Chapter 5

Electromagnetic Hypersensitivity

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ABSTRACT

Electromagnetic hypersensitive persons (EHS) attribute their nonspecific health symptoms to environmental electromagnetic fields (EMF) of different sources in or outside their homes. In general, causal attribution is not restricted to specific EMF frequencies but involves a wide range from extremely low frequencies (ELF) up to radio frequencies (RF) including mobile telecommunication microwaves and radar. EHS argue that existing exposure limits were not low enough to account for their increased sensitivities. Results of measurement campaigns are summarized. They demonstrate that environmental fields in the ELF and RF range are usually orders of magnitudes below exposure limits. The rational and biological background of recommended exposure limits are described. The existing scientific studies are reviewed, including investigations on the prevalence of EHS among the general population, ability of EHS to perceive and/or react to exposures to weak EMF (assessed in laboratory provocational studies or to the vicinity of EMF sources studied by epidemiologic approaches), and the existence of a specific symptom cluster, which could characterize a suspected EHS syndrome, or individual EHS-specific factors such as electric perception thresholds, neurophysiologic parameters, and cognitive performance and behavior. However, in spite

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of the variety of scientific attempts, a causal role of EMF remains yet unproven. This does not mean that the suffering could be ignored. It is recognized that EHS cases deserve help. Therapeutic approaches are described and the conclusion of the World Health Organisation (WHO) is summarized.

1. INTRODUCTION

An increasing number of people suffering from sometimes severe nonspecific health symptoms of unclear origin attribute their health problems to external sources such as various environmental multiple chemical or physical factors, among them environmental EMF. Frequently, affected people explain the fact that most others do not exhibit symptoms due to suspected factors at levels well below existing exposure limits by postulating being hypersensitive to such influences.

Electromagnetic hypersensitive (EHS) persons attribute their health symptoms to environmental EMF to different sources in or outside their rooms emitting EMF. In general, attribution is not restricted to specific frequencies but involves a large range of frequencies from extremely low frequencies (ELF) up to radio frequencies (RF), mobile telecommunication microwaves, and radar. Suspected electromagnetic hypersensitivity was argued to challenge EMF exposure limits. Petitions were brought forward to lower existing EMF exposure limits by several orders of magnitude. EHS has already become a social issue. In many countries, EHS self-aid groups have been established. For example, in Sweden, the association for EHS is recognized as a handicap organization. An overwhelming majority of general practitioners do not exclude or are even convinced environmental EMF could be causally related to nonspecific health symptoms and multiply their opinions during their contacts with patients and related diagnostic conclusions.

Scientific attempts to investigate and substantiate personal convictions on hypersensitivity and electromagnetic allergy began two decades ago. Since then, a body of scientific studies has been published on EHS issues. To demonstrate a causal link between environmental EMF and the development of health symptoms on the basis of the hypothesis of electromagnetic hypersensitivity the following questions were investigated:

Is there an EHS subgroup within the population characterized by a sensitivity to electromagnetic fields which is increased beyond the normal range?

Is increased sensitivity to EMF causally linked with the development of health symptoms?

If it exists, what is the prevalence of EHS within the general population?

Are the reduction factors implemented in the derivation of EMF exposure limits sufficient to account for EHS groups?

This chapter reviews the existing literature and provides answers to these questions.

2. EXPOSURE LIMITS

To protect from known adverse health effects, exposure limits for ELF and RF electromagnetic fields have been proposed and already implemented in numerous countries worldwide. Protection strategy is based on "basic restrictions" limiting intracorporal quantities relevant for biologic interactions derived from the first health-relevant interaction level, which is lowered by tenfold accounting for uncertainties of knowledge to determine the basic restriction for occupational exposure. To account for potential higher sensitivities in certain population groups such as frail and/or elderly, infants and young children, and people with diseases or taking medications, which may compromise their perception ability and/or thermal tolerance, to limit exposure of the general population, a factor of 5 had been introduced to further reduce electric current density in the ELF range and specific absorption rate (SAR) in the RF range, respectively.

In the ELF range electric and magnetic fields interact with the body by inducing intracorporal electric field strengths and current densities, although governed by different laws and, hence, with different pathways. Consequently, basic restrictions limit intracorporal current densities or intracorporal electric field strengths within a region of interest, namely, the central nervous system (CNS), which is composed of the brain and spinal cord. Starting from the excitation threshold 100 mA/m^2 of central nervous tissue, the basic restriction has been set to 10 mA/m^2 for occupationally exposed and 2 mA/m^2 for general population (ICNIRP, 1998).

The main biologic interaction mechanism of RF electromagnetic fields is heating due to absorption of RF EMF energy. Consequently, basic restrictions limit the SAR, which is absorbed power related to tissue mass. SAR limits are defined for whole body and for local exposure by relating the absorbed power either to the whole body mass (SAR_{WB}) or to any 10 g tissue (SAR_{10g}), respectively (ICNIRP, 1998). Starting from initiation of thermal regulation at 1 C temperature rise which is caused by 4 W/kg SAR_{WB}, the basic restriction has been set to 0.4 W/kg for occupational exposure, and 0.08 W/kg for the general population. This means that the maximum permitted heating by RF EMF absorption is considerably lower than that of the human metabolic rate, which is about 1.2 W/kg at rest and can increase up to 12 W/kg during heavy exercise.

Because in daily life testing compliance with basic restrictions is difficult, for practical reasons, "reference levels" of easily measurable external field quantities such as electric or magnetic field strength were derived, linking worst case homogeneous field whole body exposures to basic restriction levels. If reference levels are met, compliance with basic restrictions can be assumed. However, at more favourable exposure conditions, reference levels could be exceeded without violating basic restrictions.

Nonionising radiation is characterized by the fact that amplitudes have to exceed biological thresholds to cause health relevant effects. Such threshold effects are stimulation of nerve and muscle cells by induced electric current densities or electric field strengths in the ELF range, and heat-triggered onset of thermoregulation due to absorbed RF EMF radiation energy (ICNIRP, 1998; IEEE, 2002, 2005).

The existence of biological thresholds allows excluding these effects rather than just reducing their probability of occurrence.

3. TERMINOLOGY AND SYMPTOMS

Although widely used in public media and scientific literature, electromagnetic hypersensitivity is associated with different meanings. There is a need to separate different aspects of this term (Leitgeb and Schröttner, 2003; WHO, 2005). In general,

> "Sensibility" addresses the ability to perceive exposures without necessarily developing health symptoms
>
> "Sensitivity" addresses the development of health symptoms as a causal reaction to exposures
>
> "Hypersensitivity" addresses the development of health symptoms as a causal reaction to exposures at much lower levels than required for the general population

Attributing nonspecific health symptoms to EMF seems to be neither a problem of the rich nor the poor, nor does it depend on education. It seems to be a problem of adults; however, there is no linear dependence on age. Females and persons with high tendency to somatisation report more frequent and more severe EMF-associated symptoms than others (Frick et al., 2002). An early attempt to identify a specific symptom cluster characterizing a syndrome based on an inquiry and involving 11 European countries failed (Bergqvist et al., 1997). Both symptoms and attributions varied among individuals. Throughout Europe a north-south gradient has been found with decreasing prevalence towards the south. Until now, reported EMF-associated symptoms (Table 1) include neurasthenic, vegetative and dermatological symptoms. However, the collection of symptoms is not part of any recognized syndrome (Bergqvist et al., 1997; Frick et al., 2002; Hillert et al., 2002; ICNIRP, 2003; WHO, 2005; Mild et al., 2006; Schreier et al., 2006; Schüz et al., 2006).

The World Health Organisation (WHO) concluded that EHS resembles multiple chemical sensitivities (MCS), another disorder associated with low-level environmental exposures to chemicals. Therefore, it proposed a preference for the more general term "idiopathic environmental intolerance" (IEI) already used for sensitivities to environmental factors. This term would not insinuate unproven causation or physiological mechanisms and does not already imply chemical etiology, immunological sensitivity or EMF susceptibility (WHO, 2005). Consequently, WHO recommended replacing the term EHS with "idiopathic environmental intolerance related to EMF" (IEI-EMF). This addresses an acquired disorder with multiple recurrent symptoms without forming a characteristic symptom cluster, associated with environmental factors or situations which are tolerated by the majority of people and cannot (yet) be explained by any known medical or psychological mechanism. However, this recommendation was rarely followed, and the common use of the term EHS persists.

Table 1. Reported symptoms associated with exposures to electric, magnetic, and electromagnetic fields (in alphabetical order)

Abdominal pain	Headache	Numb limbs
Anxiety	Head pressure	Phosphenes (flickering)
Appetite loss	Heart beat irregularity	Rash
Arousal decreased	Heart palpitation	Restlessness
Blood pressure increase	Hormonal disorder	Skin burning
Breathlessness	Hypersensitivity to medication	Skin redness
Chest pain	Hypersensitivity to noise	Skin tingling
Concentration difficulties	Intestinal trouble	Sleep disturbance
Crankiness	Irregular bowl movement	Stress
Daytime sleepiness	Irritation	Sweating
Digestive problem	Itching skin	Swollen eyes
Dizziness	Limb pain	Swollen joints
Dry skin	Metabolic disorder	Tachycardia
Exhaustion	Mood changes	Tenseness
Faintness	Mood depression	Tiredness
Fatigue	Muscle cramps	Toothache
Fear	Muscle pain	Trembling
Feebleness	Nausea	Unfeelingness
Feeling hot	Neck pain	Vision blurring
Forgetfulness	Neuralgia	Vomiting
Hair loss	Neurasthenia	Weariness

Physicians are already used to the term electromagnetic hypersensitivity, and many of them are deeply convinced that environmental EMF can play a causal role in the development of nonspecific health symptoms. A survey among Austria's general practitioners (Leitgeb et al., 2005a, b) with a response rate of 49% found an overwhelming majority of 96% not excluding, and 33% deeply convinced, that EMF could cause adverse health effects. Almost two thirds of the practitioners (61%) were making such a diagnosis. In Switzerland, based on a response rate of only 28%, the majority of general practitioners (54%) judged the association between EMF and health symptoms to be plausible. Physicians practising complementary medicine were much more convinced of this hypothesis. Overall, 14% had considered EMFs as a potential cause for symptoms they had experienced themselves (Huss and Röösli, 2006).

4. PREVALENCE

Despite the lack of scientific evidence of a causal relation, EHS cases in terms of people suffering from health symptoms which they attribute to EMF do exist. Some of them are suffering severely. In extreme cases, individuals can become disabled and even unable to pursue normal work or social life. Estimates on the prevalence of EHS within the general population differ widely. Initially, mainly case descriptions were published based on self-reported nonspecific symptoms such as eye discomfort, headache, muscular pain and skin disorders, frequently associated with work at video display units (VDU) (Knave et al., 1985; Bergdahl, 1995). An early prevalence study (Leitgeb, 1994, 1995) was based on an inquiry among a random sample of 200 men and women of the Austrian population. The results were dependent on the kind of assessment. On the basis of the questionnaire and self-definition, 10% declared themselves to be very sensitive to electricity without actually suffering from health symptoms. On the basis of the measurements of perception thresholds for directly applied electric currents on a randomly selected sample of 200 persons of the general population, it could be estimated that less than 2% of the general population are EHS. This was confirmed by an enlarged measurement campaign of electric current perception involving 708 adults (349 men and 359 women) aged between 16 and 60 years (Leitgeb et al., 2005a, b). A Swedish postal questionnaire survey among 10,670 adults with a response rate of 75% identified 1.5% individuals reporting to be hypersensitive or very allergic to electricity (Hillert et al., 2002). A Californian telephone interview-based study among 2,072 adults found 3.2% allergic or very sensitive to being near electric appliances, computers or power lines (Levallois et al., 2002). A Swiss telephone interview survey among 2,048 persons older than 14 years resulted in 5% EHS (Schreier et al., 2006).

A German telephone interview-based survey (Ulmer and Bruse, 2006) of a sample of 2,406 inhabitants identified 6% attributing repetitively experienced health symptoms to EMF. However, only about 1% reported themselves to be hypersensitive to EMF. EHS did not differ with regard to any socio-demographic parameter except education. EHS persons were more highly educated: 26% of EHS had a university-entrance diploma compared to 15% of the general population. Symptoms were attributed to RF-EMF sources (mobile phones and mobile phone basestations) as well as to ELF-EMF sources (TV set, alarm clock).

Apart from regional and cultural differences and prevalence-driving parameters such as public and media attention, different estimates can be explained by the weak definition of the term electromagnetic hypersensitivity as such: prevalence numbers might refer to a percentage of individuals suffering from health symptoms and attributing them to EMF or to persons just believing themselves to be hypersensitive without suffering from health symptoms. Lacking confirmation by specific EMF-related experience or perception, individual's beliefs are mostly based on their general sensitivity and/or experiencing sensitivities to other influences such as weather changes or temperature. Further, the wording of questions asking about electromagnetic hypersensitivity strongly influences the assessed prevalence numbers. In addition to that, in Germany investigations of a random sample of the general population comprising 340 individuals (177 female, 163 men, mean age 43.6 ± 13.0 years) demonstrated that the frequency of health complaints considerably depends on factors influencing perception of risks such as media attention and the context in relation to other risks (Frick et al., 2002).

5. ENVIRONMENTAL FIELDS

Environmental levels of ELF electric and magnetic fields and RF electromagnetic fields are usually several orders of magnitude below existing limits. However, this does not necessarily apply to electric devices. Under nominal load condition and in proximity, emissions of electric appliances can approach or even exceed reference field levels; those for electric fields up to 11-fold (Leitgeb et al., 2008b) and those for magnetic fields up to 80-fold (Leitgeb et al., 2008a). However, field levels rapidly decrease with distance (Preece et al., 1997; Kaune et al., 2002; ICNIRP, 2003; Leitgeb et al., 2008a; WHO, 2007). Figure 1 shows the results measured at 1,146 devices of 166 different categories comparing root mean square (rms) B_{rms} values with frequency-weighted sums of identified spectral peaks with amplitudes larger than twice the signal to noise ratio (SNR). The summation formula (ICNIRP, 1998) was slightly modified to generate an equivalent induction $B_{\text{equ,ICNIRP}}$ as follows (Leitgeb et al., 2008a):

$$B_{\text{equ,ICNIRP}} = B_{\text{RL},50} \cdot \sum_{i=1}^{N} \frac{B_{\text{peak},i}}{B_{\text{RL},i}} \tag{1}$$

$$\text{with } B_{\text{peak},i} > 2\text{SNR}.$$

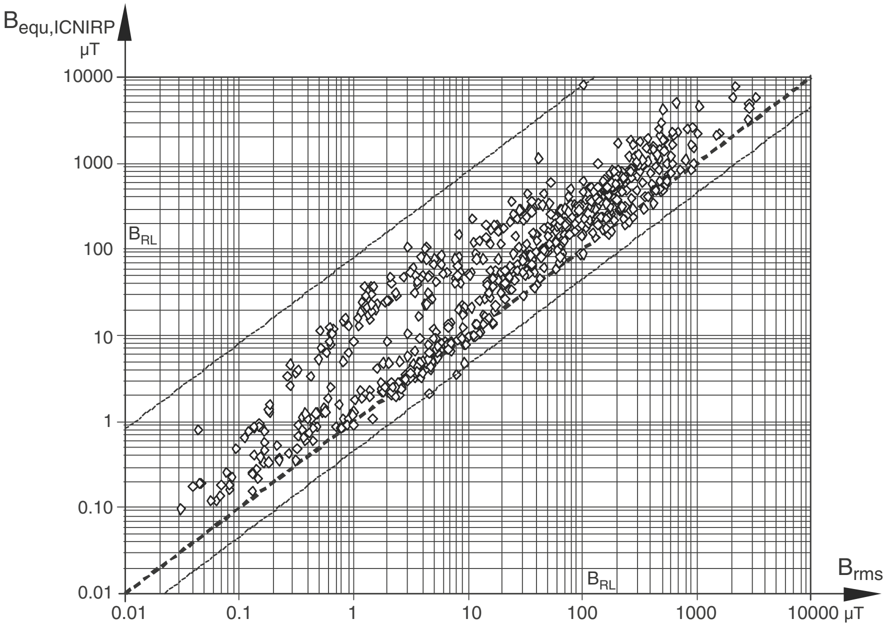

Figure 1. 50 Hz-equivalent magnetic induction $B_{\text{equ,ICNIRP}}$ emitted by 1,146 devices of 166 different categories in dependence on the B_{rms} value calculated in the frequency range 4 Hz–2 kHz (Leitgeb et al., 2008a). B_{RL}, 50 Hz magnetic field reference level; *fat dashed line*, direct proportionality; *dashed lines*, boundaries of measured values.

In homes, time-average background magnetic field levels are low. At the homes of 382 Canadian children the arithmetic mean value of magnetic fields (121 nT), determined from 2 consecutive 24 h measurements, was almost three orders of magnitude below the reference level. The span was 10–800 nT. The corresponding mean of electric field strengths, 14 V/m, was 360-fold below the reference value 5,000 V/m with a span of 0.82–65 V/m (Deadman et al., 1999). On the basis of the magnetic field measurements in children's sleeping rooms of 1,835 German residences, the 50 Hz median was 30 nT during daytime and 22 nT during nighttime (Schüz et al., 2000). Background magnetic field levels tend to be about fivefold higher in North America than in Europe, probably because of differences in power supply (more overhead wires, and lower household voltages consequently causing higher electric currents), higher power consumption and different grounding practices (Linet et al., 1997; UKCCS, 1999; Kavet et al., 2000).

Despite the rapid growth of RF-EMF emitting technologies, little is known about every day population exposure to such fields. Radio and TV transmitters are sparse because they expose large areas and, therefore, operate with high power. Mobile telecommunication antennas are forming a dense network of antennas with low output power and directional antenna characteristics. Since propagation is ruled by optical laws shadowing, scattering and multiple reflection considerably influence fields inside and outside buildings. In contrast to power line ELF magnetic fields, distance to transmitters is not an adequate surrogate for exposure levels. Relatively highest exposures are associated with direct visibility of the antenna. Determination of the general public exposure around mobile telecommunication base-stations resulted in maximum intensity values 2 orders of magnitude below limits and a span reaching down to 8 orders of magnitude (Bornkessel et al., 2007). Measurements around radio broadcast transmitters resulted in a maximum frequency-weighted sum of spectral components about 3 orders of magnitude below ICNIRP's reference level (Schubert et al., 2007).

Mobile phone handsets can approach SAR basic restriction levels up to 70% (BfS, 2008). However, this value is measured under worst case operation condition with maximum output power and continuous (pulsed) transmission. In every day use continuous power adjustment and discontinuous transmission mode considerably reduce real exposure. Studies have shown that this reduction effect critically depends on the network provider. Depending on network providers the proportion of calls with highest handset power levels was found to be 57.2% or 6.2%, respectively (Berg et al., 2004).

6. PERCEPTION

In recent centuries, numerous studies have been performed to investigate the hypothesis of self-declared hypersensitivity to EMF exposures and to clarify whether EHS are indeed able to perceive and/or react to environmental EMF exposure at environmental levels well below existing limits.

6.1. Adults

In the ELF range, both electric and magnetic fields interact with the body by inducing electric current densities. If EHS reactions are indeed associated with weak environmental fields, it should be expected as a necessary (but not sufficient) precondition that EHS cases should exhibit considerably lower thresholds than normal to perceive electric currents. Therefore, the ability to perceive electric currents was investigated. The normal range of perception of the general population was determined to compare results of EHS cases. Since EHS is not specifically restricted to RF- ELF, results gained in the ELF range should be helpful although not necessarily sufficient to quantitatively identify EHS.

Until recently, data on the ability to perceive electric currents were available only from groups which were small and did not represent the general population. Thompson (1933) reported on perception thresholds measured in 28 women and 42 men having their left hand immersed in a saline solution and contacting live parts (plates, wires). He found that women were about one-third more sensitive than men. Since that time, the factor 0.66 was used to account for women's increased electric sensitivity without further confirmation of such gender-related differences. In two series of experiments, Dalziel (1950, 1954) measured 60 Hz AC electric current perception thresholds of 115 men touching live copper wires. The integrated probability curve of data, pooled from three differently designed test series exhibited that 0.5% of men perceived currents below 400 μA. Osypka (1963) measured 50 Hz current perception thresholds of 50 healthy men aged between 19 and 39 years using two cylindrical handheld electrodes. His results were similar to Dalziel's. Irnich and Batz (1989) investigated 50 Hz electric current perception of 320 male and 166 female students, aged between 19 and 24 years while grasping cylindrical electrodes. In a second series, Batz and Irnich (1996) investigated 68 male and 133 female students putting their hands on flat live plates. The data of both studies were pooled and confirmed the existence of a gender difference; however, this time it was only 0.8-fold. Tan and Johnson (1990) investigated perception of 60 Hz electric currents flowing between two ECG electrodes placed 10 cm apart at one lower arm. They pooled data of an experiment on 38 men and 18 women and another one on 27 men and 14 women and reported considerably lower mean perception thresholds than published before, but no significant gender-related difference. Levin (1991) investigated 18 men and only 2 women with one hand resting on a 5 cm^2 metal plate and touching a live plate with the forefinger of the other hand. Reported perception thresholds were lower than in most other studies.

The inconsistent results reported by these studies could be explained by a study in a representative sample of the general population of 1,071 individuals, among them 349 men and 359 women aged between 16 and 60 years (Fig. 2). Between two paired electrodes 50 Hz electric currents were applied at the lower arm. It could be shown that the span of inter-individual perception thresholds now comprised two orders of magnitude (Leitgeb and Schröttner, 2002; Leitgeb et al., 2005a, b, 2006, 2007). This was considerably higher than the four to tenfold span reported previously (Thompson, 1933; Dalziel, 1959, 1954; Osypka, 1963; Irnich and Batz, 1989; Tan and Johnson, 1990; Levin, 1991; Reilly, 1992). Results confirmed that women (median perception threshold

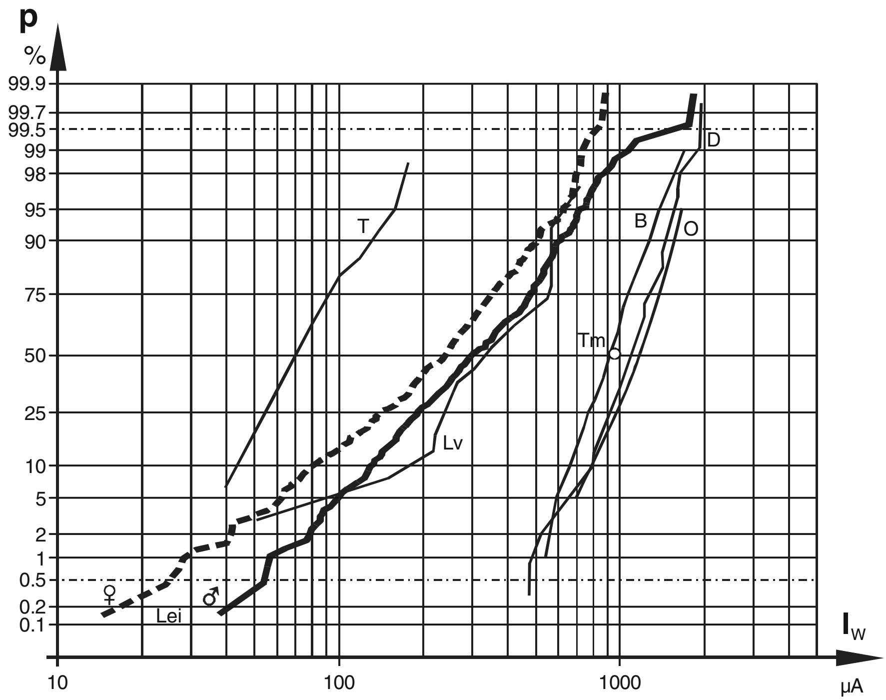

Figure 2. Cumulative probability dist ribution *p* of 50 Hz electric current perception thresholds of men: $I_{W.}$ D, Dalziel (1954), D_L, Dalziel (1946), B, Batz et al. (1996), Lv, Levin (1991), O, Osypka (1963), T, Tan et al. (1990), Tm, Thompson et al. (1933); *dash-dotted line*, let-go thresholds (Dalziel 1946) and of men ♂ and women ♀, Lei, Leitgeb et al. (2005b).

243 μA) were significantly more sensitive than men (median perception threshold 313 μA). However, quantitative gender-related differences depended on perception probability. At 0.5% perception probability, women's perception thresholds were 0.5-fold lower than men's. At 50% probability this difference was 0.77-fold (Fig. 2).

Cumulative perception probability curves showed that the lowest current level perceived was around 15 μA (Fig. 1). By numerically simulating intracorporal current density distributions, measured perception threshold currents could be associated with subcutaneous electric current densities thresholds. The lowest perceived current was associated with 12.4 μA/cm² (Leitgeb et al., 2006). It is known that apart from vision, excitation of one single cell is hardly sufficient to cause conscious perception. Therefore, stimulation of single cells can already occur below conscious perception levels. Accounting for such subliminal stimulation resulted in an excitation threshold 6.2 μA/cm², which is threefold higher than the 2 μA/cm² basic restriction level of ELF intracorporal current densities (in the CNS). Environmental fields are several orders of magnitude below reference levels and, hence, induce current densities below the lowest stimulation thresholds encountered so far.

In the ELF range both electric and magnetic fields induce intracorporal electric current densities. Since EHS persons exhibit symptoms in the vicinity of field sources emitting ELF *or* RF fields, it could be expected that if hypersensitivity existed, this should be indicated by considerably increased abilities perceiving ELF current densities (reduced perception thresholds). Therefore, specific investigations were conducted on self-declared EHS people. Since EHS is weakly defined, groups were compared which had been recruited by different strategies: The first group (12 men and 25 women) was composed of members of EHS self-aid groups which were most deeply convinced of a causal adverse role of EMFs. The second group (6 men and 23 women) comprised people who responded to advertisements seeking subjects with health symptoms attributed to electrical equipment and EHS patients. The third group (9 men and 15 women) contained worst cases selected from a list of 600 volunteers suffering from sleep disturbances they associated with RF EMF radiation from mobile telecommunication base stations. Electric 50 Hz current perception measurements performed at the lower arms showed that results within and among groups differed widely. All groups exhibited results overlapping the normal range (mean ± standard deviation) with some group members exhibiting lower-than-normal thresholds (Fig. 3). These

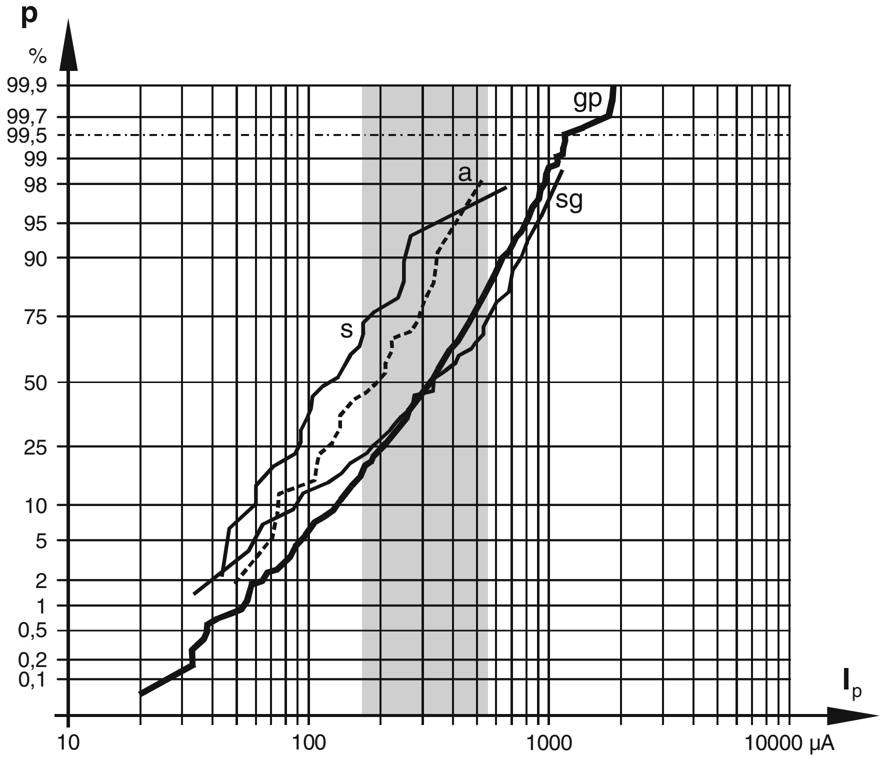

Figure 3. Cumulative frequency p of 50 Hz electric current perception thresholds I_p of pooled data of a 708 person sample of the general population (gp), 37 members of EHS self-aid groups (sg), 29 advertisement-recruited EHS volunteers (a) and 43 individuals suffering from EMF-attributed sleep disturbance (s), *gray*, normal range (Schröttner et al., 2007).

were 21% in the self-aid group 1, 52% in the advertisement responder group 2, and 60% in the RF EMF group 3 (Schröttner et al., 2007). The fact that individuals in the RF EMF group 3 exhibited similar reductions of perception thresholds to those associating their health symptoms to general "electromagnetic pollution" or ELF sources, demonstrated that lower ELF current perception thresholds are also a marker for persons claiming to be hypersensitive to RF EMF. This indicated that EHS exhibit a common signature in terms of increased sensitivity to electric currents.

The fact that EHS individuals did not exhibit perception thresholds orders of magnitude below those of the general population might be explained by different reasons:

> First, this might be due to the fact that the investigated sample of the general population might also have contained several EHS persons which enlarged the span of results. With an estimated prevalence of about 2–5%, the 708-person-sample of the general population could involve 14–35 EHS cases. However, apart from the fact that none of the volunteers had confirmed suffering from EMF-related health symptoms, data of the general population followed a log-normal distribution without any lag separating from EHS-attributable results.
>
> Second, this demonstrated that EMF-unaffected people might also have an increased ability to perceive electric current densities. Consequently, this ability might be a necessary precondition but not sufficient to develop EHS.

Detailed analysis demonstrated that the measured data of the general population follow a normal distribution overlapped (but not amended) by a second normal distribution at the sensitive end of low perception thresholds attributable to EHS cases (Leitgeb, 1998). The mean of the second normal distribution was only 6.7-fold below the general mean, and the lowest perception threshold found (15 μA) was only 18-fold below the median 270 μA of adults (men and women). These findings do not exhibit the postulated dramatic difference of orders of magnitude which should be expected as a consequence of hypersensitive reactions to environmental EMF several orders of magnitude below exposure limits. Since the span of results observed at EHS individuals did not extend beyond lowest thresholds of the general population the results did not support the hypothesis of hypersensitivity.

In Germany, perception of transcranial stimuli induced by transient magnetic fields was studied in 30 persons with self-reported electromagnetic hypersensitivity (Frick et al., 2005). Controls were recruited based on a population survey involving 758 individuals. From this, two non-EHS groups were selected according to the number of reported nonspecific health complaints. Thirty volunteers were identified with lowest level and 27 subjects with highest level of health complaints (without attribution to EMF). Onset of transcranial magnetic stimulation was identified by magnetically evoked electroencephalographic potentials (MEP). Magnetic stimulation exhibited no significant differences between any group either with regard to magnetic stimulation thresholds or MEG amplitudes. However, the three groups differed significantly with regard to differentiating between sham and true exposure. EHS exhibited the lowest ability while the control subgroup with the highest level of complaints performed best. With regard to complaints levels, EHS exhibited a high complaints level similar to the control group with highest complaints level.

Overall, these investigations demonstrated that people reporting hypersensitivity to electromagnetic fields sources were not able to perceive intracorporal electric current densities sufficiently better to justify the term hypersensitivity. Although there are indications to react more sensitively, observed differences were not large enough to explain EHS reactions to field exposures several orders of magnitude below recommended exposure-limiting reference field levels.

6.2. Children

Children are not just small adults and may respond to EMF exposures differently from adults. They have different susceptibilities during different periods of development they are going through, because of their dynamic growth and developmental processes during pregnancy, after birth, during infanthood and juvenile years. This does not already imply that children are more susceptible to any kind of exposure, but neither does it allow concluding the contrary. It is interesting to note, anyway, that EHS seems to be a phenomenon of adults, although children are supposed to have increased sensitivity to many factors including EMF (Kheifets et al., 2005a, b).

An early study suggesting an association between environmental ELF electric and/or magnetic fields was the epidemiologic study of Wertheimer and Leeper (1979) reporting on a significant increase of risk for childhood leukaemia near power supply wiring. In the meantime, a number of subsequent studies, meta-analyses and pooled analyses have been undertaken (Greenland et al., 2000; Ahlbom et al., 2000). Overall, there are consistent results indicating that the risk of childhood leukaemia might be two times greater for children exposed to 50/60 Hz magnetic fields at levels above 0.3–0.4 μT, which is about 2 orders of magnitude below recommended reference levels (IARC, 2002; ICNIRP, 2003; WHO, 2007) while no consistently elevated risks could be found for adults.

Without an established interaction mechanism or supporting evidence from other studies, in-vitro or in-vivo, and in view of the potential presence of selection bias, misclassification bias, confounding or chance, conclusions from epidemiologic findings remain difficult. In its evaluation the International Agency for Research on Cancer (IARC, 2002) came to the conclusion that, "There is limited evidence in humans for carcinogenicity of extremely low frequency magnetic fields in relation to childhood leukaemia."

If there is indeed a causal relationship, epidemiologic results would indicate that children might have a vulnerability more than 2 orders of magnitude more than that of adults.

Because of ethical reasons, quantitative results on children's sensibility to electricity are sparse. Electric currents perception of children was investigated in 240 pupils (Leitgeb et al., 2006). Overall, 117 girls and 123 boys, aged 9–16 years, were studied as part of demonstrations within their physics lessons. This was done on a voluntary basis with written consent of parents, teachers and heads of schools.

Results showed that girls were more sensitive than adult men. However, their perception ability remained well within the span of women's results. No clear age-dependence could be found for girls. In contrast to this finding, perception thresholds of boys were different. Boys and girls were similarly sensitive to electric currents at ages from 9 to 11 years. However, with age gender differences evolved and boys became more and more insensitive until their perception ability reduced to that of adult men while the sensitivity of the girls remained fairly constant with no significant difference from that of adult women (Fig. 4). These results demonstrated that the widespread precautious assumption that children were much more sensitive than adults could not be confirmed with regard to ELF electric currents.

Since biological interactions are governed by different physical mechanisms in the RF range (where heating replaces stimulation), results and risk factors gained in the ELF range cannot be directly extrapolated to RF electromagnetic fields. This explains why there are no epidemiological studies in the RF range with findings similar to those of ELF magnetic field exposures indicating potentially increased childhood cancer risks. Regarding long-term exposure and limited observation periods of new technologies, concerns about the potential vulnerability of children to RF EMF have been raised, for many reasons. Mobile phones expose their developing nervous system to a higher degree and for a longer lifetime than adults (Kheifets et al., 2005a; Leitgeb, 2008). Increased absorption can be expected because their brain tissue exhibits an increased electric conductivity, RF penetration depths are greater relative to brain structures and their decreased skull thickness, and more flexible pinna are less efficient to keep distance to mobile phone handsets. Figure 5 shows the development of several anatomical parameters with age.

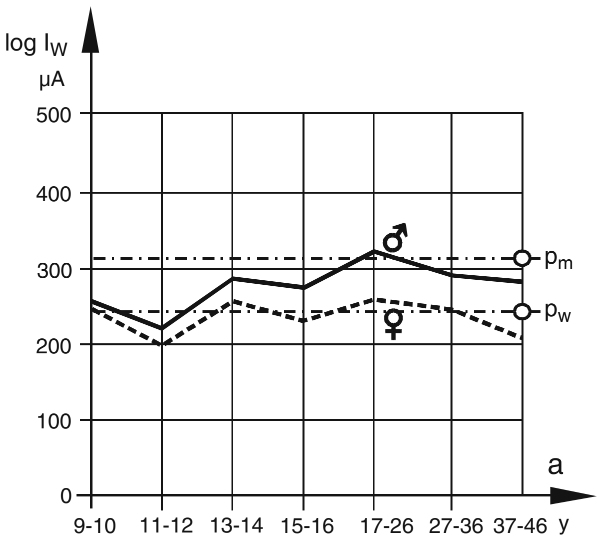

Figure 4. Dependence of electric current perception threshold medians I_w on age classes from children to adults (*full line*, male; *broken line*, female). p_m, median perception threshold of adult men, p_w, median perception threshold of adult women (Leitgeb et al., 2006).

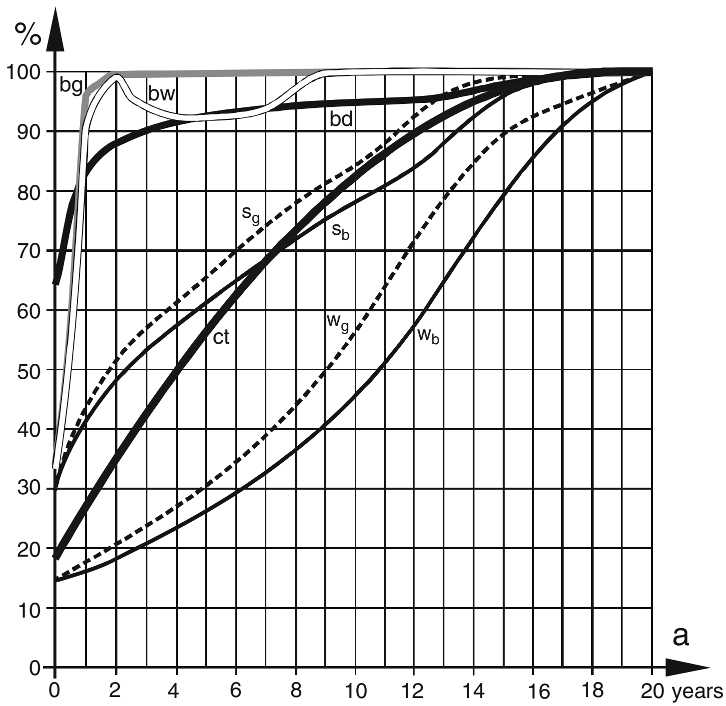

Figure 5. Relative growth curves for anatomical parameters from birth to adult. *bg* gray brain tissue, *bw* white tissue, *bd* brain diameter, *ct* cranial thickness, *sg* stature (girls), *sb* stature (boys), *wg* body weight (girls), *wb* body weight (boys) (Leitgeb, 2008b; Ogden et al., 2002).

During the first 2 weeks after conception the embryo is very sensitive to lethal effects of toxic agents and much less sensitive to induction of malformation ("all-or-none period"). During the following 6–8 week organogenic period, toxic agents with teratogenic potential might cause malformations of the visceral organs. Neuron proliferation, differentiation and migration make the CNS particularly vulnerable during weeks 8–15. During the final foetal period vulnerability to deleterious effects remains high, while it decreases for formerly susceptible organs including the CNS. Although most neurons are already existent at birth, during the first 2 postnatal years the connections grow between neurons, reducing the high water content due to increased nerval myelin in brain tissue (myelination). Because the period from embryonic life to adolescence is characterized by growth and development, deleterious effects could occur at lower levels and be more severe, or lead to effects that would not occur in adults. Therefore, timing of exposure might also be critical. For ionizing radiation, excess risk for leukaemia, brain and thyroid cancer is highest during childhood exposure.

The most relevant effect of RF EMF interaction is heating. Therefore, RF EMF impose heat load to the whole body or locally to sensitive parts. Investigations whether children brains are more susceptible to higher exposure compared with adults resulted in different conclusions. Some groups concluded that energy absorption is not increased (Christ and Kuster, 2005; Wiart et al., 2005; Hadjem et al., 2005), marginal (Andersen, 2003), more likely caused by individual differences in head anatomy and geometry rather than age (Keshvari and Lang, 2005) or larger with decreasing difference from adults towards adolescence (Leitgeb, 2008). Reasons for these different conclusions are manifold such as differences in numerical simulation, anatomic head modelling including the distance-determining pinna, tissue segmentation, electric tissue parameters, modelling the radiating source, simulation parameters (voxel size, meshing, algorithm) and kind of SAR calculation (volume size, geometry), etc. In principle, children's brains are exposed more because of the less efficient spacing of the phone by the more flexible pinna, the smaller skull thickness, the higher absorption coefficient of brain tissue (Gabriel, 2005) and the more unfavourable phone position. Reported differences are not larger than the reduction factor of 5, which had been implemented in guidelines to account for sensitive groups within the general population.

Concerning the use of mobile phones, the main difference between today's children and adults may be the longer lifetime exposure, particularly in view of the increasing prevalence among juveniles and the trend to start using mobile phones at earlier ages, with higher frequency and longer duration per use (Schüz, 2005). Regarding potential long-term health effects and the paucity of data, WHO suggests low-cost precautionary measures are appropriate in particular because some exposures are close to guideline limits.

7. PROVOCATION STUDIES

Apart from perception ability of directly applied electric currents numerous provocation studies, either blind or double-blind, were conducted with EHS to investigate their increased ability to react to field exposures either by detecting them more reliably or developing more symptoms than others (Rubin et al., 2005; Röösli, 2008). Two types of provocation studies were conducted: Laboratory studies with simulated exposures which were most frequent, and field studies with real exposure or where exposure to real environmental fields was varied by shielding (Leitgeb et al., 2008c) or randomly activating mobile phone base stations (Heinrich et al., 2007).

Typically, volunteers were subjected to two different situations with and without field exposure, usually in a random order. However, studies used quite different exposure durations ranging from some seconds to several days.

7.1. ELF Studies

Rea et al. (1991)) reported on 16 students preselected from 100 EHS colleagues also as sensitive to other chemical factors which were responding to AC magnetic fields. In a second series, these 16 students selectively exhibited symptoms during magnetic field exposures at individual "resonant" frequencies (some at 0.1–10 Hz, the majority at 50 Hz) while a healthy control group did not develop symptoms during any of these exposures. At that time the study had gained public attention and had strengthened convictions in EHS. However, it has been scientifically criticised on several methodological grounds such as selection of individuals, reproducibility of exposure and even uncertainty about whether or not it was blind (ICNIRP, 2003). A subsequent study by the same group (Wang et al., 1994) could not replicate the initial findings.

A USA study (Omura et al., 1991) reported on synergistic interaction of EMF with incorporated concentrations of mercury and/or lead. Exposures were associated with health problems and changes of hormones and neurotransmitters such as acetylcholine or thromboxane B2. Changes were reported to follow only 5 min exposure to 10 V/m (60 Hz) electric fields or 60 mT static magnetic fields from magnetic disks or credit cards. They lasted for hours after exposure.

Most early provocation studies concentrated on electric and magnetic fields of VDUs. They could not find any evidence that persons suffering from EHS reacted differently than healthy controls or experience more symptoms during periods when devices were activated (Lonne-Rahm et al., 2000; Flodin et al., 2000; Nilsen, 1982; Swanbeck and Blecker, 1989; Hamnerius et al., 1993, 1994; Sandström et al., 1993; Wennberg et al., 1994). Reactions were found to correlate with belief of the presence rather than the real exposure to fields indicating a nocebo effect (the inverse of placebo in terms of occurrence of adverse rather than benign effects due to beliefs). Comparison of individual's self-classification with measured sensitivities to electric 50 Hz currents demonstrated that convictions of individuals did not significantly correlate with reduced perception thresholds (Leitgeb, 1994). A Swedish study (Sjöberg and Hamnerius, 1995) reported significantly worse symptoms compared with sham in only one out of 10 test series; however, no correction for multiple testing was made. A Norwegian group reported on small delayed beneficial effects of electric VDU shields, however, they were not able to replicate their findings (Oftedal et al., 1995, 1999). Some morphological evidence was reported by Johanssen et al. (2001) who compared cutaneous biopsies of 13 healthy subjects before and after 2 or 4 h exposure to conventional TV or PC screens. Five of the volunteers exhibited an increase in the number of mast cells and their changed distribution in the facial skin while in 2 volunteers a decrease of the mast cell number was found but a shift towards the upper dermis was observed. One day after exposure, the number and location of mast cells were normalized in all subjects.

In Sweden (Lyskov et al., 2001a, b), 20 EHS (15 female, 5 male, mean age 45.8 ± 0.7 years) and 20 healthy controls (15 female, 5 male, mean age 45.0 ± 0.7 years) were exposed to 15 s on/off cycles of 60 Hz/10 μT magnetic fields or sham. The total test period was 40 min. It was divided into two 10-min rest periods and two 10-min periods for performing mathematical tasks. Parameters recorded were EEG, VEP, electrodermal activity, ECG, blood pressure and mathematical performance. Statistical analysis resulted in significant differences between the two groups with regard to heart rate ($p < 0.01$), heart rate variability ($p = 0.02$) and electrodermal activity ($p = 0.04$). However, no corrections were made for multiple parameter statistical testing. The authors concluded that the chosen magnetic field level would not affect EHS or controls, speculating that EHS cases exhibited a shift in baseline values of investigated parameters which could indicate a distinctive physiological predisposition to sensitivity to physical and psychosocial environmental stressors.

In a double-blind Swiss laboratory study (Müller, 2000; Müller et al., 2002), the ability to perceive weak 50 Hz electric and magnetic fields (100 V/m + 6 μT) was tested in 63 subjects (49 self-reported EHS and 14 healthy controls). Fields were applied in randomized sequence (field on/field off) in 2-min intervals. Seven out of all 63 subjects exhibited statistically significant results. However, there was no relevant difference between healthy and EHS subjects, either with regard to field perception or to number and type of symptoms developed during tests. Another part of these investigations concentrated on night-time exposure to 50 Hz magnetic fields of 53 self-declared EHS. Physiological parameters were monitored such as heart rate, breathing, movements and body position (indicating potential attempts to escape exposure). Sleep quality and daytime wellbeing, movement, breathing and heart rate did not show significant changes. However, night-time body position monitoring significantly indicated attempts to move away from the magnetic field zone (Müller, 2000).

In a German study (David et al., 2004), 24 EHS volunteers and 24 healthy controls were randomly exposed to 10 μT/50 Hz magnetic fields for 2 min with 3 min for recovery (two sessions per 10 trials). No significant difference could be found between the two groups.

7.2. RF Studies

7.2.1. RF Field Studies

In Switzerland, during 1992 and 1998, studies on 404 persons living at different distances from a short-wave transmitter antenna were performed assessing somatic and psychosomatic symptoms including sleep quality by questionnaires when the transmitter was switched off for 3 days (Abelin et al., 2005), and in another study after final shut-down some years later (Altpeter et al., 2006). In both cases prevalence of difficulty falling asleep and nocturnal arousals increased with exposure. However, the study suffered from the fact that people could become aware of their exposure and that information exchange among those exposed could not be excluded.

In France (Santini et al., 2003) and Spain (Navarro et al., 2002), inquiries were made in the neighbourhood of mobile phone base stations and results analysed independent of distance to the antenna. Both reported a higher prevalence of symptoms at smaller distances. However, shortcomings like bias, unknown response rates and the inadequate approach using distance as a surrogate for exposure make conclusions invalid.

In Austria (Hutter et al., 2006), 365 persons living in the neighbourhood of mobile phone base stations were investigated. The results were analyzed as a function of distance and measured field levels. Some associations of sleep disorders with measured base station field levels were found but they were also highly significantly associated with the people's concerns.

In Egypt (Abdel-Rassoul et al., 2007), a cross-sectional inquiry study involved 37 people living below and 48 opposite from base stations. It was reported that the prevalence of nonspecific health symptoms such as neurobehavioural complaints (headache, memory changes, dizziness, tremors, depressive symptoms and sleep disturbances) were significantly higher ($p<0.05$) among people living close to base stations compared with 80 matched controls.

In a German field study (Heinrich et al., 2007), for 3 months perception and symptoms were investigated by a daily online questionnaire. Ninety-five employees (67 male, 28 female) were randomly exposed to RF EMF emitted from a mobile phone base station on an office building which was switched on and off for 2–3 day intervals. Operation condition was not identified better than chance, and symptoms developed; however, they were significantly correlated only with the belief of phone operation rather than with real exposure.

In Austria, with a new study design of protection (shielding) from rather than provocation to EMF, 43 volunteers reporting sleep problems due to RM-EMF from mobile phone basestations were investigated in their sleeping rooms at home (Leitgeb et al., 2008c). Sleep quality of volunteers was assessed for ten consecutive nights (with the first night for accommodation) under three test conditions (true-shield, sham-shield and control) selected in random order. Shielding conditions were single-blinded for controlling shielding efficiency, while data analysis was performed double-blind. Sleep quality was assessed by subjective parameters derived from standardised questionnaires and objective parameters from polysomnographic recordings. RF-EMF emmission was continuously recorded frequency-selectively. Pooled analysis did not exhibit statistically significant EMF-dependent sleep parameters changes, either on total RF-EMF emmissions or on base station signals. The majority of volunteer-specific analysis did not show significant effects on sleep parameters. Subjective sleep parameters of several volunteers (16%) exhibited significant placebo effects. However, 9% of volunteers showed consistent statistically significant prolongations of sleep latency times in shielded nights.

7.2.2. RF Laboratory Studies

In the RF range, EHS studies concentrated on exposure to mobile telecommunication fields from handsets or base stations. In Finland (Koivisto et al., 2001), 48 healthy subjects (24 males, 24 females, mean age 26 years, span 28–49 years) were studied in two experiments with 60 min and 30 min exposures to 900 MHz GSM fields from mobile phones, respectively. The reported symptoms of headache, dizziness, fatigue, itching, tingling or redness of the skin, and a sensation of warmth did not reveal any significant differences between exposure and sham.

Hietanen et al. (2002) investigated 20 volunteers (13 women and 7 men) reporting being sensitive to cellular phones (some of them also to other EMF sources).

Volunteers were exposed to one analogue NMT phone (900 MHz) and two digital GSM handsets (900 MHz and 1,800 MHz, respectively) operated at maximum power (1 W_{rms}(cw), 0.25 W_{rms}, and 0.125 W_{rms}, respectively). One exposure (sham or true) lasted for 30 min, followed by 1 h break. Each volunteer was tested three or four times in one day. Blood pressure, heart and breathing rate were monitored. Nineteen of the volunteers reported nonspecific symptoms, most of them related to the head. However, more symptoms appeared during sham exposure. None of the persons could distinguish between sham and real exposure. Higher heart rate and blood pressure at the beginning of a session was attributable to stress. No statistically significant difference was found between sham and real exposure to any cellular phone.

In a study performed in the Netherlands (Zwamborn et al., 2003; HCN-EMFC, 2006), a group of EHS (11 men, 25 female, mean age 55.7 ± 12.0 years) and healthy volunteers (22 men, 14 female, mean age 46.6 ± 16.4 years) were exposed to RF-EMF base station signals emitted by GSM 900 MHz, GSM 1,800 MHz and UMTS antennae with effective electric field strengths of 0.7 V/m (GSM) and 1 V/m (UMTS). No effect on well-being was found in either exposure group at either GSM exposure. UMTS-like signals were associated with a small but statistically significant decrease in well-being after 30 min exposure in both exposure groups; however, the control group was more affected. Cognitive functions were significantly changed during GSM and UMTS exposure, however, with inconclusive patterns of cognitive variables with regard to type of signal and exposed group. These significant differences were found for single parameter testing. After correction for multiple parameters testing, only one significant result remained, namely, the difference in performing memory comparing tests during UMTS exposure. Performance was faster in the control group compared with sham exposure. The comparison between EHS and controls suffered from critically different composition of the two groups.

In a double-blind replication study performed in Switzerland (Regel et al. 2006), 33 persons (14 men, 19 female) with self-reported sensitivity to RF-EMF and a control group of 84 subjects (41 men and 43 female) were exposed to sham and UMTS-like base station signals (1 V/m and 10 V/m). Each exposure lasted for 45 min. In that time two series of cognitive tasks had to be performed starting at the beginning and after 20 min, respectively. Sessions were preceded by one training session and were performed three times at 1 week intervals. All subjects were between 20 and 79-years old (37.7 ± 10.9 years). The results did not show any difference between EHS and controls and no impact on wellbeing or ability to perceive exposure. Cognitive performance was not significantly changed at any field strength after correction for multiple testing.

In the United Kingdom (Eltiti et al., 2007), 44 self-reported sensitive and 114 controls were studied during open (informed) and double-blind provocation with combined 10 mW/cm² base station like GSM signals (5 mW/cm² 900 MHz + 5 mW/cm² 1,800 MHz) and with UMTS signals in comparison to sham. Subjective well-being was assessed by visual analogue scales and symptom scales. In addition, physiological parameters were measured such as pulse, heart rate, and skin conductance. Subjects performed mental arithmetics, digit symbol substitution, and digit span tasks. Exposure lasted for 15 min or 20 min for assessing well-being, 8 min for cognitive tests, and 5 min for on/off perception with 2 min washout intervals in between. During the open provocation, EHS individuals reported lower well-being during both GSM and UMTS signals, and controls developed more symptoms during open UMTS exposure compared with sham. However, double-blind exposure to GSM or UMTS signals did not cause effects in either group. No significant differences were found between EHS and controls.

In Finland (Hietanen et al., 2002), in a double-blind study the ability to detect whether mobile phones were on or off was investigated in 20 volunteers with self-declared sensitivity to mobile phone RF-EMF (7 men, mean age 47.1 years and 13 women, mean age 50.6). Apart from sham, they were exposed to an analogue NMT phone (output power 1 W), a 900 MHz pulsed GSM phone (average output power 250 mW) and a 1,800 MHz pulsed GSM phone (average power 125 mW). Tests lasted for 30 min followed by 1 h break. Blood pressure, heart rate, and breathing were monitored. Three or four tests were performed in random order. Various symptoms were reported, most of them related to the head. Women developed more symptoms than men. No significant difference could be found between sham and exposure; none of the subjects were able to distinguish between sham and real exposure. Overall, no association between exposure to mobile phone radiation and symptoms could be found.

In United Kingdom (Rubin et al., 2006a, b), 60 subjects were investigated who reported getting headache within 20 min mobile phone use (starting with 31 men and 40 female, mean age 37.1 ± 13.2 years) and 60 controls without symptoms (27 men, 33 female, mean age 33.5 ± 10.2 years). Volunteers were exposed to EMF fields emitted from a test mobile phone handset mounted slightly above and behind the left ear. Test conditions were 50 min exposure to 900 MHz GSM and 900 MHz cw signals, causing a local SAR of 1.4 W/kg. For sham exposure a similarly heated dummy handset was used. The main target of investigation was headache. Additional symptoms such as burning sensations, skin sensations, eye pain difficulty concentrating, and dizziness were noted. Volunteers were also asked to guess whether fields were on or off. The study showed that EHS cases developed partly severe symptoms, which for five individuals were the reason to withdraw prematurely. However, since severe symptoms were also developed during sham exposure, no significant difference was found between different exposure conditions. Controls developed almost no symptoms with the exception of some feeling of warmth. No evidence was found indicating that EHS could detect mobile phone signals or that they react to them with increased symptom severity. As sham exposure was sufficient to trigger severe symptoms, psychological factors, in particular nocebo, may play an important role.

In Sweden, 20 subjects experiencing symptoms when using mobile phones were compared with 20 healthy controls (Wilén et al., 2006). Each subject participated in two 30 min tests with sham and true exposure of the head to 900 MHz GSM, $SAR_{1g} = 1$ W/kg, emitted by an indoor base station antenna. No significant differences were found in heart rate, respiration, local blood flow, electrodermal activity, flicker fusion frequency, and short-term memory, except a significant prolongation of reaction time (at the first trial only, it disappeared when the test was repeated) and a shift in heart rate variability toward sympathetic dominance in the autonomous nervous system during flicker frequency and memory tests; however, these appeared in either condition.

In Norway, 42 individuals reporting developing headache when using mobile phones responded to a media call (Oftedal et al., 2007). On the basis of the outcome of an open provocation test 38 subjects were eligible, and finally 17 (5 women and 12 men) mean age 39 years (span 20–58) were included in the study. For exposure wall-mounted base station antennae emitting 900 MHz GSM signals exposed subjects to local $SAR_{10g} = 0.8$ W/kg. One session included one pair of exposures (30 min sham/true). Up to 4 sessions were planned with 2 days in between. In addition to reporting symptoms, heart rate and systolic and diastolic blood pressure were monitored. Fifty-six pairs of trials were conducted. Changes of physiological parameters occurred but did not depend on exposure condition. The degree of reported symptoms was low. If reported, the time course of symptoms was the same for headache and other symptoms and was the same for real and sham exposure. The study gave no evidence that RF-EMF from mobile phones could cause pain or discomfort or influence the measured physiological parameters.

In a Swedish double-blind crossover study, 38 EHS associating headache and vertigo with mobile phone use and 33 healthy controls were randomly exposed for 3 h to GSM handset exposure or sham (Hillert et al., 2008). Encountered symptoms were scored before and after 90 min and 165 min exposure on a 7-point Lickert scale. Neither group could detect RF exposure better than by chance. EHS did not experience more or more severe symptoms. Headache was reported even more frequently by the control group.

To test whether healthy subjects could detect mobile telecommunication RF-EMF, 84 volunteers (57 women, mean age 23.5 ± 5.4 years and 27 men, mean age 26.1 ± 6.1 years) were recruited in Turku, Finland, through advertisements announcing €50 award for good performance (Kwon et al., 2008). A 900 MHz GSM mobile phone handset was mounted in cheek position at the preferred side (17 left, 67 right) causing local SAR_{10g} of 0.86 W/kg. Scores were requested after 5 s, and the following trial was started 1 s after the answer. Tests were made in 6 sessions with 100 trials each. There was a response bias toward "handset off". Two participants in one session exhibited a high correct score of 97% and 94%, respectively. However, they could not replicate their results and, overall, did not perform better than average. Overall, none of the volunteers were able to win the prize. In spite of the many trials and volunteers, the conclusions from this study are limited because of the extremely short exposure duration and washout period.

Figure 6 shows results of provocation tests demonstrating that EHS did not exhibit increased probability to detect and/or perceive electromagnetic field exposure compared with normal volunteers.

7.3. Neurophysiological Studies

So far, attempts to identify EHS by a characteristic symptom cluster failed (Bergqvist et al., 1997). Reported symptoms comprise a variety of nonspecific health problems

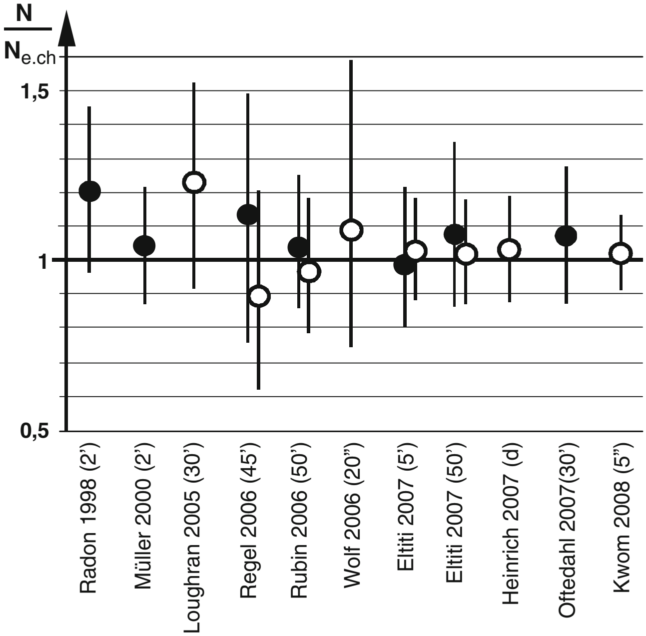

Figure 6. Number of correctly detected field exposures N divided by correct answers expected by chance $N_{e.ch}$ of nonsensitive (*open circles*) and EHS volunteers (*full circles*), exposure duration in parentheses (modified from Röösli, 2008).

similar to those known to be associated also with other environmental factors. For this reason, WHO (2005) concluded EHS resembles multiple chemical sensitivities, another disorder associated with low-level environmental exposure to chemicals. The collection of disorders such as dermatological neurasthenic and vegetative symptoms is not part of any recognized symptom. It is shared by other nonspecific medically unexplained symptoms (MUS) associated with external influences summarized as idiopathic environmental incompatibility (IEI).

Quantitative investigations of 94 patients (53 women, 41 men, mean 38 years, span 21–79 years) with health symptoms attributed to dental amalgam or indoor toxins could not substantiate personal convictions, while psychiatric disorders were found in 66% (ICD-10). Somatisation score of 0.9 was considerably higher than the 0.36 found in controls (Kraus et al., 1995).

Lyskov et al. (2001a, b) investigated 20 patients (11 female, 9 male, mean age 47 ± 5 years) with EMF exposure-associated neurasthenic symptoms such as general fatigue, weakness, dizziness, headache, and facial skin (itching, tingling, redness). Their results were compared with those of 20 healthy controls (12 female, 8 male, mean age 44 ± 7 years). Neurophysiological parameters were measured such as blood pressure, heart rate, sympathetic skin response, respiration, flicker fusion frequency, EEG, and visual evoked potentials (VEP). Single-parameter statistical analysis exhibited significant differences of flicker fusion frequency ($p=0.005$), heart rate ($p=0.044$), heart rate variability ($p=0.04$), and sympathetic skin responses such as inset latencies ($p=0.003$), peak latency ($p=0.033$), and amplitude ($p=0.01$). However, no correction for multiple testing was made. If multiple testing of 22 parameters was considered, this would lead to a Bonferroni-corrected p-value of 0.0023 (=0.05/22) with no more significant results remaining. The authors' concluded results indicate that the investigated EHS group exhibited a shift of baseline characteristics of the central and autonomous nervous system indicating a tendency toward hyper-sympathotone hyper-responsiveness to sensory stimulation and probably heightened arousal.

Medical metaanalyses confirmed that medically unexplained functional somatic symptoms are related to but not fully dependent on depression and anxiety (Henningsen et al., 2003). Sometimes medically unexplained symptoms might be associated with objective cognitive abnormalities caused by complex interaction between biological and psychological factors rather than by traditionally defined neurological diseases (Binder and Campbell, 2004).

To clarify whether dysfunctional cortical regulations could play a role in electromagnetic hypersensitivity, cortical excitability was studied in Germany by transcranial magnetostimulation (Landgrebe et al., 2007). Twenty-three individuals with self-reported EMH and two control groups (49 subjects) with low and high levels of unspecific health complaints were investigated. Compared with both control groups, EHS cases showed reduced intracortical facilitation. No differences were seen at motor thresholds and intracortical inhibition. In an extended study (Landgrebe et al., 2008) involving 89 EHS and 107 matched controls, thresholds of perceiving single transcranial magnetic stimulation pulses applied at the dorsolateral prefrontal cortex did not differ. However, discrimination ability was significantly reduced in EHS: 60% of EHS reported sensations during sham compared with 40% of controls. The authors conclude that these results demonstrated cognitive and neurobiological alterations supporting the hypothesis that altered CNS function may account for perceived symptoms in EHS and a higher genuine individual vulnerability.

8. TREATMENT

Although convincing evidence of a causal role of EMF is missing, the fact remains that there are people suffering and exhibiting symptoms. Experience shows that EHS is not suddenly appearing but evolves with time starting with temporary symptoms of unclear origin, seeking causal factors, associating them with EMF, finding reassurance in media, internet, and friend's opinions, and possibly ending with severe symptoms and deep conviction of a causal role of EMF (Hillert, 1998). Case reports demonstrate that afflictions can even be severe enough to make them change their lifestyle, quit their work, and leave urban areas to find relief in housing free from electricity. There is agreement that EHS deserve help.

A systematic review of medical treatments reported that options were limited (Rubin et al., 2006b). The investigation suggested that cognitive behavioral therapy might be effective (Hillert, 2004). Interventions to measure EMFs and taking actions to reduce exposure are assessed controversially. The advantage of responding to the concerns of the patient must be balanced against possible risks of downplaying other potentially relevant factors and inducing fear in yet unaffected persons (Hillert, 1998).

WHO (2005) recommends that rather than focusing on people's perceived need for reducing EMF, treatment of EHS should focus on health symptoms and the clinical picture including

A medical evaluation to identify and treat any specific conditions potentially responsible for the symptoms

A psychological evaluation to identify alternative psychiatric/psychological conditions potentially responsible for the symptoms

An assessment of the site where patients develop their symptoms (workplace and/or home)

Reduction of stress, as appropriate

9. DISCUSSION

Overall, convincing experimental evidence for EHS reactions to environmental EMF exposures is still missing, in the ELF range as well as in the RF range. The EHS hypothesis is challenged by the following arguments:

There is no plausible explanation for the development of similar health symptoms due to exposure to ELF and/or RF EMF. In view of the different underlying physical laws and biological interaction mechanisms of ELF and RF electromagnetic fields, it cannot be explained why EHS should be an overarching phenomenon relevant for the entire frequency range of nonionising technical fields.

Quantitative measurements of sensitivities did not convincingly support the hypothesis that hypersensitive reactions could occur at environmental field levels several orders of magnitude below thresholds for relevant biological responses. Measured differences in sensitivities were not large enough to exceed the reduction margin introduced in exposure limit derivation.

Individuals suffering from EHS did not exhibit perception thresholds of electric and magnetic stimuli below the overall span exhibited by the general population.

Provocation studies demonstrated that subjects with self-attributed EHS were not able to detect exposures better than chance, either in the ELF or in the RF range. When symptoms were developed they were correlated with belief in exposure rather than with real situations. Overall, EHS exhibited a higher false alarm rate than controls. This explains the slightly but insignificantly higher rating of the field-on situation.

Epidemiological studies on childhood leukaemia and environmental magnetic field levels indicated that, if at all, children were more sensitive to EMF. However, EHS remains a phenomenon of adults rather than children.

However, the inhomogeneity of investigated groups prevents a final conclusion whether or not hypersensitivity to electromagnetic fields exists:

Most studies selected volunteers on the weak basis of self-reported sensibility without implementing quantitative or even semi-quantitative identification criteria. Therefore, a negative outcome of provocation studies could still be challenged by assuming inappropriate composition of investigated groups. This applies in particular to volunteers recruited from responders to open calls especially in cases where financial compensation was offered.

Exposure regimes were and still are based on weak grounds. No reliable data exist on response latency. Individual reports vary widely. Therefore, durations of exposures were chosen arbitrarily. In fact, they varied from seconds to hours and days. It is unclear which minimum exposure time would be necessary to develop EMF-related reactions or symptoms.

Likewise it is unclear what minimum recovery time is needed to assure independent results in sequential testing. Therefore, washout intervals between tests were chosen arbitrarily and differed considerably, from seconds to hours. Therefore, crossover artifacts and erroneous scores cannot be excluded from many studies.

It is not even clear whether EHS, if it exists, is a phenomenon of exposure to single subject-specific resonance frequencies, to frequency ranges such as ELF or RF, or specific signal signatures. Therefore, it cannot be finally determined whether or not the chosen exposure conditions were adequate.

Therefore, WHO (2005) concluded that, "EHS is characterized by a variety of nonspecific symptoms that differ from individual to individual. The symptoms are certainly real and can vary widely in their severity. Whatever its cause, EHS can be a disabling problem for the affected individual. EHS has no clear diagnostic criteria and there is no scientific basis to link EHS symptoms to EMF exposure. Further, EHS is not a medical diagnosis, nor is it clear that it represents a single medical problem."

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