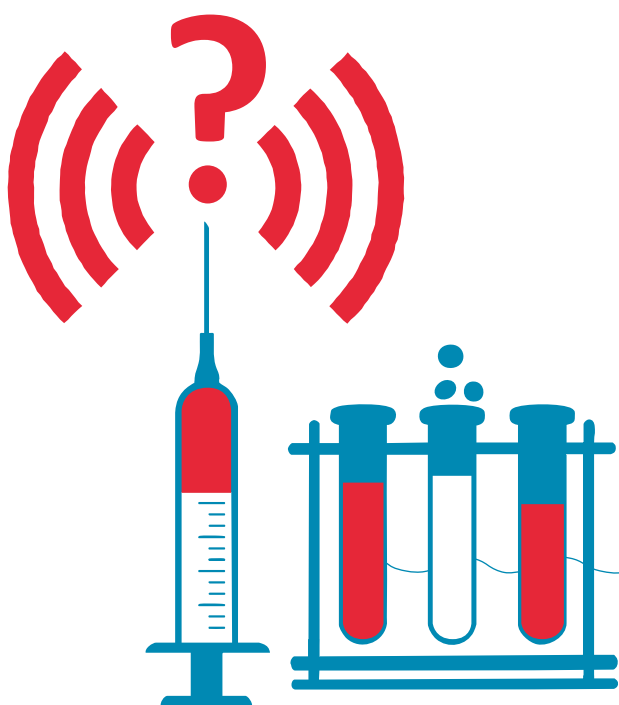


ElektrosmogReport

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



Mobile phone radiation alters erythrocytes

Short-term in vitro exposure of human blood to 5G network frequencies: do sex and frequency additionally affect erythrocyte morphometry?

Žura N, Vince S, Perić P, Vilić M, Malarić K, Rimac V, Golubić Čepulić B, Vajdić M, Jurak I, Milinković Tur S, Poljičak Milas N, Samardžija M, Nemir J, Telebuh M, Žura Žaja I. (2025). Short-Term In Vitro Exposure of Human Blood to 5G Network Frequencies: Do Sex and Frequency Additionally Affect Erythrocyte Morphometry? *Biomedicines*, 13(2), 478. <https://doi.org/10.3390/biomedicines13020478>

Various studies have shown that radiofrequency electromagnetic fields (RF-EMF) influence cell proliferation, gene expression, and membrane function, as well as the immune, hematopoietic, and reproductive systems. Medical personnel who

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handle blood samples or patients who use mobile devices may inadvertently expose specimens to RF-EMF, which could compromise sample integrity and skew diagnostic parameters, such as the complete blood counts. Similarly, the shelf life or functionality of blood-derived therapeutic products, such as erythrocyte and platelet concentrates, could be reduced during manufacturing, storage, or handling. Of particular concern in transfusion medicine is the possibility that RF exposure enhances the generation of reactive oxygen species, which can damage erythrocyte membranes and diminish deformability, a critical attribute for passing through the microvasculature. This study examines the in vitro effects of mobile phone radiation at different frequencies on complete blood count parameters, erythrocyte morphometry, and platelet activation in human blood samples.

Study design and methods:

Blood was drawn from 30 healthy volunteers (15 women and 15 men; aged 25–40 years) at the University Hospital Zagreb on three occasions, each 14 days apart. For each donor, fresh whole-blood samples were paired with unexposed controls obtained simultaneously. Four fresh whole-blood samples were obtained simultaneously from each donor: two experimental samples and two control samples. The samples were exposed to one of three radio frequencies (700 MHz, 2500 MHz, or 3500 MHz /5G) in an HCTEM chamber at room temperature for two hours at an electric field strength of 10 V/m. The controls were kept under identical conditions inside a metal enclosure made of the same material as the HCTEM chamber. Following exposure, a complete blood count was performed. Platelet activation was assessed by flow cytometry, and erythrocyte morphometry was analyzed by quantifying cytoplasmic dimensions (namely length, width, area, and contour) via image analysis.

Results:

Complete blood counts and platelet activation did not differ between the exposed samples and the controls. In contrast, significant, frequency- and sex-dependent alterations in erythrocyte morphometry occurred after radiofrequency exposure. The most pronounced effects occurred at 700 MHz. Erythrocytes both from male and female showed significantly increased size, contour irregularity, and membrane roughness. Female cells demonstrated greater sensitivity to RF-EMF exposure. At 2500 MHz and 3500 MHz, significant morphometric differences versus the controls were observed only in female erythrocytes. These cells were characterized by a higher contour index and decreased rigidity and form factor. Overall, male erythrocytes

exhibited increased membrane roughness, while female erythrocytes primarily enlarged and became more rounded. Cluster analysis of morphometric indicators identified two erythrocyte subpopulations: smaller, round cells with smooth membranes versus larger cells with rough membranes. RF-EMF exposure shifted the distribution toward the larger, rough-membrane subpopulation, but only significantly at 700 MHz and 3500 MHz.

Conclusions:

Short-term exposure to mobile phone radiation at three distinct frequencies, including 5G (3500 MHz), caused significant erythrocyte enlargement, rounding, and increased membrane roughness. It remains unclear whether these changes are transient or reversible. Female erythrocytes, which are more deformable, were more adversely affected. The authors propose the hypothesis that RF-EMF exposure causes cytoskeletal damage resulting in altered membrane permeability and deformability. The observed shift toward a larger rough-membrane subpopulation may indicate accelerated erythrocyte aging due to mobile phone radiation.

Editorial Note:

The study's strengths include repeated sampling, paired controls, and duplicate analyses. However, the absence of sham-exposed controls is a limitation. A dosimetric assessment yielding a standardized SAR value rather than uniform field strength alone might have contributed to a better understanding of the correlations. In addition, referring to "5G mobile phone radiation" throughout is misleading because only the 3500 MHz frequency corresponds to current 5G bands. Finally, situating these findings within the broader literature is challenging due to the limited and heterogeneous data on RF effects. Nonetheless, given the potential clinical implications, the authors' hypotheses warrant serious consideration. (RH)

The authors propose the hypothesis that RF-EMF exposure causes cytoskeletal damage, resulting in altered membrane permeability and deformability.



Mobile phone radiation impairs female reproductive function

Effects of 700 MHz radiofrequency radiation (5G lower band) on the reproductive parameters of female Wistar rats

Jha N, Sarsaiya P, Tomar AK, Pardhiya S, Nirala JP, Chaturvedi PK, Gupta S, Rajamani P. (2025): Effects of 700 MHz radiofrequency radiation (5 G lower band) on the reproductive parameters of female Wistar rats. *Reproductive Toxicology*, 135(March), 108910. <https://doi.org/10.1016/j.reprotox.2025.108910>

The deployment of 5G networks has reignited concerns about the biological impacts of radiofrequency electromagnetic fields (RF-EMF). Beyond the long-debated issue of carcinogenicity, increasing attention is now being paid to potential effects on reproductive health. Current regulatory limits primarily aim to prevent thermal tissue damage, while the non-thermal mechanisms and long-term effects of subthermal exposure remain poorly understood. The lower 5G frequency range (600–900 MHz), which is widely implemented in countries such as India, is particularly relevant. Previous studies on the reproductive effects of mobile phone radiation have produced inconsistent results and have largely focused on male physiology, leaving the impact on female reproduction understudied. Against this backdrop, the present study investigates the non-thermal effects of continuous wave 700 MHz RF radiation on reproductive function in female rats.

Study design and implementation:

Adult female Wistar rats were exposed inside shielded chambers and divided into two exposure regimens: short-term (6 hours per day for 10 days, $n = 6$) and long-term (4 hours per day for 60 days, $n = 8$). Both groups received continuous, unmodulated 700 MHz RF radiation at a power density of 7.192 W/m^2 , corresponding to a whole-body SAR of 0.375 W/kg . Each exposure group was compared with both sham-exposed and completely unexposed controls. Reproductive endpoints included estrous cycle length, serum levels of estradiol, progesterone, and testosterone, ovarian histopathology, and oxidative stress biomarkers, such as malondialdehyde (MDA), superoxide dismutase (SOD), and total antioxidant capacity (FRAP). Genotoxicity was assessed via comet assay.

Results:

Both exposure groups exhibited significant alterations in estrous cycle duration compared to controls. Serum testosterone levels were modestly yet significantly elevated in both groups, while estradiol and progesterone levels remained unchanged. Oxidative stress parameters revealed increased lipid peroxidation (MDA) and decreased antioxidant defense (SOD and FRAP) in both short- and long-term exposed animals. His-

tological examination of the ovaries of long-term exposed rats showed notable pathologies, including cystic follicles and abnormal vascular morphology. No genotoxic effects were detected under the applied exposure conditions.

Conclusions:

These findings suggest that both brief (10-day) and prolonged (60-day) exposure to non-thermal 700 MHz RF radiation induces oxidative stress in the ovaries of female Wistar rats. However, significant histopathological alterations, such as cystic folliculogenesis and abnormal vasculature, were observed only following long-term exposure, implying a cumulative effect. Although serum testosterone levels were elevated, they did not reach levels indicative of overt endocrine disruption. Similarly, despite disrupted estrous cyclicity, the absence of genotoxicity and mild changes in sex steroid concentrations argue against gross reproductive failure under these conditions. Nonetheless, the authors caution that non-thermal RF exposure below current safety thresholds may pose subtle risks to female reproductive health. They advocate for further research to delineate dose-response relationships and elucidate mechanistic pathways.

Editorial Note:

This study's strength lies in its real-world relevance. It examines subthermal RF exposure using a commonly deployed 5G frequency. The study includes both sham-exposed and unexposed controls and combines hormonal, histological, and oxidative stress analyses. The observed induction of oxidative stress and the resulting ovarian changes are consistent with a growing body of literature on the effects of RF on reproductive tissues (Altun et al., 2018; Kaur et al., 2023; Yadav et al., 2021). However, the interpretation of hormonal shifts would have benefitted from analyzing steroidogenesis-related signaling pathways. In addition, while the 700 MHz frequency falls within the 5G spectrum, the use of unmodulated signals limits the applicability to real-world 5G exposure, which typically employ complex modulation schemes. Despite these limitations, the study provides valuable insights into the reproductive risks associated with low-intensity RF fields. (RH)

Altun G, Deniz ÖG, Yurt KK, Davis D, Kaplan S. (2018). Effects of mobile phone exposure on metabolomics in the male and female reproductive systems. *Environmental Research*, 167(February), 700–707. <https://doi.org/10.1016/j.envres.2018.02.031>

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>

Yadav H, Rai U, Singh R. (2021). Radiofrequency radiation: A possible threat to male fertility. *Reproductive Toxicology* (Elmsford, N.Y.), 100, 90–100. <https://doi.org/10.1016/j.reprotox.2021.01.007>



Wi-Fi routers damage testicular tissue

The influence of 2.45 GHz Wi-Fi exposure duration on sperm quality and testicular histopathology: an exploration of peroxidative injury

Jamaludin N, Ibrahim SF, Jaffar FHF, Zulkefli AF, Osman K. (2025). The Influence of 2.45 GHz Wi-Fi Exposure Duration on Sperm Quality and Testicular Histopathology: An Exploration of Peroxidative Injury. *Antioxidants*, 14(2), 179. <https://doi.org/10.3390/antiox14020179>

Given the ubiquitous use of Wi-Fi technology, it is more urgent than ever to evaluate its potential health implications. One concern is the effect of non-ionizing radiation on the male reproductive system, a topic that has drawn increased scientific and public attention. One potential mechanism through which 2.45 GHz Wi-Fi radiation may cause harm is by inducing oxidative stress. A common biomarker of oxidative stress is malondialdehyde (MDA), a by-product of lipid peroxidation with mutagenic properties. This study investigated whether exposure to 2.45 GHz Wi-Fi radiation, as emitted by a commercial router, could impair sperm quality and cause histopathological damage to rat testes, focusing on duration-dependent effects.

Study design and implementation:

Twenty-four male Sprague-Dawley rats were randomly assigned to four groups (n = 6 per group) and exposed for eight weeks. One group served as the sham-exposed control, while the other three groups were exposed to 2.45-GHz Wi-Fi radiation for 4, 8, or 24 hours daily. The radiation source was a standard commercial Wi-Fi router positioned 20 cm from the cages. It was operated within a shielded chamber to eliminate external electromagnetic interference (EMI). (This setup implicates the investigation of non-thermal Wi-Fi effects, editorial note.) After the exposure period ended, the following assessments were performed: sperm concentration, motility, and viability; serum MDA levels; and histopathological analyses of testicular tissue, including Johnsen's score, seminiferous tubule diameter, and epithelial height.

Results:

In all exposure groups, MDA levels were significantly elevated, indicating increased oxidative stress. This was accompanied by significant deterioration in all sperm quality parameters and significant histopathological alterations. Interestingly, the most

severe effects occurred in the group exposed for only 4 hours per day. In contrast, the 8- and 24-hour groups displayed gradual, duration-dependent normalization of the measured parameters over time.

Conclusions:

These findings challenge the commonly held assumption that longer exposure durations correlate with greater biological harm. Although the shortest exposure elicited the strongest adverse effects, the authors suggest that compensatory mechanisms may allow for partial regeneration at longer exposure times. However, full recovery was not achieved. The correlation between MDA levels and both sperm quality and histopathology highlights oxidative stress as a potential mechanistic link. The authors call for further research into molecular mechanisms and the impact of combined exposure to different frequencies and environmental stressors.

Editorial Note:

This study benefits from a carefully controlled experimental setup that includes shielding, sham-exposed controls, and realistic Wi-Fi parameters. The use of a commercial router enhances the study's relevance, and the focus on non-thermal effects aligns with current exposure guidelines. Graded exposure times enable the dynamic observation of damage and potential adaptation. While 24/7 exposure is less realistic for human comparison, 4- and 8-hour daily exposures are considered representative. Future studies should examine antioxidant signaling cascades and protective enzymes to clarify the underlying mechanisms. The sample size (n = 6) was adequate to detect significance, but increasing the sample size could have provided greater statistical power, especially given the complexity of EMF-tissue interactions. This work offers valuable insights into time-dependent oxidative injury and partial recovery under Wi-Fi exposure. (RH)



Wi-Fi exposure disrupts CNS neurogenesis

Effect of microwave radiation on adult neurogenesis and behavior of prenatally exposed rats

Popovičová A, Račeková E, Martončíková M, Fabianová K, Raček A, Žideková M. (2024). Effect of microwave radiation on adult neurogenesis and behavior of prenatally exposed rats. *IBRO Neuroscience Reports*, 17(April), 235–244. <https://doi.org/10.1016/j.ibneur.2024.08.007>

Accumulating evidence suggests that neurogenesis persists in the adult mammalian brain. New neurons arise in two main regions: the subventricular zone (SVZ) of the lateral ventricles, followed by migration along the rostral migratory stream (RMS), and the subgranular zone (SGZ) of the dentate gyrus (DG), which is part of the hippocampus. Adult neurogenesis is essential for cognitive and emotional functions, and disruptions in these processes have been linked to neurodegenerative disorders. Among the various signaling molecules involved, nitric oxide (NO), a free radical, plays a particularly important role in regulating adult neurogenesis. Previous studies by this research group revealed that radiofrequency electromagnetic fields can adversely affect neurogenesis in the olfactory regions of rats. The current study aims to determine the influence of prenatal exposure to a pulsed 2.45 GHz microwave field on postnatal neuronal proliferation, neuronal death, and nitroergic neuron populations, and behavior in rat offspring.

Study design and implementation:

Pregnant Wistar rats were exposed daily for two hours to a pulsed 2.45 GHz electromagnetic field (power density 28 W/m²; whole-body SAR = 1.73 W/kg) within shielded chambers throughout gestation. Control rats underwent identical sham exposure procedures. Their offspring (n = 12) were evaluated at two developmental stages: juveniles at five weeks of age and adults at three months of age. For both age groups, neurogenic regions were assessed through a combination of immunohistochemical and histochemical techniques. Specifically, Ki-67 immunolabeling was used to quantify proliferating cells, and Fluoro-Jade C staining identified dying cells in the RMS and DG. In parallel, NADPH-diaphorase histochemistry enabled the quantitative analysis of nitroergic (NO-releasing) neurons, revealing both cell counts and morphological features. In addition, adult offspring underwent blinded behavioral assessments, comprising the Open Field Test, Elevated Plus Maze, and Light-Dark Box, to evaluate anxiety-like behavior and locomotor activity.

Results:

Exposure to Wi-Fi radiation during gestation produced significant alterations in neurogenesis-related markers in both juvenile and adult rats, though the direction of the changes var-

ied by age. In juveniles, a pronounced increase in proliferative cells was observed in both the RMS, particularly in the „elbow“ subregion, and the DG. This proliferation was accompanied by a significant increase in cell death within the RMS. In addition, the number of nitroergic neurons in the RMS decreased markedly, and surviving cells exhibited immature morphology, indicating delayed neuronal differentiation. In contrast, adult rats that had been exposed prenatally showed a significant decrease in cell proliferation in both the RMS and DG compared to sham-exposed controls. Apoptosis in the RMS remained elevated, while cell death in the DG showed no significant difference. Similar to the juveniles, the number of nitroergic neurons in the RMS decreased, and cellular morphology suggested developmental delay. Behaviorally, adult rats exhibited signs of reduced anxiety and hyperactivity, a phenotype that paralleled the histological findings and suggested an ADHD-like profile.

Conclusions:

The data indicate that prenatal exposure to pulsed 2.45 GHz Wi-Fi radiation produces long-lasting disruptions in postnatal neurogenesis. In the RMS, this manifests as a biphasic pattern: an initial proliferative surge in juveniles, followed by a decline in proliferative capacity in adults. This decline is accompanied by persistently elevated neuronal death in both stages. Alterations in nitroergic neuron populations, characterized by decreased cell numbers and delayed maturation, further underscore the disturbed maturation of NO-releasing neurons. According to the authors, the emergence of hyperactivity and reduced anxiety-like behavior in adult rats suggests functional consequences that parallel ADHD-like phenotypes in humans. Although extrapolation to human neurodevelopment requires caution, these findings highlight the potential impact of ubiquitous radiofrequency exposure on critical developmental processes in the central nervous system.

Editor's note:

The strength of this study lies in its rigorous dosimetric validation (pulsed 2.45 GHz, SAR < 2 W/kg, two hours per day) alongside the use of sham controls and the comprehensive, blinded analyses. These analyses included histological markers of proliferation, cell death, and nitroergic neuron populations, as well as behavioral assays. By examining both juvenile and adult offspring, the authors reveal developmental stage-dependent, biphasic responses to prenatal microwave exposure. Balanced sex distribution across groups minimizes the likelihood of gender-related confounders. Nevertheless, the direct analogy drawn between the observed hyperactivity and human ADHD remains speculative. (RH)



Mobile phone radiation causes anxiety and alters brain structure

Potential effects of radiofrequency on contextual fear conditioning, hippocampal perivascular space, apoptosis and adrenal gland microarchitecture in rats

Narayanan SN, Kumar RS, Kumar N, Prabhakar P, Nayak SB, Bhat PG. (2025). Possible effects of radiofrequency electromagnetic radiation on contextual fear conditioning, hippocampal perivascular space, apoptosis and adrenal gland microarchitecture in rats. *Behavioural Brain Research*, 481(January), 115424. <https://doi.org/10.1016/j.bbr.2025.115424>

Numerous studies have indicated the potential for non-thermal biological effects of mobile telecommunications technology, especially on the central nervous system. The hippocampus, located in the temporal lobe, is of particular interest because it is integral to episodic memory formation and behavioral inhibition. This publication characterizes the impact of 900 MHz mobile phone radiation on behavioral responses, the hypothalamic-pituitary-adrenal (HPA) axis, and structural changes in the hippocampus and adrenal cortex of rats.

Study design and implementation:

Thirty-six young male Wistar rats were equally divided into three groups: unexposed control, sham-exposed control, and RF-exposed ($n = 12$). A commercial GSM mobile phone was placed centrally within each cage, silenced, and auto-dialed 50 times per hour for one hour daily over four consecutive weeks. The radiation parameters were a frequency of 900 MHz, a manufacturer-reported specific absorption rate (SAR) of 1.15 W/kg, and a measured maximum power density of 1.466 W/m². Behavioral assessments employed a passive-avoidance paradigm to evaluate contextual fear conditioning and memory consolidation. Histological evaluations included the quantification of hippocampal perivascular spaces and apoptotic cell counts ($n = 3$) in the CA3 region, as well as the qualitative histopathology of the adrenal cortex.

Results:

RF-exposed rats exhibited pronounced hyperactivity and anxiety-like behaviors compared to both control groups. This was accompanied by significantly impaired memory performance. Enlargement of hippocampal perivascular spaces was statistically significant only versus the unexposed control group. Apoptotic cell counts in the CA3 region showed an upward trend, though they did not reach statistical significance. Qualitative observations in the adrenal zona fasciculata revealed apopto-

tic alterations, lymphocytic infiltrates, and sinusoidal congestion. Other cortical regions and the medulla remained histologically unaltered.

Conclusions:

Chronic, non-thermal exposure to 900 MHz mobile phone radiation induced significant alterations in anxiety-related memory and structural remodeling of the hippocampus and adrenal cortex. The authors propose that HPA-axis dysregulation is an underlying mechanism. However, this hypothesis requires further substantiation through the measurement of stress hormones (e.g. corticosterone). Further investigations are warranted to delineate the molecular pathways involved and to quantify endocrine parameters.

Editor's note:

The study's strengths lie in its use of a real-world RF source, conservative exposure duration, inclusion of sham and unexposed controls, and a multidisciplinary approach integrating behavior and histology. However, the small sample size for apoptotic analysis ($n = 3$) was not clearly communicated and may obscure statistically significant effects. Overall, the findings corroborate earlier reports of hippocampal damage under non-thermal RF exposure (Zheng et al., 2023; Karimi et al., 2018; Tan et al., 2022). These reports document HPA axis dysregulation, anxiety disorders, impairments of synaptic plasticity or memory, and changes in molecular signaling pathways in mammals. (RH)

Karimi N, Bayat M, Haghani M, Saadi HF, Ghazipour GR. (2018). 2.45 GHz microwave radiation impairs learning, memory, and hippocampal synaptic plasticity in the rat. *Toxicology and Industrial Health*, 34(12), 873–883. <https://doi.org/10.1177/0748233718798976>

Tan B, Canturk Tan F, Yalcin B, Dasdag S, Yegin K, Yay AH. (2022). Changes in the histopathology and in the proteins related to the MAPK pathway in the brains of rats exposed to pre and postnatal radiofrequency radiation over four generations. *Journal of Chemical Neuroanatomy*, 126, 102187. <https://doi.org/https://doi.org/10.1016/j.jchemneu.2022.102187>

Zheng R, Zhang X, Gao Y, Gao D, Gong W, Zhang C, Dong G, Li Z. (2023). Biological effects of exposure to 2650 MHz electromagnetic radiation on the behavior, learning, and memory of mice. *Brain and Behavior*, 13(6), 1–13. <https://doi.org/10.1002/brb3.3004>



Biological effects of radiofrequency radiation on the brain

Brain disease-modifying effects of radiofrequency as a non-contact neuronal stimulation technology

Sun S, Bok J, Jang Y, Seo H. (2025). Brain Disease-Modifying Effects of Radiofrequency as a Non-Contact Neuronal Stimulation Technology. *International Journal of Molecular Sciences*, 26(5), 1–21. <https://doi.org/10.3390/ijms26052268>

Accumulating evidence suggests that exposure to radiofrequency electromagnetic fields (RF-EMF) can affect key physiological and cognitive processes, including neuronal excitability, glucose metabolism, sleep architecture, and even systemic metabolic regulation. These complex interactions have been demonstrated in vitro, in animal models, and in human trials. RF-EMF has been shown to enhance and impair brain function. For example, it reduces amyloid- β secretion and plaque formation in Alzheimer's models, but it can also induce oxidative stress and apoptotic signaling under certain conditions. This review summarizes recent findings on RF-EMF-mediated neurostimulation and its potential therapeutic applications for neurodegenerative diseases, such as Alzheimer's.

Study design and implementation:

This narrative review compiles peer-reviewed studies published between 2000 and 2025. These studies include cellular assays, transgenic rodent models of Alzheimer's disease, and clinical investigations in humans. Although a formal systematic search protocol was lacking, the authors prioritized studies that specified exposure parameters, such as precise SAR values and carrier frequencies, to facilitate comparability. The main focus of the included studies was neurodegenerative pathologies, particularly Alzheimer's disease. A total of 57 studies were evaluated, 34 (60%) of which employed non-thermal SAR thresholds (≤ 2 W/kg).

Results:

Of the 57 studies surveyed, 81% reported measurable biological effects of RF-EMF, while 19% found no significant outcomes. Among the studies employing non-thermal SAR thresholds, 88% observed modulation of neurophysiological endpoints, regardless of whether the effect was beneficial or detrimental. Animal models frequently showed reductions in amyloid- β load and reactive oxygen species, accompanied by improvements in spatial memory and synaptic plasticity. Conversely, certain in vitro and human EEG studies documented increased oxidative stress markers, apoptotic cell death, and altered sleep patterns. Clinical trials often revealed subtle changes in EEG spectral power and sleep latency. Biological effects such as improved declar-

ative memory have been observed even at SAR levels as low as 6.4 mW/kg.

Conclusions:

According to the authors, the balance of evidence indicates that RF-EMF can act as a non-contact neuromodulator capable of both ameliorating and exacerbating neurodegenerative pathology, depending on exposure parameters. While preclinical models provide compelling data on Alzheimer's-related endpoints, the heterogeneity of study designs and the absence of large-scale, randomized clinical trials prevent definitive risk-benefit assessments. Thus, rigorous, standardized investigations are essential to determine optimal frequencies, intensities, and modulation schemes for therapeutic neuromodulation.

Editor's note:

Nevertheless, or precisely because of its medical approach, the publication indicates that non-thermal, biological effects of radiofrequency electromagnetic fields exist. However, its narrative approach and lack of systematic inclusion criteria limit quantitative synthesis and meta-analytic rigor. This study is not a systematic review or meta-analysis. Rather, the authors aimed to test the hypothesis that radio frequencies are effective for neural stimulation in a therapeutic context. The study was not intended to evaluate the risks associated with radiofrequency electromagnetic fields. Nevertheless, the concept of contact-free brain stimulation is an emerging field that warrants further exploration, particularly in the context of dementia treatment. (RH)



5G and gene expression

Repeated head exposure to a 5G-3.5 GHz signal does not alter behavior but does alter intracortical gene expression in adult male mice

Lameth J, Royer J, Martin A, Marie C, Arnaud-Cormos D, Lévêque P, Poirier R, Edeline JM, Mallat M. Repeated Head Exposures to a 5G-3.5 GHz Signal Do Not Alter Behavior but Modify Intracortical Gene Expression in Adult Male Mice. *International Journal of Molecular Sciences*. 2025 Mar 10;26(6):2459. <https://doi.org/10.3390/ijms26062459>

The introduction and expansion of 5G telecommunications systems requires a reassessment of the technology's biological impact on the brain. Rodent models can be used to assess spontaneous behaviors and emotional states or cognitive abilities, such as learning and memory. These models can also analyze the cellular and molecular mechanisms responsible for behavior-

al changes triggered by environmental influences. Regarding the effects of radiofrequency electromagnetic fields (RF-EMF) on learning and spatial memory in rodents, published papers show inconsistent results. Some report no effect, while others report significant changes in learning or memory abilities. This diversity most likely reflects the influence of a combination of experimental parameters that vary from study to study. While 2G, 3G, and 4G systems are still in use, the use of 5G mobile communications is growing rapidly and is expected to reach 2.3 billion subscriptions by the end of 2024. This study investigated whether chronic exposure to a 5G 3.5 GHz signal for one month (1 hour per day; 5 days per week) can alter the behavior, memory, and intracerebral gene expression in mice.

Study design and implementation:

The experiments were performed with seven-week-old male C57BL/6 J mice ($n = 32$). Exposure was performed on awake, head-tied animals to ensure homogeneous daily head exposure. Each day, a dipole antenna was positioned 5 mm from the animals' heads in a fixed, standardized position near the right temporal cortex for one hour. The exposure system included a radiofrequency generator that produced a „real“ 5G-modulated 3.5 GHz signal compliant with the 5G NR standard. Each exposed mouse ($n = 12$) was compared to a pseudo-exposed (PSD) mouse ($n = 12$) under identical conditions. Specific absorption rates (SAR) were determined both numerically using a simulated mouse model and experimentally using a homogeneous mouse model with a Luxtron probe. The difference between the two SAR values was less than 30%. After 20 days of 5G exposure (1 hour per day), the mice's locomotor activity was compared to that of the pseudo-exposed mice in an open field (OF) test. Learning and memory abilities were also tested using object recognition and object localization tasks. A camera connected to a video tracking system was placed above the OF to record the mice's activity. Once behavioral testing was complete, the brains were rapidly removed from the skulls of the anesthetized mice. mRNA sequencing was then performed using tissue collected from 5G-exposed ($n = 7$) and pseudo-exposed ($n = 8$) animals that underwent 27 hours of exposure or PSD exposure over 6 weeks. Whole-genome mRNA profiling was performed in symmetrical areas of the right and left cerebral cortex, which differed based on local energy deposition. Differences in transcript levels were analyzed using the Benjamini-Hochberg false discovery rate (FDR) control method.

Results:

Intracerebral SAR values were highest in the ventral cortical areas ipsilateral to the antenna, reaching 0.43 ± 0.12 W/kg. SAR values in the contralateral (left) cortex dropped to 0.14 ± 0.05 W/kg. The averaged SAR of the whole brain was 0.19 ± 0.12 W/kg. All SAR values are below the International Commission on Non-Ionizing Radiation Protection (ICNIRP) limits and are in the non-thermal range.

Mice exposed to 5G showed no hyperactivity or abnormal anxiety, and their level of open field activity and object exploration was similar to that of pseudo-exposed mice. In addition, long-term object recognition memory and long-term memory for the spatial position of objects were not impaired by 27 hours of chronic 5G exposure. As expected, the transcriptome profiles in the right and left cortex of pseudo-exposed animals were almost identical. Significant differences in transcript levels ($FC > 1.2$, FDR-adjusted $p < 0.05$) between the right and left cortex in pseudo-exposed mice were limited to five genes out of 12,423 detectable genes in these brain regions. Comparing 5G-exposed and PSD-exposed animals revealed significant gene modulation triggered by the 5G 3.5 GHz signal. In the right cortex, the changes in expression level ($FC > 1.2$, FDR-adjusted $p < 0.05$) were limited to 77 genes, i.e. less than 0.7% of the expressed genes in this region. These differentially expressed genes (DEGs) included 40 upregulated and 37 downregulated genes in response to chronic 5G exposure. In the left cortex, the total number of DEGs was slightly higher (84 genes), despite the lower SAR value compared to the right cortex. These 84 DEGs were divided into 30 upregulated genes and 54 downregulated genes in response to 5G exposure. The identities of the DEGs differed significantly between the right and left cortices, which had only eight DEGs in common; seven of these were downregulated in both regions. In the right cortex, the significant enrichments of gene ontology (GO) terms were mainly associated with the mitochondrial oxidative phosphorylation system (OXPHOS). The mitochondrial genome contains 13 genes that encode protein subunits of the ATP-producing OXPHOS. Ten of these genes were upregulated upon exposure to the 5G signal. These genes encode central subunits of the enzyme complexes I, III, IV, and V of OXPHOS, which are embedded in or anchored to the inner mitochondrial membrane. In addition, 9 and 11 DEGs encoded components of glutamatergic synapses in the right and left cortices, respectively.

Conclusions:

The results of this study do not show a significant effect of the 5G signal on locomotion, anxiety levels, or memory. However, they reveal biological responses in the form of modulations in gene expression in the cerebral cortex. Due to the asymmetric head exposure, the authors compared gene expression in the right and left cortices exposed to different levels of the 5G 3.5 GHz signal. They observed that a threefold decrease in the mean SAR value was associated with significant changes in DEG identity without a decrease in the number of responding genes. This result suggests that the magnitude of the gene response does not increase proportionally with the amount of energy absorbed by the tissue. Despite the significant differences in gene identities, DEG profiles in the right and left cortices showed substantial enrichment of genes associated with glutamatergic synapses, which facilitate excitatory neurotransmission between the hippocampus and cortical regions. Numerous studies have investigated the ability of RF-EMF to promote reactive oxygen

species (ROS) generation and oxidative stress in tissues. Consistent with the hypothesis that a 5G-modulated 3.5 GHz signal could promote ROS production, this study shows that 5G exposure increases the expression of mitochondrial genes that encode subunits of four of the five OXPHOS protein complexes, including ROS-producing complexes I and III. Overall, the results show that 5G exposure over a six-week period significantly alters the expression of a limited number of genes, which could affect glutamatergic synapses and mitochondrial function.

Editor's note:

Like the other French study discussed here (Dahon et al., 2025), this study stands out for its optimal execution and application of the latest methods. The study also used a „real“ 5G signal. However, as the authors state, further research is needed to clarify whether and how quickly the observed changes in the transcriptome translate to the proteome and at what point observable changes in glutamatergic neurotransmission and mitochondrial function occur after 5G exposure. (AT)



Does radiofrequency exposure affect thermoregulation?

5G radiofrequency exposure reduces PRDM16 and C/EBP β mRNA expression, two key biomarkers for brown adipogenesis

Seewooruttun C, Bouguila B, Corona A, Delanaud S, Bodin R, Bach V, Desailoud R, Pelletier A. (2025): 5G Radiofrequency Exposure Reduces PRDM16 and C/EBP β mRNA Expression, Two Key Biomarkers for Brown Adipogenesis. *International Journal of Molecular Sciences*, 26(6), 2792. <https://doi.org/10.3390/ijms26062792>

Although 5G technology offers remarkable speed improvements, concerns about its long-term health effects remain. Brown adipose tissue (BAT) is essential for generating heat in mammals, particularly in children, where it is most prevalent. It naturally declines with age. Moreover, children absorb a higher proportion of radiofrequency energy than adults, making them more susceptible to the potential effects of radiofrequency electromagnetic fields (RF-EMF). Previous animal studies have shown that low-intensity RF-EMF can stimulate cold-defense responses, such as vasoconstriction and altered norepinephrine levels. Two primary mechanisms underpin cold-induced brown adipose tissue (BAT) activation: UCP1-dependent thermogenesis and brown adipocyte hyperplasia. This study explores how 2G and 5G exposure impacts genes central to BAT thermogenesis and adipogenesis in juvenile versus young adult rats. The aim is

to clarify the age- and duration-dependent impacts and potential metabolic risks.

Study design and implementation:

Sixty male Wistar rats, aged either 3 weeks (juvenile) or 8 weeks (young adult), were divided into three groups: a sham-exposed control group and two exposure groups (2G at 900 MHz and 5G at 3.5 GHz). Each group ($n = 5$) underwent either one or two weeks of exposure. The animals were exposed twice daily for one hour at 1.5 V/m, corresponding to whole-body SAR values of 0.07 mW/kg (5G) and 0.24 mW/kg (2G). After exposure, the interscapular BAT was collected and analyzed by quantitative PCR to determine the mRNA levels of thermogenic markers (UCP1, UCP3, PGC1 α , PPAR α , PPAR γ , Cidea, ADR β 3, S100b) and adipogenic markers (PRDM16, C/EBP β , C/EBP α , Zfp423).

Results:

5G exposure induced a significant downregulation of adipogenic transcription factors PRDM16 (-49%), C/EBP β (-32%), and Zfp423 (-30%), regardless of age and exposure duration. In contrast, 2G exposure produced an age-dependent decrease in PPAR α only in young adult rats. ADR β 3 expression increased under both 2G and 5G conditions in a duration-dependent manner: juvenile rats exhibited a significant increase only after one week of exposure.

Conclusions:

The authors conclude that 5G radiofrequency exposure may impair brown adipocyte differentiation by downregulating PRDM16, C/EBP β , and Zfp423, thereby reducing BAT-mediated heat production and increasing cold sensitivity. The core UCP1 thermogenic pathway appears unaffected by RF-EMF. Alterations in PPAR α and ADR β 3 suggest exposure- and age-specific effects of RF-EMF on brown fat biology.

Editor's note:

The extremely low field strengths and SAR values at which non-thermal effects occur are alarming. ICNIRP limits for the general public allow up to 0.08 W/kg, which is roughly a thousand times higher than the 0.07 mW/kg used for 5G in this study. The lack of frequency modulation in the experimental fields suggests that real-world 5G signals could have an even greater biological impact (Lai & Levitt, 2022). Study limitations include small group sizes ($n = 5$) and the absence of proteomic validation – mRNA changes may not translate to altered protein levels. Intriguingly, low-intensity radiofrequency electromagnetic fields (RF-EMF) may indeed disrupt mammalian thermoregulation. (RH)

Lai H, Levitt BB. (2022). The roles of intensity, exposure duration, and modulation on the biological effects of radiofrequency radiation and exposure guidelines. In *Electromagnetic Biology and Medicine* (Vol. 41, Issue 2, pp. 230–255). Taylor & Francis. <https://doi.org/10.1080/15368378.2022.2065683>



Oxidative stress at non-thermal field strengths

A novel method to achieve precision and reproducibility in a 1.8 GHz radiofrequency exposure system that modulates intracellular ROS as a function of signal amplitude in human cell cultures

Dahon C, Aguida B, Lebon Y, Le Guen P, Dangremont A, Meyer O, Citerne JM, Pooam M, Raad H, Thoradit T, Jourdan N. A Novel Method for Achieving Precision and Reproducibility in a 1.8 GHz Radiofrequency Exposure System That Modulates Intracellular ROS as a Function of Signal Amplitude in Human Cell Cultures. *Bioengineering*. 2025 Mar 4;12(3):257. <https://doi.org/10.3390/bioengineering12030257>

Studies on electromagnetic fields (EMF) that have found effects at very low field strengths have often been criticized as either flawed, due to the lack of a fully understood and plausible mechanism of action, or unreliable, due to insufficient precautions taken to rule out thermal effects. A new study by researchers from the Sorbonne University in France convincingly refutes the argument of a lack of temperature control. Currently, radiofrequency (RF) exposure is generally considered safe. However, RF exposure limits only address heat-related problems. Meanwhile, it is becoming increasingly clear that significant physiological effects can occur at very low, so-called non-thermal RF exposure levels. Recent studies have shown that a major effect of RF emissions is the induction of cellular oxidative stress, as measured by increased production of reactive oxygen species (ROS), which occurs within minutes of exposure. This finding is particularly promising because it could explain the various physiological consequences that have been reported in response to RF exposure, including effects on gene expression, DNA repair, cognitive and behavioral changes, cancer risks, and reproduction and fertility. Nevertheless, there are many conflicting reports in the literature, and these conclusions remain controversial. Progress in understanding the biological effects of EMF requires obtaining precise and reproducible results. A challenge with traditional RF exposure systems is maintaining suitable incubation conditions (temperature, CO₂, and humidity) for cell cultures during relatively long experimental runs while controlling sham exposure adequately. In addition, contamination from external signals could not be consistently eliminated. In the current study, the scientists overcame many of the limitations of previous research by exposing cell cultures to a single 15-minute exposure to a 1.8 GHz carrier wave. The exposure device is small enough to easily transport and set up in an anechoic chamber (EMF-shielded room). The device is easy to construct, operate, and numerically model, so it can be easily replicated in other laboratories.

Study design and implementation:

Human embryonic kidney cells HEK 293 were cultivated in a CO₂ incubator at 37°C. The test and control samples were placed in the RF exposure box for 15 minutes. After exposure, both the test and the control cell cultures were returned to the regular incubator for an additional 2 hours and 45 minutes to allow for a gene expression response. Primers previously identified for RF exposure-regulated genes (K1AA, KRT79, DDX-50, RPS16P5, GPX1, and SOD2) were used as described in previous studies. The GAPDH gene was used as a reference gene. Regarding the RF-EMF exposure system: The Petri dish containing the cell cultures to be exposed was placed in the RF exposure box, which was housed in an anechoic chamber. This isolated the sample from any external electromagnetic radiation. A temperature sensor inside the box controlled the circulation of hot water to maintain a stable internal temperature of 37°C throughout the experiment. A pure sine wave at 1.8 GHz was used, supplied by an Anritsu microwave generator and emitted via a patch antenna. The parameters of the antenna were accurately modeled to ensure uniform exposure of the cell cultures. An Anritsu spectrum analyzer was used to determine the electric field.

Results:

The aim of this experiment was to obtain accurate and reproducible information on how RF signal amplitude modulates cellular gene expression in human cell cultures. Several genes that respond rapidly and specifically to transient changes in cellular reactive oxygen species (ROS) were identified, particularly those induced by static or pulsed electromagnetic fields.

The power density to which the cells were exposed ranged from 11 mW/m² to 0.66 µW/m². These values are very low, non-thermal values, similar to those emitted by everyday smartphones or Wi-Fi at distances between 30 cm and 50 m (editor's note). RF exposure resulted in a 2.5-fold stimulation of gene expression of the KIAA gene at an input power P_{gene} of +10 dBm (power density PEMG ca. 3 mW/m², the highest amplitude used). Gene expression progressively decreased at lower RF exposure amplitudes of 0, -10, and -20 dBm (300, 30, and 3 µW/m², respectively), which was essentially identical to the control condition. However, at P_{gene} = -30 dBm (0.66 µW/m²) and at P_{gene} = -40 dBm (< 0.66 µW/m²), gene expression increased dramatically by a factor of five at these vanishingly low RF amplitudes. These experiments were then repeated with five additional ROS-sensitive and/or ROS-signaling genes (KRT79, DDX-50, RPS, GPX-1 and SOD2).

The results showed a significant modulation of gene expression in response to RF exposure for most of the analyzed genes. For example, KRT79 showed an almost 10-fold stimulation at PEMG = 30 µW/m², while there was a more than twofold decrease in expression at PEMG = 300 µW/m². In all cases, the

amplitude of gene expression was not proportional to the RF signal amplitude, but rather showed biphasic or U-shaped features. Maximum KIAA, GPX1, and RPS expression was reached at the lowest tested power, which corresponded to less than $0.66 \mu\text{W}/\text{m}^2$ (off-scale measurement).

Conclusions:

The authors list important features that ensure the quality of the present study. First, using an anechoic chamber significantly reduces the possibility of unknown interfering signals. Second, combining numerical simulations with direct measurements significantly increases the precision of the exposure conditions. Third, unlike most RF exposure protocols, this study uses a homogeneous cell culture system that is exposed to a single, short, simple carrier wave frequency. This ensures that the physiological measurements (gene expression) are directly related to the cellular responses triggered by the RF signal. Thus, this system avoids the uncertainty arising from measuring the indirect effects of RF exposure (such as cancer occurring several months or years later), which are modulated in an uncontrollable way by many other physiological and environmental influences. In summary, the improvements of this setup provide a relatively inexpensive means to obtain well-characterized, reliable results free of experimental artifacts. In addition, thermal fluctuations during exposure were measured and recorded, and there was no increase in temperature at any time during the entire course of the experiment. An important biological finding of this study is that living cells are sensitive to RF-EMF exposure at signal strengths well below current safety limits. Moreover, these effects occur within the normal emission range of mobile phones and Wi-Fi antennas to which people are exposed daily. ICNIRP limits are several orders of magnitude higher than the power densities used in this study. They were largely based on thermal considerations, which are irrelevant at these energy levels. To avoid any confusion about the implications of these results for human health, the authors emphasize that the present data cannot be taken as proof that RF signals in this low range are dangerous. In fact, there is currently no conclusive evidence that RF exposure leads to disease. In addition, many environmental stressors such as pollution, cigarette smoke, and strong sunlight induce an increase in intracellular reactive oxygen species (ROS) in human cells. These „normal“ sources of stress, including the effects of daily RF exposure, are counteracted by efficient antioxidant mechanisms. Nevertheless, the authors state that RF signaling is physiologically effective, even at surprisingly low power density levels. (Editor's note: The French researchers first express caution here that the effects found on oxidative stress cannot be directly interpreted as harmful to health because this has not yet been investigated. Perhaps they also want to avoid negative publicity by mak-

ing bold statements. However, they emphasize that even very weak RF exposure is physiologically effective.)

The primary physical mechanism by which these RF signals interact with cellular receptors should be investigated further. Hormesis is a dose-response phenomenon characterized by a biphasic relationship, whereby low doses of a substance produce a stimulatory or beneficial effect whereas higher doses lead to inhibitory or toxic results. Hormesis is particularly well documented for ROS signaling: low concentrations of ROS can stimulate adaptive and beneficial cellular responses, while excessive concentrations of ROS cause oxidative stress and cellular damage. The biphasic response to RF exposure indicates that RF radiation likely interacts with biological receptors, such as enzymes that catalyze redox reactions. Conventional models determine a no observed adverse effect level (NOAEL) and assume that all doses below this threshold are without effect. However, the evidence of hormetic responses shows that, even if RF exposure at certain amplitudes does not cause measurable effects, it does not exclude the possibility that RF exposure at lower doses may have harmful physiological effects. Therefore, current RF exposure assessment practices must be reevaluated to account for the potential for stimulation at low doses and the non-linear nature of dose-response relationships. These cellular responses occur at RF signal amplitudes several orders of magnitude below those required to produce thermal effects and within the range of everyday mobile phone and Wi-Fi use.

Editor's note:

This new study discloses and simplifies all procedures and processes with high methodological finesse, showing for the first time how EMF studies should optimally be conducted. Other research groups can easily reuse this approach, which could lead to greater consistency and reproducibility in this still new and underdeveloped field of research in the long term. However, the most impressive result of the study is the consistent finding of effects on the expression of genes involved in oxidative stress and ROS signaling at very low field strengths ($< 1 \mu\text{W}/\text{m}^2$), some of which are even below the BioEMF recommendations. The exact mechanism by which these observed non-thermal effects occur remains exciting and mysterious and should be thoroughly investigated. (AT)

The effects are consistent with a biological receptor-driven mechanism whereby RF exposure modulates intracellular ROS and ROS signaling pathways.



EMF mechanisms

The radical pair mechanism cannot explain the effects of telecommunication frequencies on reactive oxygen species

Talbi O, Zadeh-Haghighi H, Simon C. The Radical Pair Mechanism Cannot Explain Telecommunication Frequency Effects on Reactive Oxygen Species. *bioRxiv*. 2024 Jun 25:2024-06.
<https://doi.org/10.3389/frqst.2025.1544473>

Reactive oxygen species (ROS) play an important role in various physiological processes. However, excessive ROS accumulation can trigger oxidative stress, causing significant damage to lipids, proteins, and DNA. This can impair cell function and lead to various diseases, including cancer, cardiovascular disease, and neurodegenerative diseases. It is known that weak magnetic fields can influence chemical reactions. Numerous studies have documented the effects of static magnetic fields (SMFs) on ROS production, highlighting their biological importance. The radical pair mechanism (RPM), originating in spin chemistry, can explain the effects of static magnetic fields on chemical reactions, with magnetoreception in birds being a notable example. The radical pair model is a well-known model to explain the biological effects of magnetic fields or radiofrequency electromagnetic radiation (RF-EMR). It is based on the Zeeman effect of magnetic fields on spin states. In a reaction system containing radical pairs in singlet and triplet states, an external magnetic field shifts the energy level of the triplet states. This in turn shifts the equilibrium of the singlet-triplet conversion and alters the concentrations of the different radicals and their reaction products. This model can be applied to biochemical reactions, as seen with the photoreceptor cryptochrome. The dynamics of radical pairs are highly influenced by Zeeman and hyperfine interactions. The Zeeman interaction aligns the electron spins with an external magnetic field, which changes the energy states and influences the reaction pathways. One commonly mentioned magnetosensitive photoreceptor is flavin adenine dinucleotide (FAD), which is associated with cryptochrome (Cry). It is assumed that the FAD is excited by a blue photon (FAD/FAD^*) and then protonated ($\text{FAD}^*/(\text{FADH}^+)^*$). Three electron transfers then occur in succession, generating magnetosensitive singlet and triplet radical pairs. However, the question of whether the FAD-binding cryptochrome is the molecular magnetic compass remains controversial. Another model proposes that the MagR/Cry protein complex is the magnetic receptor because its protein crystals exhibit a strong intrinsic magnetic polarity and rotate synchronously with an external magnetic field. According to the

radical pair model, an external static magnetic field causes the hyperfine splitting of the triplet states. Furthermore, the magnetic sensitivity of the corresponding biochemical reactions can be influenced by electromagnetic radiation at the Larmor frequency; that is, by photons whose energy corresponds exactly to the difference in energy levels between the singlet and triplet states. There is experimental evidence to support the radical pair model. The flight direction of navigating birds is disrupted by EMR at the Larmor frequency. In addition, the biochemical reactions involving the triplet (O_2^*) and singlet (H_2O_2) states of ROS in cells are affected by 7 MHz EMR in the presence of a 45 mT static magnetic field (Liu et al., 2024).

Study design and implementation:

The authors explain how they derive the magnetic field strength H from the specific absorption rate (SAR) using the electric field E and various constants. Using these principles, the authors investigate how these magnetic fields affect the quantum states and reaction yields of radical pairs. They do so by employing the spin Hamiltonian function for a typical radical pair system in the presence of a static magnetic field. They update the equation to calculate the RPM effect of oscillating magnetic fields, which introduces time-dependent dynamics.

Results:

Subsequent computer modeling made it possible to derive frequencies that result in peak resonances. One of these resonance peaks corresponds to the Larmor frequency of the electrons. This resonance effect is particularly pronounced when the static and oscillating magnetic fields are perpendicular to each other, which agrees with the theoretical predictions. In addition, another resonance effect was detected at a higher frequency of about 22.5 MHz. This resonance corresponds to the transitions between the highest and lowest energy levels of the hyperfine spin Hamiltonian. Notably, this maximum frequency at which an effect was observed is significantly lower than the telecommunication frequencies, which are typically above 800 MHz.

Conclusions:

In agreement with simple resonance arguments, this study shows the limitations of the radical pair mechanism (RPM) in explaining the observed effects of radiofrequency fields, especially those associated with mobile communications at 800 MHz and above. While the radical pair mechanism can explain the effects of static magnetic fields on reactive oxygen species (ROS), it cannot explain the effects of radiofrequency radiation on ROS. Several studies have described enhancement pathways that could amplify otherwise subtle RPM-based effects. These studies suggest that enhancement factors could be as high as one hundred under favorable biochemical conditions. Even at this level of amplification, the predicted effect remains extremely small. In the absence of resonance, the present simu-

lations estimate the RPM effect to be $6.11 \times 10^{-7}\%$, and even with the largest plausible amplification factor, the effect would still only reach $6.11 \times 10^{-5}\%$. These results suggest that RPM-based processes are not responsible for the observed effects at telecommunications frequencies. Given these limitations, it seems more plausible that these effects are due to the electric component of the electromagnetic field of telecommunications devices. Electric fields interact directly with charged cellular structures, in particular with voltage-gated ion channels and membrane-bound enzymes. This provides a non-magnetic pathway for ROS modulation. RF-induced ion channel perturbations can disturb the redox balance and increase oxidative stress; however, further research is needed to fully understand these mechanisms.

Editor's note:

This theoretical and simulation study builds on earlier work, taking the theoretical understanding of radical pair biology a step further (Barnes & Greenebaum, 2015). Further research is needed to verify these results and develop alternative explanations for the robustly observed but so far poorly understood effects of radiofrequency electromagnetic radiation. At the very least, the RPM appears to be involved in the biological effects of static and low frequency magnetic fields (AT).

Liu, L., Huang, B., Lu, Y., Zhao, Y., Tang, X., & Shi, Y. (2024). Interactions between electromagnetic radiation and biological systems. *iScience*, 27(3), 109201. <https://doi.org/10.1016/j.isci.2024.109201>

Barnes FS, Greenebaum B. The effects of weak magnetic fields on radical pairs. *Bioelectromagnetics*. 2015 Jan;36(1):45-54. <https://doi.org/10.1002/bem.21883>



Critical observations

A critical analysis of the World Health Organization (WHO) 2024 systematic review on radiofrequency radiation exposure and cancer risks

Hardell L, Nilsson M. A Critical Analysis of the World Health Organization (WHO) Systematic Review 2024 on Radiofrequency Radiation Exposure and Cancer Risks. *Journal of Cancer Science and Clinical Therapeutics*. 2025;9:09-26. <https://doi.org/10.26502/jcsct.5079261>

In 2011, the WHO's International Agency for Research on Cancer (IARC) classified radiofrequency radiation as a possible human carcinogen. The WHO is currently conducting a systematic review of human studies on cancer risks. In 2024, two reviews on radiofrequency electromagnetic radiation (RF-EMF) and cancer risks were published. The first review, commissioned by the WHO, was published by Karipidis et al. in 2024. The second study, by Moon et al. (2024), was published by scientists in Korea. Their conclusions on the risk of brain tumors were completely contradictory to those of the Karipidis review. The Karipidis review argued with „moderate certainty“ that mobile phone use „probably does not increase the risk of gliomas, meningiomas, acoustic neuromas, pituitary tumors, and salivary gland tumors in adults or of pediatric brain tumors.“ In contrast, Moon et al. concluded that the available studies as a whole show that mobile phone use increases the risk of brain tumors. One reason for these contradictory conclusions, despite using the same scientific evidence, could be that Moon et al. did not disclose any conflicts of interest, whereas several authors of the Karipidis review have conflicts of interest due to their direct links to the International Commission on Non-Ionizing Radiation Protection (ICNIRP) or other mobile phone industry lobbies. In correspondence from the International Commission on the Biological Effects of Electromagnetic Fields (ICBE-EMF, Frank et al., 2025), several problems were raised about the Karipidis study on cancer. These include reliance on conclusions from studies with design flaws, the use of RF radiation exposure categories that do not reflect current exposure levels, omission of studies showing increased incidence of brain tumors, use of studies with short latency periods, and failure to follow standard recommendations for summarizing primary study results. In the current study, Hardell and Nilsson detail some of the most glaring scientific errors in the WHO report by Karipidis et al.

Problems with the methodology and scientific reliability of the approach used in the study by Karipidis et al.:

- > Ignoring the studies with the highest cumulative call time exposure that show an increased risk of brain tumors. Karipidis et al. seem to give too much weight to the statistically non-significant results of studies with low exposure rather

than to studies that found statistically significant increased odds ratios (ORs) in the most exposed groups. They also claim that there is no increased risk, despite relying on a dataset of studies that contain results showing a statistically significant increased risk with cumulative call time exposure of > 896 to > 1,640 hours.

- > Unreasonable exclusion of laterality analyses that provided clear evidence of an increased risk of brain tumors with ipsilateral mobile phone use (on the same side as the brain tumor), including cordless phones. Thus, the results for the most exposed part of the brain were excluded. This conclusion is contradicted by Schüz (author of a cohort study that Karipidis et al. highly rated and used in their analysis, editor's note). Schüz admits that, in the largest published part of the Interphone study to date, „an observed increased OR for ipsilateral use was not compensated for by a similarly decreased OR for contralateral use (ORs of 1.39 versus 0.98), especially as this was found among the cases with the longest time since first use... this is what one would expect assuming a causal effect.“
- > Inclusion of poorly conducted and therefore unreliable studies as scientific evidence of a lack of risk. These are cohort studies on mobile phone use that were given relatively large weight. Both cohorts, especially the Danish cohort, suffer from serious misclassification of exposure and unknown actual exposure, which invalidate the results of these studies in relation to cancer and other health outcomes. The consequences of including studies that have incorrectly defined or assigned treatment and control groups in a meta-analysis are well known in epidemiology. „The result will always be dilution, and the effect size will be pulled towards the null.“
- > Only five studies modeling exposure from transmitters or base stations were included, and only those on cancer in children were considered. This excluded several studies showing an increased risk of cancer in children and adults in the vicinity of transmitters and base stations. Of the two included studies on base stations, one reported an increased risk of all neoplasms in children with above-median RF exposure from mobile phone base stations. However, Karipidis et al. claimed that there was „moderate certainty“ that there was no evidence of an increased risk of leukemia in children.
- > Risk of bias (RoB) assessment: The studies were categorized into three groups based on the potential for bias: low, moderate, or high. These groups do not appear to be based on sound scientific evaluation. Hardell and Nilsson provide examples of misinterpretation and distortion of scientific facts in the RoB assessment. Comparing the ratings with the actual studies reveals that the evaluation by Karipidis et al. is very biased and rather arbitrary or unscientific.
- > Several authors in the Karipidis group have conflicts of interest in the form of links to ICNIRP. ICNIRP is the organization that recommended the exposure limits adopted by most countries worldwide. The telecommunications industry has adapted its technology to these limits. Recognizing a cancer risk from mobile phone technology below the ICNIRP limits would have economic consequences for the industry. In addition, the ICNIRP limits are also important for the industry's introduction of new technologies, such as 5G. Lower limits than those of the ICNIRP would make the introduction of 5G more difficult, according to the industry.

Conclusions:

The conclusions of the WHO-Karipidis group that using mobile and cordless phones or being exposed to RF radiation from transmitters and base stations does not pose a cancer risk are based on several errors in interpreting scientific results, omitting facts that contradict the conclusions, and inherent conflicts of interest. Most of the results on which the authors base their conclusions are derived from very low exposure levels that are too low to be representative of today's population exposure, and the authors have excluded or ignored results from the highest exposure categories. The authors' conclusions that RF-EMF exposure does not cause cancer with varying degrees of „certainty“ are unscientific and unjustified in light of the available scientific evidence. Their clear but unacknowledged conflicts of interest call the entire Karipidis et al. study into question. Assessments of health risks from RF radiation should be conducted by scientists who are not affiliated with ICNIRP or industry. Direct or indirect links to industry can interfere with objective and robust scientific assessments. Hardell and Nilsson call for the retraction of the Karipidis et al. article due to serious scientific misconduct and a fatally flawed assessment of the cancer risks of RF radiation. (AT)

Frank, J. W., Moskowitz, J. M., Melnick, R. L., Hardell, L., Philips, A., Héroux, P., & Kelley, E. (2025). The Systematic Review on RF-EMF Exposure and Cancer by Karipidis et al. (2024) has Serious Flaws that Undermine the Validity of the Study's Conclusions. *Environment International*, 195, 109200. <https://doi.org/10.1016/j.envint.2024.109200>

Karipidis, K., Baaken, D., Loney, T., Blettner, M., Brzozek, C., Elwood, M., Narh, C., Orsini, N., Rösli, M., Paulo, M. S., & Lagorio, S. (2024). The effect of exposure to radiofrequency fields on cancer risk in the general and working population: A systematic review of human observational studies - Part I: Most researched outcomes. *Environment International*, 191, 108983. <https://doi.org/10.1016/j.envint.2024.108983>

Moon, J., Kwon, J., & Mun, Y. (2024). Relationship between radiofrequency-electromagnetic radiation from cellular phones and brain tumor: Meta-analyses using various proxies for RF-EMR exposure-outcome assessment. *Environmental Health*, 23(1), 82. <https://doi.org/10.1186/s12940-024-01117-8>



A WHO overview of RF-EMF and animals and plants

Investigation of the effects of anthropogenic radiofrequency electromagnetic fields on animals and plants in the environment: analysis using a systematic map

Brzozek C, Mate R, Bhatt CR, Loughran S, Wood AW, Karipidis K. Investigating the impact of anthropogenic radiofrequency electromagnetic fields on animals and plants in the environment: analysis from a systematic map. *International Journal of Environmental Studies*. 2024 Sep 2;81(5):2343-58. <https://doi.org/10.1080/00207233.2024.2375861>

The development of new technologies and the proliferation of radiofrequency electromagnetic field (RF-EMF)-emitting devices have raised public concern and have been identified as high-priority research needs by the World Health Organization (WHO). The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has established guidelines to protect human health from overexposure to RF-EMF. However, there are no specific exposure guidelines to protect plants and animals. Several reviews have examined RF-EMF exposure in various plants and animals. However, a detailed systematic search with clear inclusion and exclusion criteria for relevant studies has been lacking, according to the authors. Since no current systematic compilation of research on the effects of anthropogenic RF-EMF exposure on plants and animals existed, the authors attempted to produce a systematic map, which was published in 2023 and discussed in EREP 2024/1 (Karipidis et al., 2023). Over 24,000 articles were screened, resulting in the identification of 334 relevant studies (237 on animals and 97 on plants). The systematic map identified research clusters, showing that birds and insects were the most studied species and that the results mainly focused on reproduction, development, and behavior. The systematic map compiled all available evidence on the environmental effects of anthropogenic RF-EMF but did not analyze the actual effects of RF exposure on animals and plants in the environment. The current study (from the same team of authors) builds on the previously published systematic map. It aims to analyze the magnitude of RF-EMF's effect in the available studies and how this effect relates to the different exposure parameters and study quality.

Study design and implementation:

Studies investigating the effects of RF-EMF on animals and plants reported a range of effects, from none or small to large. Therefore, it is important to determine the distribution of effect sizes (ES) across the different studies, given that an ES of 0 indicates no statistically significant effect and while an ES greater

than 0 indicates a significant effect size, with larger numbers corresponding to larger effects. In this case, the ES, Cohen's *d*, was estimated using various methods. Two reviewers assigned a quality score (QS) to each study, and the final quality score was the average. For experimental studies, the method of Vijayalaxmi and Prihoda was used, which assesses five quality criteria: adequate dosimetry, use of controls, use of positive controls, use of blinding, and use of temperature monitoring. For observational studies, the following five quality criteria were used for assessment: appropriate exposure assessment, appropriate subject selection / comparison groups, consideration of confounding factors, follow-up assessment, and appropriate outcome assessment.

Results:

Most of the included studies were experimental (95%) and conducted in laboratories (88.6%). Among the animals studied, vertebrates (52%) and invertebrates (48%) were almost evenly distributed. The most frequently studied groups were insects/arthropods (43%), birds (36%), and mammals (10%). Exposure duration was recorded in 87% of the studies. Power density and SAR were reported in 72% and 30% of the studies, respectively.

The authors extracted the effect size from the data provided for 291 studies (87%), with similar proportions for animal studies (88%) and plant studies (86%). Most animal studies had an effect size of less than 1 (62%), compared to 29% of plant studies. The median effect size (ES) was higher in plant studies (3.4) than in animal studies (0.7). In addition, significant negative correlations were found between ES and exposure level (power density and SAR) or duration in animal studies, suggesting that studies with higher and longer exposure reported fewer effects. This contradicts logic, as one would expect an increase in RF-EMF exposure to increase the magnitude of the effect, but this inconsistency could be related to the poor quality of most studies, according to the authors. For plants, there were no significant correlations between ES and exposure level or duration in any of the studies. Thus, although there was no decrease in the effect of RF-EMF with higher exposure, there was also no increase.

The mean „quality score“ (QS) of 2 (minimum 0.25, maximum 4.25) was higher for animal studies than for plant studies, which had a mean score of 1.82 (minimum 0.5, maximum 4.25). Overall, most studies were classified as „poor,“ but the proportion of „poor“ studies was higher for plant (66 %) than for animal (58.8 %) studies. Consequently, 35.6% of the animal studies were rated „average“ and 5.6% were rated „good“ and 31.9% of the plant studies were rated „average“ and only 2.1% were rated „good.“ Examining the correlations between QS and the parameters exposure level and duration revealed significant positive correlations between the quality rating and SAR, power density and exposure duration for animal studies. This suggests that studies using higher exposure levels for longer dura-

tions employed better methods than those using lower exposure levels or shorter durations. However, this was not reflected in the plant studies. Information is available on the magnitude of effects (the effect size or ES) depending on whether the exposure is above or below the ICNIRP limits. Among animal studies, about one third of those with exposure above the limits (8 out of 23, 35%) reported no effect (ES = 0), compared to 22% (40 out of 182) of those with exposure below the limits. In addition, studies with exposure above the cut-off values generally showed lower effect sizes (ES = median 0.2, minimum 0, maximum 4.3) than studies with exposure below the cut-off values (ES = median 0.8, minimum 0, maximum 112.2). The authors also noted that this „defies logic.“ These results could be related to the quality of the studies, as the mean QS was 1.96 for studies reporting exposure below the ICNIRP limits and 2.35 for studies reporting exposure above the ICNIRP limits (Editor's note: as these are minimal differences in QS, this reasoning is questionable).

Conclusions:

Overall, a large proportion of the studies were considered to be of low quality, and the analysis revealed „problems“ that could be related to study quality. It was expected that the effect size would increase with increasing exposure level and duration, which is typical of a dose-response relationship. However, an inverse relationship was found between effect size and exposure level (power density and SAR) and study duration in animals. The comparable trends observed in plant studies were not statistically significant. The decreasing effect size with increasing power density also corresponds to the results of the Cucurachi et al. (2013) review.

Editor's note:

The thermal paradigm states that all biological effects of radiofrequency radiation (mostly in the microwave range) are caused by actual heating. This paradigm would be confirmed by a clear dose-response relationship. The „problem“ is that Brzozek and Karipidis' analysis did not reveal this; rather, they discovered an inverse dose-response relationship for animal studies. The authors tried to explain this away by claiming that most of the included studies were of poor quality. However, this justification is highly questionable, because studies of poor quality should normally find the same effect size as studies of higher quality, only with larger confidence intervals / greater uncertainty. According to Occam's razor, the simpler and more elegant explanation would be that the thermal paradigm is simply wrong and that more complex physical principles or mechanisms are probably needed to understand the biological effects of EMF. It was encouraging to see that the original 2023 systematic map was published as open data, providing direct access to the Excel spreadsheet containing the collected data. Unfortunately, this is no longer the case with this follow-up evaluation. (AT)

Cucurachi, S., Tamis, W., Vijver, M., Peijnenburg, W., Bolte, J., & De Snoo, G. (2013). A review of the ecological effects of radiofrequency electromagnetic fields (RF-EMF). *Environment International*, 51, 116-140.

Karipidis, K., Brzozek, C., Mate, R., Bhatt, C. R., Loughran, S., & Wood, A. W. (2023). What evidence exists on the impact of anthropogenic radiofrequency electromagnetic fields on animals and plants in the environment: A systematic map. *Environmental Evidence*, 12(1), 9. <https://doi.org/10.1186/s13750-023-00304-3>

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/departments-of-radiobiology/?lang=en>

Shortened Link: kurzlinks.de/belyaev

Blog by Prof. Dariusz Leszczynski (Finland):

Website: betweenrockandhardplace.wordpress.com

Databases:

www.emfdata.org

www.emf-portal.de

www.orsaa.org