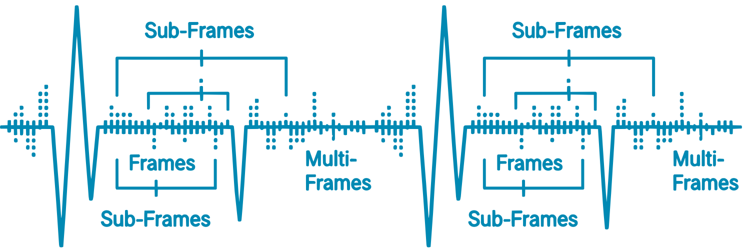
02/2026

ElektrosmogReport

Technical information on the significance of electromagnetic fields for the environment and health.



Imprint

ElektrosmogReport Issue 02/2026, Volume 32
Online publication at www.EMFdata.org

Order print edition:
shop.diagnose-funk.org/ElektrosmogReport, Order No. 52602

Editorial team ElektrosmogReport:

Roman Heeren (RH), M.Sc., Alain Thill (AT), M.Sc.
Contact: report@emfdata.org

Publisher and responsible according to § 5 TMG

Diagnose-Funk e.V. | P.O. Box 15 04 48 | D-70076 Stuttgart
kontakt@diagnose-funk.de

Donation account:

Diagnose-Funk e.V. | IBAN: DE39 4306 0967 7027 7638 00
BIC: GENODEM1GLS | GLS Bank

Your donation enables the analysis and review of the research situation as well as the continued publication of the ElektrosmogReport.

About us:

diagnose:funk is an independent environmental and consumer organization that has been campaigning for protection from electromagnetic fields since 2009.

TABLE OF CONTENT

PAGE

How many ELF pulses go into wireless communication?

Recording the extremely low frequency pulsations of wireless communication electromagnetic fields

Panagopoulos DJ, Litovsky R, Chamberlin K (2026). Recording the extremely low frequency pulsations of wireless communication electromagnetic fields. *Electromagnetic Biology and Medicine*, 1–10. https://doi.org/10.1080/15368378.2026.2654072

In the scientific literature, real-world cellular and Wi-Fi signals are often described as radiofrequency electromagnetic fields (RF-EMFs). However, this classification only partially captures the physical reality. All wireless communication signals (cellular, Wi-Fi, DECT, and Bluetooth) are transmitted in the form of discontinuous on/off pulses, also known as "frames," "multiframes," and "subframes," etc. The actual radiofrequency carrier signal is emitted in combination with extremely low frequency (ELF: 3–3000 Hz) or very low frequency (VLF: 3–30 kHz) repetition rates. In addition, signal amplitude varies greatly in the ultra low frequency range (ULF: 0–3 Hz). Mounting evidence suggests that this modulation with low frequency signals is crucial for the biological effects of real-world wireless communication technologies. Nevertheless, the current risk assessment of health authorities completely ignores this connection. This publication charts the ELF pulses of commercially available wireless devices, Wi-Fi routers, and mobile phones with LTE (4G) and New Radio (5G) technology over time.

Study design and implementation:

The scientists used a broadband UWB (ultra wideband) spiral antenna connected to an RF spectrum analyzer that was calibrated to the respective carrier frequencies: 2.45 GHz for Wi-Fi, 840 MHz for 4G, and 1876 MHz for 5G. In "zero span" mode, the spectrum analyzer operated as an oscilloscope, displaying the transmitted power as a function of time. The emission sources were a commercial Wi-Fi router (TP-Link, Wi-Fi 6) with active video streaming and a commercial mobile phone (Apple iPhone 15) in either 4G or 5G mode during a phone call. The distance between the antenna and the Wi-Fi router was 1 m, and the distance to the mobile phone was 10 cm. Ten recordings were made for each set of measurement conditions. A background measurement was performed with the emission sources turned off.

Results:

The Wi-Fi router's carrier frequency pulsed at a rate of around 10 Hz (5–20 Hz), and the pulse amplitude was around 20 dB above background noise levels. The iPhone's 4G signal exhibited a "hierarchical" pulse structure. "Subframes" (approx. 500 Hz) were contained within "frames" (approx. 100 Hz), which were then grouped into "multiframes" (approx. 3 Hz). The pulse amplitudes were 40 to 53 dB above background noise levels. The iPhone's 5G signal exhibited a similar pattern. It had subframes at around 500 Hz within frames at around 100 Hz, which were grouped into multiframes at around 13 Hz. The amplitudes were 40 to 45 dB above background noise levels. Variability in the amplitude, duration, and repetition frequency of the pulses was observed in all measured signals. Similar measurements were performed using both a Vivaldi horn antenna and the aforementioned UWB spiral antenna, and the results were comparable.

Conclusions:

This study clearly demonstrates through measurement that all examined communication signals contain ELF pulse components that vary greatly in terms of amplitude, repetition frequency, duration, waveform, etc. According to the authors, the high variability of real-world communication signals in the ELF range, combined with being fully polarized and coherent, significantly contributes to the biological activity of wireless communication technologies. Living organisms cannot adapt to highly variable, polarized, and coherent stressors. The scientists identify ion-forced oscillation at voltage-gated ion channels as the mediating mechanism. They argue that this oscillation is responsible for the non-thermal biological effects of cellular and Wi-Fi signals rather than the unmodulated radiofrequency carrier wave.

Editor's note:

This publication presents direct, time-domain measurements of the ELF pulse structures of commercially available Wi-Fi, 4G, and 5G devices. These measurements are methodologically transparent and reproducible. The strength of the testing method lies in its use of zero span mode as an oscilloscope to measure ELF signals. One limitation of this method is the resolution bandwidth of the spectrum analyzer, which can reduce the signal's amplitude. Although the frequency ranges are clearly defined, the authors do not use the ITU nomenclature. According to ITU, ULF is defined as the range from 300 to 3000 Hz, and TLF is defined as the range from 0.3 to 3 Hz. The range from 3 to 300 Hz is subdivided into ELF (3–30 Hz) and SLF (30–300 Hz). Identifying ELF components as mediators of biological potency is consistent with the studies of Jangid et al. [1, 2] in this issue of the ElektrosmogReport (EREP, 02/2026), which show that real-world wireless communication signals are more effective than generic, unmodulated radiofrequency waves. Another publication in this issue of EREP by Kim et al. [3] identifies the molecular mechanism by which ELF fields can alter gene expression rates. Though the mechanistic relationships differ between Kim's experiment and Panagopoulos's model, ion-forced oscillations and voltage-gated ion channels play a key role in both. The regulatory implications are clear. Exposure limits based on thermal effects and the specific absorption rate (SAR) are unsuitable for risk assessments of pulsed fields. A risk assessment that explicitly considers the identified mechanism of action is necessary. (RH)

1. Jangid P, Rai U, Sevak JK, Ranjan R, Singh S, Singh R (2026). Radiofrequency radiation-induced changes in Leydig cell function. *Scientific Reports*, 16, 14999. https://doi.org/10.1038/s41598-026-39244-6

2. Cellular redox disruption and apoptosis: Differential effects of RFR frequencies on Leydig cells. *Toxicology and Applied Pharmacology*, 511, 117807. https://doi.org/10.1016/j.taap.2026.117807

3. Kim J, Hwang Y, Kim S, Kwon D, Park J, Cho B et al. (2026): Electromagnetic field-inducible *in vivo* gene switch for remote spatiotemporal control of gene expression. *Cell*, 1–16. https://doi.org/10.1016/j.cell.2026.03.029

RF radiation damages testosterone-producing cells

Radiofrequency radiation-induced changes in Leydig cell function

Jangid P, Rai U, Sevak JK, Ranjan R, Singh S, Singh R (2026). Radiofrequency radiation-induced changes in Leydig cell function. *Scientific Reports,* 16, 14999. https://doi.org/10.1038/s41598-026-39244-6

Leydig cells are the primary producers of testosterone and play a crucial role in male fertility. Damage to these cells can compromise spermatogenesis and lead to testicular dysfunction. While a growing body of research suggests that radiofrequency electromagnetic fields (RF-EMF) can induce oxidative stress, mitochondrial dysfunction, and sperm abnormalities, our understanding of their direct influence on cell cycle regulation and Leydig cell proliferation remains limited. This study addresses this knowledge gap by examining frequency- and time-dependent effects.

Study design and implementation:

The authors exposed the murine TM-3 Leydig cell line to three different RF sources under non-thermal conditions: a commercial 4G mobile phone (Xiaomi Note 7, 2318 MHz, 9.25 V/m), an 1800 MHz unmodulated field from a signal generator (continuous wave, 14.69 V/m), and a 2450 MHz unmodulated field from a signal generator (continuous wave, 13.44 V/m). The specific absorption rate (SAR) value for the mobile phone was calculated to be 0.5 W/kg. Cells exposed to a sham field were used as controls. Exposure durations were 15, 30, 45, 60, 90, and 120 minutes. The temperature difference between the exposed cells and the controls was less than 0.1°C. The electric field was monitored using a Narda 520 system. The scientists investigated morphological changes using microscopy and examined cell proliferation and DNA synthesis using an enzyme-linked immunosorbent assay (ELISA) with bromodeoxyuridine (BrdU). They also analyzed the cell cycle using flow cytometry. All experiments were independently repeated three times (n = 3). The statistical analysis included one- and two-way ANOVA with a Dunnett's multiple comparisons test.

Results:

All RF sources resulted in frequency- and time-dependent morphological signs of cellular stress. These included cell rounding, loss of adherence, and reduced cell density, which is a sign of cell death. The strongest and earliest effects were observed at 2450 MHz, followed by the 4G mobile phone and 1800 MHz sources. Consistent with these findings, the BrdU assay revealed a progressive reduction in DNA synthesis, indicating decreased cell division. This reduction was statistically significant with mobile phone radiation exposure after 45 minutes, with 1800 MHz exposure after 60 minutes, and with 2450 MHz exposure after 90 minutes. However, the greatest reduction in relative cell division was observed with 2450 MHz exposure, dropping below 50% after 90 and 120 minutes. Cell cycle analysis revealed an accumulation of the cell population in the G1 phase, accompanied by a decrease in the S phase. The G2/M phase percentage remained unchanged across all conditions. These results suggest cell cycle arrest in the G1 phase.

Conclusions:

The results of this study demonstrate that non-thermal RF exposure, including that from a commercial mobile phone, can impact the morphology, division, and cycle of Leydig cells in vitro. This influence was frequency- and dose-dependent. Concurrent findings from the BrdU assay and cell cycle analysis suggest sequential damage. DNA replication is functionally inhibited, which subsequently manifests as cell cycle arrest in the G1 phase. The authors discuss oxidative stress as the mechanistic basis because they had previously observed reduced cell proliferation and testosterone production, as well as increased levels of reactive oxygen species, following RF exposure.

Editor's note:

The strengths of the present study lie in its controlled, non-thermal experimental design. This design included independently verified exposure parameters and statistically robust replication of the experiment. Notably, the DNA synthesis and cell cycle analyses are systematically coherent and support the hypothesis of progressive replication stress. Another recent study by this research group investigated the effect of various RF sources on the redox system of Leydig cells that contributes to the elucidation of the mechanistic background of the present study (see "Disruption of cellular redox balance and apoptosis: Different effects of RF frequencies on Leydig cells" [1]widely emitted from modern wireless devices, has raised questions regarding its possible impact on male reproductive health. In this comparative study, we examined the redox and apoptotic responses of TM3 Leydig cells following exposure to mobile phone radiation, as well as 2450 MHz, and 1800 MHz frequencies for 15, 30, 45, 60, 90 & 120 min, and redox imbalance was assessed by quantifying nitric oxide (NO, which is also discussed in this issue, EREP 02/26). Interestingly, despite its lower field strength, the commercial mobile phone has almost always produced more harmful effects than the 1800 MHz signal generator. Regarding cell proliferation, the mobile phone produced statistically significant effects even with the shortest exposure duration. This suggests that real-world modulated mobile phone signals have greater biological potency than continuous waves. However, the study has limitations, including the use of an in vitro cell line, which restricts its applicability to primary cells or in vivo models. The study confirms the results of earlier findings (reviewed in ElektrosmogReport) that describe the harmful effects of RF radiation on testosterone production [2–4]the specific impact of RF-EMFs on the metabolism of reproductive cells and their underlying mechanisms remain unclear. This study aims to explore the effects of RF-EMFs on the metabolism of mouse Leydig cells (TM3. (RH)

1. Jangid P, Rai U, Sevak JK, Singh S, Singh R (2026). Cellular redox disruption and apoptosis: Differential effects of RFR frequencies on Leydig cells. *Toxicology and Applied Pharmacology,* 511, 117807. https://doi.org/10.1016/j.taap.2026.117807

2. Miao X, Lin Y, Guo J, Lin J, Gao P, Zhang W et al. (2025). Differential metabolic responses of mouse Leydig and spermatogonia cells to radiofrequency electromagnetic field exposure. *Frontiers in Public Health*, 13, 1623701. https://doi.org/10.3389/fpubh.2025.1623701

3. Kaur P, Rai U, Singh R (2023). Genotoxic risks to male reproductive health from radiofrequency radiation. *Cells,* 12(4), 1–20. https://doi.org/10.3390/cells12040594

4. Maluin SM, Jaffar FHF, Osman K, Zulkefli AF, Mat Ros MF, Ibrahim SF (2024). Exploring edible bird nest's potential in mitigating Wi-Fi's impact on male reproductive health. *Reproductive Medicine and Biology,* 23(1), 1–13. https://doi.org/10.1002/rmb2.12606

RF-induced oxidative stress in testosterone-producing cells

Cellular redox disruption and apoptosis: Differential effects of RFR frequencies on Leydig cells

Jangid P, Rai U, Sevak JK, Singh S, Singh R (2026). Cellular redox disruption and apoptosis: Differential effects of RFR frequencies on Leydig cells. *Toxicology and Applied Pharmacology,* 511, 117807. https://doi.org/10.1016/j.taap.2026.117807

Leydig cells are essential for maintaining spermatogenesis because they produce testosterone. There is growing evidence that radiofrequency (RF) radiation negatively affects male fertility. This evidence suggests that oxidative stress and apoptosis are key pathological mechanisms. This study aims to conduct a systematic investigation of the frequency-specific effects of RF radiation on the redox balance and apoptosis of Leydig cells.

Study design and implementation:

The study used the murine TM3 Leydig cell line. The cells were exposed to three types of RF radiation: a 4G mobile phone (Xiaomi Note 7, 2318 GHz), an 1800 MHz signal generator (continuous wave), and a 2450 MHz signal generator (continuous wave). The exposure durations for the cell cultures were 15, 30, 45, 60, 90, and 120 minutes. (See "Radiofrequency radiation-induced changes in Leydig cell function" in EREP 02/26; the basic study design is identical; editor's note.) Temperature effects were ruled out. Nitric oxide and superoxide were quantified as markers of oxidative stress. Cell apoptosis was determined by Annexin V-FITC/propidium iodide double staining, followed by flow cytometry to detect early and late apoptotic fractions. All experiments were independently repeated three times (n = 3). Statistical analysis included one- and two-way ANOVA with a Dunnett's multiple comparisons test.

Results:

The nitric oxide concentration exhibited a frequency-specific, biphasic pattern. When the exposure source was a mobile phone, a statistically significant increase was observed after 30 and 45 minutes, followed by a transient decrease and another statistically significant increase after 120 minutes. However, when exposed to an 1800 and 2450 MHz signal generator, hardly any significant increases in nitric oxide levels were observed. Instead, significant decreases were noted after 15 minutes (in both conditions), after 30 minutes (in the 1800 MHz condition), and after 90 minutes (in the 1800 MHz condition). Intracellular superoxide levels rose progressively under all three conditions. Exposure to a mobile phone or 2450 MHz resulted in earlier and more pronounced accumulation than exposure to 1800 MHz. A progressive, statistically significant increase in total apoptotic cells was observed for all exposure sources and frequencies. Most cells exposed to mobile phones or 2450 MHz underwent early apoptosis, while most cells exposed to 1800 MHz underwent late apoptosis.

Conclusions:

This study suggests that RF radiation from various sources and frequencies can disrupt the redox balance and induce apoptosis in TM3 Leydig cells. These frequency- and source-dependent differences may point to distinct signaling pathways through which RF radiation exerts its effects. The biphasic pattern may indicate an adaptive response followed by the exhaustion of protective mechanisms. As potential underlying mechanisms, the authors discuss the release of mitochondrial reactive oxygen species (ROS), subsequent peroxynitrite formation, lipid peroxidation, and activation of apoptotic cascades.

Editor's note:

This issue of the ElektrosmogReport also discusses the "sister study" of this research group (see page 3), which is convincing due to the study design described in the accompanying review. The observations exhibit a high degree of consistency regarding the mechanistic basis (oxidative stress/apoptosis) and biological effect (reduced testosterone production). The stronger biological effect of higher or modulated frequencies (mobile phone) correlates with the described patterns of the redox and apoptosis systems. One limitation is that, although the authors identified this as a possible mechanism, they did not examine mitochondrial functional parameters (membrane potential, ATP production, and cytochrome C release). Furthermore, the exposure setup and dosimetry were not described in detail, so one must rely on the findings from the "sister study." (RH)

Key mechanism identified: EMF as a genetic switch

Electromagnetic field-inducible in vivo gene switch for remote spatiotemporal control of gene expression

Kim J, Hwang Y, Kim S, Kwon D, Park J, Cho B et al. (2026). Electromagnetic field-inducible in vivo gene switch for remote spatiotemporal control of gene expression. Cell, 1–16. https://doi.org/10.1016/j.cell.2026.03.029

Researchers have studied the ability of electromagnetic fields (EMFs) to modulate gene expression in experimental studies for years, yet a satisfactory mechanistic explanation remains elusive. The authors of this publication address this knowledge gap. While searching for a precise regulatory mechanism for gene therapy applications, they identified the protein cytochrome b5 type B (Cyb5b) as a potential sensor. They also describe, for the first time, the molecular mechanism by which extremely low frequency electromagnetic fields (ELF-EMFs) directly influence gene expression and cellular regulatory processes. Though this work originates from a medical/therapeutic approach, the editor of the ElektrosmogReport believes that it has significant implications for radiation protection.

Study design and implementation:

The authors performed single-cell RNA sequencing on murine brain cells exposed to ELF-EMFs (2.0 mT, 60 Hz). They identified the *Lgr4* gene as the only gene whose expression is consistently and reversibly altered by EMFs, regardless of tissue type. The authors then isolated an EMF-inducible element (IE) from the promoter region of the *Lgr4* gene. Using a reporter assay with a transgenic IE-coupled green fluorescent protein (GFP), they identified Cyb5b as an essential mediator. Knocking out Cyb5b completely abolished the cells' EMF response, and reintroducing Cyb5b fully restored it. Building on this finding, the scientists examined the molecular mechanisms by which Cyb5b mediates the EMF response using live cell imaging. This revealed that a rhythmic oscillatory influx of calcium ions (Ca^{2+}), mediated by the voltage-gated calcium channel Cacna1f, activate the IE. The authors subsequently validated their "gene switch" in vivo using transgenic IE-GFP and various therapeutic IE transgenes in a mouse model. Using the described ELF-EMF (2.0 mT, 60 Hz), they specifically modulated Alzheimer's phenotypes and serotonin function in depression phenotypes in the manner of a gene therapy.

Results – The mechanism:

The core component of the study relevant to radiation protection is the mechanistic decoding of the EMF signaling cascade. A series of robust reporter and knockout assays indicate that Cyb5b, a membrane-bound electron carrier primarily located in the mitochondrial membrane, functions as an EMF sensor. An applied ELF field induces a change in Cyb5b activity, which alters the redox status of voltage-gated calcium channels (VGCCs), particularly L-type VGCCs (Cacna1f). This modulates the opening probability of Cacna1f and triggers a characteristic pattern of rhythmic, sustained intracellular calcium oscillations. Only these calcium oscillations can generate the biological response, as opposed to calcium influx induced by pharmacological or physical means. This response consists of the activation of the transcription factor Sp7, which binds to the EMF-inducible element of the *Lgr4* gene and initiates *Lgr4* expression. Thus, ELF-EMF controls the formation of the *Lgr4* protein.

Results – The application in gene therapy:

To test the applicability of the IE gene switch in vivo, scientists placed various proteins under the control of the EMF-inducible element (IE) in transgenic mouse models. These proteins included OSK factors (used in regenerative medicine to reprogram cells), a pathogenic amyloid precursor protein (induces Alzheimer's disease), and Tph2 (synthesizes serotonin and is used to treat depression-like diseases). The authors were able to induce the transgenes via EMF in a targeted manner, limited by time and to specific anatomical regions. OSK therapy partially restored aging mouse models. Similarly, locally applied EMF effectively triggered pathological Aβ42 accumulation, plaque formation, and neuroinflammation in the Alzheimer's model. In the depression model, EMF exposure restored serotonergic activity and normalized depression-associated behavioral parameters.

Editor's note:

This publication stands out for its excellent methodology. It employs comprehensive screening methods, repeated validation (knockout and rescue), live cell imaging, transgenic animal models, and long-term data to establish a robust evidence chain. While the authors found no evidence of harmful effects of EMF exposure in wild-type mice, the study is highly relevant from a radiation protection standpoint. For the first time, the study provides a plausible, verified molecular mechanism through which EMF can trigger specific changes in gene expression. These mediators are voltage-gated calcium channels (VGCCs), as Pall postulated in 2013 [1]studies in the literature, reviewed here, provide substantial support for such direct targets. Twenty-three studies have shown that voltage-gated calcium channels (VGCC s. The authors interpret the observed calcium oscillations as a biological frequency code. The cell translates these specific calcium dynamics into a defined transcription program in a bioorthogonal manner. Thus, the question of whether similar signaling pathways can be activated by environmental and everyday EMF sources is more pressing than ever. It has now been demonstrated that ELF-EMFs, such as those from alternating current (50 Hz), can alter gene expression. The implications of this for other everyday EMF sources, such as wireless communication, are not yet foreseeable [2]especially those of wireless communications (WC. The authors suspect that ELF pulse modulation of the radiofrequency carrier wave plays a significant role in the biological activity of real mobile phone signals. The results show that the models underlying current exposure limits are too simplistic to make reliable predictions. For a long time, scientific publications have suggested that the biological effects of EMFs cannot be explained solely by thermal effects. Now, a key mechanism has been identified that renders the thermal dogma obsolete. However, the authors point out that more research is needed to determine the exact molecular mechanism by which EMF-induced changes in Cyb5b modulate the open state of Cacna1f. Nevertheless, the available data are robust enough to urge decision-makers to take action and reconsider existing exposure limits and the underlying models. (RH)

1. Pall ML. Electromagnetic fields act via activation of voltage-gated calcium chanels to produce beneficial or adverse effects. *Journal of Cellular and Molecular Medicine*. 17(8),958–965. https://onlinelibrary.wiley.com/doi/10.1111/jcmm.12088

2. Panagopoulos DJ, Yakymenko I, De Iuliis GN, Chrousos GP. 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://www.frontiersin.org/articles/10.3389/fpubh.2025.1585441/full

EMFs interfere with fear memory retrieval

Involvement of the primary auditory cortex-basolateral amygdala circuit in altered conditioned fear memory retrieval following electromagnetic field exposure in mice

Cui Z, Shi L, Yang M, Chang C, Jin S, Hao Y et al. (2026). Involvement of the primary auditory cortex-basolateral amygdala circuit in altered conditioned fear memory retrieval following electromagnetic field exposure in mice. Journal of Integrative Neuroscience, 25(4), 48640. https://doi.org/10.31083/JIN48640

Numerous studies have demonstrated that exposure to electromagnetic fields (EMFs) can impair cognitive function and emotional behavior. In this context, conditioned fear memory is particularly relevant because the dysregulation of this memory is a defining characteristic of post-traumatic stress disorder (PTSD). However, the impact of EMFs on the underlying neural circuits remains largely unexplored. Two key circuits involved in processing and retrieving fear memories are the primary auditory cortex (Au1) and the basolateral amygdala (BLA). This study investigates how exposure to a static magnetic field combined with radiofrequency radiation affects the Au1-BLA circuit at behavioral, structural, and signal transmission levels.

Study design and implementation:

Ten-week-old C57BL/6N mice were randomly divided into four groups: Group 1: sham-exposed control; Group 2: magnetic field exposure (MF; 100 mT for 1 h/day); Group 3: RF exposure (RF; 9.375 GHz unmodulated carrier frequency, SAR 2.58 W/kg for 15 min/day); and Group 4: combined exposure (MF and RF). Thermal effects were ruled out by rectal temperature measurements. The animals underwent auditory fear conditioning. Activation of fear memory was assessed by freezing behavior. In addition, auditory function and structural-morphological tissue changes in the Au1 and BLA regions were analyzed. Furthermore, projection neurons (Au1-BLA connection) and the calcium dynamics of Au1 and BLA neurons were investigated. To characterize their function, (CaMKII-expressing) excitatory Au1 neurons and examined their downstream excitatory and inhibitory neurons in the BLA were activated or inhibited. Depending on the analysis, six or eight samples per group (n = 6|8) were used.

Results:

Only the group exposed to a combination of MF and RF fields showed significant changes in freezing behavior after seven days, a clear sign of an impairment in fear memory. Hearing function remained unchanged. Compared to the control group, structural changes were observed in the exposed groups, including mitochondrial swelling, chromatin condensation, and endoplasmic reticulum degranulation. These changes were more pronounced in groups exposed to a combination of fields than in groups exposed to MF or RF fields alone, and in Au1 neurons than in BLA neurons. Consistent with this finding, Nissl bodies were significantly reduced in Au1 neurons exposed to a combination of fields. The connection between the Au1 and BLA areas (neuron projection) exhibited weakened signal transmission. Correspondingly, calcium activity during the fear response was significantly reduced in the combined-field group. Functionally, chemically activating excitatory Au1 neurons partially restored fear behavior and BLA calcium dynamics, while the chemical inactivation of these neurons exacerbated the phenotype. In the BLA area, combined exposure resulted in increased activation of excitatory neurons but not inhibitory neurons. This effect was attenuated by Au1 activation.

Conclusions:

The results demonstrate that exposure to a static magnetic field and RF-EMF weakens the Au1-BLA circuit functionally, impairing fear memory retrieval. Functional analysis suggests that reduced glutamatergic output from Au1, coupled with dysregulation of downstream cholinergic BLA neurons, plays a role in this impairment. The observed impairment is not due to disturbances in peripheral auditory function or initial sensory stimulus processing.

Editor's note:

The present study is distinguished by its multimodal approach. Behavioral testing, chemogenetics, calcium imaging, electron microscopy, and viral tracing of projection neurons were combined to establish a consistent chain of evidence. This study has potential clinical relevance due to its connection to post-traumatic stress disorder (PTSD). However, data from animal studies cannot be directly transferred to humans. The static magnetic field strength is below the ICNIRP safety threshold of 400 mT, and the RF-EMF's specific absorption rate (SAR) of 2.58 W/kg is in the ballpark of the permissible exposure limit for the head, which is 2 W/kg. EMF effects primarily occur synergistically, as in real-world wireless communication technologies. However, the extremely low frequency (ELF) component of wireless communication technologies differs significantly from the static magnetic field used here because it is pulsed and considerably weaker. (RH)

EMF, microtubules, and cancer therapy

Low-energy amplitude-modulated radiofrequency electromagnetic fields as a systemic treatment for cancer: Review and proposed mechanisms of action

Tuszynski JA, Costa F (2022). Low-energy amplitude-modulated radiofrequency electromagnetic fields as a systemic treatment for cancer: Review and proposed mechanisms of action. *Frontiers in Medical Technology,* 4, 869155.
https://doi.org/10.3389/fmedt.2022.869155

Liver cancer is currently the fourth leading cause of cancer-related deaths. Based on the 5-year survival rate, it is the second deadliest form of cancer. This review focuses on medical devices that emit low-power electromagnetic fields (EMFs) with a carrier frequency of 27.12 MHz and an amplitude modulation between 10 Hz and 150 kHz. The study summarizes the available evidence on the efficacy and safety of exposure to low-energy, amplitude-modulated radiofrequency electromagnetic fields (LEAMRFEMF) in patients with liver cancer. The emitted power is too low to cause noticeable tissue heating. Rather, the effects of LEAMRFEMF exposure are based on the resonant interactions of electromagnetic waves with subcellular structures in normal and cancerous human cells. Within cells, charged molecules are distributed across membranes, creating electrical and chemical potential differences similar to those in a battery. These potential differences generate the forces that move ions, which underlie nearly all physiological processes in cells. Cells also contain highly charged macromolecular structures, including microtubules (MTs). In addition to their known role in cell division, microtubules propagate electrical signals within cells.

Study design and implementation:

The study reports on two medical LEAMRFEMF devices operating at 27.12 MHz: P1 (TheraBionic GmbH, Ettlingen, Germany) and AutEMdev (Autem Therapeutics, Hanover, New Hampshire, USA). These devices have a power output of 100 mW, which is about 1,000 times lower than a cell phone and 100,000 times lower than devices used for thermal tumor ablation. The specific absorption rate (SAR) is 1.77 mW/kg. Furthermore, the frequency ranges differ from those used in telecommunications. Both devices use sinusoidal amplitude modulation of the carrier wave. The AutEMdev uses frequencies between 10 Hz and 20 kHz, while the P1 uses frequencies between 0.1 Hz and 150 kHz. The devices' physiological and therapeutic effects may be due to the fixed 27.12 MHz carrier wave and amplitude modulation. The authors hypothesize that electromagnetic waves at these frequencies resonate with the vibrations of charged macromolecular structures and ionic currents within cells, much like a bell resonates when exposed to sound waves of the correct frequency. This means that although the device's antenna is placed in the patient's mouth, the entire human body also becomes an antenna. With the exception of bones, the effects of exposure are distributed throughout the body.

Results:

The first reported potential clinical benefit of LEAMRFEMF is its ability to promote sleep in patients with insomnia. The effect of radiofrequency EMF on the human brain's alpha waves, which oscillate at 8 to 13 Hz, could explain these observations. Two in vitro studies found that growth inhibition of liver cancer cell lines occurred more readily at previously identified liver cancer-specific frequencies than at breast cancer-specific or randomly selected frequencies. Evidence suggests that calcium influx via the voltage-gated CACNA1H calcium channel is involved in the anticancer effects. To date, five reports have been published in which the AutEMdev or P1 device were used in patients with liver cancer. A pooled analysis revealed that the median overall survival (OS) for patients who received the TheraBionic P1 device treatment as first-line therapy was 6.7 months, which is slightly higher than the 4.6-month median OS for historical control patients who received sorafenib chemotherapy. These results led to the initiation of a larger, multicenter clinical trial, which yielded similar results. Studies with the AutEMdev and P1 device provided evidence of antitumor efficacy and/or maintenance or improvement of health-related quality of life in patients who continued treatment. The prospective study cohort had longer overall survival than the control group. Apart from mild fatigue and occasional irritation of the oral mucosa (when combined with standard chemotherapy), the treatment is free of side effects.

Conclusions:

Carcinogenesis can be viewed as a phase transition in which normally synchronized, homogeneous, and differentiated cells in ordered tissues become asynchronous, heterogeneous, dedifferentiated, and proliferative cancer cells in disordered tumors. Resting membrane potentials are also altered (significantly reduced), and metabolism shifts from oxidative phosphorylation to glycolysis. Nearly all cells possess a resting membrane potential, and voltage-gated ion channels are present in non-excitable cells as well. (These ion channels are located in cell and mitochondrial membranes. Microtubules form a "cabling" system that extends within the cell and docks onto the membranes or ion channels; editor's note.) Microtubules conduct electrical currents via surrounding counterions and are more conductive than the cytoplasm. Therefore, they act as a main pathway for ionic wave propagation in the cell. The resonant coupling of electromagnetic fields (EMFs) with microtubules, whereby microtubules act as cellular biological antennas, could form the basis for medical applications of EMFs. Disrupting ionic currents in microtubules could impair cell division and the subcellular mitochondrial trafficking. Microtubules are highly conductive to alternating currents at frequencies near the 27.12 MHz carrier wave of medical LEAMRFEMF devices in the longitudinal direction. The carrier wave likely amplifies ionic currents along microtubules, making cells susceptible to amplitude modulation at lower frequencies. LEAMRFEMF can shift the metabolism of cancer cells away from glycolysis, thus restoring the normal phenotype. The authors calculated the energy dissipated per cell due to EMF-induced ionic currents in microtubules and compared it to total metabolic energy production per cell. They concluded that the energy input from the treatment could significantly contribute to shifting the cellular energy balance from glycolysis toward fatty acid oxidation. Estimates of about 50 fW for the EMF power emitted per cell correspond to about 1.5% of the metabolic power in normal cells. In liver cancer cells, mitochondrial oxidative phosphorylation can be reduced by up to 50%. The human liver normally consumes about 15 W (or 15% of the body's total metabolic energy). Since glycolysis is nine times less efficient than oxidative phosphorylation, cells must increase their glucose consumption by the same factor to maintain the same energy yield. Consequently, 50 fW per cell can account for up to 13.5% of glucose consumption in glycolytic cells compared to 1.5% in cells undergoing oxidative phosphorylation. The authors demonstrated that the frequency of charge transfer via isolated microtubules in vitro (around 30 Hz) falls within the amplitude modulation frequency range of therapeutic LEAMRFEMF devices. Resonant coupling can generate oscillating ionic currents in the condensed ions surrounding and within the microtubules. These currents can then disrupt ion channels, cell division, motor proteins, mitochondrial trafficking and morphology, and cellular energy balance. These presumed mechanisms of action potentially overlap and are not mutually exclusive. Further investigation of these mechanisms is required. The authors conclude that exposure to LEAMRFEMF is a potential method of altering the behavior of cancer cells in patients with advanced disease.

Editor's note:

Although many details remain unclear, this is a promising approach. Since this electromagnetic method of fighting or slowing the progression of cancer has virtually no side effects, further research into this biomedical application of EMF would be highly desirable. (AT)

EMF, microtubules, and the brain

Differences in brain microtubule electrical activity of the hippocampus and neocortex from the adult rat

Cantiello HF, Porcari CY, Albarracín VH, Murphy D, Mecawi AS, Godino A et al. (Nov 18, 2025). Differences in brain microtubule electrical activity of the hippocampus and neocortex from the adult rat. *bioRxiv,* 688943. https://doi.org/10.1101/2025.11.18.688943

Brain waves are believed to reflect synchronized electrical oscillations produced by large groups of active neurons. These oscillations can be observed using electroencephalography (EEG) or local field potential (LFP) recordings. The presence of these waves in various animal phyla, including insects and vertebrates, suggests that they play a fundamental role in the brain's computational processes. Different types of brain waves are characterized by their frequency and amplitude. Examples include alpha, beta, delta, theta, and gamma waves, which exhibit distinct oscillatory activity patterns. Recent studies have emphasized the importance of wave coherence for various cognitive functions, particularly attention and memory. Increased coherence between specific brain regions is associated with improved attention performance, while reduced coherence is associated with attention deficits. Maintaining short-term memory requires coordinated activity between the prefrontal cortex and the hippocampus. Previous studies have shown that cytoskeletal polymers, including actin filaments and microtubules (MTs), have electrical properties that contribute to intracellular neuronal circuits and may interact with ion channels involved in neuronal activity. MTs in the brain generate spontaneous electrical oscillations with frequencies similar to brain waves, suggesting a central role in brain function. In this study, the authors used LFP measurements in conjunction with a patch-clamp system to investigate the presence of endogenous oscillations in specific regions of the adult rat brain. They detected specific patterns with distinct frequency peaks.

Study design and implementation:

Rat brain tissue samples (n = 43), which were stored in an extracellular solution, were examined using a patch-clamp amplifier and a pipette electrode that was filled with an intracellular saline solution. (The solution contained an identical concentration of KCl in both the pipette and the bath.) To evaluate the impact of ion concentration on electrical currents, the tissue was incubated in a KCl solution for 24 to 48 hours. Then, the tissue was examined under symmetric KCl conditions using a patch-clamp amplifier as before. To evaluate the role of microtubules (MTs) in electrical oscillations of the rat brain, the authors examined the impact of paclitaxel, an MT stabilizer that eliminates electrical oscillations in MT preparations.

Results:

Voltage-clamped cortex samples exhibited spontaneous, self-sustaining electrical oscillations that responded directly to the amplitude and polarity of the electrical stimulus. Similar results were obtained with hippocampus samples. The Fourier spectra showed a fundamental frequency of approximately 38 Hz for both cortex and hippocampus samples. This frequency was present at 0 mV, suggesting the presence of a chemical gradient between the brain tissue and the pipette's interior. The oscillation was more pronounced in cortex samples than in hippocampus samples. Voltage-clamped cortex samples incubated in KCl exhibited spontaneous, self-sustaining electrical oscillations that responded directly to the amplitude and polarity of the electrical stimulus. Similar results were obtained with hippocampus samples. The Fourier spectra showed a fundamental frequency of approximately 38 Hz for both types of samples (cortex and hippocampus). This oscillation frequency was also present at 0 mV. After incubation with KCl, the oscillations in the cortex and hippocampus samples were similar. Spontaneous electrical oscillations were significantly reduced (though still measurable) after the addition of paclitaxel, with nearly complete inhibition achieved in the hippocampus. These results suggest that microtubules (MTs) play a fundamental role in the intracellular oscillations observed in the rat brain. According to electron microscopic images, the longitudinal microtubules in the cortex appear less organized than those in the hippocampus. These electrical differences may correspond to the degree of order in microtubule arrangements, as suggested by related studies.

Conclusions:

This study significantly advances our understanding of the role of microtubules in neuronal electrical oscillations. The microtubule-stabilizing agent paclitaxel interacts with binding sites within microtubules. The significant reduction of electrical oscillations in the cortex and hippocampus caused by paclitaxel highlights the critical role of microtubules in these oscillations. Previous studies by the authors' research group demonstrated that microtubule bundles isolated from bovine brains generate spontaneous, self-sustaining electrical oscillations with frequency components within the range of brain waves [1]. MT-driven electrical oscillations with distinct peaks around 38 and 90 Hz have previously been observed in honeybee brains, suggesting the intriguing possibility that MTs act as central oscillators in the brain [2]. These data imply that the cytoskeleton may mediate intracellular electrical signals, a phenomenon that could be crucial to brain tissue.

Editor's note:

Microtubules are thought to act as biological waveguides. Due to their hollow, cylindrical structure and crystal lattice, they can conduct electromagnetic waves within cells. Their geometry, dielectric contrast, and symmetry are similar to those of artificial optical waveguides, such as fiber-optic cables. Microtubules are the first macromolecules whose electromagnetic behavior can be fully modeled. Since microtubules are connected to voltage-gated ion channels in the cell membrane, they are likely involved, either directly or indirectly, in the biological effects of (external) electromagnetic fields. (AT)

1. Gutierrez BC, Pita Almenar MR, Martínez LJ, Siñeriz Louis M, Albarracín VH, Cantero MD, Cantiello HF (2021). Honeybee brain oscillations are generated by microtubules. The concept of a brain central oscillator. *Frontiers in Molecular Neuroscience*, 14, 727025. https://doi.org/10.3389/fnmol.2021.727025

2. Scarinci N, Priel A, Cantero MD, Cantiello HF (2023). Brain microtubule electrical oscillations – Empirical Mode Decomposition analysis. *Cellular and Molecular Neurobiology, 43(5), 2089 –2104.* https://doi.org/10.1007/s10571-022-01290-9

Current exposure limits too high

Exposure limits to radiofrequency EMF do not account for cancer risk or reproductive toxicity assessed from data in experimental animals

Melnick RL, Moskowitz JM (2026). Exposure limits to radiofrequency EMF do not account for cancer risk or reproductive toxicity assessed from data in experimental animals. *Environmental Health,* 25(1), 42. https://doi.org/10.1186/s12940-026-01288-6

The exposure limits currently set by the FCC (Federal Communications Commission, USA) and ICNIRP (International Commission on Non-Ionizing Radiation Protection, EU) are based on behavioral studies of rats (n = 8) and monkeys (n = 6) from the 1980s. These studies examined only one criterion. Specifically, they investigated the frequencies and power densities at which the response rate for pressing a lever to release food pellets would be significantly lower than that of the control group after 40 or 60 minutes of exposure. No other endpoints or exposure durations were evaluated. An increase in core body temperature of approximately 1.0°C was used to establish a specific absorption rate of 4 W/kg as the threshold for harmful health effects of radiofrequency (RF) radiation. This limit remains in effect today. For the general population, the limit was reduced to 0.08 W/kg by applying arbitrary safety factors. Chronic exposure and non-thermal effects are not considered. However, two recent systematic reviews [1,2] the World Health Organization's (WHO by the World Health Organization (WHO) concluded with "high certainty of evidence" that RF exposure is associated with an increased risk of cancer and reduced male fertility. The authors, including a former senior scientist at the U.S. National Toxicology Program (NTP), used data from existing animal models to calculate more verifiable exposure limits.

Study design and implementation:

Regarding the tumor data, the scientists performed benchmark dose (BMD) analyses using the tumor rates from the rat models in the NTP and Ramazzini Institute studies. Since the tumor induction mechanism is unknown, the scientists used low-dose linear extrapolation of the BMD01 (1% increased risk) and BMDL01 (lower 95% confidence interval for a 1% increased risk) values in accordance with Environmental Protection Agency (EPA) guidelines for cancer risk assessment. This linear extrapolation provides estimates of the whole-body specific absorption rate (SAR) associated with an additional cancer risk of one in 100,000. For the adverse effect on male fertility, the authors used the linear potency of a 3% reduction in the conception rate per W/kg, as reported in reference [2]. They also applied standardized uncertainty factors (10X for extrapolation from animals to humans, 10X for differences between individual humans, and 3X if a no-observed-adverse-effect level (NOAEL) was not identified).

Results:

Depending on the underlying study, the derived SAR value, which corresponds to a 1 in 100,000 increase in cancer risk, ranges from 0.7 to 5.3 mW/kg for one hour of daily RF exposure. The current ICNIRP/FCC whole-body limit for the general population is 80 mW/kg. With one hour of daily exposure, the current limit exceeds the acceptable cancer risk by a factor of 15 to 114. With eight hours of daily exposure, the excess risk is 121 to 909 times greater. For male fertility, applying the standardized uncertainty factors yields limits of 3.3 to 10 mW/kg. Thus, the current limit is eight to 24 times too high.

Conclusions:

The exposure limits for mobile phones currently set by the FCC and ICNIRP do not ensure the physical safety of the general population. For occupational exposure groups (400 mW/kg), the prognosis worsens by a factor of five. The authors call for an independent reassessment of these limits that incorporates scientific findings from the past 30 years and applies standardized risk assessment methods. Furthermore, the authors acknowledge the possibility of underestimating the actual risk because the SAR value alone is an inadequate metric (in that it disregards the biological interactions at the molecular level caused by wireless devices used next to one's body).

Editor's note:

The authors use the same tools that health authorities worldwide use to evaluate the risks of chemical carcinogens. According to the same standards, if mobile phone radiation were a chemical, it would be classified as an unacceptable health risk. It is alarming that even one hour of daily mobile phone use within regulatory limits significantly exceeds the acceptable cancer risk. This publication provides a solid foundation that makes the need to reform the outdated thermal dogma undeniable. (RH)

1. Mevissen M, Ducray A, Ward JM, Kopp-Schneider A, McNamee JP, Wood AW et al. (2024). Effects of radiofrequency electromagnetic field exposure on cancer in laboratory animal studies, a systematic review. *Environmental International*, 199, 109482. https://doi.org/10.1016/j.envint.2025.109482

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. *Environmental International*, 185, 108509. https://doi.org/10.1016/j.envint.2024.108509

Sleep disorders on the rise

Increasing numbers of persons with sleeping problems in Sweden

Nilsson M, Hardell L (2026). Increasing numbers of persons with sleeping problems in Sweden. *Diseases,* 14(1):25.
https://doi.org/10.3390/diseases14010025

Since the beginning of the millennium, the general public has been exposed to significantly more radiofrequency (RF) radiation due to the widespread use of smartphones and the gradual expansion of mobile infrastructure, including 3G, 4G, and 5G networks. During this same period, sleep disorders have become more prevalent in Sweden, particularly among children, adolescents, and young adults – historically low-risk age groups for sleep disorders. This study investigates whether the prevalence of clinically diagnosed sleep disorders increased between 2001 and 2024, and if so, whether this increase is temporally associated (correlation) with increased RF exposure and/or screen time.

Study design and implementation:

The authors analyzed Sweden's National Patient Registry from 2001 to 2024. The study included outpatients with a primary diagnosis of G47 (sleep disorders of organic origin) or F51 (non-organic disorders) according to the tenth edition of the International Classification of Diseases (ICD-10). They conducted the analysis across five age cohorts (0–4, 5–19, 20–39, 40–59, and 60+ years) and standardized it to 100,000 people in each group.

Results:

Significant increases in G47 diagnoses were documented across all age cohorts. The sharpest increase was observed in the 5- to 19-year-old age group. In this group, the number of diagnosed patients increased 17-fold, rising from 13.8 to 235.6 per 100,000 people between 2001 and 2024. This increase accelerated significantly after 2009, coinciding with the widespread adoption of smartphones and the expansion of the 4G network. The rate of sleep disorder diagnoses also increased in all other age groups: among children ages 0–4, it rose from 41.5 to 215.8; among adults ages 20–39, it rose from 40.4 to 220.9; among adults ages 40–59, it rose from 169.5 to 362.8; and among adults ages 60 and older, it rose from 116.4 to 322.9. No significant changes were observed for F51 diagnoses.

Conclusions:

The authors point out that a population-wide increase in clinically diagnosed sleep disorders occurred in Sweden, coinciding with the expansion of mobile infrastructure and the increased use of mobile devices. They discuss the effects of RF radiation on brain activity and the suppression of melatonin production by blue light from screens as possible causes. However, the scientists emphasize that this study generates hypotheses and call for further studies that specifically assess sleep disorders, RF exposure, and biological parameters. The increase is definitely not due to a higher reporting rate.

Editor's note:

Of particular concern is the significant increase in sleep disorder diagnoses among children and adolescents. These age groups are undergoing developmental changes and are therefore especially vulnerable to the effects of RF exposure. According to a 2022 statistical study by the Swedish Media Council, more than 70% of 15-year-olds and 40% of 12-year-olds use a mobile phone for more than three hours a day. A key limitation of the study is its purely correlative, registry-based approach. Causal conclusions are methodologically impossible, and confounders, such as pandemic-related stress symptoms, cannot be controlled for. Nevertheless, the study provides relevant epidemiological findings that should not be ignored in the context of the growing body of literature on RF-induced neurophysiological pathologies. (RH).

High-voltage power lines and health

Long-term residential magnetic field exposure and neurodegenerative disease mortality: An 18-year nationwide cohort study in Switzerland

Sandoval-Diez N, Loizeau N, Huss A, Röösli M, Vienneau D (2026). Long-term residential magnetic field exposure and neurodegenerative disease mortality: An 18-year nationwide cohort study in Switzerland. *Environment International,* 208, 110145. https://doi.org/10.1016/j.envint.2026.110145

The potential health risks associated with exposure to extremely low frequency magnetic fields (ELF-MFs) are still being debated. In 2001, the International Agency for Research on Cancer (IARC) classified ELF-MFs as a possible human carcinogen (Group 2B). The IARC based this classification on "inadequate" evidence from animal studies and "limited" epidemiological evidence linking exposure above 0.3 to 0.4 μT to childhood leukemia. In addition to cancer, exposure to ELF-MFs is suspected to increase the risk of neurodegenerative diseases. One previous study [1] observed an increased mortality rate from Alzheimer's disease among individuals who had lived near high-voltage power lines for a long time in Switzerland. Subsequent studies in Denmark and Italy provided weak evidence of an increased rate of Alzheimer's disease and negative results for other neurodegenerative diseases. Electrical appliances and indoor wiring are the most common sources of indoor ELF-MF exposure for the general population. However, such exposure is typically intermittent and of short duration. In contrast, proximity to outdoor sources, such as high-voltage power lines and railway infrastructure, is a better indicator of long-term exposure.

Study design and implementation:

The analysis is based on data from approximately 3.5 million adults from the Swiss National Cohort (2001–2018). Using the SNC database, the researchers created a closed cohort with an 18-year follow-up period, including only individuals who were 30 years of age or older at the start of the study (2001). Long-term ELF-MF exposure from high-voltage power lines (50 Hz) and railway lines (16.7 Hz) was modeled using validated proximity models. The horizontal distance to the nearest high-voltage power line or railway line was calculated and entered into the models as an input parameter. The proximity models were validated using a subset of measurements taken in 59 private households. Strong correlations were observed between the predicted and measured exposure for single- and multi-track railway lines. However, measured ELF-MF exposure decreased with increasing distance from high-voltage power lines only for the lines with the highest voltages (220–380 kV). In contrast, distance from 36 to 150 kV high-voltage power lines did not correlate with measured ELF-MF exposure, likely because other sources (e.g. household appliances) dominated the measured exposure levels. For this reason, these were excluded from the analysis. Long-term ELF-EMF exposure levels were calculated as a time-weighted average over 10-year time windows. Hazard ratios (HRs) were estimated for mortality due to Alzheimer's disease (AD), other types of dementia (OTD), amyotrophic lateral sclerosis (ALS), Parkinson's disease (PD), and multiple sclerosis (MS), also considering sociodemographic and environmental co-exposures. Air pollution and noise levels were also included.

Results:

Less than 1% of the population was exposed to long-term ELF-MF levels of ≥ 0.3 μT from high-voltage power lines, while 2.4% were exposed from railway lines. No associations were observed for ALS, PD, or MS. After adjusting for sociodemographic and environmental co-exposure, an increase of 1 μT in exposure to high-voltage power lines was associated with a 54% higher risk of AD-related mortality (95% CI 1.23–1.92). For other types of dementia, the associations were weaker. Each 1 μT increase in exposure was associated with a 31% higher risk of mortality (95% CI 1.13–1.52). The associations between ELF-MFs from railway lines and mortality from AD and other types of dementia were less consistent than those observed for high-voltage power lines. Exposure to railway lines was positively associated with AD mortality in minimally adjusted models (HR = 1.15; 95% CI 1.06–1.24) and in models adjusted for sociodemographic factors. However, the association weakened after adjusting for environmental co-exposures (HR = 1.08, 95% CI 0.99–1.18). A similar pattern was observed for the other types of dementia.

Conclusions:

The results presented here regarding the risk of dying from Alzheimer's disease are consistent with an earlier analysis of the Swiss National Cohort [1]. These findings also align with the repeatedly observed increased risk of dementia among individuals exposed to strong ELF-MF fields. However, the underlying biological mechanisms remain unclear. Several neurodegenerative mechanisms have been proposed to explain this association, including alterations in neuronal ion channels, epigenetic dysregulation, and oxidative stress. Assuming the observed associations are causal and considering that exposure to high levels of ELF-MFs from high-voltage power lines or railway lines is uncommon, the population-attributable fractions of Alzheimer's cases would be 1.01% and 0.43%, respectively. (AT)

1. Huss A, Spoerri A, Egger M, Röösli M, Swiss (2009). Residence near power lines and mortality from neurodegenerative diseases: Longitudinal study of the Swiss population. *American Journal of Epidemiology*, 169(2), 167–175. https://doi.org/10.1093/aje/kwn297

900 MHz and the behavior of honeybees

The influence of an electromagnetic field at a radiofrequency of 900 MHz on the behavior of a honeybee

Migdał P, Plotnik M, Bieńkowski P, Berbeć E, Latarowski K, Białecka N, Murawska A (2025). The influence of an electromagnetic field at a radiofrequency of 900 MHz on the behavior of a honey bee. *Agriculture,* 15(12), 1266.
https://doi.org/10.3390/agriculture15121266

There is little data available on how electromagnetic fields (EMFs) affect the fundamental behavior of honeybees. In laboratory studies, behavioral analysis typically focuses on five behaviors: walking (time spent moving), flight (wing movement), social contact (including mutual grooming), self-cleaning (grooming of body surfaces), and immobility (the time a bee remains motionless). These behaviors – flight, walking, cleaning, social contact, and immobility – are crucial for maintaining the health of bee colonies and the fitness of individual bees. Analyzing flight behavior can provide insight into the cognitive and sensory abilities of honeybees. This study investigated whether 900 MHz EMFs influence these behaviors in honeybees. In addition, the study examined whether potential changes would be visible immediately after exposure or only after some time (delayed effect).

Study design and implementation:

The frames containing the brood were transported to the laboratory and placed in an incubator that mimicked the conditions of a beehive. After emerging, the honeybee workers were transferred to wooden cages and divided into one control group and nine experimental groups. The bees in the experimental groups were exposed to 900 MHz EMFs at intensities of 12 V/m, 28 V/m, or 61 V/m for 15 minutes, 1 hour, or 3 hours. The RF source was a patch antenna connected to an amplifier powered by a 900 MHz radiofrequency (RF) generator modulated with 2G frequency hopping. Immediately after the exposure period ended (and again 7 days later), bees were randomly selected from each group, and their behavior was recorded for six minutes using a camera. Behavioral analysis was performed using Noldus Observer XT 9.0 software (Wageningen, Netherlands). Although one-day-old bees cannot fly, the behavioral analysis assessed flight activity based on wing movements and movements between the walls. The analysis examined two factors: the average duration of a behavior (how much time the bees in the group spent performing a specific behavior) and the average number of occurrences of a behavior (how often individual bees in the group exhibited the selected behavior during the observation period).

Results:

Regarding the average time spent on a specific behavior, the effects of acute exposure on "individual contact" were peculiar: partly reduced and partly increased, yet without a clear correlation with field strength or exposure duration. One week later, individual contact decreased slightly in almost all exposure groups, except for the control group. A similar, albeit less pronounced, trend is evident in grooming behavior. The only clear result of this study is the effect of RF exposure on "flight behavior." All exposed groups exhibited less flight behavior than the control group, and the effect was stronger at higher field strengths. Similar trends were observed one week later. All exposed groups continued to exhibit reduced flight behavior compared to the control group by roughly the same percentage (25–68%) as seven days earlier. Groups exposed for three hours appear to be more affected than groups exposed for shorter durations. Similar trends were observed in the number of flight behaviors recorded.

Conclusions:

According to the authors, this study shows that 2G-modulated 900 MHz EMFs slightly affect bee behavior compared to the control group. Furthermore, statistically significant differences were found between test groups exposed to RF radiation immediately and seven days after exposure. These results suggest that certain behavioral changes may occur with a time delay following RF exposure. The study found reduced flight activity in bees immediately after exposure and one week later. These results provide further evidence that 2G radiofrequency radiation could weaken bee colonies by reducing their food supply, thereby contributing to increased bee mortality.

Editor's note:

The study used a new method to automatically categorize bee behavior. Most of the findings were not statistically significant. However, flight behavior, field strength, and exposure duration were clearly and nearly linearly associated with the extent of reduction or disruption of behavior, especially flight behavior. This remained the case even one week after exposure. A larger sample size (about three to four times larger) would reveal statistically significant differences in almost all exposure groups. However, the field strengths used in the study were unrealistically high. The lowest field strength used was 12 V/m, which corresponds to 380 mW/m^2 (such levels can generally only be measured within ten meters of a base station). This calls into question the generalizability of the findings. Future studies should examine why flight activity is particularly disrupted by 2G radiation and explore this phenomenon at the level of neurotransmitters. (AT)

EMF and plants

Study on evaluation of effects of electromagnetic radiation on pollen viability in some commonly occurring plant species following different staining methods

Sharma A, Bala N, Sharma M, Katnoria JK, Bahel S (2025). Study on evaluation of effects of electromagnetic radiation on pollen viability in some commonly occurring plant species following different staining methods. *Protoplasma*, 263(1), 231–46.
https://doi.org/10.1007/s00709-025-02093-7

Pollen viability is a key factor in reproductive success because non-viable pollen often results in the failure of reproductive and vegetable crops. A previous study examined the effects of extremely low frequency electromagnetic fields on wheat pollen viability and found decreased viability. However, no study has investigated the effects of electromagnetic radiation (EMR) at different power densities on pollen viability in plants under field conditions using actual mobile phone base stations.

Study design and implementation:

Four sites with lush natural vegetation near mobile phone base stations were selected. All of the sites were located near Guru Nanak Dev University in Punjab, India. Since the sites were close to one another, they had similar microclimatic conditions, including temperature and humidity. All plant samples were collected from gardens or parks that were maintained using similar horticultural practices. At each site, three power density measurements were taken at similar times of day. The average power density for each site is as follows: S-1: 10 mW/m^2, S-2: 28 mW/m^2, S-3: 55 mW/m^2, and S-4: 150 mW/m^2. In February 2023, flowers from 12 different plant species, including chrysanthemums, dahlias, poppies, and roses, were collected at each site to test pollen viability. Four different stains were used for the pollen viability tests. All experiments were conducted in triplicate. Regarding the stains: Aceto-orcein (AO) stains nuclear chromatin; Alexander's stain (AS) indicates cytoplasmic integrity; triphenyl tetrazolium chloride (TTC) stains cellular respiration; and Lugol's stain (LS) highlights the starch content of each pollen grain. About 20,000 pollen grains were observed and counted under a light microscope, providing a sufficient sample size to detect subtle changes in viability. S-1 was defined as the control for the statistical tests.

Results:

Pollen viability ranged from 91% down to 68%. A trend toward lower viability with increasing power density was observed for certain strains across all species and strains. The difference in pollen viability within the same species when comparing S-4 to S-1 (the control) was at least 1%, with a maximum deviation of 12%. In many cases, the difference between S-1 and S-4 was statistically significant at $p < 0.05$. In general, the difference in pollen viability between the heavily exposed S-4 samples and the S-1 controls ranged from 4% to 6%.

Conclusions:

Aceto-orcein produced the highest pollen viability in all species, while TTC produced the lowest values consistently. The authors suggest that these results indicate EMR from base stations disrupts pollen grain metabolism because TTC detects cellular respiration and enzymatic activity, both of which are direct indicators of metabolic activity. This study presents a novel methodology for field research.

Editor's note:

The observed effects are consistent and are therefore unlikely to be due to chance. However, the effects are quite weak. A 1% difference in pollen viability at 87% is likely irrelevant. The largest observed difference was a 12% reduction in viability (from 90% at S-1 to 78% at S-4). This could potentially have a slightly detrimental effect over many generations. One drawback of the study design is the questionable control site (S-1), which had an average power density of 10 mW/m^2. This would be considered a "high-exposure site" in similar field studies near base stations. A control site with less than 1 mW/m^2 would have been preferable. The authors noted that their highest observed viability (91%) was lower than figures typically reported for this species under optimal conditions (approaching 99% viability). Therefore, it is possible that site S-1, with the lowest EMR exposure, still had adverse effects on pollen viability. Stronger effects would have been observed with a "truly EMR-free" control site. (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