. YouTube). Scientists performed extensive dosimetric analyses. Depending on their position within the aquarium, the specific absorption rate (SAR) ranged from 0.716 to 2.59 W/kg and the power density ranged from 1.9 to 6.8 W/m^2. The water temperature was kept constant to rule out thermal effects. Control animals were exposed to sham radiation. After 10, 20, and 30 days, adult zebrafish were randomly selected for reproduction. The resulting embryos were cultivated without further exposure. This experiment was repeated three times to generate statistically robust data. To more reliably evaluate the effects of Wi-Fi exposure, clutch or tank were included as random effects in the statistical models. Histomorphological examinations of the ovaries and testes of the parent animals were performed in a blinded manner. To evaluate stress, anxiety, and cognitive function in the offspring, their hatch and mortality rates, as well as morphological and behavioral abnormalities, were examined.

Results:

The scientists found evidence of Wi-Fi-induced impairment of gametogenesis (germ cell formation and maturation) in the exposed adult animals. Compared to the control group, the exposed female animals showed a significant increase in atretic follicles and disrupted stroma architecture, along with a decrease in healthy egg cells. Male animals showed pronounced degenerative changes in their testes, including disorganization of the seminiferous tubules and a significant decrease in spermatogonia and sperm. Dose–response effects of Wi-Fi were observed in the offspring. There was a statistically significant increase in embryonic mortality and morphological malformations. Neurobehavioral tests revealed significant changes, including reduced locomotor activity, heightened stress and anxiety responses, and diminished cognitive performance.

Conclusions:

This study provides consistent evidence that exposure to Wi-Fi can cause structural damage to the reproductive organs of adult zebrafish. This damage can have adverse effects on offspring across generations. Damage to both parental and offspring generations shows a dose–response relationship. The authors discuss oxidative stress, mitochondrial dysfunction, and epigenetic changes as potential mechanisms of Wi-Fi-induced damage.

Editor's note:

The work presented is characterized by a structured design, defined and controlled exposure parameters, and multimodal analyses, including histological, developmental biological, and neurobehavioral analyses. A notable strength is the realistic exposure scenario, which involves four hours of daily video streaming via Wi-Fi combined with comprehensive dosimetry. Temporal staggering enables one to draw conclusions about the progression of the effect. The reliability of the findings is increased by independently repeating the offspring experiments and conducting blinded histological examinations. However, the study is limited by the small number of adult animals examined. Ideally, molecular markers of oxidative stress or epigenetic changes would have been investigated as well. These markers could have provided insight into the underlying mechanistic factors. Nevertheless, the study provides relevant evidence of germline vulnerability to radiofrequency radiation resulting in persistent damage to offspring. (RH)

EMF and insects

Behaviour and reproduction of *Drosophila* melanogaster exposed to 3.6 GHz radiofrequency electromagnetic fields

De Boose P, Ribas FO, Bell D, Bouga M, De Borre E, Fröhlich J et al. (2025). Behaviour and reproduction of *Drosophila* melanogaster exposed to 3.6 GHz radio-frequency electromagnetic fields. *PLOS One*, 20(12), e0336228. https://doi.org/10.1371/journal.pone.0336228

Given that insect populations and biodiversity are already under considerable pressure, it is crucial to investigate factors that could further exacerbate their decline. Previous studies have examined the effects of radiofrequency electromagnetic fields (RF-EMFs) on *Drosophila* fruit flies. The Panagopoulos group at the University of Athens, for example, conducted a series of studies on the fertility of fruit flies exposed to low, non-thermal RF-EMF levels between 0.1 and 6 GHz. Other studies have examined the impact of RF-EMF exposure on the ovaries of female *Drosophila* within the same frequency range. (These earlier studies used devices that emit pulsed EMF, primarily 1G, 2G, or DECT; editor's note.) The study presented here was conducted by a European research team that examined adult *Drosophila* fruit flies using RF dosimetry and tests of locomotor activity, circadian rhythm, and fertility at 3.6 GHz. This study quantifies the absorbed power levels in this species for the first time using numerical simulations.

Study design and implementation:

Computer models of *Drosophila* were created using microCT scans. These models were used to estimate the actual energy absorbed by tissue. To expose the fruit flies, a directional antenna emitting a pure, not pulsed 3.6 GHz frequency (similar to 5G NR, but without the variable pulses of a real 5G signal) was used. The antenna was connected to a signal generator and positioned 25 cm from the fruit flies. During behavioral experiments, the fruit flies were exposed to 3.6 GHz RF-EMF and their activity and circadian rhythms were studied. The flies were exposed for 5 days, 12 hours per day. In fertility experiments, reproductive performance was tested under continuous exposure to 3.6 GHz. Ten male and ten female fruit flies were placed in six test tubes and exposed for 48 hours. Absorbed power levels were estimated using simulations and in situ electric field measurements.

Results:

This study used a digital 3D model to estimate the absorption of RF-EMFs by adult fruit flies. Maximum absorption occurred at approximately 90 GHz, with 1 V/m equaling 6 nW. No effects on locomotor activity were observed at absorbed power levels between 3.56 and 9.88 nW (an electric field of approximately 5.5 to 9 V/m). In addition, no effects on fertility were observed at 1.91 mW over a 48-hour period.

Conclusions:

A digital 3D model of *Drosophila* allows for more precise dosimetry of radiofrequency electromagnetic fields (RF-EMFs) when studying their biological effects. Calculations of absorbed power reveal fluctuations based on frequency, polarization, and distance. In behavioral and fertility experiments in which fruit flies were exposed to 3.6 GHz RF-EMFs, no significant changes in locomotor activity, circadian rhythm, or reproduction were observed. These results suggest that exposure to this level of RF-EMFs does not cause biological effects. However, it was hypothesized that there was no significant heating. The model allows accurate simulation of RF-EMF exposure. Next, the researchers plan to test higher frequencies and immature stages (larvae or pupae).

Editor's note:

From a methodological standpoint, this is a well-conducted study representing significant progress in this field. Using 3D modeling to calculate either absorption hotspots or general absorption efficiency, depending on the RF-EMF frequency, enhances our understanding of the subject. The international collaboration is also encouraging. While the study found slight differences between the exposed and control groups in some cases, post hoc tests revealed that these differences were not significant, classifying them as "no effect," which is methodologically acceptable. However, compare this with Cappucci (2022), who found clear signs of harm and used a real Wi-Fi signal at 2.4 GHz [1]. The study's only notable shortcoming is that it used a pure 3.6 GHz frequency from a signal generator rather than a real 5G signal from a "5G small cell," next-generation NodeB, or 5G device. Many previous studies cited by De Boose et al., especially those by the Margaritis and Panagopoulos group in Athens, used real 1G, 2G, or DECT devices and found clear signs of reproductive damage. In several studies, Panagopoulos used real signals from devices, as well as Helmholtz coils and signal generators, in the same experimental setup. The real signals were significantly more harmful on multiple occasions [2]. The exact mechanism has not yet been identified, but Panagopoulos and Yakimenko have described a potential mechanism that has been independently confirmed several times. Héroux recently published an insightful analysis of the physics of thermal absorption, postulating that the crest factor of the signal is crucial for biological effects. Ideally, future studies by this European group will use a wider range of frequencies, realistic modulations, and actual 5G signals. (AT)

1 Cappucci U, Casale AM, Proietti M, Marinelli F, Giuliani L, Piacentini L (2022). WiFi related radiofrequency electromagnetic fields promote transposable element dysregulation and genomic instability in *Drosophila melanogaster*. *Cells*, 11(24), 4036. https://doi.org/10.3390/cells11244036 (Reviewed in ElektrosmogReport 1/2023)

2 Panagopoulos DJ (2019). Comparing DNA damage induced by mobile telephony and other types of man-made electromagnetic fields. *Mutation Research / Reviews in Mutation Research*, 781, 53–62. https://doi.org/10.1016/j.mrrev.2019.03.003 (Reviewed in ElektrsmogReport 2/2022)

3 Panagopoulos DJ, Yakymenko I, De Iuliis GN, Chrousos GP (2025). A comprehensive mechanism of biological and health effects of anthropogenic extremely low frequency and wireless communication electromagnetic fields. *Frontiers in Public Health*, 13, 1585441. https://doi.org/10.3389/fpubh.2025.1585441 (Reviewed in ElektrosmogReport 3/2025)

4 Héroux P (2025). The collision between wireless and biology. *Heliyon*, 11(10). https://doi.org/10.1016/j.heliyon.2025.e42267 (Reviewed in ElektrosmogReport 4/2025)

Mobile phone radiation alters brain activity

Modulation of brain functional connectivity in healthy young adults following GSM radiofrequency exposure: A magnetoencephalography and magnetic resonance imaging study

Iranfar S, Wallace J, Selmaoui B, Yahia-Cherif L (2025). Modulation of brain functional connectivity in healthy young adults following GSM radiofrequency exposure: A magnetoencephalography and magnetic resonance imaging study. *Neuroscience*, 591, 103–109. https://doi.org/10.1016/j.neuroscience.2025.11.007

Due to the widespread use of wireless communication technologies and the proximity of mobile phones to the head, it is important to consider the potential impact of radiofrequency electromagnetic fields (RF-EMFs) on brain physiology. Previous studies have shown that alpha brain waves (8–12 Hz) are particularly sensitive to mobile phone radiation. (Alpha waves typically occur in healthy, awake adults with their eyes closed during periods of rest. The alpha rhythm is associated with cognitive and visual relaxation; editor's note). However, previous studies of brain activity have been limited to electroencephalography (EEG) analyses, which primarily examine the strength of brain activity in different frequency ranges. To determine whether mobile phone radiation influences the interaction between different brain regions, magnetoencephalography (MEG) is necessary. This study is the first to investigate the effects of mobile phone radiation on connectivity between different brain regions using MEG. Connectivity refers to the interaction and coordination between different groups of neurons when the brain processes information. MEG can determine how well the electrical oscillations of different brain regions synchronize over time and if they operate in synchrony.

Study design and implementation:

Thirty-two healthy subjects (15 men and 17 women with an average age of 25 years) participated in a randomized, double-blind, counterbalanced crossover procedure consisting of two sessions one week apart. Each test session included a baseline phase, an exposure phase, and a post-exposure phase. The exposure phase lasted 25 minutes and 30 seconds. Two Nokia 6650 mobile phones (GSM at 900 MHz with 217 Hz modulation) served as the RF radiation source. One phone was a "dummy device" that did not emit RF radiation. The measured SAR value, averaged over 10 g of tissue, was 0.7 W/kg. The mobile phone was placed on the left ear of the test subjects. MEG measurements were performed before and after the exposure phase. Functional connectivity was calculated using cIPLV, which quantifies phase synchronization. The brain was divided into 68 regions, resulting in a total of 2,278 compared connections (each region compared with every other region). A two-way ANOVA test with Bonferroni correction was performed for statistical analysis.

Results:

The results show that mobile phones modulate connectivity in a statistically significant manner. After applying the Bonferroni correction, three connections within the right hemisphere showed a statistically significant decrease when comparing the sham-exposed group to the exposed group: 1) connectivity between the right transverse temporal cortex (rTTC) and the right entorhinal cortex (rEC), 2) connectivity between the rTTC and the right insular cortex (rIC), and 3) conncectivity between the rTTC and the right posterior cingulate cortex (rPCC). These modulations predominantly occurred in the alpha frequency range.

Conclusions:

The scientists' data revealed significant changes in connectivity values between cortical areas in the right hemisphere of the brain, particularly in and around the temporal lobe. This region contains the TTC, also known as Heschl's gyrus, which processes auditory information. The EC plays a central role in memory, the IC is involved in consciousness and emotions, and the PCC is a central hub in the brain. The authors speculate that mobile phone radiation may influence neural activity in the ear because auditory processing largely occurs contralaterally (on the opposite side of the mobile phone, which is located on the left ear).

Editor's note:

This study's strengths lie primarily in its rigorous methodology, which minimizes confounding factors and artifacts. Of particular significance is the use of magnetoencephalography (MEG) to address the lack of knowledge about how mobile phone radiation affects brain activity. However, the study has limitations, including its small sample size and focus on acute effects. A long-term study on chronic effects would also be highly relevant. (RH)

Mobile phones and breast cancer

Radiofrequency radiation from mobile phones and the risk of breast cancer: A multicenter case-control study with an additional suspected comparison group

Tahmasebi S, Mortazavi SMJ, Pourghayoomi M, Sheikhzadeh P, Welsh JS, Seif F et al. (2025). Radiofrequency radiation from mobile phones and the risk of breast cancer: A multicenter case-control study with an additional suspected comparison group. *Journal of Research in Medical Sciences*, 30, 63. https://doi.org/10.4103/jrms.jrms_679_25

Several large cohort and case-control studies have examined the relationship between mobile phone use and brain tumors. However, the results are inconclusive, and there is little evidence of an association with other malignant tumors, such as breast cancer. Current findings from large cohort studies do not support a clear link between mobile phone use and an increased overall cancer risk. To address this knowledge gap, the authors conducted a multicenter case-control study that included an additional comparison group of individuals receiving radiation therapy for suspected cancer at medical centers in Iran.

Study design and implementation:

A total of 226 women were included in the final analysis: 77 had confirmed breast cancer, 52 had suspected breast cancer, and 97 were control subjects. Although conventional case-control studies usually include more control subjects, the limited number of suitable volunteers resulted in an imbalanced ratio. Logistic regression models were used to account for this imbalance without compromising analytical validity. Trained interviewers administered a structured questionnaire that included data on demographics, reproductive history, lifestyle, and the environment. This questionnaire also included questions about the duration of mobile phone use, screen time, and phone placement. The associations were analyzed using multinomial logistic regression with sequential adjustments for demographic, reproductive, environmental, and lifestyle variables. Two multivariable models were created: Model 1 was adjusted for age, weight, education, and reproductive factors (e.g. age at menarche). Model 2 builds on Model 1 by including environmental and lifestyle variables such as exposure to pollutants, sleep habits, mobile phone use, and screen time.

Results:

Several lifestyle factors differed significantly between the groups. These factors included the number of pregnancies ($p < 0.001$), consumption of fruits and vegetables ($p < 0.001$), income level ($p = 0.017$), use of hormone therapy ($p = 0.015$), history of surgery or biopsies ($p = 0.007$), exposure to pollutants ($p = 0.036$), time spent outdoors ($p < 0.001$), duration of mobile phone calls ($p = 0.004$), screen time ($p = 0.003$), difficulty falling asleep ($p = 0.003$), and early morning awakening ($p = 0.001$). However, there were no statistically significant differences between the groups in terms of other variables, such as drug use, menopausal status, fat intake, sugar consumption, processed food consumption, radiation therapy, alcohol consumption, and physical activity.

In the fully adjusted model (Model 2), some variables were associated with a higher risk of confirmed and/or suspected breast cancer.

- Educational level was significantly associated with case status (high school: OR = 5.11 [1.5–17.9], $p = 0.011$).
- Age at menarche was a significant predictor of case status (OR = 1.39 [1.0–1.9], $p = 0.040$).
- Exposure to pollutants was strongly associated with case status (OR = 7.29 [1.9–27.8], $p = 0.004$).
- The duration of mobile phone calls was significant. More than 60 minutes of phone use was associated with both confirmed (OR = 3.49, 95% CI: 1.0–11.9, $p = 0.046$) and suspected (OR = 10.84 [2.3–51.4], $p = 0.003$) cases.
- Longer screen time (> 4 hours/day) was also associated with increased odds.

Conclusions:

This study sheds new light on how lifestyle and environmental factors – such as mobile phone use, screen time, and light-at-night exposure – may impact breast cancer development. The most consistent and robust finding was the significant association between longer daily mobile phone use and an increased risk of breast cancer. Compared to women who reported using their phones for less than 10 minutes per day, women who used their phones for more than 60 minutes per day were 3.5 times more likely to be diagnosed with confirmed breast cancer and more than 10 times more likely to be classified as suspected cases. This dose-dependent relationship strengthens the biological plausibility of a link between long-term RF-EMF exposure and breast cancer development.

In this multinomial analysis, longer mobile phone use was associated with an increased risk of both suspected and confirmed breast cancer cases. However, this association does not establish causality because exposure was not measured independently and potential confounding factors cannot be ruled out. Therefore, these results should be interpreted with caution. Larger prospective studies with objective exposure measurements are needed to clarify whether this association reflects causality or merely correlation. (AT)

Thyroid cancer and mobile phone use

Increasing incidence of thyroid cancer and use of smart phones

Lin JC (2026). Increasing incidence of thyroid cancer and use of smart phones [Health Matters]. *IEEE Microwave Magazine*, 27(1), 14–16. https://doi.org/10.1109/MMM.2025.3613612

James C. Lin, a professor emeritus, is a leading authority in the field of bioelectromagnetics. A member of the IEEE, AAAS, AIMBE, and URSI, he served as editor-in-chief of the journal Bioelectromagnetics from 2006 to 2022. Lin was also a member of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) from 2004 to 2016. In a recent review in "Health Matters," Lin summarizes the current state of knowledge on the relationship between thyroid cancer and mobile phone use. The thyroid gland is located in the center of the front of the neck. It produces thyroid hormones, which are essential for growth and metabolism. A recently updated study from Sweden suggests that exposure to microwave and radiofrequency (RF) radiation from mobile phones or smartphones could cause an increased incidence of thyroid cancer [1].

Hardell und Carlsberg 2025:

Hardell and Carlberg [1] demonstrate that the incidence of thyroid cancer has steadily increased in the adult population over the past 40 years, especially in the last 20 years. From 2000 to 2020, the incidence rate increased by a factor of 1.85 in women aged 20 to 60 and by a factor of 1.3 in men of the same age range. The main communication antenna in current-generation smartphones is typically positioned at the bottom. When holding a smartphone to the ear during a call, the antenna is closer to the thyroid gland. Consequently, the gland may receive higher levels of RF radiation than with older models of mobile phones, which had antennas located at the top of the case. However, merely observing an increased incidence of thyroid cancer in the population does not allow one to establish a direct causal link with electromagnetic fields (EMFs) from mobile phones.

Luo et al. 2019, 2020:

Lin refers to an earlier study by Luo et al. from 2019 [2] that included a cohort of about 500 cancer patients and their respective control subjects. Several groups showed a slightly increased risk of thyroid microcarcinomas compared to non-users of mobile phones, with increased odds ratios (OR) ranging from 1.2 to 1.58. The highest risk was observed among those who had used a mobile phone for more than 15 years (OR: 1.29), for more than two hours per day (OR: 1.4), and who had the most cumulative hours of use (OR: 1.58) and the most cumulative hours of calls (OR: 1.2).

A more recent cohort study from 2024 that used UK Biobank data [3] found an OR of 1.26 for men, but only an OR of 0.90 for women when comparing frequent mobile phone users to a control group of non-users. However, exposure was only roughly estimated in this study.

A follow-up study by the Luo research group investigated genetic susceptibility [4]. They found that single nucleotide polymorphisms (SNPs) within DNA repair genes modify the effects of microwave and radiofrequency radiation from mobile phone use. Their results showed that ten SNPs had a p-value < 0.01 for interaction in all thyroid cancer types. Individuals carrying SNPs associated with impaired gene repair exhibited ORs > 2 for thyroid cancer incidence. In other words, the results revealed a significant correlation between mobile phone radiation and thyroid cancer in the presence of certain genetic variants. Furthermore, this correlation increased with longer exposure and greater frequency.

Conclusions:

Since the turn of the millennium, mobile phone use, especially smartphone use, has increased significantly. In Sweden, for example, the number of mobile phone users increased more than tenfold between 2001 and 2024. Lin points out that the widespread use of computed tomography (CT) for diagnostic radiology over the past two decades has led to an apparent increase in cancer incidence due to early detection. However, early detection should also lead to a subsequent decline in incidence, which did not occur in this case. Instead, the study revealed an increasing incidence of thyroid cancer, which coincided with the thyroid gland's increased exposure to microwaves and radiofrequency radiation from smartphones during that same period. (AT)

1 Hardell L, Nilsson M, Carlberg M (2025). The increasing incidence of thyroid cancer in Sweden revisited. *Fortune Journal of Health Sciences*, 8(3), 716–722. https://doi.org/10.26502/fjhs.328

2 Luo J, Deziel NC, Huang H, Chen Y, Ni X, Ma S et al. (2019). Cell phone use and risk of thyroid cancer: a population-based case-control study in Connecticut. *Annals of Epidemiology*, 29, 39–45. https://doi.org/10.1016/j.annepidem.2018.10.004

3 Zhang Y, Zhang Y, Ye Z, Yang S, Liu M, Wu Q et al. (2024). Mobile phone use and risks of overall and 25 site-specific cancers: A prospective study from the UK Biobank study. *Cancer Epidemiology, Biomarkers & Prevention*, 33(1), 88–95. https://doi.org/10.1158/1055-9965.EPI-23-0766

4 Luo J, Li H, Deziel NC, Huang H, Zhao N, Ma S et al. (2020). Genetic susceptibility may modify the association between cell phone use and thyroid cancer: A population-based case-control study in Connecticut. *Environmental Research*, 182, 109013. https://doi.org/10.1016/j.envres.2019.109013

Antiviral EMF?

Identifying resonant frequencies of viruses for microwave-based detection and inactivation of pathogenic viruses

Kuang Z, Luginsland J, Hung CS, Stamps BW, Thomas RJ, Kelley-Loughnane N et al. (2025). Identifying resonant frequencies of viruses for microwave-based detection and inactivation of pathogenic viruses. *Scientific Reports*, 15(1), 43920. https://doi.org/10.1038/s41598-025-27669-4

The natural vibration frequencies of biological particles contain important information about their structure and properties. Biophysical methods based on resonant frequencies could be an interesting alternative to conventional vaccines and antiviral drugs. In the future, it may be possible to use radiofrequency emissions to deactivate or reduce the virulence of pathogenic viruses, such as SARS-CoV-2, by interfering with their replication or docking mechanisms. Two resonant frequencies were previously measured directly using a coplanar waveguide-based sensor: 4 and 7.5 GHz for SARS-CoV-2 and 4.2 and 7.5 GHz for HCoV-229E. However, measuring the natural oscillating frequencies of a single virion in a biological environment is challenging. Assigning structural features to the measured spectra is even more difficult. Currently, it is unclear to which components of the virus the measured resonant frequencies at 4 and 7.5 GHz correspond. Thus, the authors of this paper investigated the dynamic motion of the SARS-CoV-2 spike protein using a precise molecular dynamics simulation that considers all of the protein's atoms.

Study design and implementation:

The SARS-CoV-2 spike protein (S) is one of the four structural components of the virus. The other components are the nucleocapsid, membrane, and crown. The S protein consists of three identical chains, each containing 1,273 amino acids. Computer simulations were used to map the molecule within a physical simulation box. First, molecular dynamics (MD) simulations were performed on overlapping sections of the three chains. Then, the overlapping sections were integrated into the overall molecule. Starting from a previously equilibrated configuration, three independent MD simulations were performed. All MD simulations were performed using the NAMD 3.0 package.

Results:

The spike protein exhibited a resonant frequency between 7.3 and 7.4 GHz. Further examination revealed that this frequency corresponds to the S2 fragment, which is the part of the S protein anchored in the lipid membrane of the virus.

Conclusions:

A detailed molecular dynamics simulation revealed specific resonant frequencies and attributed the experimentally observed SARS-CoV-2 microwave absorption peaks at approximately 7.5 GHz to the intrinsic vibration of the spike protein. This differs from the dipole model of the viral envelope and core proposed by other research groups. Novel physical strategies, such as ultrasound and non-thermal microwaves, show promise for virus inactivation because they can be tuned to the resonant frequencies of specific virion structures without damaging human cells. Microwave-assisted inactivation could destroy virion structures through non-thermal effects and structural resonance energy transfer phenomena.

Editor's note:

It is encouraging that this and other related studies frequently use the term "non-thermal," presumably because the studies focus on the beneficial applications of electromagnetic fields (EMFs). However, little information is currently available on the power intensities necessary to deactivate viruses in living organisms. This information could enable groundbreaking medical applications. Now that we can satisfactorily simulate the specific resonant frequencies of viral proteins, it is important to thoroughly research their practical applicability in animal experiments. Conversely, there is the question of which macromolecules, such as those of exosomes, existing technologies might resonate with. This, too, should be thoroughly researched. (AT)

1 Sadraeian M, Kabakova I, Zhou J, Jin D (2024). Virus inactivation by matching the vibrational resonance. *Applied Physics Reviews*, 11(2). https://doi.org/10.1063/5.0183276

EMF and birds

The impact of non-ionizing radiation (NIR) on birds: Legal situation, scientific status, and recommendations for bird protection

Bächler E (2025). Zum Einfluss von nichtionisierender Strahlung (NIS) auf Vögel: rechtliche Situation, wissenschaftlicher Stand und Empfehlungen für den Vogelschutz. *Ornithologischer Beobachter*, 122(4). https://www.ala-schweiz.ch/images/stories/pdf/ob/2025_122/OrnitholBeob_2025_122_352_Baechler.pdf

A new scientific review summarizes the current state of knowledge regarding the effects of electromagnetic fields (EMFs) on birds. Non-ionizing radiation (NIR) can heat and damage bird tissue, especially that of embryos and nestlings, when emitted at close range. The scientific community has confirmed this thermal effect and determined that legal protection is necessary. Of particular concern is the installation of transmitters in buildings used as nesting sites, such as church towers. Extremely low frequency electric and magnetic fields (ELF-EF/MF, 1 Hz – 100 kHz) are generated by alternating currents or pulsed direct currents. The main sources of these fields are railway networks and power grids (50 Hz). In the radiofrequency range (100 kHz – 300 GHz), electric and magnetic field components combine and propagate as electromagnetic waves. Thermal effects only occur at high field strengths. However, scientific studies have also proven the existence of non-thermal effects in birds, such as impaired magnetic orientation and oxidative stress.

Summary of the current state of knowledge:

Extremely low frequency electric and magnetic fields (ELF-EF/MF): Studies have investigated the teratogenic effects and embryonic mortality associated with these fields. Certain genotypes react more strongly to these fields, while others are insensitive. In addition to malformations, increased ornithine decarboxylase enzyme activity, oxidative stress, and heat shock protein (Hsp70) production have been observed at low field strengths close to the system limit value [1]. Biological systems react to weak EFs/MFs and EMFs, and cryptochrome proteins are discussed as possible receptors. Cryptochromes regulate physiological processes, such as circadian rhythms and oxidative balance, and play a key role in magnetic field orientation in birds.

Radiofrequency electromagnetic fields (RF-EMFs): Weak RF-EMFs up to about 100 MHz can disrupt the magnetic compass of birds; however, the impact on migratory birds remains unclear. Engels et al. (2014) demonstrated interference at conventional RF-EMFs (20 kHz – 5 MHz), and Leberecht et al. (2022) confirmed effects up to 85 MHz and 5.6 nT [2]. Theoretically, the upper limit for influence is 116 MHz. Other studies have shown increased oxidative stress in birds at around 1800 MHz or 900 MHz. The antioxidant protective mechanisms have limits, especially in young or old individuals. Molecular evidence of non-thermal effects, such as the influence of Hsp70, underscores their importance.

Field studies: Sakraoui et al. (2024) found lower survival rates in white storks nesting near mobile phone base station antennas in Algeria [3]. Balmori and other researchers found a correlation between the breeding success of white storks and house sparrows and the intensity of mobile phone base stations (900/1800 MHz) [4]. However, these studies did not consider other factors. More recently, a study found no effect on house sparrows, whose populations increased in Switzerland. Nevertheless, it is unclear whether laboratory findings can be applied to natural conditions because organisms can partially compensate for damage. Multifactorial causes, such as genetics and the environment, also play a role.

Conclusions:

Although birds must be protected from non-ionizing radiation (NIR) according to environmental regulations, there are currently no specific regulations in place. The Swiss Ornithological Institute recommends applying the provisions of the Ordinance on the Protection Against Non-Ionizing Radiation (NISV) to birds, especially in breeding areas. Bird embryos are at risk with an increase in temperature of just 0.5°C, whereas humans can tolerate up to 1°C. These limits are too high for birds. Scientifically undisputed risks, such as thermal effects, are sometimes ignored, even by the Swiss government (www.5g-info.ch). Protecting flora and fauna requires science-based, case-by-case assessments that are updated regularly. (AT)

1 Mevissen M, Schürmann D (2021). Gibt es Hinweise auf vermehrten oxidativen Stress durch elektromagnetische Felder? Eine Zusammenfassung neuerer relevanter Tier- und Zellstudien in Bezug auf gesundheitliche Auswirkungen. Bern and Basel Universities, on behalf of Federal Office for the Environment (BAFU), Switzerland.

2 Engels S, Schneider N-L, Lefeldt N, Hein CM, Zapka M, Michalik A et al. (2014). Anthropogenic electromagnetic noise disrupts magnetic compass orientation in a migratory bird. *Nature 509: 353–356.* https://doi.org/10.1038/nature13290

Leberecht B, Kobylkov D, Karwinkel T, Döge S, Burnus L, Wong SY et al. (2022). Broadband 75–85 MHz radiofrequency fields disrupt magnetic compass orientation in night-migratory songbirds consistent with a flavin-based radical pair magnetoreceptor. *Journal of Comparative Physiology,* 208(1), 97–106. https://doi.org/10.1007/s00359-021-01537-8

3 Sakraoui D, Ziane N, Ghalem R, Boukheroufa M, Habbachi W (2023). Is there an effect of electromagnetic waves from base stations on the breeding success of Ciconia ciconia in Algeria? *Biosystems Diversity*, 31(4), 493–499. https://doi.org/10.15421/012358

4 Balmori A (2009). Possible effects of electromagnetic fields from phone masts on a population of white stork (Ciconia ciconia). *Electromagnetic Biology and Medicine*, 24(2), 109–119. https://doi.org/10.1080/15368370500205472

Industry in conflict with science

Building the gulf of opinions on the health and biological effects of electromagnetic radiation

Héroux P (2025). Building the gulf of opinions on the health and biological effects of electromagnetic radiation. *Frontiers in Public Health*, 13, 1589021. https://doi.org/10.3389/fpubh.2025.1589021

Paul Héroux is a professor at McGill University in Montreal, Canada. He specializes in environmental health, focusing on topics such as electromagnetic fields and their effects on health. He has published numerous research papers and books on these subjects. This article examines different perspectives on the health effects of electromagnetic radiation based on the author's experiences. Since the 1980s, the health effects of non-thermal electromagnetic radiation in the extremely low frequency (ELF) and radiofrequency (RF) ranges have been embroiled in controversy. Industry representatives and environmentalists rely on different expert opinions and interpretations of the same scientific literature. Over time, various perspectives on the health effects of technological electromagnetic radiation have emerged. Scientific conferences are held worldwide to discuss these effects, advance science, and form opinions. The author aims to clarify the various opinions on the health effects of electromagnetic radiation through personal accounts of conferences attended.

Adair, 1990:

After retiring, nuclear physicist Robert Adair began studying the health effects of extremely low frequency magnetic fields (ELF-MFs). His wife, Eleanor Adair, who was involved in setting standards for RF health effects, influenced this decision. At a 1991 meeting of the Bioelectromagnetics Society (BEMS), Adair argued that the health effects of ELF-MFs contradict conventional physics, including quantum mechanics. He criticized Lednev's quantum-based mechanism as “crackpot.” At an Environmental Protection Agency (EPA) meeting in April 1991, physicists agreed to delete references to Adair's article from their recommendations. However, Adair's ideas were well received at the BEMS meeting. The participants, including industry representatives and researchers, did not question his industry-friendly comments due to funding incentives and the nature of the panel presentations. In retrospect, Adair's most important argument was flawed. He had confused DC and AC fields – an oversight that went unnoticed during the discussion. Nevertheless, he presented his arguments emphatically, possibly influencing those who were already skeptical about the biological effects of ELF-EMFs. Physicists at the EPA challenged his conclusions.

Armstrong, 1994:

In 1991, Héroux developed an electromagnetic dosimeter, and in 1994, he and Armstrong published a study titled "Cancer Risks Associated with Occupational Exposure to Magnetic Fields Among Electric Utility Workers in Ontario and Quebec, Canada, and France." Héroux's dosimeter could measure power frequency electric and magnetic fields, as well as pulsed electromagnetic fields (PEMFs) and high frequency transients (HFTs). They added the PEMF-HFT detection function to expand the frequency range of the measured fields. Initially, the study focused on 60 Hz and 50 Hz frequencies. Armstrong found a strong correlation between PEMF-HFT exposure and lung cancer among utility workers. The two researchers requested an additional $50,000 to investigate a possible link between PEMF-HFT exposure and cancer, but their request was denied. They had to return all dosimeters and data to the utility company and were never permitted to use them again. After publishing with Armstrong, Héroux was asked to present his cancer research findings to the IEEE committee chaired by Eleanor Adair. He was intimidated by Ms. Adair's well-known skepticism.

The committee decided to form an investigative group. Héroux raised his hand in the hope of being selected because he had more inside information about the dosimeters and had been part of the epidemiological team. However, he was excluded from further IEEE work on PEMF-HFTs, possibly due to confirmation bias, or a lack of trust in researchers who appeared to be too independent (from industry). Limited research using Danish dosimeters followed. Uncertainty about the dosimeter readings caused the utility and telecommunications industries to distance themselves from concerns about cancer rates. In 1995, the Electric Power Research Institute (EPRI), the research arm of the electric utility industry, commissioned two companies to develop a PEMF-HFT dosimeter. However, the project failed due to the challenge of developing a compact device for epidemiological studies. The industry may have avoided focusing on transients because they could exceed thermal noise levels.

Research on PEMF-HFTs and mobile phones is challenging and costly. Uncertain results can alter safety perspectives, making further investigation unappealing to companies and government agencies. In a capitalist system, it is difficult to blame companies for this. Researchers such as Robert Becker have used PEMFs for tissue regeneration. Héroux deliberately used the term "high frequency transients" to avoid negative associations with therapeutic applications of PEMFs. However, Armstrong replaced HFT with PEMF, which displeased Becker due to possible cancer risks. Today, PEMFs are still used, but the term HFT has fallen into disuse. The dichotomy of morbidity and therapy depends on the biological context, exposure intensity, duration, and pulse rate. RF modulations and crest factors significantly impact biological results.

Lai 1997, Phillips 2009:

In 1997, Lai and Singh presented their research on DNA strand breaks caused by magnetic fields at a conference. Motorola criticized Lai's work, calling for further research. The industry ostracized Lai, demanding his dismissal from his university position. The industry often rejected biological study findings due to uncertainty. This led to mistrust between engineers and life scientists. The industry's skepticism was likely due to economic and political factors rather than scientific validity. Interdisciplinary communication remains challenging to this day. There are differing opinions on the health effects of EMFs. The industry dominates the debate by focusing on heat while neglecting biological aspects. Participation in scientific conferences is biased, and conflicting interpretations arise due to differences in education and employment.

In 2009, the author attended a conference where Dr. Phillips presented a study based on Lai and Singh's methodology, titled "Electromagnetic Fields and DNA Damage." Héroux's supervisor deemed the comet assay unsuitable, but it has since been proven to be a reliable method. Dr. Phillips quoted Francis Crick: "... scientists who hold theoretically opposed positions may engage in fruitful debate to enhance understanding of underlying principles and advance science in general ... there are external factors involving economics and politics that keep this from happening."

Héroux concludes his reflections with the following questions: “Does the specific absorption rate, a heat variable, provide more clarity than electric and magnetic fields? Should the engineering view of the problem smother its biological aspects? Can humans truly be simulated as a salt and sugar solution, as is done in SAR measurements? What of the issues of not pursuing challenging leads (Armstrong), pressuring the messengers of unwelcome observations (Lai) and undermining or underrating the techniques of biology (Phillips)?” [...] The issue of EMR health impacts was viewed as critical to industry interests at certain times, while for the bio-medical community it may have appeared less urgent. So, was the industry justified in taking control of the debate and limiting it to heat, given that they had acute interests in the outcomes? Was industry justified in publicizing its thermalist agenda through the IEEE with so many governments worldwide? Was industry justified in controlling the evolution of EMR research, using its expertise in electromagnetism to dominate the area, while the most critical elements resided in biology and medicine?” (AT)

Addresses for additional reliable information

Diagnose-Funk e. V. - Environmental and consumer organization for protection from electromagnetic radiation (Germany):
Website: diagnose-funk.org
Email: info@diagnose-funk.de

Microwave News (USA):
Website: microwavenews.com
Email: louis@microwavenews.com

Prof. Joel Moskowitz, Director of the Center for Family and Community Health, School of Public Health, Berkeley (USA):
Institute Website: publichealth.berkeley.edu/people/joel-moskowitz
EMF Website: www.saferemr.com

Prof. Devra Davis (USA):
Website: ehtrust.org
Email: info@ehtrust.org

Prof. Igor Belyaev, Biomedical Research Center of the Slovak Academy of Science, Department of Radiobiology:
http://www.biomedcentrum.sav.sk/research-departments/department-of-radiobiology/?lang=en
Shortened Link: kurzlinks.de/belyaev

Blog by Prof. Darius Leszczynski (Finland):
Website: betweenrockandhardplace.wordpress.com

Databases:

www.emfdata.org
www.emf-portal.de
www.orsaa.org