Overview of the epidemiologic studies on the health effects of ELF electric and magnetic fields (ELF-EMF) published in the third quarter of 2025.

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1. Reviews and meta-analyses

1.1 A Systematic Review of the Impact of Electromagnetic Waves on Living Beings

Danho, S., Escobar Huertas, J., Schoellhorn, W. I. (2025). *Cureus* 17(8): e90355. http://doi.org/10.7759/cureus.90355

Background: The effects of electromagnetic fields (EMFs) have been extensively debated among researchers and the public, with their critical consequences often dismissed or deemed unscientific. In light of this, the authors conducted this systematic review that extensively focuses on the detrimental effects of EMFs on living organisms.

Methods: A comprehensive and systematic literature search was performed on various electronic databases, including PubMed, Scopus, and the Cochrane Library, using Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines. This review concentrates on experimental studies published between 2017 and 2024 that investigated physiological or behavioral responses to EMF exposure, with particular attention given to those reporting harmful or concerning effects. Documented impacts include effects on humans, animals, and plants, targeting various cell types (e.g., blood, cancer, thyroid, cochlea), genotoxicity, cardiovascular parameters (e.g., heart rate, blood pressure), male fertility (e.g., testes, sperm), neuronal brain activity, and photosynthesis in plants. Methodological quality was assessed using established bias assessment tools, and certainty of evidence was evaluated according to the GRADE framework.

Results: After screening, 24 studies were included in the present review; five studies were non-randomized and involved humans, seven studies were in vitro, and 12 studies were conducted on animals. The findings demonstrated that EMFs negatively affect a wide array of biological systems of living organisms, including mechanisms of oxidative stress, inflammatory responses, and disruptions in cellular, physiological, and ecological processes. Most of the included studies showed a moderate to high risk of bias, which contributed to a lower overall certainty of the evidence. These findings underscore the significant health and environmental risks associated with rising exposure levels of EMF, highlighting the urgent need for strategies to mitigate the risks. Despite these valuable insights, significant research gaps persist because the long-term effects of EMF exposure, especially on human populations, remain poorly understood and warrant further investigation and targeted mitigation strategies.

Comments: This study exhibits significant methodological weaknesses. For instance, it fails to distinguish between the various categories of non-ionizing radiation, even though such differentiation is crucial for accurate interpretation. Moreover, there is a clear selection bias: the literature review focuses predominantly on studies reporting negative outcomes, rather than considering all relevant research. This phenomenon, commonly known as cherry-picking, severely undermines the methodological integrity of the investigation.

2. Residential exposure

2.1 Extremely low-frequency magnetic fields (ELF-MF) and radiofrequency: Risk of childhood CNS tumors in a city with elevated ELF-MF exposure

Correa-Correa, V., Núñez-Enríquez, J.C., et al. (2025). Environmental Research, 286(2), 122858.

https://doi.org/10.1016/j.envres.2025.122858.

Background: Central nervous system tumors (CNSTs) are the second most common childhood cancer. While their etiology is unclear, exposure to extremely low-frequency magnetic fields (ELF-MF) and radiofrequency (RF) may be associated with increased risk. This study aims to examine the relationship between ELF-MF and RF exposure and CNST risk in Mexico City's pediatric population.

Methods: A case-control study was conducted in Mexico City (2017–2022) to assess ELF-MF and RF exposure in 200 CNST patients and 793 controls under 16 years old. Residential ELF-MF exposure was measured over 24 h, and RF exposure was assessed through the total duration of cell phone calls and electronic device usage (with and without internet). ELF-MF exposure levels below 0.1 μT and the lowest RF exposure quartile (Q1) served as reference groups for adjusted odds ratio (aOR) analyses. Data analysis was performed using R and SPSS software.

Results: Of all participants, 5.1 % had ELF-MF exposure ≥0.3 μT. Elevated ELF-MF exposure (≥0.4 μT) was significantly associated with an increased risk of CNST (aOR (95 % confidence interval) = 2.39 (1.15–5.00). While cell phone use showed no differences between cases and controls, prolonged tablet use (with and without internet) was significantly associated with increased CNST risk (aOR = 2.53 (1.39–4.61) and 3.53 (1.45–8.59), respectively).

Conclusion: A high proportion of children in Mexico City are exposed to ELF-MF levels ≥0.3 μT, exceeding levels reported in other populations. Elevated residential ELF-MF exposure, as well as prolonged tablet use, both with and without internet connectivity, were significantly associated with an increased risk of developing CNST in childhood.

Limitations:

- A 24-h measurement is a short-term assessment and may be inade quate to evaluate the effects of long-term ELF-MF exposure. For selecting a reference category, the authors use of a level of <0,1μT to enable comparison with other studies that have also used this threshold as their reference exposure level. However, there is no biological basis for recommending an exposure level of <0,1μT as the unique reference value.
- Since exposure to ELF-MF is strongly influenced by residential proximity to power lines and the configuration of local electrical infrastructure, selecting controls from same small geographic areas could have resulted in overmatching on environmental exposures, potentially masking associations of interest.
- Another limitation of this study is that no stratified analysis was performed to explore whether associations differed among tumor types to know if malignant or benign tumors have different risk rates.

- An evident mechanism through which exposure to EMF or RF may be associated with CNST has not been established. Therefore, it is possible that other factors related to ELF-MF exposure, which the authors could not identify in the present study, may be more relevant as risk factors for childhood CNST development.
- Recall bias, particularly differential recall between cases and controls, cannot be entirely excluded given that parents were aware of their child's diagnosis, several observations reduce the likelihood that this bias significantly affected the results.
- In relation to the risk category, there is no accepted consensus to determine a cut-off point, so several researchers have used different elements to compare The authors analyze their own data, based on epidemiological studies, empirical observations and relevant measurements in clinical practice.

3. Occupational exposure

3.1 Differential impacts of co-exposures to ELF-EMFs and noise on prostate-specific antigen levels: A longitudinal study

Elyasi, H., Kakavandi, M.G., Almasi, A. et al. (2025). Environmental Research, 286(1), 122790.

https://doi.org/10.1016/j.envres.2025.122790.

Background: Animal studies indicating an association of exposure to extremely low frequency electromagnetic fields (ELF-EMFs) and noise with reproductive dysfunctions. Nonetheless, the potential impacts of exposure to these hazardous agents on the human prostate gland remain unidentified. To assess the relationship between co-exposure to ELF-EMF and noise and the levels of prostate-specific antigen (PSA), a longitudinal study was conducted over eight years among workers at a thermal power station from 2016 to 2024.

Method: The 8-h equivalent noise level (LAeq and LZeq; dB unit) and the 8-h average of ELF-EMFs (mG unit) were calculated to measure noise and ELF-EMF exposures, respectively. The changes in the levels of PSA were estimated by different linear regression models. In total, the authors examined data from 974 observations.

Results: Per 10-dB increment of LAeq, the significant increases in the log-transformed PSA levels were found in both unadjusted (Coefficient: 0.068 and 95 % CI: 0.044, 0.091) and adjusted (Coefficient: 0.040 and 95 % CI = 0.012, 0.069) models. This association remained significant after further adjusting for ELF-EMFs (no significant effect modification for ELF-EMFs). In all regression models, no significant changes were observed in the PSA levels per unit raise in the ELF-EMFs levels.

Conclusion: No significant interaction was found between ELF-EMFs and noise. In conclusion, our findings indicate that noise may affect prostate health. Additional studies are needed to investigate the mechanisms involved and to validate this connection.

3.2 Investigating the Effects of Occupational Noise and Extremely Low-Frequency Electromagnetic Field Exposure on Oxidative Response in Power Plant Workers.

Jafarimanesh, S., Ehsani, H., Shaki, F., Moosazadeh, M., Samaei, S.E. (2025). *Bioelectromagnetics,* 46:e70027

https://doi.org/10.1002/bem.70027

Background: Occupational noise and extremely low-frequency electromagnetic fields (ELF-EMF) are common in power plants and represent important risk factors that may contribute to oxidative stress. This study examined how simultaneous exposure to these hazards affects oxidative stress biomarkers in workers under real-world conditions.

Methods: Participants were assigned to one of four exposure groups: Control (C), Noise (N), ELF-EMF (E), or a combined Noise and ELF-EMF group (NE). Occupational noise and ELF- EMF exposures were measured according to ISO 9612 and IEEE Std C95.3.1, respectively. To assess oxidative stress, venous blood samples were collected from all participants, and plasma levels of malondialdehyde (MDA), glutathione (GSH), super-oxide dismutase (SOD), and total antioxidant capacity (TAC) were analyzed using validated biochemical assays.

Results: The NE group showed the highest MDA levels, indicating elevated lipid peroxidation compared with controls ($p < 0.001$). GSH concentrations were lower in NE relative to controls ($p < 0.001$). SOD activity was significantly reduced in both the N and NE groups compared with the control group ($p < 0.005$). TAC was lowest in the NE group, showing a significant decrease compared with both the control and Noise-only groups ($p < 0.05$).

Conclusion: While these findings suggest that concurrent exposure to noise and ELF-EMF can influence oxidative stress biomarkers, they do not provide direct evidence to mandate specific workplace monitoring or interventions. Further studies are needed to clarify potential health risks and to guide evidence-based occupational safety measures.

Limitations:

- The cross-sectional design restricts the ability to draw causal inferences, and the relatively small, potentially biased sample may limit the representativeness of the findings.
- In addition, important occupational risk factors, including work-related stress and chemical exposures, were not assessed, which could confound the observed associations.
- Variability in noise and EMF characteristics across industries, as well as the geographic restriction to a single region, further constrain the generalizability of the results.

4. Exposure Assessment

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5. Leukaemia Studies

5.1 Childhood cancer incidence around nuclear installations in Great Britain, 1995–2016.

Davies, B. , Piel, F.B., Roca-Barcelo, A. et al. (2025). *International Journal of Epidemiology*, 54(4), dyaf107

https://doi.org/10.1093/ije/dyaf107

Background: Concerns remain about the potential harmful health impact of nuclear installations. Historical clusters of leukaemia and non-Hodgkin's lymphoma (LNHL) in children living near Sellafield and Dounreay installations in Great Britain remain aetiologically unexplained, and the sites remain under surveillance. The authors assess the risk of LNHL, central nervous system (CNS) and all solid tumours in children aged 0–14 years living within 25 km of nuclear installations in Great Britain, between 1995 and 2016.

Methods: A Poisson regression model was used to estimate the expected number of cases of each cancer type at the community-level in the study population, and present standardized incidence ratios compared to the national population. The authors used a hierarchical Poisson regression model to estimate the adjusted incidence rate ratios for each cancer type by distance between the community of residence and nearest nuclear installation.

Results: No evidence of elevated incidence of LNHL, CNS, or all solid tumours was found in children resident in communities in proximity to nuclear sites. Within the 25-km zone, there was no evidence of an increased risk of childhood cancer in communities closer to installations.

Conclusion: In post-1994 data, there was no evidence of an increased risk of childhood cancers in communities within 25 km of nuclear installations in Great Britain. Previously raised risks are no longer evident.

5.2 Cancer Incidence and Childhood Residence Near the Coldwater Creek Radioactive Waste Site.

Leung, M., Tang, I.W., Lin, Y.L.L. (2025). *JAMA Network Open*, 8(7), e2521926. https://doi.org/10.1001/jamanetworkopen.2025.21926

Background: Beginning in the 1940s, radioactive waste from the effort to develop an atomic bomb was stored in the open near the St Louis, Missouri, airport, and over several decades contaminated nearby Coldwater Creek. The objective of this study is to evaluate whether living near Coldwater Creek in childhood was associated with self-reported cancer incidence in the St Louis Baby Tooth–Later Life Health Study (SLBT).

Methods: The SLBT cohort study was centered in St Louis and included individuals who donated their baby teeth from 1958 to 1970 to assess exposure to atmospheric nuclear weapons testing. Participants for the present analysis were recruited from June 22, 2021, to September 18, 2024. Exposure was assessed through residential proximity to Coldwater Creek (1, >1 to 5, >5 to 20, and >20 km) in childhood when participants donated their baby teeth. Outcome was self-reported cancers, from which several composite outcomes were constructed: any cancer, solid cancers (all except leukemias and lymphomas), known radiosensitive cancers (thyroid, breast, leukemia, and basal cell), and nonradiosensitive cancers (all except thyroid, breast, leukemia, and basal cell). Odds ratios (OR) and 95% CIs between living near Coldwater Creek and several self-reported cancer outcomes were estimated, adjusting for sociodemographic characteristics and neighborhood median income.

Results: There were 4209 eligible SLBT participants, of whom 2369 (56.3%) were female. The mean age at enrollment was 63 (range, 55-77) years. The background risk of any form of cancer was 24%. The OR was 1.44 (95% CI, 0.96-2.14) for any form of cancer comparing participants living 1 km or nearer with those living further than 20 km. There was a significant association for radiosensitive cancers (OR, 1.85; 95% CI, 1.21-2.81) but not for nonradiosensitive cancers (OR, 1.41; 95% CI, 0.86-2.30) for participants living 1 km or nearer vs further than 20 km. There was evidence of a dose-response association, where cancer risks were still elevated (albeit smaller) for those living in buffers of greater than 1 to 5 km and greater than 5 to 20 km. Despite imprecision in some of the site-specific estimates, clear signals for some organs, such as the thyroid, were still detected (OR for living 1 vs >20 km, 5.00; 95% CI, 1.23-20.32).

Conclusion: In this cohort study of baby teeth donors from the Greater St Louis area, evidence suggested a positive association between living near Coldwater Creek in childhood and risk of cancer.

Limitations:

- The outcomes were self-reported, and so there may be errors in reporting site-specific cancers.
- The study had a relatively small sample size to study associations with site-specific cancers, which led to some unstable estimates. This also meant that the authors were not able to examine effect modification or incorporate the age of diagnosis (eg, in a Cox proportional hazards model), as they could not stratify the data further.
- There was potential selection bias, as the authors were conditioning on cancer survival for enrollment into our study—that is, those with cancer may have died or were less likely to participate in our later-life study. If this were related to living near Coldwater Creek, which is possible given that the authors found that those living 20 km or nearer were less likely to participate, a bias of the results toward the null is expected.

5.3 Per- and polyfluoroalkyl substance concentrations during pregnancy and at birth and risk of childhood acute lymphoblastic leukemia.

Morimoto, L.M., Metayer, C., Dolios, G. et al. (2025). Environmental Research, 285(3), 122436. https://doi.org/10.1016/j.envres.2025.122436.

Background: Per- and polyfluoroalkyl substances (PFAS) comprise a class of persistent environmental pollutants with potential carcinogenic effects, but their impact on childhood cancer remains underexplored. A child's exposure to PFAS can occur through various pathways postnatally, including contaminated food, water, and consumer products; and in utero, as PFAS can cross the placenta. Methods: To investigate the association between early-life PFAS exposure and the risk of childhood acute lymphoblastic leukemia (ALL), the authors analyzed archived blood samples from children diagnosed with ALL and matched cancer-free controls. Using novel untargeted liquid chromatography-high resolution mass spectrometry (LC-HRMS), PFAS levels were measured in paired maternal pregnancy and child newborn blood samples.

Results: This study identified an independent association between MeFOSAA levels at birth and increased ALL risk, particularly among children diagnosed at 2 years of age or younger. MeFOSAA measured in maternal second-trimester blood showed a weak association with ALL, although it was not statistically significant.

Conclusions: These results suggest that early-life exposure to MeFOSAA may play a critical role in the development of childhood ALL. These findings corroborate previous reports linking MeFOSAA exposure during pregnancy to childhood ALL, highlighting its potential carcinogenicity during key developmental windows.

Limitations:

- While untargeted analysis has recently emerged as a robust analytical method for measuring PFAS chemicals in epidemiological studies, the measures are relative intensities and not concentration values. While this limits direct comparisons to other studies, including NHANES data to assess the generalizability of our population, it does not bias the risk estimates of ALL.
- Several PFAS compounds were below the limit of detection in a substantial proportion of samples, which can lead to less stable effect estimates. To address this, the authors conducted multiple imputations, and the results were consistent with the original analysis (results not shown).
- Finally, because pregnancy serums were archived from only seven California counties (Fresno, Madera, Kings, Tulare, Kern, Orange, and San Diego) beginning in the year 2000, and the study population includes only mother-child pairs up until birth year 2009 (when our linkage ended), the sample size was relatively small and underpowered for stratified analyses, particularly by ALL cytogenetic subtypes.

5.4 A case-control study of early-life residential exposure to tetrachloroethylene and risks of childhood cancer and birth defects.

Rhee, J., Michalski, A.M., Kuliszewskic, M.G. et al. (2025). Environment International, 201, 109600. https://doi.org/10.1016/j.envint.2025.109600.

Background: Residential buildings with a co-located dry-cleaning facility (CL-DC) can have substantially higher indoor tetrachloroethylene concentrations than buildings without a CL-DC. The authors conducted a case-control study to investigate associations between early-life indoor tetrachloroethylene exposure from CL-DCs and risks of childhood cancers (overall, acute lymphoblastic leukemia) and birth defects.

Methods: Records between the New York City (NYC) Bureau of Vital Statistics and the New York State Cancer Registry and Birth Defects Registry were linked to identify cases of childhood cancers (n = 5,334) and birth defects (n = 171,553) diagnosed among children born in NYC between 1988 and 2016, and controls without these conditions (n = 596,599). The authors identified CL-DC exposure by mapping addresses from birth certificates and DC permits involving tetrachloroethylene use to building footprints, and modeled tetrachloroethylene concentrations using measurement data from a survey of NYC CL-DCs. Using unconditional logistic regression, odds ratios (ORs) and 95 % confidence intervals (CIs) relating study endpoints to CL-DC exposure were computed.

Results: Living in a building with a CL-DC at birth was associated with aortic valve stenosis (AVS; OR = 3.1, 95 % CI = 1.6, 5.9), with an exposure–response effect for predicted tetrachloroethylene concentration (≤44 μg/m3 : OR = 2.7, 95 % CI = 1.0, 7.4; >44 μg/m3 : OR = 3.9, 95 % CI = 1.6, 9.5) and stronger associations for children whose mother was non-White, less than college-educated, or lived at birth in majority non-White or poorer neighborhoods. The authors observed null findings for other endpoints.

Conclusions: In this case-control study, early-life tetrachloroethylene exposure from CL-DCs in residential buildings was associated with increased AVS risk. These findings warrant further investigation.

5.5 Prenatal exposure to air pollution and pediatric acute leukemia: A nationwide study.

Yen, S., Chen, I.C., Lin, W.Z., Lin, K.C., Wu, M.C., Lin, C.H. (2025). Science of The Total Environment, 992, 179975.

https://doi.org/10.1016/j.scitotenv.2025.179975.

Background: Childhood cancer, particularly leukemia, remains a leading cause of mortality among children, with unclear etiologies. Epidemiological studies suggest that air pollution could be a credible factor in triggering genotoxic effects, oxidative stress, and mutagenic characteristics. This article

investigated the impact of prenatal air pollution exposure on childhood leukemia occurrences in Taiwan.

Methods: This research constitutes a comprehensive nationwide investigation, utilizing population-based data and employing a matched case-control design. Data from Taiwan's Maternal and Child Health Database (MCHD) were used to identify 965 children under 16 years old with leukemia and matched them with controls without leukemia from 2004 to 2020. Prenatal exposure to air pollutant levels were derived from 71 Environmental Protection Administration monitoring stations across Taiwan, based on maternal residency during pregnancy. Incidence cases were identified as patients with either three clinic visits or being admitted to the hospital with a diagnosis of leukemia.

Results: This nationwide study included 965 leukemia cases and 3860 controls in Taiwan. Prenatal O_3 exposure showed a marginal overall association with leukemia risk (OR = 1.02, 95 % CI: 1.00–1.04, p = 0.059), with significant dose-response effects at higher quartiles (Q3: OR = 1.31, 95 % CI: 1.07–1.60, p = 0.010; Q4: OR = 1.32, 95 % CI: 1.08–1.62, p = 0.007). Conversely, NO showed a protective association (OR = 0.97, 95 % CI: 0.95–0.99, p = 0.010), especially at higher exposure (Q4: OR = 0.79, 95 % CI: 0.64–0.96, p = 0.020). Trimester-specific analyses revealed protective effects of NO in the first and second trimesters, and CO in the first trimester. No significant associations were observed for $PM_{2.5}$, PM_{10} or SO_2.

Conclusion: Prenatal O_3 exposure increases childhood leukemia risk in Taiwan, while NO and CO exhibit protective effects, supporting targeted air quality interventions and highlighting critical windows for prenatal environmental protection.

Limitations:

- Pollutant exposure was assigned using township-level estimates derived from the nearest monitoring station, which may be several kilometers away from participants' actual residences. This approach may have led to exposure misclassification, particularly in rural areas. Future studies that incorporate finer-scale exposure assessments, such as restricting analysis to participants living within one kilometer of monitoring stations, are warranted to better address this potential limitation.
- Individual-level data on residential mobility during pregnancy were unavailable, which may have further contributed to exposure misclassification if participants moved between trimesters. Although national household registration statistics in Taiwan suggest that residential changes are relatively infrequent, with an annual migration rate of approximately 7 %, unmeasured mobility remains a potential source of bias.
- The observational nature of our study limits the ability to draw causal inferences.
- Moreover, individual-level information on important covariates, including indoor exposures and potential co-exposures such as tobacco smoke, dietary factors, and infections, was unavailable, and residual confounding cannot be excluded.

6. REFERENCES

Correa-Correa, V., Núñez-Enríquez, J.C., et al. (2025). Extremely low-frequency magnetic fields (ELF-MF) and radiofrequency: Risk of childhood CNS tumors in a city with elevated ELF-MF exposure. *Environmental Research*, 286(2), 122858. https://doi.org/10.1016/j.envres.2025.122858.

Danho, S., Escobar Huertas, J., Schoellhorn, W. I. (2025). A Systematic Review of the Impact of Electromagnetic Waves on Living Beings. *Cureus*, 17(8): e90355. http://doi.org/10.7759/cureus.90355

Davies, B. , Piel, F.B., Roca-Barcelo, A. et al. (2025). Childhood cancer incidence around nuclear installations in Great Britain, 1995–2016. *International Journal of Epidemiology*, 54(4), dyaf107. https://doi.org/10.1093/ije/dyaf107

Elyasi, H., Kakavandi, M.G., Almasi, A. et al. (2025). Differential impacts of co-exposures to ELF-EMFs and noise on prostate-specific antigen levels: A longitudinal study. *Environmental Research*, 286(1), 122790. https://doi.org/10.1016/j.envres.2025.122790.

Jafarimanesh, S., Ehsani, H., Shaki, F., Moosazadeh, M., Samaei, S.E. (2025). Investigating the Effects of Occupational Noise and Extremely Low-Frequency Electromagnetic Field Exposure on Oxidative Response in Power Plant Workers. *Bioelectromagnetics,* 46:e70027. https://doi.org/10.1002/bem.70027

Leung, M., Tang, I.W., Lin, Y.L.L. (2025). Cancer Incidence and Childhood Residence Near the Coldwater Creek Radioactive Waste Site. *JAMA Network Open*, 8(7), e2521926. https://doi.org/10.1001/jamanetworkopen.2025.21926

Morimoto, L.M., Metayer, C., Dolios, G. et al. (2025). Per- and polyfluoroalkyl substance concentrations during pregnancy and at birth and risk of childhood acute lymphoblastic leukemia. *Environmental Research*, 285(3), 122436. https://doi.org/10.1016/j.envres.2025.122436.

Rhee, J., Michalski, A.M., Kuliszewskic, M.G. et al. (2025). A case-control study of early-life residential exposure to tetrachloroethylene and risks of childhood cancer and birth defects. *Environment International,* 201, 109600. https://doi.org/10.1016/j.envint.2025.109600.

Yen, S., Chen, I.C., Lin, W.Z., Lin, K.C., Wu, M.C., Lin, C.H. (2025). Prenatal exposure to air pollution and pediatric acute leukemia: A nationwide study. *Science of The Total Environment*, 992, 179975. https://doi.org/10.1016/j.scitotenv.2025.179975.