

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

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1. Reviews and meta-analyses

1.1 Risk Factors of amyotrophic lateral sclerosis: a global meta-summary

Duan, Q.-Q., Jiang, Z., Su, W.M., et al. (2023). *Frontiers in Neuroscience*, 17.
<https://doi.org/10.3389/fnins.2023.1177431>

Background and Objectives: The etiology of amyotrophic lateral sclerosis (ALS) remains largely unknown. This study aimed to summarize the relationship between ALS and its genetic and non-genetic risk factors.

Methods: A search of relevant literature from PubMed, Embase, and Cochrane Database from inception to December 2022 was performed. Random-effects or fixed-effects models were performed by Stata MP 15.0 to pool multivariate or adjusted ratios (OR).

Results: 230 eligible studies were included, of which 67 involved 22 non-genetic factors, and 163 involved genetic factors. Four aspects of non-genetic factors, including lifestyle, environmental and occupational exposures, pre-existing diseases/comorbidity and medical exposures, and others, were analyzed. Exposure to heavy metals (OR = 1.79), pesticides (OR = 1.46), solvents (OR = 1.37), previous head trauma (OR = 1.37), military service (OR = 1.29), stroke (OR = 1.26), magnetic field (OR = 1.22) and hypertension (OR = 1.04) are significant risk factors, but use of antidiabetics (OR = 0.52), high BMI (OR = 0.60 for obese and overweight vs. normal and underweight), living in urban (OR = 0.70), diabetes mellitus (OR = 0.83), and kidney disease (OR = 0.84) decrease the risk for ALS. In addition, eight common ALS-related genes were evaluated, the mutation frequencies of these genes were ranked from highest to lowest in all the ALS patients.

Conclusions: These findings suggested that effective intervention for risk exposure and timely modification of lifestyle might prevent the occurrence of ALS. Genetic mutations are important risk factors for ALS and it is essential to detect genetic mutations correctly and scientifically.

Comment by dr. Els De Waegeneer: The exposure assessment of magnetic fields in the obtained studies is not clear, neither is the source or the type of magnetic fields. This makes it hard to draw conclusions. A well-designed systematic review and meta-analysis that focuses solely on the possible effect of a certain type of magnetic fields could give more insight. The conclusion of the authors goes against the findings of WHO and the European risk assessment. Nevertheless, the issue should be followed up further.

1.2 Effects of man-made electromagnetic fields on heart rate variability parameters of general public: a systematic review and meta-analysis of experimental studies

Mansourian, M., Marateb, H., Nouri, R., Mansourian, M. (2023). *Review of Environmental Health*, ahead of publishing. <https://doi.org/10.1515/reveh-2022-0191>

Background and Objectives: The effects of man-made electromagnetic fields (EMFs) on the cardiovascular system have been investigated in many studies. In this regard, the cardiac autonomic nervous system (ANS) activity due to EMFs exposure, assessed by heart rate variability (HRV), was

targeted in some studies. The studies investigating the relationship between EMFs and HRV have yielded conflicting results. The authors performed a systematic review and meta-analysis to assess the data's consistency and identify the association between EMFs and HRV measures.

Methods: Published literature from four electronic databases, including Web of Science, PubMed, Scopus, Embase, and Cochrane, were retrieved and screened.

Results: Initially, 1601 articles were retrieved. After the screening, 15 original studies were eligible to be included in the meta-analysis. The studies evaluated the association between EMFs and SDNN (standard deviation of NN intervals), SDANN (Standard deviation of the average NN intervals for each 5 min segment of a 24 h HRV recording), and PNN50 (percentage of successive RR intervals that differ by more than 50 ms). There was a decrease in SDNN (ES=-0.227 [-0.389, -0.065], p=0.006), SDANN (ES=-0.526 [-1.001, -0.05], p=0.03) and PNN50 (ES=-0.287 [-0.549, -0.024]). However, there was no significant difference in LF (ES=0.061 (-0.267, 0.39), p=0.714) and HF (ES=-0.134 (0.581, 0.312), p=0.556). In addition, a significant difference was not observed in LF/HF (ES=0.079 (-0.191, 0.348), p=0.566).

Conclusion: This meta-analysis suggests that exposure to the environmental artificial EMFs could significantly correlate with SDNN, SDANN, and PNN50 indices. Therefore, lifestyle modification is essential in using the devices that emit EMs, such as cell phones, to decrease some signs and symptoms due to EMFs' effect on HRV.

Comment by dr. Els De Waegeneer: Since the characteristics and effects of different parts of the non-ionizing electromagnetic spectrum differ substantially, they should be reviewed separately and not be treated as similar sources/types of exposure. This study mixes up the different types of EMF and thereby their possible effects.

1.3 Electromagnetic fields exposure on fetal and childhood abnormalities: Systematic review and meta-analysis

Kashani, Z.A., Pakzad, R., Fakari, F.R. , et al. (2023). *Open Medicine*, 18.
<https://doi.org/10.1515/med-2023-0697>

Background and Objective: Today, people are often exposed to electromagnetic waves, which can have undesirable effects on cell components that lead to differentiation and abnormalities in cell proliferation, deoxyribonucleic acid (DNA) damage, chromosomal abnormalities, cancers, and birth defects. This study aimed to investigate the effect of electromagnetic waves on fetal and childhood abnormalities.

Methods: PubMed, Scopus, Web of Science, ProQuest, Cochrane Library, and Google Scholar were searched on 1 January 2023. The Cochran's Q-test and I² statistics were applied to assess heterogeneity, a random-effects model was used to estimate the pooled odds ratio (OR), standardized mean difference (SMD), and mean difference for different outcomes, and a meta-regression method was utilized to investigate the factors affecting heterogeneity between studies.

Results: A total of 14 studies were included in the analysis, and the outcomes investigated were: change in gene expression, oxidant parameters, antioxidant parameters, and DNA damage parameters in the umbilical cord blood of the fetus and fetal developmental disorders, cancers, and childhood development disorders. Totally, the events of fetal and childhood abnormalities were more common in parents who have been exposed to EMFs compared to those who have not (SMD and 95%

confidence interval [CI], 0.25 [0.15–0.35]; I², 91%). Moreover, fetal developmental disorders (OR, 1.34; CI, 1.17–1.52; I², 0%); cancer (OR, 1.14; CI, 1.05–1.23; I², 60.1%); childhood development disorders (OR, 2.10; CI, 1.00–3.21; I², 0%); changes in gene expression (mean difference [MD], 1.02; CI, 0.67–1.37; I², 93%); oxidant parameters (MD, 0.94; CI, 0.70–1.18; I², 61.3%); and DNA damage parameters (MD, 1.01; CI, 0.17–1.86; I², 91.6%) in parents who have been exposed to EMFs were more than those in parents who have not. According to meta-regression, publication year has a significant effect on heterogeneity (coefficient: 0.033; 0.009–0.057). Maternal exposure to electromagnetic fields, especially in the first trimester of pregnancy, due to the high level of stem cells and their high sensitivity to this radiation, the biochemical parameters of the umbilical cord blood examined was shown increased oxidative stress reactions, changes in protein gene expression, DNA damage, and increased embryonic abnormalities. In addition, parental exposure to ionizing and non-ionizing radiation can lead to the enhancement of different cell-based cancers and developmental disorders such as speech problems in childhood.

Comment by dr. Els De Waegeneer: Since the characteristics and effects of different parts of the ionizing electromagnetic spectrum differ substantially, they should be reviewed separately and not be treated as similar sources/types of exposure. This study mixes up the different types of EMF and thereby their possible effects. The fact that even ionizing radiation is taken into account in the same review and meta-analysis is very concerning, since this is a known carcinogenic agent. Next to the different types of EMF, also the role of the participants in the studies is very diverse: both occupational and residential exposure are considered at the same time.

2. Residential exposure

2.1 Prevalence of migraine disease in electrohypersensitive patients.

Grecco, F., Garnier, O., Macioce, V., Picot M.-C. (2023). *Journal of Clinical Medicine*, 12, 4092. <https://doi.org/10.3390/jcm12124092>

Background and objectives: The vast majority of electrohypersensitive (EHS) patients present headaches on contact with an electromagnetic source. Clinical features suggest that the headaches of these patients could be a variant of the migraine disease and could be treated as such. The authors aimed to assess the prevalence of migraine disease in EHS patients using a validated questionnaire.

Methods: Patients with EHS defined according to WHO criteria were contacted through EHS patient support associations. They were required to answer a self-questionnaire including clinical data and the extended French version of the ID Migraine questionnaire (ef-ID Migraine) to screen for the migraine disease. Migraine prevalence and its 95% confidence interval (CI) were reported. Patients' characteristics, symptoms (rheumatology, digestive, cognitive, respiratory, cardiac, mood, cutaneous, headache, perception, genital, tinnitus and tiredness) and impact on daily life were compared between migraineur and non-migraineur patients.

Results: A total of 293 patients were included (97% women, mean age 57 ± 12 years). Migraine was diagnosed in 65% (N = 191; 95% CI: 60–71%) with the ef-ID Migraine. The migraine diagnosis was accompanied by nausea/vomiting in 50% of cases, photophobia in 69% or visual disturbances in 38%. All of the 12 symptoms assessed were of higher intensity in migraineurs than in non-migraineurs. The symptoms prevented social life in 88% of migraineurs and 75% of non-migraineurs ($p < 0.01$).
Conclusions: This work encourages to consider the headaches of these patients as a possible variant of the migraine disease and, possibly, to manage them according to the current recommendations.

2.2 Residential exposure to magnetic fields from high-voltage power lines and risk of childhood leukemia

Malagoli, C., Malavolti, M., Wise, L., et al. (2023). *Environmental Research*, 232. <https://doi.org/10.1016/j.envres.2023.116320>

Background and Objective: Several studies have suggested an excess risk of leukemia among children living close to high-voltage power lines and exposed to magnetic fields. However, not all studies have yielded consistent results, and many studies may have been susceptible to confounding and exposure misclassification.

Methods: The authors conducted a case-control study to investigate the risk of leukemia associated with magnetic field exposure from high-voltage power lines. Eligible participants were children aged 0–15 years residing in the Northern Italian provinces of Modena and Reggio Emilia. The authors included all 182 registry-identified childhood leukemia cases diagnosed in 1998–2019, and 726 age-, sex- and province-matched population controls. Exposure was assessed by calculating distance from

house to nearest power line and magnetic field intensity modelling at the subjects' residence. Conditional logistic regression models were used to estimate odds ratios (ORs) and 95% confidence intervals (CIs), with adjustment for potential confounders (distance from nearest petrol station and fuel supply within the 1000 m-buffer, traffic-related particulate and benzene concentrations, presence of indoor transformers, percentage of urban area and arable crops).

Results: In multivariable analyses, the OR comparing children living <100 m from high-voltage power-lines with children living ≥400 m from power-lines was 2.0 (95% CI 0.8–5.0). Results did not differ substantially by age at disease diagnosis, disease subtype, or when exposure was based on modeled magnetic field intensity, though estimates were imprecise. Spline regression analysis showed an excess risk for both overall leukemia and acute lymphoblastic leukemia among children with residential distances <100 m from power lines, with a monotonic inverse association below this cut point.

Conclusions: In this Italian population, close proximity to high-voltage power lines was associated with an excess risk of childhood leukemia.

Comment by dr. Els De Waegeneer: This results is in line with earlier findings of a statistical association between ELF-EMF and childhood leukaemia. More research is needed since essential elements to establish a causal relation are not found at the moment, such as a mechanical model or consistent animal studies to back up and explain the possible effects. For now, the issue should be handled with caution – as is done by the precautionary principle policy at hand.

2.3 Modifiable risk factors for glioblastoma: a systematic review and meta-analysis

Yoshikawa, M.H., Rabelo, N.N., Telles, J.P.M., Figueiredo, E.G. (2023). *Neurosurgical Review*, 46, 143. <https://doi.org/10.1007/s10143-023-02051-y>

Background and Objective: Glioblastoma (GBM) is the most common and aggressive glioma histological subtype, associated with high disability and poor survival. The etiology of this condition is still mostly unknown, and evidence about risk factors is elusive. The aim of this study is to identify modifiable risk factors for GBM.

Methods: Electronic search was performed by two reviewers independently using the keywords and MeSH terms 'glioblastoma' OR 'glioma' OR 'brain tumor' AND 'risk factor'. The inclusion criteria were (1) observational studies or experimental studies on humans, (2) studies assessing the association between glioblastoma and exposure to modifiable conditions, and (3) studies published in English or Portuguese. Studies on the pediatric population or about exposure to ionizing radiation were excluded.

Results: A total of 12 studies were included. Seven were case–control studies, and five were cohort studies. The risk factors assessed included body mass index, alcohol consumption, exposure to magnetic fields, diabetes mellitus type 2 (DM2), and use of non-steroidal anti-inflammatory drugs (NSAID). No significant link was found between GBM incidence and DM2 or magnetic field exposure. On the other hand, higher BMI, alcohol consumption, and NSAID use demonstrated a protective effect on GMB risk. However, given the limited number of studies, it is not possible to obtain a behavioral recommendation; instead, these findings are relevant to guide future basic scientific studies on GBM oncogenesis.

3. Occupational exposure

3.1 Can extremely low frequency magnetic field affect human sperm parameters and male fertility?

Delli Muti, N., Salvio, G., Ciarloni, A., et al. (2023). *Tissue and Cell*, 82.

<https://doi.org/10.1016/j.tice.2023.102045>

Background and Objective: Exposure to extremely low frequency magnetic fields (ELF-MF) may have different effects on spermatozoa depending on the waveform, magnetic flux density, frequency of ELF-MF, and duration of exposure. In this study, the authors investigated the possible role of ELF-MF (50 Hz; 1 mT) exposure in altering sperm parameters.

Methods: The authors studied the effects of exposure to ELF-MF at the frequency of 50 Hz (1 mT) for two hours on sperm motility, morphology and reactive oxygen species (ROS) in semen samples of 30 healthy men. The mean values obtained for the exposed and control samples were compared using the Wilcoxon non-parametric test for paired data.

Results: Exposure to ELF-EMF in this study induces statistically significant alterations in progressive motility, morphology and reactive oxygen species (ROS) production of human spermatozoa, suggesting a role of ELF-MF in altering reproductive function of spermatozoa.

Conclusion: These results could be important in the field of occupational exposure. However, since other studies and reviews give contrasting or no effects, more research is needed.

4. Exposure Assessment

4.1 Extremely Low Frequency Electric and Magnetic Fields Exposure: Survey of Recent Findings

Bonato, M., Chiaramello, E., Gajšek, P., Ravazzani, P. (2023). Journal of Electromagnetics, RF, and microwaves in medicine and Biology. sek@inis.si). <https://doi.org/10.1109/JERM.2023.3268555>

Background and Objective: Extremely Low Frequency Electric (ELF-EF) and Magnetic Field (ELF-MF) exposure is caused by different types of sources, from those related to the production, transmission, and distribution of electric currents, to technologies of common use, such as domestic appliances or electric transportation. Establishing the levels of exposure for general public is a fundamental step in the health risk management process but could be challenging due to differences in the approaches used in different studies. The goal of this study is to present an overview of the last years research efforts (from 2015 to nowadays) about ELF-EF and MF exposure in everyday environments, considering different sources and different approaches used to assess the exposure.

Results: All ELF-EMF exposure levels were found to be below the ICNIRP guidelines for general public exposure. The higher MF levels were measured in apartments very close to built-in power transformers. Household electrical devices showed high levels of MF exposure in their proximity, but the duration of such exposure is extremely limited.

5. Leukaemia Studies

5.1 Maternal and Paternal Household Pesticide Exposure During Pregnancy and Risk of Childhood Acute Lymphoblastic Leukemia

Ruth, A.L., Rehman, U., Stewart, P., Moore, L.E., Yucel, R., Wilson, R.T. (2023). *Journal of Occupational and Environmental Medicine*, 65, 595-605.

<https://doi.org/10.1097/JOM.0000000000002859>

Objective: The aim of this study was to investigate whether risk estimates for childhood acute lymphoblastic leukemia change when restricting model comparison groups to “nonpesticide exposure” (NPE10) households.

Methods: Cases (n = 1810) 15 years or younger were identified through Children's Cancer Group institutions between 1989 and 1993 and age-/sex-matched to controls (n = 1951). Household pesticide use during pregnancy/month prior was collected via telephone. NPE10 comparison group reporting no parental exposure to 10 pesticide classes was identified.

Results: Adjusted odds ratios increased from 15% to 49% when limiting the comparison to NPE10. Maternal termite insecticide exposure was associated with greatest risk (adjusted odds ratio, 4.21; 95% confidence interval, 2.00–8.88). There was minimal evidence of interaction by child sex or occupational pesticide exposure, and no monotonic dose-response pattern with frequency of use (times per year).

Conclusions: Elevated risks are consistent with published pooled-/meta-analyses and DNA damage. The consistency and magnitude of these associations warrant product labeling, exposure reduction interventions, or both.

5.2 Does congenital cytomegalovirus infection contribute to the development of acute lymphoblastic leukemia in children?

Toor, R.K., Semmes, E.C., Walsh, K.M., Permar, S.R., Giulino-Roth, L. (2023). *Current opinion in Virology*, 60. <https://doi.org/10.1016/j.coviro.2023.101325>

Background and Objective: Cytomegalovirus (CMV) is a ubiquitous herpesvirus that has a profound impact on the host immune system. Congenital cytomegalovirus (cCMV) infection modulates neonatal immune cell compartments, yet the full impact of in utero exposure on developing fetal immune cells remains poorly characterized. A series of recent studies have identified a potential link between cCMV infection and the development of acute lymphoblastic leukemia (ALL) in childhood. Here, the authors review the emerging evidence linking CMV and ALL risk, discuss what is known about the causes of childhood ALL, and propose how CMV infection in early life may confer increased ALL risk.

Conclusion: The data presented here on a series of studies that link CMV to ALL show an association but should not be overinterpreted to prove causation, which requires further epidemiologic and mechanistic studies. Larger cohorts, perhaps on the international level, are needed to confirm findings and define the timing of maternal and infant CMV infection that confers increased risk. Although most of the work on the origins of ALL have focused on B-ALL, studies linking CMV and ALL include both B-

cell and T-cell subtypes. As such, it will be essential to better understand the impact of congenital CMV infection on the development of B- and T- lymphocytes as well as other immune compartments that may impart risk leukemic transformation. This type of work will be greatly accelerated with collaborations across the disciplines of epidemiology, infectious disease, immunology, and oncology, and could be a cornerstone for improving therapies and establishing the first pathway for prevention of the most common childhood cancer, ALL.

5.3 Residential proximity to petrol stations and risk of childhood leukemia

Malavolti, M., Malagoli, C., Filippini, T. et al. (2023). *European Journal of Epidemiology*, 38, 771-782. <https://doi.org/10.1007/s10654-023-01009-0>

Background and Objective: Petrol stations emit benzene and other contaminants that have been associated with an increased risk of childhood leukemia. The authors carried out a population-based case-control study in two provinces in Northern Italy.

Methods: The authors enrolled 182 cases of childhood leukemia diagnosed during 1998–2019 and 726 age- and sex-matched population controls. The addresses of child residences and 790 petrol stations located in the study area were geocoded. Leukemia risk was estimated according to distance from petrol stations within a 1000 m buffer and amount of supplied fuel within a buffer of 250 m from the child's residence. The authors used conditional logistic regression models to approximate risk ratios (RRs) and 95% confidence intervals (CIs) for associations of interest, adjusted for potential confounders. They also modeled non-linear associations using restricted cubic splines. In secondary analyses, the authors restricted to acute lymphoblastic leukemia (ALL) cases and stratified by age (<5 and ≥5 years).

Results: Compared with children who lived ≥1000 m from a petrol station, the RR was 2.2 (95% CI 0.5–9.4) for children living <50 m from nearest petrol station. Associations were stronger for the ALL subtype (RR=2.9, 95% CI 0.6–13.4) and among older children (age ≥5 years: RR=4.4, 95% CI 0.6–34.1; age <5 years: RR=1.6, 95% CI 0.1–19.4). Risk of leukemia was also greater (RR=1.6, 95% CI 0.7–3.3) among the most exposed participants when assigning exposure categories based on petrol stations located within 250 m of the child's residence and total amount of gasoline delivered by the stations.

Conclusion: Overall, residence within close proximity to a petrol station, especially one with more intense refueling activity, was associated with an increased risk of childhood leukemia, though associations were imprecise.

5.4 Role of Maternal Diet in the Risk of Childhood Acute Leukemia: A Systematic Review and Meta-Analysis

Blanco-Lopez, J., Iguacel, I., Pisanu, S., et al. (2023). *International Journal of Environmental Research and Public Health*, 20, 5428. <https://doi.org/10.3390/ijerph20075428>

Background and Objective: Many studies have investigated the etiology of acute leukemia, one of the most common types of cancer in children; however, there is a lack of clarity regarding preventable risk factors. This systematic review and meta-analysis aimed to summarize the current evidence regarding the role of maternal dietary factors in the development of childhood leukemia.

Methods: All epidemiological studies published until July 2022 that evaluated maternal dietary risk factors for childhood acute leukemia were identified in two electronic databases (PubMed and Web of Science) without limits of publication year or language.

Results: A total of 38 studies (1 prospective cohort study, 34 case-control studies and 3 studies with pooled analysis) were included. The published risk estimates were combined into a meta-analysis, using the Generic Inverse Variance method. The maternal consumption of fruits (two or more daily servings vs. less) was inversely associated with acute lymphoblastic leukemia (odds ratio = 0.71; 95% CI, 0.59–0.86), whereas maternal coffee intake (higher than two cups per day vs. no consumption) was associated with an increased risk of acute lymphoblastic leukemia (odds ratio = 1.45; 95% CI, 1.12–1.89). Despite these findings, more high-quality research from cohort studies and the identification of causal factors are needed to develop evidence-based and cost-effective prevention strategies applicable at the population level.

5.5 Environmental, social and behavioral risk factors in association with spatial clustering of childhood cancer incidence

Hülsa, A., Van Cora, S., Christensana, G.M., Lib, Z., et al. (2023). Spatial and Spatio-Temporal Epidemiology, 45. <https://doi.org/10.1016/j.sste.2023.100582>

Background and Objectives: Childhood cancer incidence is known to vary by age, sex, and race/ethnicity, but evidence is limited regarding external risk factors. The authors aim to identify harmful combinations of air pollutants and other environmental and social risk factors in association with the incidence of childhood cancer based on 2003–2017 data from the Georgia Cancer Registry.

Methods: The authors calculated the standardized incidence ratios (SIR) of Central Nervous System (CNS) tumors, leukemia and lymphomas based on age, gender and ethnic composition in each of the 159 counties in Georgia, USA. County-level information on air pollution, socioeconomic status (SES), tobacco smoking, alcohol drinking and obesity were derived from US EPA and other public data sources. They applied two unsupervised learning tools (self-organizing map [SOM] and exposure-continuum mapping [ECM]) to identify pertinent types of multi-exposure combinations. Spatial Bayesian Poisson models (Leroux-CAR) were fit with indicators for each multi-exposure category as exposure and SIR of childhood cancers as outcomes.

Results: The authors identified consistent associations of environmental (pesticide exposure) and social/behavioral stressors (low socioeconomic status, alcohol) with spatial clustering of pediatric cancer class II (lymphomas and reticuloendothelial neoplasms), but not for other cancer classes. More research is needed to identify the causal risk factors for these associations.