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Electromagnetic fields (EMF): Do they play a role in children's environmental health (CEH)?

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Abstract

Possible adverse health effects of exposure to electric, magnetic and electromagnetic fields (EMF), and especially the question of whether there exists a special vulnerability of children, have been a much discussed topic during the last two decades. Static fields produce health effects only in very rare and exceptional circumstances at extremely high field intensities. As for low-frequency EMF, the results of epidemiological research with respect to childhood leukaemia prompted the International Agency for Research on Cancer (IARC) in 2001 to classify these fields as "possibly carcinogenic to humans". Current hypotheses on the mechanism of such action are presented. The effect, if existent, appears to be not very important in relation to established other causes of childhood leukaemia. High-frequency EMF, as used in mobile and wireless communication (mobile telephony according to the GSM and UMTS standard, cordless DECT phones, wireless local area networks (WLAN), Bluetooth) and since many decades also in radio and television technology, are practically omnipresent. At high intensities, the generation of heat is the principal effect. Current guidelines, limits and regulations prevent any such effect. Mobile phone calls may, in certain circumstances, lead to local exposures close to limit values. Base stations typically produce exposures lower by 2–5 magnitudes. The discussion centres on the so-called non-thermal effects, which are supposedly occurring at field intensities, which are by orders of magnitude lower than those responsible for thermal effects. The reproducibility of these effects is usually poor, and no physiologic or pathogenic mechanism, so far, has been found to explain the alleged effects. Equally, epidemiologic studies have not furnished clear and reproducible data as arguments for negative health effects. Final results of the INTERPHONE study on the risk of brain tumours, acoustic neurinoma and parotid gland tumours associated with the use of mobile phones will be soon available. Preliminary results do not seem to indicate a substantial increase in risk. There are presently no scientific data supporting the concept of a special vulnerability of children and adolescents to high-frequency EMF, even if the usual caveats (developing organisms and structures may be more vulnerable, decades of life to come) are considered. The concept of precautionary measures adapted to such concerns is critically discussed.

Introduction

During decades of health-related EMF research a large body of knowledge in this area has been accumulated. The nature of basic interactions – depending on the field frequency – between electromagnetic fields and cells, tissues and organisms is now well understood.

Nevertheless, there is still an open controversy in science and in the public on the health impact of high-voltage power lines, DECT (cordless) phones, mobile phones and their base stations, wireless local area networks (WLAN) and Bluetooth. To a lesser extent, this holds true also for electric blankets, visual display units, microwave ovens, radio and TV stations. Do

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electromagnetic fields pose a threat to the health of an individual and/or the general population? Are children possibly more vulnerable than adults? Is precaution necessary? If yes, to which extent? Is "electromagnetic hypersensitivity" a real or a virtual phenomenon? There exist several reasons for this controversy.

In epidemiological studies, dosimetry and control of confounders are difficult and may lead to contradictory results. Sometimes, a result can only partly be reproduced in follow-up studies, but a thorough meta-analysis of all studies may yield a statistically significant effect. This is the case e.g. with childhood leukaemia and residential magnetic fields.

In *in vitro* or animal experiments, often enough a dose–response relationship between a certain biological effect and a field parameter cannot be established. Instead, "window effects", i.e. effects at discrete parameter values are observed.

Another reason for this controversy might be the lack of proper communication of scientific results between the scientific community and the public.

As a response to public concern over these issues the World Health Organisation (WHO) initiated in 1996 the International EMF Project which became one of the largest frameworks for research on health and environmental effects associated with exposure to electric and magnetic fields (WHO, 2006a). Research results have been published both in the scientific literature and in WHO monographs (Environmental Health Criteria series) (WHO, 2006d). In recent years, the WHO (2001, 2005a, b, 2006b, c) published a number of fact sheets in this field.

Later on, in the era of mobile communication a number of national and international research programs aiming at these fields in the microwave range have been established. The INTERPHONE study, the REFLEX project of the European Union and the German Mobile Phone Research program are well known examples. Other joint research activities are e.g. the CEMFEC, the RAMP2001 and the PERFORM-A project. A few years ago, a specialized data base on EMF literature (the "EMF portal") comprising more than 10,000 commented scientific articles had been established by the Research Center for Bio-Electromagnetic Interaction (FEMU) of the Technical University of Aachen (FEMU, 2006).

In this article, it is attempted to give an up-to-date overview on health effects of the electric, magnetic and electromagnetic field at low, intermediate and high frequencies. Special emphasis is placed on the aspect of a possible special vulnerability of children.

Types and classification of electromagnetic fields

To address health issues of electromagnetic fields properly, the nature of the field (electric or magnetic, static or alternating at low, intermediate or high frequency (HF) and possibly also the modulation (constant wave or pulsed)) has to be considered. Also, the exposure conditions expressed in terms of electric/magnetic field strength, power density and duration play a role.

Table 1 presents electric, magnetic and electromagnetic fields (categorized according to their frequencies) and lists examples of uses.

Health effects from electric, magnetic and electromagnetic fields

In this section, EMF-related health effects (both proven and speculative) for different frequency ranges are discussed.

Static electric fields

The WHO concludes in its fact sheet No. 299 (WHO, 2006a) on static fields, that few studies aimed at static electric fields have been carried out. The most obvious acute effects are the well-known body hair movement and spark discharges.

Static magnetic fields

Persons moving in strong static magnetic fields (>2 T (Tesla)) may experience sensations of vertigo and nausea and sometimes perceive also light flashes (WHO, 2006c). Very strong fields (>8 T) might have an influence on blood flow and heartbeat. People wearing cardiac pacemakers or ferromagnetic implants are at risk in static magnetic fields exceeding 0.5 mT.

The mechanisms of interaction with living matter are well known, they comprise magnetic induction, magnetomechanical effects and electronic interactions (ICNIRP (International Commission on Non-Ionizing Radiation Protection), 1994). ICNIRP proposes to limit the continuous exposure of the general public to 40 mT. Continuous occupational whole-body exposure should not exceed 200 mT as a time average per working day.

The natural static magnetic field of the earth has a magnetic flux density of about 50 μT, varying between 30 and 70 μT, depending on the location. With rare other sources as passenger trains based on magnetic levitation (level: 10–100 mT) and MRI diagnostic instruments (0.5–2 T), the time of exposure is usually short.

Thus, except for the special circumstances mentioned above, static magnetic fields do not seem to play a role in environmental health.

Table 1. Frequency ranges of electromagnetic fields and typical applications

Band name	Abbreviation	Frequency range (typical values)	Common occurrence/uses (examples)	Medical uses (examples)
Static electric field	–	0 Hz	Clouds and thunderclouds, charged surfaces (e.g. TV sets) and spark discharges, DC rail systems	–
Static magnetic field	–	0 Hz	Terrestrial magnetic field and permanent magnetism	Magnetic resonance imaging (MRI) magnetic remedies (paramedicine)
Extremely low frequency	ELF	1–300 Hz	Railway power supply (16 2/3 Hz) **household power supply (50 Hz)** household devices (**electric blankets or water beds**, night storage heaters)	
Low frequency	LF	1 (300)–100 kHz	**Visual display units**	Stimulation currents, gradient fields (MRI)
High frequency	HF	100 kHz–300 GHz	Radio, TV, other radio applications, **mobile phones, cordless phones, microwave oven, WLAN, Bluetooth, anti-theft devices** radar	Diathermy

Items marked in bold are discussed in greater detail in the text.

Extremely low-frequency (ELF) and low-frequency (LF) fields

The interaction between LF fields and living matter is well known (WHO, 2005a). The electric component of the electric field does not penetrate deeply into the organism, but is largely absorbed by skin and muscle. This is due to the high conductivity of these tissues. The magnetic field component of fields up to about 30 kHz is able to penetrate deeply into the body and may-under appropriate conditions-induce electric currents. If the current density exceeds a certain threshold value, excitation of muscles and nerves due to membrane depolarisation is possible. The current regulatory (ICNIRP) exposure limits are set in such a way as to safely prevent this effect. Chronic exposure to a LF electric field is limited to an electric field strength of 5000 V/m. The limit value for the magnetic field is a magnetic flux density of 100 μT.

In common life, there is practically no situation where these limits would be permanently exceeded.

Residential magnetic fields and childhood leukaemia

Since the original report by Wertheimer and Leeper (1979) quite a number of epidemiological studies and meta-studies on residential magnetic fields (50 or 60 Hz) and childhood leukaemia have been published. Most of them report a positive association and a small but significant increase in risk (cf. Kheifets and Shimkhada, 2005).

In 2001, an expert group of the International Agency for Research on Cancer (IARC, an institution belonging to the WHO) reviewed reports on the carcinogenicity of ELF electromagnetic fields. Weighting the evidence from cellular, animal and human studies (especially from epidemiological studies on childhood leukaemia), they classified these fields as "possibly carcinogenic to humans" (WHO, 2001).

In the same year, the German Commission on Radiation Protection (SSK) classified the possible association between residential magnetic fields and childhood leukaemia as "suspect on scientific grounds (SG)" and underlined the importance of further intense research for causal links (Strahlenschutzkommission, 2001).

As mentioned before, most evidence for such an association is based on epidemiological studies. However, epidemiological approaches to this question encounter a number of difficulties (Kheifets and Shimkhada, 2005):

- Electromagnetic fields are ubiquitous and have multiple sources.
- These fields may vary considerably over time and space.
- A number of possible confounders (e.g. socio-economic status, viral infections, ionising radiation, tobacco smoke, etc.) have to be controlled (cf. Lightfoot, 2005; Schüz et al., 2005).
- As leukaemia occurs relatively rarely (about 4 cases in 100,000 children under the age of 15 per year) in Western countries, only retrospective studies with its inherent shortcomings are possible from a practical point of view.

It appears that the observed association is restricted to children. There is little or no evidence for such an association in adults and in animals. In addition, leukaemia is the only type of cancer under discussion in relation to ELF magnetic fields.

Thus, it is quite difficult to provide an explanation for the effect. Up to now, no robust mode of action is known. ELF fields belong to the non-ionising part of the electromagnetic spectrum, their quantum energy is far too low to cause an effect at the molecular level, e.g. producing a direct damage to the DNA by formation of radicals. With respect to an interaction of ELF fields at the cellular level, the magnetic flux density of 0.3–0.4 μT is orders of magnitude below the density needed for a biophysically plausible effect on cells or tissues. Also, one should keep in mind, that the exposure actually occurs to a total magnetic field, i.e. to the superposition of the alternating power frequency magnetic field (0.3–0.4 μT) and the (static) magnetic field of the earth (about 50 μT). The contribution of the former is obviously negligible in comparison to the latter (IET (Institution of Engeneering and Technology), 2006).

The *initiation* of cancer by ELF fields is improbable on theoretical grounds. Thus, mechanisms of cancer *promotion* have to be investigated instead. A number of hypotheses have been generated. It has been speculated that magnetic fields could have an inhibiting influence on the production of melatonine in the pineal gland (Schüz and Michaelis, 2000; Schüz et al., 2001; Henshaw and Reiter, 2005). Melatonine is supposed to act as a radical scavenger and as an antioxidant protecting nuclear DNA and membrane lipids from oxidative damage. There is some evidence for a decreased blood serum level of melatonine under the influence of power frequency magnetic fields and even of geomagnetic field disturbances (see Henshaw and Reiter, 2005 for a review).

Within the framework of the European REFLEX program (risk evaluation of potential environmental hazards from low energy electromagnetic field exposure using sensitive in vitro methods) the effects of ELF fields on cell growth, cell differentiation and apoptosis were studied in a multi-centre approach (cf. www.verum-foundation.de). No effect – except one reported by an Austrian group – could be observed. This group described the occurrence of genotoxic effects in fibroblasts during exposure with ELF fields well below the current limit values. However, attempts to reproduce this result have failed (Scarfi et al., 2005).

Another hypothesis is based on ‘‘contact currents’’. The system of electric wiring applied in houses in the United States may lead to a small voltage between the residential water supply system and the ground. In addition, a high degree of correlation between the residential magnetic field and the contact current is observed. Thus, a child in a grounded bathtub or shower may experience a contact current upon manual contact with the faucet or the water stream. It is speculated that this contact current is sufficiently high to produce an electrical field of biophysical relevance in the quite narrow bone marrow of the extremities (Kavet, 2005). This is an intriguing hypothesis. In most European or Asian countries, a different electric wiring scheme is used. Investigations in these countries might provide a possibility to verify the contact current hypothesis.

Another open issue is genetics. The existence of a sub-population of children with an increased genetic susceptibility to environmental factors is still a matter of investigation and discussion. The same holds for a hypothetical ‘‘window of special vulnerability’’, e.g. during development in utero.

Further epidemiological research in this field will have to focus on better exposure assessment and on highly exposed or highly susceptible sub-populations (Kheifets and Shimkhada, 2005).

Under the assumption of a causal relationship between residential magnetic fields and childhood leukaemia, it has been estimated from real exposure data in Germany, that about 1% of all cases childhood leukaemia could be attributed to this environmental factor (Schüz and Michaelis, 2000).

In a recent review on childhood central nervous (CNS) system tumours, the author concluded that – although the causes of childhood CNS tumours are still unknown – ELF electromagnetic fields do not represent a probable aetiological factor (McKinney, 2005).

Other adverse health effects

A number of studies addressed the question whether or not there is a link between ELF fields and breast cancer, testicular cancer, cardiovascular diseases, sleep disorders, fatigue and Alzheimer's disease. Often exposure of adults under conditions at work (radar monitors, arc welding, railways, etc.) have been studied. In summary, there is no consistent evidence for such a link (Strahlenschutzkommission, 2001; IET, 2006).

About 20 years ago, it was reported that the pregnancy outcome might be influenced by the use of electric blankets and heated water beds (Wertheimer and Leeper, 1986). Also work at video display units (video terminals, monitors) was suspected to cause abortion (for a review see Luchini and Parazzini,1992). Follow-up studies did not confirm the initial findings (Bracken et al., 1995; Belanger et al., 1998).

An issue rarely discussed in relation to children's health are electronic article surveillance devices installed in shops, libraries and other locations. These devices operate at frequencies ranging from a few ten kHz up to several hundred MHz. In certain circumstances, the body may be exposed to a magnetic field which is above the current ICNIRP guidelines (Gandhi and Kang, 2001). However, the exposure time is usually very short.

High frequency (HF) fields

Radio and television broadcast stations are typical applications to be mentioned in this frequency range. They operate in a range between approximately 1 (longwave radio broadcast) and 900 (UHF TV broadcast) Mega Hertz (MHz). Their antenna power output is in the range of several thousand Watt and they emit a more or less omnidirectional field.

In several studies, the cancer incidence among residents living in proximity to radio and TV stations was investigated. In 2002, the local health authority of Rome published epidemiological results on excess adult and childhood leukaemia in the vicinity of Vatican Radio (Michelozzi et al., 2002). A causal relationship was not implied. Similar reports came from Australia, Great Britain, Hawaii and Korea. Limitations of studies of this kind are mostly related to dosimetry and to the usually small number of cases resulting in a low power of study.

The most prominent and controversial issue, however, is mobile communication. This term is used here to subsume mobile phones (cellular phones), their base stations, cordless phones operating according to the DECT standard and some of the babyphone devices. In a broader sense, new wireless communication technologies such as WLAN and Bluetooth also belong to this category.

Mobile phone technology is a rather complex matter. Thus, in this article only very basic facts necessary for an understanding of the debate on ‘‘mobile phones and health’’ are presented.

In the 1990s, the Global System for Mobile communication (GSM), 2G = 2nd generation) standard was predominant. Now UMTS (Universal Mobile Telecommunication System, 3G = 3rd generation) is the up-to-date standard. GSM and UMTS both use frequencies in the microwave range for the transmission of speech and data packets. They differ, e.g., in the way how these packets are transmitted. GSM uses a time slot transmission protocol (TDMA), which results in a low-frequency modulation of the HF field (‘‘pulsed field’’). UMTS uses a code division transmission protocol and the associated high-frequency field is not pulsed.

Table 2 lists typical values for the frequency range, the type of modulation and the antenna power output of various equipment for mobile and wireless communication.

In the following part, the field exposure through a mobile phone base station, the mobile phone itself and wireless computer applications will be discussed.

Antennas of mobile phone base stations usually emit a field, which is slightly downtilted in order to reach potential customers in the near surrounding.

The law of decreasing field strength with increasing distance from the antenna holds strictly only along the axis of the main beam. When measured on the ground, the field strength in the immediate vicinity of the mast on a building is initially very low. With increasing distance the field strength increases slightly and reaches a relative maximum at the point where the main beam hits the ground. Afterwards it decreases again. This circumstance makes public requests for large ‘‘safety zones’’ around mobile phone base stations rather unfounded. The field strength measured on the ground rarely exceeds a few percent of the limit value proposed by the International Commission on non-ionising Radiation (ICNIRP). Quite often a local DECT base in an apartment station emits a larger field than a mobile phone base station, which is farther away.

In mobile phone technology, the technically usable field strength covers at least 6–7 orders of magnitude. A power control software regulates the emission of electromagnetic power both on the side of the mobile phone base station and the mobile phone itself to the minimum which is sufficient for a communication of good quality. In practice, exposure of individuals to HF fields in the vicinity of mobile phone base stations is

Table 2. Parameters of various equipment for mobile and wireless communication

Standard	Frequency range	Modulation	Antenna power output
GSM 900	890–960 MHz	Pulsed (217 Hz)	10 W (base station, per traffic channel) 1–2 W (mobile phone, peak value)
GSM 1800	1710–1880 MHz	Pulsed (217 Hz)	10 W (base station, per traffic channel) 1–2 W (mobile phone, peak value)
UMTS	1900–2170 MHz	Miscellaneous (not pulsed)	10–20 W (base station, per traffic channel) 0.25 W (mobile phone, UMTS protocol)
DECT	1800–1900 MHz	Pulsed (100 Hz)	0.25 W (DECT base station) 0.25 W (DECT handset (peak value)) 0.01 W (DECT handset (mean value))
WLAN	2.4 and 5–6 GHz	Miscellanous	0.1 W (2.4 GHz), 0.2–1 W (5–6 GHz)
Bluetooth	2.4–2.5 GHz	Miscellaneous	0.001 W (class 3)–0.1 W (class 1)

100–10,000 times below the currently valid limit values – depending on the direction of the main beam, distance, shielding by buildings and other factors.

Under certain conditions (e.g., phone calls made at a long distance from the base station) the mobile phone will have to operate at its maximum level to ensure good communication. Here, the head may be exposed to a considerable local field ("near field" type).

WLAN, Bluetooth and similar applications – due to their (weak) transmitting power, see Table 2 – contribute in general very little to the total HF immission. Of course, in a discussion of possible health effects, again the distance between the radio-frequency-emitting source and the organism is to be considered. This exposure situation was thoroughly studied by Christ et al. (2006) and Schmid et al. (2005).

Mode of action

The frequencies shown in Table 2 belong to the microwave band of the electromagnetic spectrum. The principal effect of electromagnetic radiation in this band is the production of heat. The underlying mechanism is the one known from a microwave oven: molecules having a dipol moment (especially water molecules) oscillate in the applied HF field. This leads to friction, which in turn produces heat. Excitation of nerves and muscles is not possible at these frequencies.

Whether there exist the so-called "non-thermal" effects or not will be discussed later.

Absorption of mobile phone fields (GSM, UMTS)

Electromagnetic fields in the frequency range used by mobile phone and similar technologies do not penetrate deeply into the body. Most of the field energy is absorbed by the skin and the directly underlying tissue. This is mostly due to the high electric conductivity of the skin. Heat generated in the tissue is readily distributed, mainly by blood flow. The parameter describing the amount of energy absorbed per unit of tissue within a given time is called the specific absorption rate (SAR, units: W/kg).

A SAR value of 4 W/kg would result in a temperature increase by 1 °C.

Limit values

The SAR concept has been used to derive basic limit values for occupational and non-occupational exposure to HF fields. Guidelines proposed by the ICNIRP (www.icnirp.de/) have been widely accepted by international and national bodies involved in legal and regulatory measures (WHO, 2006a). The limit values for non-occupational whole body and partial body exposure are 0.08 and 2 W/kg, respectively. There is a margin of safety of 50 between the whole body SAR limit value and the threshold for thermal effects. This is part of the ICNIRP concept to protect even the most vulnerable groups in the population (Vecchia, 2005).

The SAR values can be suitably converted into corresponding values of power flux density (W/m^2) or electric field strength (V/m). These entities can be more easily measured.

Non-thermal effects

In addition to the well-known thermal effects, numerous reports on so-called athermal effects have been published. Athermal effects are biological effects, which occur at very low levels of the field and cannot directly be attributed to heating. Quite often the "pulse character" of GSM fields has been held responsible for athermal effects. However, this hypothesis has never been proved (Liesenkötter, 2002; Gollnick, 2006). There are reports on the effect of mobile phone fields on the CNS system (changes in the EEG and in cognitive task performance, disturbances in sleeping behaviour and in well-being, "electromagnetic hypersensitivity"), but also on the release of hormones (melatonine), on cell membranes (blood–brain barrier, calcium flux through membranes) and on genotoxic effects (DNA strand breaks, formation of micro nuclei). Also, promotion of cancer has been discussed and clusters of cancer assigned to local base stations. There is no plausible biological or physical mode of action known for these claimed effects. Reticulocyte count increases and rouleau formation ("Geldrollenbildung") of red blood cells has repeatedly discussed in the "grey" literature. Plausible mechanisms or proven associations were not the basis of this discussion, and this postulated effect does not exist (Kommission "Methoden und Qualitätssicherung in der Umweltmedizin", 2006).

Reports on thermal effects have been partly published in the peer-reviewed scientific literature and partly also in the "grey" literature including the Internet. All scientific reports are continuously monitored and reviewed by international and national expert panels such as the ICNIRP, the WHO, the national radiation protection committees and renowned scientists. Their review is performed relying upon internationally accepted criteria of sound science, such as clear and unequivocal study design, consideration of confounders and artefacts, reproducibility of results by independent groups, publication in peer review journals etc.

On the overwhelming majority these institutions come to the conclusion that "there is no convincing scientific evidence that the weak radio frequency signals from base stations and wireless networks cause adverse health effects" (cited from WHO fact sheet No. 304, WHO, 2006b).

It should be mentioned that a few institutions and a number of scientists and health professionals come to a different conclusion. A probable cause for this discrepancy is the large emphasis, which these groups often put on studies of inadequate scientific quality. It is hoped that the ongoing national and international studies such as the German "Mobilfunk-Forschungsprogramm", the "British Mobile Telecommunications and Health Research Programme" and the "Interphone study" of the International Agency for Research on Cancer (IARC) will help to resolve the controversy.

Use of mobile phones

Mobile phones have to be designed in such a way that they do not exceed a SAR value of 2 W/kg. Many modern mobile phones operate at a maximal SAR well below this value. Recently, field exposure during mobile phone calls under everyday conditions have been measured. The results were surprising: often enough the real exposure was higher than assumed before (Georg (Ingenieurbüro Telecom Consult), 2005).

In some situations, the mobile phone has to emit quite a strong RF signal to establish and maintain a good-quality communication link. This may occur especially in places far from base stations, in the basement of buildings and in other shielded locations.

To assess the risk of brain tumours, acoustic neurinoma and parotid gland tumours associated with the use of mobile phones, the WHO within its EMF project initiated the Interphone study (IARC (International Agency for Research on Cancer), 2006), which is coordinated by the IARC. Final results of this multicenter study comprising 13 participating countries are not yet available. The results published so far seem to indicate that there *is no substantial increase* in the risk to develop a tumour as a consequence of frequent mobile phone calls. In some countries, an increased risk for certain tumour species (doubled risk for acoustic neurinoma on ipsilateral use in Sweden, doubled risk (confidence interval 0.94–5.11) for glioma in Germany) has been observed which has to be evaluated in the context of the overall results (IARC (International Agency for Research on Cancer), 2006). In the Interphone study, children had not been considered as a subgroup. An Interphone-kids study is under way.

Sensitivity of children and adolescents to (high-frequency) EMF

In view of the rapidly increasing use of mobile phones by children and adolescents it is important to address the question of a possible special sensibility and a possible vulnerability of the latter towards HF electromagnetic fields. This issue was first raised by the British Independent Expert Group on Mobile Phones (IEGMP (Independent Expert Group on Mobile Phones), 2000, "Stewart Report").

It was argued that

- the children's nervous system is still in development,
- their brain tissue has a greater conductivity due to its higher water content,
- children's heads would – for anatomical reasons – absorb more radio frequency energy than that of an adult and
- children have a longer life time exposure.

The greater flexibility of a child's pinna was supposed to lead to a lower distance between the mobile phone and the skull and thus to cause a higher exposure. Also, theoretical studies on HF EMF absorption initially indicated a larger absorption in a child's head as compared with the head of an adult (Gandhi et al., 1996, for a recent review see Christ and Kuster, 2005).

As a result, a project "Mobile communications and children" within the European COST framework was launched in 2002 in Rome. Two years later, the WHO organised a symposium on "Sensitivity of children to EMF" in Istanbul (WHO, 2004). Also, national boards on radiation protection dealt with this issue, e.g. the Health Council of the Netherlands in 2004 and the German Radiation Protection Commission (SSK) in 2006. In November 2006, the Research Association for Radio Applications (Forschungsgemeinschaft Funk (FGF), Bonn, Germany) has recently organised a workshop on this topic.

In summary, presently there are no science-based arguments for a higher sensitivity of children to HF EMF compared with adults. Most anatomical parameters (head's circumference, thickness of cranial bones, brain volume, thickness of the skin) and the developmental stage of the CNS system (myelinisation, synaptogenesis) of, for instance, a 5-year-old child is already quite comparable to the situation in adults. However, little is known about the dielectric properties of the developing human brain. Also, the higher elasticity of the pinna of young children may lead to a higher-energy absorption. Simulation-based studies seem to indicate however, that the effects of both factors will not be very large. They are comparable to differences in energy absorption due to the interindividual variability in anatomical parameters.

Microwave oven

About a decade or two ago concern was expressed that domestic microwave ovens might be a source of microwave radiation and – in addition – be able to alter the amino acid composition of the food.

Measurements of leakage radiation from microwave ovens carried out by consumer protection organisations clearly show that there is no radiation risk from properly functioning devices. The field strength in front of the door in no case exceeded the current limits. Persons with a pacemaker are advised to keep a minimum distance of 30 cm from the oven to avoid electronic interference. With respect to food, no health consequences of the observed slight changes in food composition are known (BfS, 2003). Of course, protein composition and configuration are changed by microwave heating, as equally by cooking and frying.

UV light

In the electromagnetic spectrum, UV light is positioned at the transition from non-ionising to ionising radiation. Usually, three ranges (UV-A, UV-B and UV-C) are distinguished. There are well-known positive and negative health effects from UV light, which will not be discussed here.

Electromagnetic hypersensitivity (EHS)

The WHO in its fact sheet No. 296 describes EHS in the following manner (WHO, 2005b):

"EHS is characterized by a variety of non-specific symptoms, which afflicted individuals attribute to exposure to EMF. The symptoms most commonly experienced include dermatological symptoms (redness, tingling, and burning sensations) as well as neurasthenic and vegetative symptoms (fatigue, tiredness, concentration difficulties, dizziness, nausea, heart palpitation and digestive disturbances). The collection of symptoms is not part of any recognised syndrome.

EHS resembles multiple chemical sensitivities (MCS), another disorder associated with low-level environmental exposures to chemicals. Both EHS and MCS are characterized by a range of non-specific symptoms that lack apparent toxicological or physiological basis or independent verification."

There are no clear-cut diagnostic criteria for EHS and no mode of action is known by which electromagnetic fields well below the current guidelines might be involved in EHS. Thus, WHO in its recommendations on EHS puts emphasis on a good physician–patient relationship and on the treatment of symptoms instead of a reduction or elimination of EMF in the workplace or at home.

Electromagnetic fields and the precautionary principle

The precautionary principle (PP) states that prudent action should be taken when "there is sufficient scientific evidence (but not necessarily absolute proof) that inaction could lead to harm and where action can be justified on reasonable judgements of cost-effectiveness." In addition, the number of possibly affected persons (small risk to all or a large risk to a few?) as well as the benefits of EMF usage should be taken into consideration (Kheifets, 2001; WHO, 2003).

The European Commission (EC (European Commission), 2000) requires options of actions:

- to be taken proportional to the desired level of protection,
- to be non-discriminatory in their application and
- to be consistent with the measures already adopted in similar circumstances.

Several recommendations on further limitation of exposure (i.e. well below the currently valid guidelines) to low, intermediate and HF electromagnetic fields are currently very popular. They are offered by non-governmental institutions, individual scientists, consumer protection organisations, activist groups, and some also by national boards.

These recommendations are usually derived:

- from preliminary or non-peer-reviewed scientific results,
- from an (illegitimate) extrapolation from other exposure situations,
- from a misconception of deterministic versus stochastic processes (existence of a threshold versus irreversible damage) and
- from a "gut feeling" ("children are always more susceptible to environmental hazards than adults").

On closer inspection of the numerous individual recommendations, both inconsistencies, discrepancies and violations of the above-cited criteria ("sufficient scientific evidence, cost-effectiveness, consistent and non-discriminatory application", etc.) become apparent. Do they offer a greater level of protection? The answer is: no. Most (if not all) known effects related to non-ionising electromagnetic fields are deterministic in their nature. Thus, a threshold for a given effect (e.g., membrane depolarisation for LF fields, heating for HF fields) can be defined. This threshold – after suitable inclusion of safety factors – is used by national and international boards for the definition of official guidelines and limit values. Exposures below the threshold necessarily can offer no further degree of protection.

Concluding remarks

At the end, some of the more frequently cited recommendations on EMF applications are evaluated and classified into those based on scientific grounds (SG), into those based on the precautionary principle

(PP) and those based on a more or less emotional base ("gut feeling", GF).

Low frequency residential magnetic fields:

1. New houses, kindergartens and schools should preferably be built in a distance of more than about 100 m from high voltage power lines and transformers (SG, epidemiological data).
2. The electrical wiring in a residential house should be designed in a way as to minimise exposure to magnetic fields (SG, epidemiological data).
3. In the bedroom a switch can be installed "to switch off electricity" during night time (PP).
4. Clock radios should be placed in a distance of at least 1 m from the bed or be replaced by battery-operated alarm clocks (GF).

Intermediate frequency fields:

1. Baby phones should be placed in a distance of at least 1 m from the child's bed (PP).
2. Baby phones should be preferred which operate in a voice-controlled modus (PP).

High frequencies:

1. Mobile phone base stations should not be erected in the vicinity of nurseries, kindergartens, schools, children's hospitals (GF).
2. Mobile phones: children and adolescents should be taught as to make a "reasonable use" of their mobile phone with respect to the number and duration of calls, to prefer short messages or to use hand-free kits where possible, and to look for good conditions of radio reception (PP).
3. Mobile phones: patients with cardiac pulse generators ("pacemakers") should keep a minimal distance of 15–25 cm between the phone and the pacemaker (SG, electronic interference in older devices).
4. Base stations of DECT phones should be placed outside the bedroom (GF).
5. WLAN routers should be placed outside the bedroom (GF).

Curiously enough, UV light, a "high energy" electromagnetic radiation, is much less in the focus of the public perception of risks. Recommendations related to UV light ("Protect children – especially at young age – from long-lasting sun-bathing and especially from sunburns!" "Reduce visits to a solarium to the minimum!") are based on hard scientific facts, but are largely ignored by the general public.

In conclusion, extremely low, low and HF electromagnetic fields encountered in common life are most probably not a priority issue in children's environmental health. A better risk communication targeted at health professionals, opinion leaders and the general population is needed to establish a priority-based perception of environmental risks.

References

Belanger, K., Leaderer, B., Hellenbrand, K., Holford, T.R., McSharry, J., Power, M.E., Bracken, M.B., 1998. Spontaneous abortion and exposure to electric blankets and heated water beds. Epidemiology 9, 36–42.

BfS, 2003. Häufig gestellte Fragen zum Thema "Andere Quellen hochfrequenter Strahlung". 〈http://www.bfs.de/elektro/faq/faq_andere_quellen.html/#6〉.

Bracken, M.B., Belanger, K., Hellenbrand, K., Dlugosz, L., Holford, T.R., McSharry, J.E., Addesso, K., Leaderer, B., 1995. Exposure to electromagnetic fields during pregnancy with emphasis on electrically heated beds: association with birthweight and intrauterine growth retardation. Epidemiology 6, 263–270.

Christ, A., Kuster, N., 2005. Differences in RF energy absorption in the heads of adults and children. Bioelectromagn. Suppl. 7, 31–44.

Christ, A., Klingenböck, A., Samaras, T., Neufeld, E., Kuster, N., 2006. Exposition durch körpernahe Sender im Rumpfbereich. Abschlußbericht. Zürich. 〈http://www.emf-forschungsprogramm.de/forschung/dosimetrie/dosimetrie_abges/dosi_055.html〉.

EC (European Commission), 2000. Communication on "The Precautionary Principle". 〈http://europa.eu.int/eur-lex/en/com/cnc/2000/com2000_0001en01.pdf〉.

FEMU, 2006. Bibliographic database on electromagnetic fields. 〈http://wbldb.femu.rwth-aachen.de〉.

Gandhi, O.P., Kang, G., 2001. Calculation of induced current densities for humans by magnetic fields from electronic article surveillance devices. Phys. Med. Biol. 46, 2759–2771.

Gandhi, O.P., Lazzi, G., Furse, C.M., 1996. Electromagnetic absorption in the human head and neck for mobile telephonesat 835 and 1900 MHz. IEEE Trans. Microwave Theory Technol. 44, 1884–1897.

Georg, R. (Ingenieurbüro Telecom Consult), 2005. Bestimmung der spezifischen Absorptionsrate (SAR-Werte), die während der alltäglichen Nutzung von Handys auftritt. 〈http://www.emf-forschungsprogramm.de/forschung/dosimetrie/dosimetrie_abges/dosi_050.html〉.

Gollnick, F., 2006. Gepulste Vorgänge im menschlichen Körper. Bieten sie Angriffspunkte für die Einwirkung gepulster elektromagnetischer Felder? Newslett. FGF 1/2006, 14–27 〈www.fgf.de〉.

Henshaw, D.L., Reiter, R.J., 2005. Do magnetic fields cause increased risk of childhood leukemia via melatonin disruption? Bioelectromagnetics (Suppl. 7), 86–97.

IARC (International Agency for Research on Cancer), 2006. Interphone Study. 〈http://www.iarc.fr〉 and 〈http://www.iarc.fr/ENG/Units/RCAd.html〉.

ICNIRP (International Commission on Non-Ionizing Radiation Protection), 1994. Guidelines on Limits of Exposure to Static Magnetic Fields. Health Physics Society.

IEGMP (Independent Expert Group on Mobile Phones), 2000. Mobile Phones and Health (Stewart Report). 〈http://www.iegmp.org.uk/〉.

IET (Institution of Engeneering and Technology), 2006. The possible harmful biological effects of low-level electromagnetic fields of frequencies up to 300 GHz. IET Position Statement. ⟨www.theiet.org/publicaffairs/bepag/postat02final.pdf⟩.

Kavet, R., 2005. Contact current hypothesis: summary of results to date. Bioelectromagnetics (Suppl. 7), 75–85.

Kheifets, L., 2001. The Precautionary Principle & EMF. ⟨www.who.int/entity/peh-emf/meetings/southkorea/en/Precaution-Leeka.pdf⟩.

Kheifets, L., Shimkhada, R., 2005. Childhood leukemia and EMF: review of the epidemiologic evidence. Bioelectromagnetics 26 (Suppl. 7), 51–59.

Kommission "Methoden und Qualitätssicherung in der Umweltmedizin," 2006. Parameter des roten Blutbildes bei Exposition durch Mobilfunkanlagen. Bundesgesundheitsblatt – Gesundheitsforschung – Gesundheitsschutz 48, 1436.

Liesenkötter, B., 2002. Eine Analyse zur häufig behaupteten Schädlichkeit digital modulierter Mobilfunkstrahlen. ⟨www.fh-augsburg.de/~liese/downloads/Mobilfunk.pdf⟩.

Lightfoot, T., 2005. Aetiology of childhood leukemia. Bioelectromagnetics (Suppl. 7), 5–11.

Luchini, L., Parazzini, F., 1992. Exposure to low-frequency electromagnetic fields and pregnancy outcome: a review of the literature with particular attention to exposure to video terminals. Ann. Ostet. Ginecol. Med. Perinat. 113 (2), 102–113.

McKinney, P.A., 2005. Central nervous system tumours in children: epidemiology and risk factors. Bioelectromagnetics (Suppl. 7), 60–68.

Michelozzi, P., Capon, A., Kirchmayer, U., Forastiere, F., Biggeri, A., Barca, A., Perucci, C.A., 2002. Adult and childhood leukemia near a high-power radio station in Rome, Italy. Am. J. Epidemiol. 155, 1096–1103.

Scarfi, M.R., Sannino, A., Perrotta, A., Sarti, M., Mesirca, P., Bersani, F., 2005. Evaluation of genotoxic effects in human fibroblasts after intermittent exposure to 50 Hz electromagnetic fields: a confirmatory study. Radiat. Res. 164, 270–276.

Schmid, G., Lager, D., Preiner, P., Überbacher, R., Neubauer, G., Cecil, S., 2005. Bestimmung der Exposition bei Verwendung kabelloser Übermittlungsverfahren in Haushalt und Büro. Abschlussbericht. ⟨www.emf-forschungsprogramm.de/forschung/dosimetrie/dosimetrie_verg/dosi_017_ZwB_02.pdf⟩.

Schüz, J., Michaelis, J., 2000. Abschlussbericht der EMF II-Studie. Epidemiologische Studie zur Assoziation von Leukämieerkrankungen bei Kindern und häuslicher Magnetfeldexposition. ⟨www.imsd.uni-mainz.de/EMFIIABSCHLUSS.pdf⟩.

Schüz, J., Grigat, J.P., Brinkmann, K., Michaelis, J., 2001. Residential magnetic fields as a risk factor for childhood acute leukaemia: results from a German population-based case–control study. Int. J. Cancer 91, 728–735.

Schüz, J., Blettner, M., Michaelis, J., Kaatsch, P., 2005. Ursachen von Leukämien im Kindesalter. Deutsches Ärzteblatt 102 (38), A2557–A2564.

Strahlenschutzkommission, 2001. Grenzwerte und Vorsorgemaßnahme zum Schutz der Bevölkerung vor elektromagnetischen Feldern. Empfehlung der Strahlenschutzkommission. ⟨http://www.ssk.de/werke/kurzinfo/2001/ssk0103.htm?thema⟩.

Vecchia, P., 2005. The approach of ICNIRP to protection of children. Bioelectromagnetics (Suppl. 7), 157–160.

Wertheimer, N., Leeper, E., 1979. Electrical wiring configurations and childhood cancer. Am. J. Epidemiol. 109, 273–284.

Wertheimer, N., Leeper, E., 1986. Possible effects of electric blankets and heated waterbeds on fetal development. Bioelectromagnetics 7 (1), 13–22.

WHO, 2001. Fact sheet 263. Electromagnetic fields and public health: Extremely low frequency fields and cancer. ⟨http://www.who.int/mediacentre/factsheets/fs263/en/⟩.

WHO, 2003. Application of the precautionary principle to EMF. ⟨http://www.who.int/peh-emf/meetings/Lux_PP_Feb2003/en/⟩.

WHO, 2004. Children's EMF Research Agenda. ⟨http://www.who.int/peh-emf/research/children/en/print.html⟩.

WHO, 2005a. Information sheet February 2005. Electromagnetic fields and public health: Intermediate frequencies (IF). ⟨http://www.who.int/peh-emf/publications/facts/intmedfrequencies/en/⟩.

WHO, 2005b. Fact sheet 296. Electromagnetic fields and public health. Electromagnetic Hypersensitivity. ⟨http://www.who.int/mediacentre/factsheets/fs296/en/index.html⟩.

WHO, 2006a. The International EMF Project. Progress Report June 2005–2006. ⟨www.who.int/entity/peh-emf/publications/reports/IAC_Progress_Report_2005-2006.pdf⟩.

WHO, 2006b. Fact sheet 304. Electromagnetic fields and public health. Base stations and wireless technologies. ⟨www.who.int/mediacentre/factsheets/fs304/en/index.html⟩.

WHO, 2006c. Fact sheet 299 Electromagnetic fields and public health. Static electric and magnetic fields. ⟨www.who.int/mediacentre/factsheets/fs299/en/index.html⟩.

WHO, 2006d. Environmental Health Criteria (series; e.g. monograph No. 238). ⟨www.who.int/ipcs/publications/ehc/en/index.html⟩.