

# Electromagnetic Fields and Health Outcomes<sup>†</sup>

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## Abstract

*Over the past two decades, there has been increasing interest in the biological effects and possible health outcomes of weak, low-frequency electric and magnetic fields. Epidemiological studies on magnetic fields and cancer, reproduction and neurobehavioural reactions have been presented. More recently, neurological, degenerative and heart diseases have also been reported to be related to such electromagnetic fields. Furthermore, the increased use of mobile phones worldwide has focussed interest on the possible effects of radiofrequency fields of higher frequencies. In this paper, a summary is given on electromagnetic fields and health outcomes and what policy is appropriate—"no restriction to exposure", "prudent avoidance" or "expensive interventions"?*

*The results of research studies have not been unambiguous; studies indicating these fields as being a health hazard have been published and so were studies indicating no risk at all. In "positive" studies, different types of effects have been reported despite the use of the same study design, e.g., in epidemiological cancer studies. There are uncertainties as to exposure characteristics, e.g., magnetic field frequency and exposure intermittence, and not much is known about possible confounding or effect-modifying factors. The few animal cancer studies reported have not given much help in risk assessment; and in spite of a large number of experimental cell studies, no plausible and understandable mechanisms have been presented by which a carcinogenic effect could be explained.*

*Exposure to electromagnetic fields occurs everywhere: in the home, at work, in school, etc. Wherever there are electric wires, electric motors and electronic equipment, electromagnetic fields are created. This is one of the reasons why exposure assessment is difficult. For epidemiologists, the problem is not on the effect side as registers of diseases exist in many countries today. The problem is that epidemiologists do not know the relevant exposure characteristics to be used in their studies.*

*In international guidelines, limits for restrictions of field exposure are several orders of magnitude above what can be measured from overhead power lines and found in "electrical" occupations. These guidelines emphasize that the state of scientific knowledge today does not warrant limiting exposure levels for the public and the work force, and that further data are required to confirm whether health hazards are present. In some countries, however, the "principle of caution" or "prudent avoidance" has been adopted; meaning the low-cost avoidance of unnecessary exposure as long as there is scientific uncertainty about its health effects.*

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**Key words:** Mobile phones, Occupational exposures, Over-head power lines

## Introduction

Over the past two decades, there has been increasing interest in the biological effects and possible health outcomes of weak, low-frequency electric and magnetic fields. Epidemiological studies on the effects of magnetic fields on cancer, reproduction and neurobehavioural reactions have been presented. More recently, neurological, degenerative and heart diseases have also been reported to be related to these fields. Furthermore, the increased use of mobile phones worldwide has focussed interest on the possible effects of radiofrequency (RF) fields of higher frequencies. In this paper, a summary is given on low-frequency electromagnetic fields and health outcomes,<sup>1</sup> what we want to know for the future, and what policy is

appropriate—"no restriction to exposure", "principle of caution" or "prudent avoidance" or "expensive interventions"? A summary of ongoing studies about the possible health effects of RF exposure when using mobile phones is also given.<sup>2,3</sup>

## Exposure

Exposure to low-frequency fields occurs everywhere: in the home, at work, in schools, etc. Wherever there are electrical wires and motors, and electronic equipment, electric and magnetic fields are created. Work day average field strengths of 0.2 to 0.4  $\mu$ T appear to be the level above which there could be an increased risk, and similar levels have been calculated for those living under or near power

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lines. Many people are similarly exposed above these levels, though for shorter periods, in their homes (electric radiators, household appliances, shavers, hairdryers, stray currents due to imbalance in the electrical grounding system in buildings), at work (in certain industries and offices near electric and electronic equipment) or while travelling in trains and other electric conveyances. Thus, for a risk assessment, there are apparent uncertainties as to the assessment of exposure (e.g., the importance of intermittent exposure, transient, field frequency, knowledge of the total exposure day and night, and also the existence of any modifying or confounding factors).

## Cancer

Some epidemiological studies on the relationship between childhood leukaemia and residential exposure to power lines indicate a slight risk increase, while excess leukaemia and brain tumour risks have been reported in “electrical” occupations. Some of the more recent studies, with improved techniques for exposure assessment, seem to have, in an overall perspective, strengthened the evidence of an association. However quite recently, published studies from the UK<sup>4</sup> and New Zealand<sup>5</sup> have not been able to confirm excess risks for childhood leukaemia (or childhood cancer) due to residential exposure.

As mentioned above, there are uncertainties as to exposure characteristics, and not much is known about possible confounding or effect-modifying factors. There are also inconsistencies as to type of cancers; e.g., many occupational studies have indicated one special form of leukaemia—acute myeloid leukaemia, while others have found higher incidence of another form—chronic lymphatic leukaemia. Quite recently, Swedish studies have also suggested that electromagnetic fields could cause hormone-related cancers.<sup>6</sup>

Results of research studies have not been unambiguous; studies reporting the electromagnetic fields as a health hazard have been published and so were studies reporting no excess risks. In “positive” studies, different types of effects have been reported despite using the same study design. The few animal cancer studies reported have not given much help in risk assessment; and in spite of a large number of experimental cell studies, no plausible mechanisms have been presented by which a carcinogenic effect could be explained.

In Scandinavian residential studies, results indicate a doubling of childhood leukaemia risk with exposure above 0.2  $\mu$ T, which corresponds to a distance of 50 to 100 m from an overhead power line. However, the number of childhood leukaemia cases for those living under power lines is few. The risk is low compared to other environmental hazards. It has been calculated that each year in Sweden, there are

2 cases of childhood leukaemia for those living under or near power lines. One of these 2 cases is attributable to the magnetic field exposure.

Occupational exposure to magnetic fields is generally higher than residential exposure and, if there is a true risk, calculations of leukaemia and brain tumour risks also give higher values for exposed workers than for children living close to power lines. From calculations on the attributable risk in a Swedish study, approximately 20 cases of leukaemias and 20 cases of brain tumours could be attributed to magnetic fields each year. These figures are compared with the annual total of 40,000 cancer cases in Sweden, of which 800 have been calculated to have an “occupational” origin.

## Reproduction (With Special Reference to Pregnancy Outcomes)

In epidemiological studies, adverse pregnancy outcomes and childhood cancer have been reported after maternal as well as paternal exposure to magnetic fields, with the paternal exposure indicating a genotoxic effect. Efforts to replicate positive results by other research teams have not been successful. Epidemiological studies on VDT operators, exposed to the electric and magnetic fields emitted by the screens, have been mainly negative, and animal teratogenic studies with VDT-like fields have been too contradictory for conclusions. Use of electrical blankets has been studied in pregnant women without consistent findings.

## Neurobehavioural Reactions, e. g., Electrical Hypersensitivity

Provocation studies on young volunteers seem to indicate physiological changes such as slowing of heart rate and EEG changes after exposure to relatively weak low-frequency electromagnetic fields. The recent phenomenon of “hypersensitivity to electricity” seems to be multifactorial in origin, and it is not clear whether the electromagnetic fields are involved. Some studies reported a flickering light to be the cause, while others reported that persons with a hypersensitive sympathetic autonomous nervous system react to different external stimuli (including electromagnetic fields) in this way.

A great variety of symptoms and discomforts have been reported, mainly of the skin and the nervous system. Most complained of flush, rosiness, ruddiness, heat, warmth, prickling sensations, aches and tightness on the skin of the face. Symptoms of the nervous system such as headache, dizziness, fatigue and faintness, tingling and prickling sensations in the extremities, shortness of breath, heart palpitations, profuse sweating, depression and memory difficulties are also reported. No characteristic organic neurological disease symptoms have been reported. However for neurasthenia and depression, some studies

showed an association with electromagnetic field exposure. Laboratory provocations though have been negative.

### Neurodegenerative Diseases

Neurodegenerative diseases due to electrical “hypersensitivity” and other more “acute” neurobehavioural electromagnetic field effects have attracted the interest of some epidemiologists. Studies thus far have reported senile dementias, Alzheimer’s disease, and amyotrophic lateral sclerosis to be associated with occupational low-frequency magnetic field exposure. However, methodological limitations have made it difficult to compare the results obtained (control group variations, unclear disease definitions and exposure assessments, confounders not considered, small number of cases and risk for selection bias). So far, the evidence is inadequate to conclude a causal relationship to the electromagnetic fields.

### Cardiovascular Diseases

Cardiovascular diseases have also been reported in excess in a few epidemiological studies. One study (a cohort study of utility workers)<sup>7</sup> reported mortality from cardiovascular disease related to exposure to electromagnetic fields. Deaths from myocardial infarcts and arrhythmia-related deaths were significantly increased related to cumulative exposure through years. As for neurodegenerative diseases, the evidence is—for obvious reasons—so far inadequate to make any conclusions on causality.

### Need for Knowledge on Mechanisms

It is quite clear that more research is needed to get a satisfactory understanding of the low-frequency electric field and magnetic field epidemiological study results obtained so far. There are additional ongoing epidemiological studies worldwide, but the question is if these will add more to the knowledge we already have. As a matter of fact, we do not know which characteristics of the fields are causal to the effects. Hence, we definitely need more studies on possible mechanisms to explain the findings we have up till now.

There is in the literature, though, a vast number of *in vitro* studies in the search of possible mechanisms. Several cancer promotion models have been presented, based on changes in the cell surface and in the cell membrane transport of calcium ions, disruption of cell communication, modulation of cell growth, activation of specific gene sequences by modulated RNA transcription, depression of pineal melatonin production, modulation of ornithine decarboxylase activity, possible disruption of hormonal and immune-system anti-tumour control mechanisms. Each of these mechanisms has features applicable to explaining reported magnetic field cancer effects; however, none has been free of problems and essential objections.

To summarise, there is a need for more studies on possible mechanisms. Epidemiologists need information on which characteristics they should use in their field exposure assessment. In most epidemiological studies, a mean or median of 50/60 Hz field strength has been used; in others, cumulative measures of exposure were used. Finally, in some animal studies, field transients have been found to be important. For epidemiologists, the problem is not on the effect side as registers on diseases exist in many countries today. The problem is that epidemiologists do not know the relevant exposure characteristics to be used in their studies.

### Policies for Restrictions of Exposure

Generally, there are different systems of protection to be considered when discussing regulations, guidelines and policies. More often, the health-based system is used, in which a specific adverse health effect can be identified at a certain exposure level, irrespective of exposure type, chemical or physical. A second system could be characterised as an optimisation of a known and accepted hazard, which has no threshold below which the risk is absent. An example on an exposure falling within this kind of system is ionising radiation. A third system covers hazards or risks where causal relationships between exposure and outcome have not been shown with reasonable certainty, but for which there are general concerns about possible risks. This system of protection has been denoted the “principle of caution”, or more recently “prudent avoidance”, which can be summarised as the future low-cost avoidance of unnecessary exposure in the absence of scientific certainty. Exposure to electric and magnetic fields has been discussed in this way, and systematic strategies have been presented; for instance, on how future power lines should be routed, how work places are arranged and how household appliances are designed in order to minimise exposure. In Sweden, the National Radiation Protection Institute has proposed that action could be taken to reduce exposure where the exposure levels exceed the normal levels by more than a factor of ten, provided such reductions can be done at reasonable costs.

In international guidelines, health-based limits for restrictions of field exposure are several orders of magnitude above what can be measured from overhead power lines and found in “electrical” occupations. These guidelines emphasise that the state of scientific knowledge today does not warrant limiting exposure levels for the public and the work force, and that further data are required to confirm whether health hazards are present. In some countries, however, the “principle of caution” or “prudent avoidance” has been adopted advocating the low-cost avoidance of unnecessary exposure as long as there is scientific uncertainty about its health effects. The International

Commission on Non-Ionizing Radiation Protection (ICNIRP) issued guidelines on limits of exposure to time-varying electric, magnetic and electromagnetic fields in 1998,<sup>8</sup> which have been adopted as a basis in many national standards.

The guidelines emphasise that the state of scientific knowledge today does not warrant limiting exposure levels for the public and the work force down to the  $\mu\text{T}$  level, and that further data are required to confirm whether health hazards are present at such levels. The guidelines are based on the effects of field-induced currents in the body, corresponding to those normally found in the body (up to about  $10 \text{ mA/m}^2$ ). Occupational exposure to fields should therefore be limited so as not to cause an induced current density in excess of  $10 \text{ mA/m}^2$  for workers and  $2 \text{ mA/m}^2$  for the general public. For example at 50 Hz, restricting the magnetic fields below  $0.5 \mu\text{T}$  for workers and below  $0.1 \mu\text{T}$  for the public would ensure compliance with this requirement. For electric fields, the corresponding levels are 10 and 5 kV/m, respectively.

### Mobile Phones—Health Effects Under Study

In the 1990s, mobile phones conquered the world. In the beginning of 2000, calculations in some countries showed that almost half of their populations were using this new radiofrequency (0.9 and 1.8 GHz) technique for communication. From a health point of view, there are reports of cases suffering from aches and burning feelings in the region of the head, close to the phone, and also, more generally, neurasthenic symptoms similar to those of “electric hypersensitivity”. From a scientific point of view, concerns were expressed about the risk of cancer as the relationship between radiofrequency fields and cancer had been studied and discussed many years earlier in different occupational settings. The concerns now are focus on brain cancer due to radiation exposure. However, RF exposure when using mobile phones is normally only a few percent of the international RF guidelines;<sup>8</sup> even in “worst case situations”, exposures are well below what is recommended. The radiation levels from the relay “base stations” with which the mobile phones communicate are also well below what is recommended.

The following are some recent studies merit to be mentioned:-

A symptom questionnaire study on 10,600 mobile phone users in Sweden and Norway<sup>9</sup> reported on the feelings of warmth behind and on the ear to be related to the length and the number of calls. The warmth was not primarily considered to be caused by any RF radiation-induced heat; a more plausible explanation would be due to the heat generated by the battery circuitry system. Headaches and

some neurasthenic symptoms were also found to be related to the length and the number of calls, which according to the investigators not necessarily meant that the cause was radiation, but more probably stress and other lifestyle factors of frequent mobile phone users.

Another is the Swedish epidemiological brain cancer study by Hardell et al,<sup>10</sup> in which they found no significant differences between users and non-users. However, when relating tumour laterality to the side on which the phone was said to be used, a possible relationship was reported. Other brain cancer studies are in progress, which undoubtedly will follow-up on this finding.

Quite a few experimental, human laboratory studies have also been performed:<sup>2</sup> studies on EEG, reaction times, sleep parameters, blood pressure, heart rates, hormone levels, ability to detect/feel mobile phones in function, etc. None of these studies have so far revealed any adverse health effects. Some of the results are interesting as a basis for continued research.

### Conclusions

In this paper, a summary of what we know and the need to investigate on the possible health effects of low-frequency electric and magnetic fields is given. No answer has yet been given to the question on which policy should be used but optional systems of protection have been presented. With reference to this, it seems clear that the scientific database at hand are insufficient to develop limits of exposures at the  $\mu\text{T}$  level, which in turn means that there are no reasons for expensive interventions down to these exposure levels. Whether some form of strategy of caution (e.g. prudent avoidance) should be adopted, is a matter for decisions by public and occupational health authorities of individual countries. If such a strategy is not adopted, it usually means that no restrictions of exposure are done because the health-based threshold limits are well above everyday public and occupational exposure. Different steps have been taken in different countries through regulations, guidelines and policies.

As to the RF radiation risks of mobile phone use, we do not have adequate knowledge at all for any action or recommendations for restriction of exposure. As mentioned above, there is a need for future epidemiological and experimental research.

Finally in conclusion, the author commended the important step taken by the WHO to launch an International Electromagnetic Fields (EMF) Project.<sup>11-14</sup> The WHO research and evaluation programme will undoubtedly give us a better basis for future international guidelines on how to interpret and handle risks from exposure to low-frequency electrical and radiofrequency electromagnetic radiation.

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