Overview of the epidemiologic studies on the health effects of ELF electric and magnetic fields (ELF-EMF) published in the fourth quarter of 2023.

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1. Reviews and meta-analyses

1.1 Potential health effects of exposure to electromagnetic fields (EMF): 14 Update with regard to frequencies between 1Hz and 100 kHz

Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) (2023).
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Summary:

The exposure of the general population in Europe remains below the exposure limits recommended in Council Recommendation 1999/519/EC.

There are no systematic reviews and meta-analysis available for melatonin hypothesis, radical pair mechanisms, oxidative stress or epigenetic effects. There is weak evidence regarding the involvement of interaction mechanisms (oxidative stress, genetic/epigenetic effects) on health risks from ELF-MF observed in epidemiological and in vivo studies.

More research is needed, making use of standardized exposure conditions and optimized in vitro cell lines, with the possibility to extrapolate to in vivo models where the metabolic processes play an important role for the interpretation of the biological responses relevant in terms of human health. No systematic reviews or meta-analysis on ELF-EMF exposure and self-reported symptoms could be identified. Therefore, the SCENIHR conclusion still stands, i.e., there is no convincing evidence for a causal relationship between ELF-MF exposure and self-reported symptoms.

Published systematic reviews concerning leukemia and ELF-EMF exposure, based mainly on case-control studies, revealed that ELF-MF exposure showed consistent but moderate risk estimates, but there was too little evidence to establish a dose-response curve. With respect to childhood leukemia, there is weak to moderate weight of evidence from epidemiological studies (the primary line of evidence). However, the animal models used in the majority of studies were not appropriate for studying childhood leukemia, therefore there is weak evidence from this line of evidence. Moreover, there is weak evidence from interaction mechanisms on the induction of neoplasia by ELF-MF exposure. Consequently, overall, there is weak evidence concerning the association of ELF-MF exposure with childhood leukemia.

Overall, there is moderate evidence (mainly from human studies) on the association between occupational exposure to ELF-EMF and ALS, weak evidence for the association of occupational LF-EMF exposure with Alzheimer's disease, and dementia, but only uncertain to weak evidence for residential exposure and these neurodegenerative diseases. No significant association can be established between EMF exposure and Parkinson's or multiple sclerosis disease.

No systematic reviews or meta-analyses could be identified on exposure to ELF-EMF and neurophysiological outcomes. Therefore, it is still not possible to draw a definite conclusion on potential effects.

The available systematic reviews and meta-analyses have not shown an association between ELF-EMF exposure and pregnancy or reproductive outcomes.

The weight of evidence on the health effects of IF-EMF exposure is due to contradictory information from different lines of evidence. No conclusive results can be reached based on human studies, either.

The exposure of animals and plants to ELF-EMFs may become higher than that of humans, if they are close to anthropogenic sources in the environment. Moreover, animals and plans possess receptors and structures not existing in humans, which could give rise to species specific biological effects.

1.2 Electromagnetic Radiation Exposure and Childhood Leukemia: Meta-Analysis and Systematic Review

Guo, H., Kang, L., Qin, W., Li, Y. (2023). *Alternative Therapies, 29(8),* 75-81.

Background and objective: Leukemia is the most prevalent cancer among children and adolescents. This study investigated the potential association between exposure to magnetic fields and the risk of pediatric leukemia.

Methods: The authors conducted a comprehensive search of electronic databases, including Scopus, EMBASE, Cochrane, Web of Science, and Medline, up to December 15, 2022, to identify relevant studies examining the link between childhood leukemia and magnetic field exposure.

Results: The first meta-analysis revealed a statistically significant inverse association between pediatric leukemia and magnetic field strengths ranging from 0.4 μT to 0.2 μT, suggesting a reduced risk associated with this range. The second meta-analysis focused on wiring configuration codes and observed a potential link between residential magnetic field exposure and childhood leukemia. Pooled relative risk estimates were 1.52 (95% CI = 1.05-2.04, P = .021) and 1.58 (95% CI = 1.15-2.23, P = .006) for exposure to 24-hour magnetic field measurements, suggesting a possible causal relationship. In the third meta-analysis, the odds ratios for the exposure groups of 0.1 to 0.2 μT, 0.2 to 0.3 μT, 0.3 to 0.4 μT, and 0.4 μT above 0.2 μT were 1.09 (95% confidence interval = 0.82 to 1.43 μT), 1.14 (95% confidence interval = 0.68 to 1.92 μT), and 1.45 (95% confidence interval = 0.87 to 2.37 μT), respectively. In contrast to the findings of the three meta-analyses, there was no evidence of a statistically significant connection between exposure to 0.2 μT and the risk of juvenile leukemia. A further result showed no discernible difference between the two groups of children who lived less than 100 meters from the source of magnetic fields and those who lived closer (OR = 1.33; 95% CI = 0.98-1.73 μT).

Conclusions: The collective results of three meta-analyses, encompassing magnetic field strengths ranging from 0.1 μT to 2.38 μT, underscore a statistically significant association between the intensity of magnetic fields and the occurrence of childhood leukemia. However, one specific analysis concluded that no apparent relationship exists between exposure to 0.1 μT and an elevated risk of leukemia development in children.

Limitations: This study has several limitations that should be acknowledged. Firstly, the inherent heterogeneity among the included studies, such as variations in study design, exposure assessment methods, and data collection, may introduce potential sources of bias. Secondly, while efforts were made to control for confounding factors, the possibility of residual confounding cannot be completely ruled out. Additionally, most studies relied on self-reported exposure data, which can introduce recall bias. Furthermore, including studies conducted in different geographic regions with varying radiation exposure levels may limit the findings' generalizability. Lastly, the analyses in this meta-analysis were primarily based on observational studies, which can only establish associations and not causation. Therefore, caution should be exercised when interpreting the results, and further research, including prospective cohort studies and randomized controlled trials, is needed to establish a causal relationship between radiation exposure and childhood leukemia.

Comments: we note a number of methodological flaws that prevent the results of this study from being taken into account.

1.3 Electromagnetic Fields: Insight into Sources, and Their Effects on Vital Organs and the Risk of Cancer

Khalat, A.M., Yahya, R.A.M., Azab, A.E. (2023). *SAR Journal of Anatomy and Physiology, 4(3),* 20-32. https://doi.org/10.36346/sarjap.2023.v04i03.001

Background and objectives: The biological effects of electromagnetic radiation have attracted considerable attention worldwide. The current review was aimed to highlight on sources of electromagnetic fields and their effects on vital organs and the risk of cancer. Electromagnetic sources can be classified into natural electromagnetic sources (sun, some distant stars, atmospheric discharges like thunder, or human body) and unnatural or human made sources.

Methods: The authors did not describe their review methods.

Comment: The authors follow an unsystematic approach to gather data and offer no transparency at all about their review process. There is no sufficient distinction between the health effects of different frequencies from the EMV-spectrum. The authors include no limitations. The conclusion by the author is not valid given the methods used.

2. Residential exposure

2.1 Low-frequency magnetic fields and the risk of developing of Alzheimer's dementia

Sauter, C., Dorn, H., Hellmann-Regen, J., Bueno-Lopez, A., Danker-Hopfe, H. (2023). *Somnologie, 27*, 255–264. https://doi.org/10.1007/s11818-023-00425-4

Background and objectives: Some of the population fear the negative effects of low-frequency of low-frequency magnetic fields (ELF-MF), e.g. from high-voltage power lines and other installations and devices with a frequency of 50 Hz or 16 2/3 Hz. Some studies show a correlation between exposure to LF-MF and an increased risk of neurodegenerative diseases, including Alzheimer's disease (AD).

Methods: This narrative review summarizes the current state of research on ELF-MF and possible effects on AD risk and sleep are summarized on the basis of epidemiological and experimental studies. The study critically discusses the methods used.

Results: In epidemiological studies, both studies on occupational exposure to low-frequency magnetic fields as well as in studies on domestic exposure to high-voltage, a slightly increased risk of Alzheimer's dementia was observed. However, this risk only proved to be significant in the meta-analyses on occupational exposure. The studies are characterized by great heterogeneity, which is why it remains unclear whether the observations are based on a causal underlying the observations. While a mechanism of action is not yet known, sleep could play a key role in the search for one. As disturbed sleep has been shown to lead to an increased concentration of the biomarkers of Alzheimer's dementia (amyloid and tau and their deposits), a disorder caused by external factors as triggers or amplifiers is conceivable.

Limitations: In epidemiological studies, sleep can only be measured very imprecisely and is susceptible to confounders that can be better controlled in experimental studies. Some experimental studies show a negative effect of ELF-MF on human sleep. However, it should be noted that the validity of most of these studies is very limited due to poor study quality which is why there is a clear need for studies of good quality

3. Occupational exposure

3.1 Occupational exposure to extremely low-frequency magnetic fields and follicular lymphoma risk: a family case-control study

Odutola, M.K., van Leeuwen, M.T., Bruinsma, F.J. (2023). *Occupational and Environmental Medicine, 80(10),* 599–602. https://doi.org/10.1136/oemed-2023-108949

Background and objective: The authors aimed to examine the relationship between occupational exposure to extremely low-frequency magnetic fields (ELF-MF) and follicular lymphoma (FL) risk.

Methods: A family case-control study was conducted between 2011–2016 in Australia and included 681 cases. Controls were either a family member of cases (related (n=294), unrelated (n=179)) or were unrelated recruited for a similarly designed Australian multiple myeloma study (n=711).

Results: The authors obtained detailed job histories using lifetime work calendars. Exposure to ELF-MF was assigned using an enhanced JEM, with a lag period of 10 years. The authors examined associations with FL risk using logistic regression accounting for relatedness between cases and controls. They performed sensitivity analyses including by control type, by sex, complete case analyses, ELF-MF exposure percentiles in addition to quartiles, ELF-MF exposure in the maximum exposed job, a shorter lag period (1 year), and the cumulative exposure in the most recent time period (1–9 years).

Results: No association was observed with the average intensity, duration or lifetime cumulative exposure to occupational ELF-MF exposure in the primary or sensitivity analyses.

Conclusions: These findings do not support an association between occupational ELF-MF exposure and FL risk. Although the inclusion of family members as part of the larger control group may have biased the risk estimates towards the null, findings were similar in sensitivity analyses restricted to cases and unrelated controls. Further research incorporating enhanced exposure assessment to ELF-MF is warranted to inform occupational safety regulations and any potential role in lymphomagenesis.

3.2 Occupational risk factors for multiple sclerosis: a systematic review with meta-analysis

Vitturi, B.K., Montecucco, A., Rahmani, A. et al. (2023). *Frontiers in Public Health 11*:1285103. https://do.org/10.3389/fpubh.2023.1285103

Background and objective: The authors present the first systematic review with meta-analysis to provide the highest level of up-to-date evidence on the occupational risk factors for Multiple Sclerosis.

Methods: A systematic, comprehensive literature search was performed in four electronic academic databases. The authors included any case-control study that enrolled working-age subjects and compared the proportion of MS cases with controls who were not exposed to an occupational risk factor. The primary outcome was the occurrence of MS. The quality assessment was performed with the Critical Appraisal Checklist for Case Control Studies, developed, and validated by the Joanna Briggs Institute. All the selection process was also carried out by two independent and previously trained researchers.

Results: Overall, the total sample included 19,004 people with MS and 4,164,162 controls. Agricultural workers (OR = 1.44, 95% CI 1.13–1.83), offshore workers (OR = 3.56, 95% CI 2.74–4.61), and hairdressers (OR = 8.25, 95% CI 1.02–66.52) were associated with a higher probability of being diagnosed with MS. In parallel, workers exposed to toxic fumes from oil wells (OR = 16.80, 95% CI 8.33–33.90), low-frequency magnetic fields (OR = 1.71, 95% CI 1.03–2.72), and pesticides (OR = 3.17, 95% CI = 2.53–3.99) also had an increased likelihood of having MS.

Conclusion: This study has the potential to influence more assertive public policies. Nevertheless, future studies on how the occupational setting may contribute to the incidence of MS are highly recommended.

Limitations: Given the inherent methodology of a systematic review, it is not possible to exclude that there were some differences in the way the results were evaluated by the authors of each study, which could be responsible for some kind of methodological bias and significant heterogeneity. Unfortunately, most studies neither measured the degree of exposure to potential risk factors nor described them to exhaustion in the case of job characteristics and MS. There was an imbalance in the availability of literature across countries and thus these results may not be representative of some countries or regions. The influence of the country in terms of longitude and national income status could not be considered in the analysis. Moreover, it is known that patients with MS experience work difficulties from the earliest stages of the disease, including the pre-symptomatic phase, which can affect the likelihood of exposure.

3.3 Association of prolonged occupational co-exposures to electromagnetic fields, noise, and rotating shift work with thyroid hormone levels

Khosravipour, M., Gharagozlou, F., Kakavandi, M.G. (2024). *Ecotoxicology and Environmental Safety.* https://doi.org/10.1016/j.ecoenv.2023.115837

Background and objective: The purpose of this study was to determine the association of prolonged occupational co-exposure to extremely low-frequency electromagnetic fields (ELF-EMFs), noise, and rotating shift work with the levels of thyroid hormones (triiodothyronine (T3), thyroxine (T4), and thyroid-stimulating hormone (TSH).

Methods: From 2016 to 2017, all male workers without a history of thyroid disorders were enrolled and followed until 2020. To measure ELF-EMFs and noise exposures, the authors calculated the 8-hour equivalent sound pressure levels (Leq) and the 8-hour average of ELF-EMFs, respectively. Shift work schedules involved 8-hr fixed day and 8-hr clockwise 3-rotating night schedules. The participant's thyroid hormone levels were obtained from blood test results in their medical records. The percentage change in the levels of T3, T4, and TSH was estimated by using different mixed effects linear regression models.

Results: The TSH levels were significantly elevated per a 10-dB increment of noise. The levels of T4 hormone were significantly changed per a unit increase in the levels of ELF-EMFs. Compared to the fixed-day workers, the authors observed workers exposed to shift work had a significantly lower T4 level. For T4 and TSH hormones, significant interactions were found among noise, ELF-EMFs, and shift work variables.

Conclusion: In summary, this study warranted that prolonged exposure to ELF-EMFs, noise, and rotating shift work might be associated with thyroid dysfunction.

Limitations: It is important to note that the authors did not implement any measures to control exposure during non-work hours. Furthermore, they measured total T3 and T4 hormones instead of free T3 and T4. Accordingly, the potential influence of some lifestyle variables, such as sleep patterns and nutritional choices, on the observed outcomes has yet to be ascertained.

4. Exposure Assessment

4.1 Adjusting for Berkson error in exposure in ordinary and conditional logistic regression and in Poisson regression

Oraby,T., Chakraborty, S., Sivaganesan, S. et al. (2023). *BMC Medical Research Methodology 23*:225
https://doi.org/10.1186/s12874-023-02044-x

Background and objectives: INTEROCC is a seven-country cohort study of occupational exposures and brain cancer risk, including occupational exposure to electromagnetic felds (EMF). In the absence of data on individual exposures, a Job Exposure Matrix (JEM) may be used to construct likely exposure scenarios in occupational settings. This tool was constructed using statistical summaries of exposure to EMF for various occupational categories for a comparable group of workers.

Methods: In this study, Canadian data from INTEROCC was used to determine the best EMF exposure surrogate/ estimate from three appropriately chosen surrogates from the JEM, along with a fourth surrogate based on Berkson error adjustments obtained via numerical approximation of the likelihood function. The authors examine the case in which exposures are gamma-distributed for each occupation in the JEM, as an alternative to the log-normal exposure distribution considered in a previous study conducted by our research team. They also study using those surrogates and the Berkson error adjustment in Poisson regression and conditional logistic regression.

Results: Simulations show that the introduced methods of Berkson error adjustment for non-stratified analyses provide accurate estimates of the risk of developing tumors in case of gamma exposure model. Alternatively, and under some technical assumptions, the arithmetic mean is the best surrogate when a gamma-distribution is used as an exposure model. Simulations also show that none of the present methods could provide an accurate estimate of the risk in case of stratified analyses.

Conclusion: While a previous study found the geometric mean to be the best exposure surrogate, the present study suggests that the best surrogate is dependent on the exposure model; the arithmetic means in case of gamma exposure model and the geometric means in case of log-normal exposure model. However, The authors could present a better method of Berkson error adjustment for each of the two exposure models. These results provide useful guidance on the application of JEMs for occupational exposure assessments, with adjustment for Berkson error.

5. Leukaemia Studies

5.1 Maternal medically diagnosed infection and antibiotic prescription during pregnancy and risk of childhood cancer: A population-based cohort study in Taiwan, 2004 to 2015

Sirirungreung, A., Lee, P.-C., Hu, Y.H. (2024). *International Journal of Cancer, 154,* 626–635. https://doi.org/10.1002/ijc.34744

Background and objective: While associations between maternal infections during pregnancy and childhood leukemia in offspring have been extensively studied, the evidence for other types of childhood cancers is limited. Additionally, antibiotic exposure during pregnancy could potentially increase the risk of childhood cancers. This study investigates associations between maternal infections and antibiotic prescriptions during pregnancy and the risk of childhood cancer in Taiwan.

Methods: The authors conducted a population-based cohort study using the Taiwan Maternal and Child Health Database (TMCHD), linked with national health and cancer registries.

Results: The study included 2 267 186 mother-child pairs, and the median follow-up time was 7.96 years. Cox proportional hazard models were utilized to estimate effects. Maternal infections during pregnancy were associated with a moderate increase in the risk of childhood hepatoblastoma (adjusted hazard ratio [HR] = 1.34; 95% confidence interval [CI]: 0.90-1.98) and a weaker increase in the risk of childhood acute lymphoblastic leukemia (ALL) (adjusted HR = 1.15; 95% CI: 0.99-1.35). Antibiotic prescriptions during pregnancy were also associated with an elevated risk of childhood ALL (adjusted HR = 1.30; 95% CI: 1.04-1.63), particularly with tetracyclines (adjusted HR = 2.15; 95% CI: 1.34-3.45). Several specific antibiotics were also associated with an increased risk of hepatoblastoma and medulloblastoma. Children exposed in utero to antibiotic prescription or both infections and antibiotics during pregnancy were at higher risk of developing ALL.

Conclusion: These findings suggest that there are associations between maternal infections, antibiotic use during pregnancy and the risk of several childhood cancers in addition to ALL and highlight the importance of further research in this area.

5.2 Agricultural intensification and childhood cancer in Brazil Marin

Skidmorea, I.D, Sims, K.M., Gibbs, H.K. (2023). *PNAS Environmental Sciences, 120(45),* e2306003120. https://doi.org/10.1073/pnas.2306003120

Background and objectives: Over the last several decades, Brazil has become both the world's leading soy, producer and the world's leading consumer of hazardous pesticides. Despite identified links between pesticide exposure and carcinogenesis, there has been little population level research on the effects of pesticide intensification on broader human health in Brazil. The authors estimate the relationship between expanded soy production—and related community exposure to pesticides—on childhood cancer incidence using 15 y of data on disease mortality.

Methods: The authors use a 15-y (2004 to 2019), municipal-level panel on health outcomes, land use, surface water, and demographics. Mortality data are publicly available from Data SUS. These encounters are defined by ICD-10 (International Classification of Disease) diagnosis category codes and

stratified by age bins, allowing the authors to identify fatal cases of lymphoidl eukemia (ICD-10 code C91) in the population under ages 5 and 10 at the municipal-year level. Among children (under age 5 and under age 10), these cases should overwhelmingly consist of deaths from ALL. Population data are available from the Brazilian Institute of Geography and Statistics (IBGE), although they are not available annually stratified by age group. The authors impute annual population under 5 and under 10 by multiplying the proportion of the population in that age group in the most recent census (every 5 y) by the annual total population. The authors compile data on soy, sugarcane, all other temporary crops, pasture, mining, and natural vegetation using land cover maps from Map biomas version7 . Using these data, they calculated the total number of hectares in the municipality planted in soy as well as control for sugarcane, remaining forest, natural vegetation, and area in pasture. In Brazil, corn is intercropped with soy and is not the dominant cash crop. Land use data reflect this by categorizing land used in a soy-corn rotation as area in soy.

Results: The authors find a statistically significant increase in pediatric leukemia following expanded local soy production, but timely access to treatment mitigates this relationship. They show that pesticide exposure likely occurs via water supply penetration. These findings represent only the tip of the iceberg for substantial health externalities of high-input crop production and land use change. These results are of particular interest in developing contexts with demand for intensified food production systems and underscore the need for stronger regulation of pesticides and increased public health attention to exposure in the broader community.

5.3 Pesticides as a potential independent childhood leukemia risk factor and as a potential confounder for electromagnetic fields exposure

Nguyen, A., Crespi, C.M., Vergara, X., Kheifets, L. (2023). *Environmental Research, 238.* https://doi.org/10.1016/j.envres.2023.116899

Background and objectives: Both pesticides and high magnetic fields are suspected to be childhood leukemia risk factors. Pesticides are utilized at commercial plant nurseries, which sometimes occupy the areas underneath high-voltage powerlines. This study want to evaluate whether potential pesticide exposures (intended use, chemical class, active ingredient) utilized at plant nurseries act as an independent childhood leukemia risk factor or as a confounder for proximity to, or magnetic fields exposure from, high-voltage powerlines.

Methods: The authors conducted a state-wide records-based case-control study for California with 5788 childhood leukemia cases and 5788 controls that examined specific pesticide use, magnetic field exposures and distances to both powerlines and plant nurseries. Exposure assessment incorporated geographic information systems, aerial satellite images, and other historical information.

Results: Childhood leukemia risk was potentially elevated for several active pesticide ingredients: permethrin (odds ratio (OR) 1.49, 95% confidence interval (CI) (0.83–2.67), chlorpyrifos (OR 1.29, 95% CI 0.89–1.87), dimethoate (OR 1.79, 95% CI 0.85–3.76), mancozeb (OR 1.41, 95% CI 0.85–2.33), oxyfluorfen (OR 1.41, 95% CI 0.75–2.66), oryzalin (OR 1.60, 95% CI 0.97–2.63), and pendimethalin (OR 1.82, 95% CI 0.81–2.25). Rodenticide (OR 1.42, 95% CI 0.78–2.56) and molluscicide (OR 1.22, 95% CI 0.82–1.81) exposure also presented potentially elevated childhood leukemia risks. Childhood leukemia associations with calculated fields or powerline proximity did not materially change after adjusting for pesticide exposure. Childhood leukemia risks with powerline proximity remained similar when pesticide exposures were excluded.

Conclusion: Pesticide exposure may be an independent childhood leukemia risk factor. Childhood leukemia risks for powerline proximity and magnetic fields exposure were not explained by pesticide exposure.

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