1. Rev Environ Health. 2023 Apr 7;39(3):519-529. doi: 10.1515/reveh-2023-0023.
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Cellular and molecular effects of non-ionizing electromagnetic fields.

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The way that living cells respond to non-ionizing electromagnetic fields (EMF), including static/extremely-low frequency and radiofrequency electromagnetic fields, fits the pattern of 'cellular stress response' - a mechanism manifest at the cellular level intended to preserve the entire organism. It is a set pattern of cellular and molecular responses to environmental stressors, such as heat, ionizing radiation, oxidation, etc. It is triggered by cellular macromolecular damage (in proteins, lipids, and DNA) with the goal of repairing and returning cell functions to homeostasis. The pattern is independent of the type of stressor encountered. It involves cell cycle arrest, induction of specific molecular mechanisms for repair, damage removal, cell proliferation, and cell death if damage is too great. This response could be triggered by EMF-induced alternation in oxidative processes in cells. The concept that biological response to EMF is a 'cellular stress response' explains many observed effects of EMF, such as nonlinear dose- and time-dependency, increased and decreased risks of cancer and neurodegenerative diseases, enhanced nerve regeneration, and bone healing. These responses could be either detrimental or beneficial to health, depending on the duration and intensity of the exposure, as well as specific aspects of the living organism being exposed. A corollary to electromagnetic hypersensitivity syndrome (EHS) could be an inappropriate response of the hippocampus/limbic system to EMF, involving glucocorticoids on the hypothalamic-pituitary-adrenal axis.

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2. Sci Rep. 2021 Jun 7;11(1):11939. doi: 10.1038/s41598-021-91349-2.

Residential exposure to electromagnetic fields and risk of amyotrophic lateral sclerosis: a dose-response meta-analysis.

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Amyotrophic lateral sclerosis (ALS) is neurodegenerative disease characterized by a fatal prognosis and still unknown etiology. Some environmental risk factors have been suggested, including exposure to magnetic fields. Studies have suggested positive associations in occupationally-exposed populations, but the link with residential exposure is still debated as is the shape of such relation. Due to recent availability of advanced biostatistical tools for dose-response meta-analysis, we carried out a systematic review in order to assess the dose-response association between ALS and residential exposure to magnetic fields. We performed an online literature searching through April 30, 2021. Studies were included if they assessed residential exposure to electromagnetic fields, based either on distance from overhead power lines or on magnetic field modelling techniques, and if they reported risk estimates for ALS. We identified six eligible studies, four using distance-based and one modelling-based exposure assessment, and one both methods. Both distance-based and particularly modelling-based exposure estimates appeared to be associated with a decreased ALS risk in the highest exposure category, although estimates were very imprecise (summary RRs 0.87, 95% CI 0.63-1.20, and 0.27, 95% CI 0.05-1.36). Dose-response meta-analysis also showed little association between

distance from power lines and ALS, with no evidence of any threshold. Overall,
we found scant evidence of a positive association between residential magnetic
fields exposure and ALS, although the available data were too limited to conduct
a dose-response analysis for the modelled magnetic field estimates or to perform
stratified analyses.

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PMID: 34099747 [Indexed for MEDLINE]

Conflict of interest statement: The authors declare no competing interests.

3. Epidemiology. 2004 Nov;15(6):687-94. doi: 10.1097/01.ede.0000142147.49297.9d.

Occupational exposure to electromagnetic fields and risk of Alzheimer's disease.

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BACKGROUND: Extremely-low-frequency magnetic field (ELF-MF) exposure is suspected to increase the risk of Alzheimer's disease. Such fields are present
in the vicinity of electrical motors and other electric appliances containing
coils.
METHODS: We investigated lifetime occupational ELF-MF exposure in relation to
Alzheimer's disease and dementia among a community dementia-free cohort (n =
931) age 75 years and older in Stockholm, Sweden. This cohort was followed from
1987-1989 until 1994-1996 to detect dementia cases (Diagnostic and Statistical
Manual of Mental Disorders, revised 3rd edition criteria). Information on
lifetime job history was obtained by interview, usually of next of kin. ELF-MF
exposure was assessed using a job-exposure matrix, measurement on historical
equipment, and expert estimation. We analyzed the data with Cox models
controlling for potential confounders.
RESULTS: Dementia was diagnosed in 265 subjects, including 202 with Alzheimer's

disease. Among men, ELF-MF exposure > or=0.2 microT in lifetime principal job
was related to multivariate-adjusted relative risks of 2.3 (95% CI = 1.0-5.1)
for Alzheimer's disease and 2.0 (1.1-3.7) for dementia. We found no association
among women. A similar sex-specific pattern was seen for the associations with
average ELF-MF exposure throughout the work life. A dose-response relation was
suggested in men, with multivariate-adjusted relative risks of 2.4 (0.8-6.8) for
Alzheimer's disease and 2.5 (1.1-5.6) for dementia for the upper tertile of
lifetime average exposure.
CONCLUSIONS: Long-term occupational exposure to a higher ELF-MF level may
increase the risk of Alzheimer's disease and dementia in men. Similar patterns
were not seen in women, which may in part be the result of a greater exposure
misclassification in women than in men.

DOI: 10.1097/01.ede.0000142147.49297.9d
PMID: 15475717 [Indexed for MEDLINE]

4. Int J Environ Res Public Health. 2019 Jan 26;16(3):337. doi: 10.3390/ijerph16030337.

Occupational Exposures and Neurodegenerative Diseases-A Systematic Literature
Review and Meta-Analyses.

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Objectives: To carry out an integrated and stratified meta-analysis on
occupational exposure to electromagnetic fields (EMFs), metals and pesticides
and its effects on amyotrophic lateral sclerosis (ALS) and Parkinson's and
Alzheimer's disease, and investigate the possibility of publication bias.
Methods: In the current study, we updated our recently published meta-analyses
on occupational exposures in relation to ALS, Alzheimer's and Parkinson's
disease. Based on 66 original publications of good scientific epidemiological

standard, according to the Meta-analysis of Observational Studies in Epidemiology (MOOSE) and the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) guidelines, we analysed subgroups by carrying out stratified meta-analyses on publication year, statistical precision of the relative risk (RR) estimates, inspection of the funnel plots and test of bias. Results: Based on 19 studies the weighted RR for occupational exposure to EMFs was 1.26 (95% confidence interval (CI) 1.07⁻1.50) for ALS, 1.33 (95% CI 1.07⁻1.64) for Alzheimer's disease and 1.02 (95% CI 0.83⁻1.26) for Parkinson's disease. Thirty-one studies concerned occupational exposure to pesticides and the weighted RR was 1.35 (95% CI 1.02⁻1.79) for ALS, 1.50 (95% CI 0.98⁻2.29) for Alzheimer's disease and 1.66 (95% CI 1.42⁻1.94) for Parkinson's disease. Finally, 14 studies concerned occupational exposure to metals and only exposure to lead (five studies) involved an elevated risk for ALS or Parkinson's disease and the weighted RR was 1.57 (95% CI 1.11⁻2.20). The weighted RR for all the non-lead exposures was 0.97 (95% CI 0.88⁻1.06). Conclusions: Exposure to pesticides increased the risk of getting the mentioned neurodegenerative diseases by at least 50%. Exposure to lead was only studied for ALS and Parkinson's disease and involved 50% increased risk. Occupational exposure to EMFs seemed to involve some 10% increase in risk for ALS and Alzheimer's disease only.

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PMID: 30691095 [Indexed for MEDLINE]

Conflict of interest statement: The authors declare no conflict of interest.

5. Mutat Res Rev Mutat Res. 2019 Jul-Sep;781:53-62. doi: 10.1016/j.mrrev.2019.03.003. Epub 2019 Mar 11.

Comparing DNA damage induced by mobile telephony and other types of man-made electromagnetic fields.

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The number of studies showing adverse effects on living organisms induced by
different types of man-made Electromagnetic Fields (EMFs) has increased
tremendously. Hundreds of peer reviewed published studies show a variety of
effects, the most important being DNA damage which is linked to cancer,
neurodegenerative diseases, reproductive declines etc. Those studies that are
far more effective in showing effects employ real-life Mobile Telephony (MT)
exposures emitted by commercially available mobile phones. The present review -
of results published by my group from 2006 until 2016 - compares DNA
fragmentation induced by six different EMFs on the same biological system - the
oogenesis of Drosophila melanogaster - under identical conditions and
procedures. Such a direct comparison between different EMFs - especially those
employed in daily life - on the same biological endpoint, is very useful for
drawing conclusions on their bioactivity, and novel. It shows that real MT EMFs
are far more damaging than 50 Hz alternating magnetic field (MF) - similar or
much stronger to those of power lines - or a pulsed electric field (PEF) found
before to increase fertility. The MT EMFs were significantly more bioactive even
for much shorter exposure durations than the other EMFs. Moreover, they were
more damaging than previously tested cytotoxic agents like certain chemicals,
starvation, dehydration. Individual parameters of the real MT EMFs like
intensity, frequency, exposure duration, polarization, pulsing, modulation, are
discussed in terms of their role in bioactivity. The crucial parameter for the
intense bioactivity seems to be the extreme variability of the polarized MT
signals, mainly due to the large unpredictable intensity changes.

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PMID: 31416578 [Indexed for MEDLINE]

6. Croat Med J. 2019 Apr 30;60(2):127-140. doi: 10.3325/cmj.2019.60.127.

Molecular mechanisms of microglia- and astrocyte-driven neurorestoration

triggered by application of electromagnetic fields.

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AIM: To propose potential mechanisms of action of electromagnetic fields (EMF)
on astrocytes and microglia and to elucidate the role of heat shock proteins
(HSP), adenosine triphosphate (ATP), calcium ions (Ca2+), and hypoxia-inducible
factor 1α (HIF1α) in neurorestoration following the application of EMF.
METHODS: We reviewed the existing studies within the public domain and
cross-evaluated their results in order to conclude on the molecular mechanisms
of microglia-astrocyte crosstalk at work during EMF treatment.
RESULTS: The existing studies suggest that EMF induces the increase of HSP70
expression and inhibition of HIF1α, thus decreasing inflammation and allowing
the microglia-astrocyte crosstalk to initiate the formation of a glial scar
within the central nervous system. Furthermore, by potentially up-regulating A2A
and A3 adenosine receptors, EMF increases cAMP accumulation from astrocytes and
reduces the expression of inflammatory cytokines TNF α and IL-8, thus initiating
neurorestoration.
CONCLUSION: The microglia-astrocyte crosstalk during EMF treatment is crucial
for the initiation of neurorestoration. Elucidating the exact mechanisms of EMF
actions upon microglia and astrocytes, and its role in neurorestoration could be
a key step in further research of the therapeutic potential of EMFs in various
neurological disorders.

DOI: 10.3325/cmj.2019.60.127
PMCID: PMC6509634
PMID: 31044584 [Indexed for MEDLINE]

7. Neuroepidemiology. 2007;28(4):197-206. doi: 10.1159/000108111. Epub 2007 Sep 11.

Mortality from neurodegenerative disease and exposure to extremely low-frequency
magnetic fields: 31 years of observations on Swiss railway employees.

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AIMS: The objective of the present study was to investigate the relationship
between extremely low-frequency magnetic field (ELF-MF) exposure and mortality
from several neurodegenerative conditions in Swiss railway employees.
METHODS: We studied a cohort of 20,141 Swiss railway employees with 464,129
person-years of follow-up between 1972 and 2002. For each individual, cumulative
exposure was calculated from on-site measurements and modelling of past
exposure. We compared cause-specific mortality in highly exposed train drivers
(mean exposure: 21 microT) with less exposed occupational groups (for example
station masters: 1 microT).
RESULTS: The hazard ratio for train drivers compared to station masters was 1.96
[95% confidence interval (CI) = 0.98-3.92] for senile dementia and 3.15 (95% CI
= 0.90-11.04) for Alzheimer's disease. For every 10 microT years of cumulative
exposure senile dementia mortality increased by 5.7% (95% CI = 1.3-10.4),
Alzheimer's disease by 9.4% (95% CI = 2.7-16.4) and amyotrophic lateral
sclerosis by 2.1% (95% CI = -6.8 to 11.7). There was no evidence for an increase
in mortality from Parkinson's disease and multiple sclerosis.
CONCLUSIONS: This study suggests a link between exposure to ELF-MF and
Alzheimer's disease and indicates that ELF-MF might act in later stages of the
disease process.

(c) 2007 S. Karger AG, Basel.

DOI: 10.1159/000108111
PMID: 17851258 [Indexed for MEDLINE]

8. Neurologia. 2014 Nov-Dec;29(9):541-9. doi: 10.1016/j.nrl.2012.04.001. Epub 2012
Jun 14.

Parkinson disease and Alzheimer disease: environmental risk factors.

[Article in English, Spanish]

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INTRODUCTION: The purpose of this review is to update and summarise available evidence on environmental risk factors that have been associated with risk of Parkinson disease (PD) or Alzheimer disease (AD) and discuss their potential mechanisms.
DEVELOPMENT: Evidence consistently suggests that a higher risk of PD is associated with pesticides and that a higher risk of AD is associated with pesticides, hypertension and high cholesterol levels in middle age, hyperhomocysteinaemia, smoking, traumatic brain injury and depression. There is weak evidence suggesting that higher risk of PD is associated with high milk consumption in men, high iron intake, chronic anaemia and traumatic brain injury. Weak evidence also suggests that a higher risk of AD is associated with high aluminium intake through drinking water, excessive exposure to electromagnetic fields from electrical grids, DM and hyperinsulinaemia, obesity in middle age, excessive alcohol consumption and chronic anaemia. Evidence consistently suggests that a lower risk of PD is associated with hyperuricaemia, tobacco and coffee use, while a lower risk of AD is associated with moderate alcohol consumption, physical exercise, perimenopausal hormone replacement therapy and good cognitive reserve. Weak evidence suggests that lower risk of PD is associated with increased vitamin E intake, alcohol, tea, NSAIDs, and vigorous physical exercise, and that lower risk of AD is associated with the Mediterranean diet, coffee and habitual NSAID consumption.
CONCLUSIONS: Several environmental factors contribute significantly to risk of PD and AD. Some may already be active in the early stages of life, and some may interact with other genetic factors. Population-based strategies to modify such factors could potentially result in fewer cases of PD or AD.

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9. Arch Environ Health. 1998 Jan-Feb;53(1):71-4. doi: 10.1080/00039899809605691.

Electrical occupations and neurodegenerative disease: analysis of U.S. mortality
data.

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Investigators have hypothesized that occupations involving electric and magnetic
field exposure are associated with a variety of health problems, including neurological disease. The authors conducted a case-control study, and they used
U.S. death certificates with occupational coding to compare male cases of Alzheimer's disease (n = 256), Parkinson's disease (n = 168), and amyotrophic
lateral sclerosis (n = 114) with controls matched for age and calendar time. The
authors selected controls in a 3:1 ratio to cases from persons who died of causes other than leukemia, brain cancer, and breast cancer. Overall associations with electrical occupations were modest (i.e., adjusted odds ratios
of 1.2, 1.1, and 1.3 for Alzheimer's disease, Parkinson's disease, and amyotrophic lateral sclerosis, respectively). Individual electrical occupations
were associated more strongly with disease than overall electrical occupations,
particularly amyotrophic lateral sclerosis, for which relative risks ranged from
2 to 5 across several job categories. The largest associations with all three
diseases occurred for power plant operators.

DOI: 10.1080/00039899809605691
PMID: 9570311 [Indexed for MEDLINE]

10. Int J Epidemiol. 2008 Apr;37(2):329-40. doi: 10.1093/ije/dym295. Epub 2008 Feb
1.

Occupational exposure to extremely low frequency electric and magnetic fields
and Alzheimer disease: a meta-analysis.

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Comment in
Int J Epidemiol. 2008 Apr;37(2):341-3. doi: 10.1093/ije/dyn024.

BACKGROUND: Among potential environmental risk factors for Alzheimer disease
(AD), occupational exposures have received some attention, including extremely
low frequency electromagnetic fields (ELF-EMF). A systematic review and meta-analysis of published epidemiological studies on this subject was carried
out.
METHODS: The search was concluded in April 2006. Bibliographic databases consulted included PubMed, EMBASE, Cochrane Library and NIOSHTIC2. Pooled estimates were obtained using random-effects meta-analysis. Sources of heterogeneity between studies were explored, as was publication bias.
RESULTS: Fourteen different studies (nine case-control and five cohort studies)
accomplished inclusion criteria. All these studies followed standardized criteria for AD diagnosis and most of them obtained quantitative estimates of
exposure. Pooled estimates suggest an increased risk of AD from case-control
studies (OR(pooled) 2.03; 95% CI 1.38-3.00) and from cohort studies (RR(pooled)
1. 62; 95% CI 1.16-2.27), with moderate to high statistical heterogeneity in both
cases (respectively, I(2) = 58% and I(2) = 54%). Cohort studies showed consistently increased risks for exposed men (RR(pooled) 2.05; 95% CI 1.51-2.80,
I(2) = 0%). Evidence of dose-response relationship was not present. Test for
publication bias suggests small study effects, mostly for case-control studies.
CONCLUSIONS: Available epidemiological evidence suggests an association between
occupational exposure to ELF-EMF and AD. However, some limitations affecting the
results from this meta-analysis should be considered. More information on relevant duration and time windows of exposure, on biological mechanisms for
this potential association and on interactions between electromagnetic fields
exposure and established risk factors for AD is needed.

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PMID: 18245151 [Indexed for MEDLINE]

11. Electromagn Biol Med. 2026;45(1):94-118. doi:
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Electromagnetic fields and oxidative stress: The link to the development of cancer, neurological diseases, and behavioral disorders.

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BACKGROUND: Epidemiological studies suggest an association between exposure to electromagnetic fields (EMFs) and an increased incidence of malignant, cardiovascular, and neurodegenerative diseases. This study aims to elucidate the fundamental principles and plausible mechanisms by which EMFs may influence physiological and pathological processes that lead to disease development.
MATERIALS AND METHODS: Published reports of oxidative stress, DNA damage, and disease risk related to EMF exposure were examined. The literature review provided the foundation for building a new conceptual model called the Electromagnetic Pathogenesis (EMP) model.
MECHANISMS: The EMP model proposes an increase in the probability of electron tunneling through the mitochondrial electron transport chain as the primary pathophysiological mechanism triggered by non-ionizing EMFs. Induced electric fields and quantum tunneling may enhance electron leakage during mitochondrial respiration, which is a major source of free radicals.
FINDINGS: There is a deep connection between quantum tunneling, entropy, and Heisenberg's principle. As a direct consequence of Heisenberg's principle, electron tunneling is essentially involved in free radical production and entropy generation in cells. Both normal aging and chronic diseases may be considered as the biologic manifestations of increasing entropy. Heisenberg's principle underlies normal aging and sets the limit to life expectancy.
SOCIAL IMPLICATIONS: The human brain, particularly the structural and functional networks that support social communication, is highly vulnerable to oxidative stress associated with EMF exposure. Long-term exposure may negatively affect social and reproductive behaviors in both men and women, potentially contributing to a decline in fertility rates and the acceleration of population aging.

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PMID: 41117390 [Indexed for MEDLINE]

12. Int J Environ Res Public Health. 2022 Dec 2;19(23):16150. doi: 10.3390/ijerph192316150.

Open Questions on the Electromagnetic Field Contribution to the Risk of Neurodegenerative Diseases.

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This work presents the current state of knowledge about the possible contributory influence of the electromagnetic field on the occurrence of neurodegenerative diseases such as Alzheimer’s and Parkinson’s disease, amyotrophic lateral sclerosis, and multiple sclerosis. Up-to-date literature indicates both favourable and adverse effects of electromagnetic exposure on human health, making it difficult to come to valid and unambiguous conclusions. The epidemiological data analysis from the World Health Organization statistics shows a substantial rise in neurological mortality compared with rises in total populations in developed countries over a mere 15-year period. The largest of the analysed countries produced odds ratios of >100%. The contribution of electromagnetic exposure to the incidence of neurodegenerative diseases is still undoubtedly open to discussion, and it requires further in-depth research to assess the action mechanism of electromagnetic fields in neurodegenerative diseases. The limitations of research published hitherto and the problem of drawing unequivocal conclusions are also in focus.

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