

**International Workshop**  
**on**  
**Electromagnetic Fields**  
**and**  
**Non-Specific Health Symptoms**

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**Proceedings**

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Austrian Federal Chancellery  
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**INTERNATIONAL WORKSHOP ON ELECTROMAGNETIC FIELDS AND NON-SPECIFIC HEALTH  
SYMPTOMS  
Graz, Austria, September 19 - 20, 1998**

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International Commission on Non-Ionizing Radiation Protection

## **Workshop topics**

Our society is facing an unprecedented increase in the number and diversity of sources of electric and magnetic fields. Such sources include power lines, computers, radios, television, mobile phones, microwave ovens, and radar. However, this development shows two faces:

On the one hand, it has made our life richer, safer and easier. On the other hand, it was and still is accompanied by concerns about possible health risks due to electromagnetic fields.

Among the reported cases of various suspected environmental illnesses there are people claiming that the reason for their adverse health symptoms is the exposure to electric, magnetic or electromagnetic fields (EMF) from nearby electric appliances.

Since many years, research has been trying to investigate the possible role of EMF exposure in non-specific health symptoms using different approaches like case studies, laboratory experiments and epidemiological studies.

This workshop gives a survey of the existing knowledge in this field by comprehensive overviews by leading internationally recognized experts.

Besides this, a state of the art document on the role of electromagnetic fields in non-specific health symptoms with recommendations for further activities was worked out during the workshop.

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### **The workshop is organized by**

**COST 244bis** (European Cooperation in the Field of Science and Technical Research, Project 244bis: „Biomedical Effects of Electromagnetic Fields“): This European research framework provides a unique form of cross-border research cooperation and allows to coordinate research activities, to establish a cooperative network of scientists and institutions and to advance science by complementary use of equipment, instruments, laboratory resources, and human potential. The project is chaired by Dr. A. Wennberg, Sweden, and organized in 3 working groups: Epidemiology and Human Health Effects (chairman: Dr. U. Bergqvist, Sweden), Basic Research (chairman: Dr. N. Leitgeb, Austria), Engineering and Measurements (chairman: Dr. G. D'Inzeo, Italy). In addition, 3 experts are responsible for frequency-specific interdisciplinary coordination of activities: Dr. P. Vecchia, Italy, for extremely low frequencies, Dr. L. Miro, France, for the intermediate frequency range and Dr. T. Kenny, Great Britain, for radio frequencies.

**Austrian Federal Chancellery**, section VI: Health Care, headed by Minister Mag. B. Prammer. She is responsible for women affairs, consumer protection, foodstuffs, veterinary affairs, genetic engineering and radiation protection. In the field of non-ionizing radiation protection Minister Prammer intends to introduce a comprehensive legislation in Austria taking into account the recommendations of the World Health Organization.

**Department of Clinical Engineering**, Institute of Biomedical Engineering, Graz University of Technology, head: Dr. N. Leitgeb

### **in cooperation with**

**WHO** (World Health Organization), International EMF Project: This international project is devised to bring together key international and national agencies and scientific institutions to identify and fill gaps in the scientific knowledge on health risks of exposure to electromagnetic fields. It is chaired by Dr. M. Repacholi, Switzerland. Support for this part of the EMF project was provided by Verum Foundation for Behaviour and Environment (Munich, Germany)

**ICNIRP** (International Commission on Non-Ionizing Radiation Protection): This is an independent scientific organization to provide guidance and advice on health hazards of exposure to non-ionizing radiation. It is chaired by Dr. J. Bernhardt, Germany.

### **Scientific Committee**

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## **Environmental Incompatibility Syndrom**

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The environmental incompatibility syndrom will be dealt with from a public health point of view, not from a clinical point of view.

Many public health aspects are to be considered: epidemiological findings, social marketing, risk perception and risk communication and public health balance, just to mention a few.

The environmental incompatibility syndrom is not only observed in relation to electromagnetic fields, but becoming increasingly prevalent as an issue becomes aware to the public. This is especially the case when it comes to mobile communication and electric powerlines. Own experience is based on handling problem situations in relation to the two issues mentioned.

Environmental incompatibility syndrom is also related to political debates because public discussion is very easily used for creating problem awareness and subsequent decision making attempts.

When it comes to epidemiology one has to discuss the possibilities of scientific research in that area, also taking into account the limits of investigations into environmental incompatibility syndrom by using epidemiological techniques.

In Austria we have established a new epidemiological service, which focuses on self-reported morbidity in order to find out what health problems might be prevalent in a given population. Information about background morbidity are helpful in assessing environmental and other risks, which are perceived by the population in a very different manner. The influence of medical coverage of new environmental risks influence the attitudes and information levels of people very much.

The SERMO-study (SERMO stands for self-reported morbidity, also for sermo, sermonis in latin) is based on many thousands of face-to-face interviews, done on regular intervalls on representative of the Austrian population.

It provides a clear picture of health problems in the population. Clinical observations might lead to a different epidemiological situation, but self-reported morbidity studies are as important as classic epidemiological investigations based on conventional scientific investigation procedures.

The information society needs and looks for issues. The so called "issue-management" becomes an important part of public health. There are many mechanisms, which complicate the handling of environmental incompatibility syndrom. Some of them will be addressed in this paper.

One example: if legal aspects and discussions about regulatory measures are expanded too much, one creates a problem awareness, which then leads to risk perception different to the scientifically evaluated risks of an environmental problem. If the technical details and scientific measurements are discussed too broadly, and brought repeatedly into discussion this may also lead to stress related mechanisms which may contribute to environmental incompatibility syndroms.

As far as electromagnetic fields are concerned, currently there is a lack of consistent epidemiological evidence concerning presence or absence of adverse effects. Similarly, there is not replicated evidence from laboratory studies to expect any long-term adverse health effects at typical radiofrequency exposure levels occurring in the occupational or residential environment.

These conclusions of the 1998 ICOA Waipuna II meeting, Auckland, New Zealand are a very good example, why even very balanced statements are not too helpful, when it comes to the management of environmental incompatibility syndrom. They leave much room for further discussion and create a feeling of uncertainty among people who are prone to risk perception in a very definite way. From a risk communication point of view, we need clear statements like the following one: "At the given point of time there is no evidence of health risks; this does not mean the further research may at some stage lead to a revised statement."

To cope with problems like the environmental incompatibility syndrom on a public health scale (not necessarily on an individual scale) it might be helpful among other strategies to consider the following ones: Regular reports on safety issued by generally accepted researchers and research organizations; research activities which not only involve continuous review of scientific literature, but also take into account how and what people feel about the given environmental issue. If one offers counselling services to people a preventive measure could be put in place.

Understanding and applying the knowledge about stress might be very helpful. One has to differentiate between the stress reaction itself, which is an "old" physiological reaction to main kind and stressors (the numerous possible causes to stress reactions).

We came to the following conclusion, when dealing with related problems in Austria, like the following ones. Scientific research does not indicate that human health is in danger by electromagnetic fields, when the current protection measures are in place. But: From a psychological point of view one has to acknowledge: It is not only the scientific evidence which has to be taken into account, but also the issue of risk perception. Prolonged stress caused by stressors on the basis of risk perception may consequently lead not



only to disturbances in well being, but also to real health problems. The physiological evidence of this mechanism is established and should be taken into account.

Emotions cannot be handled by offering rational information alone. And it is one of the great issues of modern public health dealing with many new phenomena present in our society, which can contribute to an increasing incidence of environmental incompatibility syndrom.

Some of those phenomena are the following: Politics needs issues and so does information society, modern technology is an easy catch, because it is a perfect natural reaction of people to be scared by too many new developments, especially when they are related to invisible risks. Electromagnetic fields are a typical example for that.

Health is in issue of interest to everybody, and the electromagnetic field issue is very similar to problems like vaccinations or gen-diagnosis or bioengineering.

The providers of modern technology usually "wait". They do not act in a preventive way, and usually are surprised by criticism. The next reaction very often is focussing on scientific issues and scientific measurements and forgetting about the emotional aspects.

But it is always a more or less similar sequence of events, which are to be observed when it comes to new developments, which are perceived as risk. And usually the same questions are then asked by the public.

The most often heard one is: "Can you guarantee, that there will be no risk?" We always have to consider what we answer to questions like that. Then the reply very often is based on scientific findings and becomes very complicated for the public. The next question or statement put forward might be: "It started with nuclear energy the same way" and then the providers of modern technology are in real trouble.

Instead we should communicate (on a more or less general basis) what risks people experience in modern society, and that we try to manage risks not only by personal behaviour, but also by selective perception. That means, we overestimate very often risks, which are minor by standards of science and underestimates risks which are dramatic from an epidemiological point of view. The risks of tobacco consumption or automobil driving are the best examples.

We have to learn much more about the psychological mechanism of risk perception, risk communication and the mechanism of modern information society.

We performed a review of 350 publications on psychological aspects of electromagnetic fields and did not find evidence that there is direct influence of electromagnetic fields on human psychology.

But one piece of scientific or semi-scientific information may change the attitude of people in a short period of time.

When it comes to the environmental incompatibility syndrom on a individual level, the clinical approach might even complicate the picture, as it has to exclude "real diseases". The consequence is a wide variety of diagnostic procedures, the patients are exposed to. Learning mechanism are a logic consequence, which then lead to an aggravation of symptoms, at least some times.

There is no easy solution and no easy way to handle the environmental incompatibility syndrom on a public health level (nor on the individual level). But some of the remarks outlined in this paper might help to come to a different attitude towards the management of this new phenomenon.

# Electromagnetic Hypersensitivity

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## 1 Introduction

In many countries there is an increasing number of people claiming their adverse symptoms could be caused by external, in particular environmental factors like the building as such, gas emission of the furniture etc.. This has been coined environmental incompatibility syndrom (EIS) /10,13/.

Among these factors exposure to electromagnetic fields (EMFs) from nearby electric appliances has attracted increasing attention as a possible cause for non-specific health symptoms. Afflicted persons explain the fact that under similar conditions the majority of people does not experience any influence by the hypothesis, that they have a significantly increased sensitivity to electromagnetic fields and call themselves „electromagnetic hypersensitive“, „hypersensitive to electricity“ or „electrosensitive“.

In some countries „electromagnetic hypersensitivity“ has already become a social issue and led to the formation of self aid groups of afflicted persons.

According to its ethiology, in general the term „electromagnetic hypersensitivity“ is used for people that claim to have already problems due to nearby electric appliances. It is still weakly defined and used to coin a medical syndrom. The use of the term cannot be considered to imply an already established causal relationship between EMFs and adverse health reactions. The weak description might be sufficient for a phenomenological approach to handle people that do have problems in daily life or at their workplace but does not meet scientific needs.

To properly differentiate between the scientific aspect and the medical needs in this paper electromagnetic hypersensitivity is understood as ***ability of people to react to EMFs at significant lower levels than normal.***

This definition includes four aspects:

- a) there is a need to investigate what is „normal“, that means characteristic for the general population;

- b) it is based on a causal role of electromagnetic fields and does not have the meaning of a medical syndrom to address a certain group of patients with symptoms of unclear origin;
- c) it does not necessarily imply that electromagnetic hypersensitive people do have problems in their daily life although this ability might turn out to be an additional risk factor to develop symptoms.
- d) it might help in the review of existing exposure standards and to account for the increased sensitivity of EHS people

It has to be acknowledged that there are people that do have problems of unknown origin and that these people do need help. In some cases the symptoms can become so severe that people quit their workplace and even change their entire life in avoiding EMF exposure.

However, to be able to give them efficient support, it is important to identify the possible causal factors. This is because low frequency electric and magnetic fields and high frequency electromagnetic waves not only interact in different ways with the human body but also need different actions for exposure reduction.

To differentiate these „cases“ attributed to electromagnetic hypersensitivity from healthy electromagnetic hypersensitive persons (EHS) with the ability to react to EMFs at significant lower levels than normal, they are addressed in this paper as CEHS.

## 2 Prevalence

Depending on the media and their standpoints, there are different estimates on the percentage of electromagnetic hypersensitive people among the general population. Given figures range from some few percent to more than 30 %.

An international project, supported by DG V of the European Union, based on an inquiry among national centers of occupational medicine (COM) and self aid groups (SAG) showed, that there are important national differences in respect to CEHS in various European countries /7/. Since, on the one hand, the data are based on individual judgements of the person within a COM or SAG that filled out the questionnaire, and on the other hand, the knowledge of the existing COMs or SAGs was incomplete and the reply rate limited, the results are qualitative rather than quantitative. However, there was a remarkable systematic difference of nearly one magnitude between the case estimates from SAGs compared with COMs.

The results show two important facts:

- a) There is a significant north-south gradient in respect to CEHS awareness: In the Nordic countries (Sweden, Norway, Denmark and Finland) and Germany centers of occupational medicine have to deal with persons claiming to be electromagnetic hypersensitive and several self aid groups are already established; the reported

cases range between 100 and 10,000 per country. In contrary, in southern European countries this phenomenon is rarely known. There were no answers received from Greece, Portugal and Spain and also from smaller countries like Belgium, Luxembourg, Iceland and Faroe Island which might suggest that in these countries there is limited occurrence or at least awareness of CEHS.

b) There is a significant difference concerning the electrical appliances attributed to non-specific health symptoms: While in nordic countries in-house electrical devices, in particular video display units are dominant, in more southern regions like Germany and Austria symptoms are primarily attributed to external sources like power lines and basestations for mobile personal communication.

These differences indicate, that besides EMFs as such, additional local factors are important for CEHS, one among them is the individual attitude and risk perception and the mass media attention given to the EMF issue.

To identify individuals as EHS or CEHS due to his/her own appraisal is the most straitforward approach to identify the target group. However, it has a serious methodological drawback: Since in general persons do not get aware of exposures to different field levels of EMFs in daily life, their self-definition is derived from other clues like general sensitivity to become ill or existing allergies and might be only weakly associated with EMFs as causal factors. Therefore, relying on self identification may indicate the perception of the issue within the general population rather than be interpreted as verification of the EHS hypothesis.

In another study the potential of EHS people was assessed at a statistical cross section of the general population, sample size 200 people, randomly chosen among the rural and urban customers of a power utility /14,16,17/. Self classification of the individual's sensitivity according to a 5-graded scale, ranging from 1 (very unsensitive to EMFs) to 5 (very sensitive to EMFs) resulted in 10% people classifying themselves to be very sensitive to EMFs. The other scale groups 1 to 4 showed gender dependent differences (Table 1).

<b>sensitivity</b>	<b>very unsensible %</b>	<b>unsensible %</b>	<b>normal %</b>	<b>sensible %</b>	<b>very sensible %</b>
<b>women</b>	16,4	34,4	19,4	19,4	<b>10,5</b>
<b>men</b>	20,5	32,9	28,8	8,2	<b>9,6</b>

*Table 1: Self classification of individual's sensitivity to electric and magnetic fields of a statistical cross section of the general population (69 women, 71 men) /14/.*

In parallel, to assess the potential of EHS without the bias of individual attitudes as quantitative parameter of the individual's sensitivity to electromagnetic fields the perception threshold of directly applied electric 50 Hz-currents was measured. The analysis of the double-blind measurements at the lower forearm of 297 men and 309 women indicated the presence of a second normally distributed subgroup of 2% people

with significantly increased sensitivity in addition to the normally distributed perception thresholds of the general population (fig.1).

On the one hand, this result cannot be interpreted neither as proof of the existence of EHS nor as evidence of a possible causal role of EMFs in the development of symptoms at CEHS. However, on the other hand, it does more support than falsify the hypothesis of the existence of electromagnetic hypersensitivity in the sense of increased perception ability.

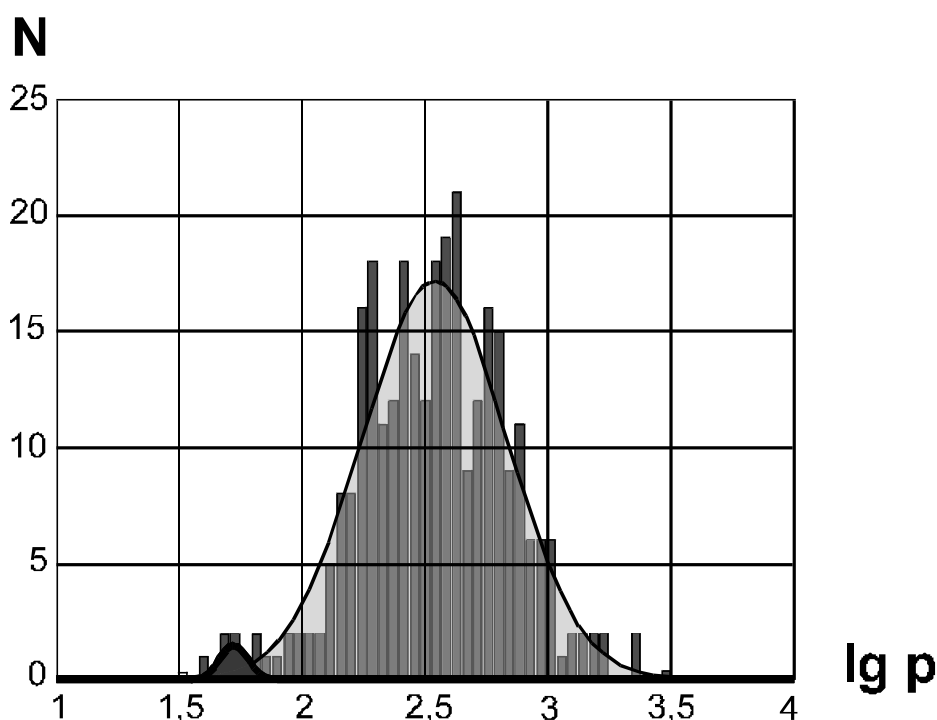


Fig. 1: Frequency distribution of 50 Hz- electric current perception thresholds of a statistical cross-section of the general population (297 men) modeled by two log-normal distributions (N...number of individuals, p...perception threshold,  $\mu A$ ).

It has to be noted that among the sample none of the persons reported direct perception of fields or adverse effects in daily life. Therefore, the percentage of people with problems with their electromagnetic hypersensitivity (CEHS), if it exists, should be significantly lower than 2% [2].

### 3 Evidence for EHS

#### 3.1 Provocation studies

Experimental evidence for a causal role of EMFs in CEHS are facing the problem to identify the target group for study. There are three approaches reported:

- a) persons with symptoms attributing them to electric appliances (CEHS), e.g. afflicted persons approaching centers for occupational health or members of self aid groups;

There are several blinded provocational studies reported in the literature, mostly performed in Sweden and Norway /9,21,22,23,24/. The results show that CEHS were not able to detect applied fields better than random, neither electric nor magnetic. They were not able either in a simulated workplace situation to detect wheter a device, in particular a VDU was switched on or off. Moreover, blood hormone levels did not show correlation with 30 min exposures to a VDU. In the test situation persons experienced symptoms, however in relation to their guess whether the device was on or off rather than the true exposure situation /1/. CEHS did not show an increased sensitivity to directly applied electric currents /17/.

b) persons with other sensitivities, e.g. multichemical;

There are few reports on tests with persons with multichemical sensitivities. In a study at 100 subjects 25 individuals reported a change in the number or intensity of symptoms, however at different individually „tuned“ exposure conditions in terms of frequency and amplitude /21/. Another study aimed to reproduce this results with an improved experimental design failed to verify this results /23/.

c) cross sections of the general population or subgroups like healthy students.

In a cross sectional study already mentioned /14,16,17/, directly applied electric 50 Hz- currents were chosen as surrogate for actual field exposure. Among others the reason for doing this was the possibility to make the test in the homes of the subjects and therefore to avoid the psychologic influence of a strange laboratory environment. The justification for choosing the direct electric current perception as parameter for EHS was checked in a further study. Measurements of the 50 Hz- magnetic field perception level of healthy individuals in a similar part body exposure situation showed, that direct perception is possible, though by levels well above the existing limits, and that it correlates with the electric current perception level /17/.

The experimental results can be summarized as follows:

a) in a blinded situation CEHS have not shown to be able to detect electric or magnetic fields similar to those they claim to have problems with neither by direct perception nor by change or development of their usual symptoms. This does not necessarily imply that there does not exist any (C)EHS with high detection ability.

b) CEHS appear to react related to their belief that they are exposed rather than to the real exposure situation.

Since the results depend on the strategy of the recruitment of test persons it may be argued that the test exposure situation may be responsible for this negative result since it significantly differs from the situation in daily life in terms of amplitudes, frequency content, duration, the emotional situation and the environment.

Therefore, in spite of the present data it cannot be excluded, that EMFs may be involved in the development of symptoms, however the results so far do not strengthen the hypothesis of a causal role of EMFs.

c) The restriction of the investigations to CEHS does not allow to conclude whether or not people with increased sensitivity to electromagnetic fields exist. Although there is no convincing evidence, the results so far tend to support rather than falsify this assumption. This does not necessarily imply that EHS subjects do already have or will in future have problems with EMFs in daily life. However, if EHS can be proven people with this ability may warrant further investigations to confirm or reconsider the existing exposure standards.



### 3.2 Identification of CEHS

There are several attempts to identify CEHS by characteristic properties or symptom clusters. Overall, it was not possible to find neither an available medically evaluated diagnostic test or criteria nor a symptom cluster attributable to CEHS /11/. In contrary, the group of CEHS turned out to be rather inhomogenous not only in terms of their education, social and economic status but also in respect to the reported symptoms. The latter differed considerably among different European nations /7/: In Nordic countries skin symptoms are reported fairly often but played a minor role in other countries. Neurasthenia followed by headache were the most common symptoms among the nervous system symptoms, but no obvious symptom pattern could be identified neither among the different European nations nor in an individual country like Sweden. The reported symptoms are varied and non-specific. They are known to appear in medical diseases as well as results of physiological reactions of healthy people.

Medical experience show that the basis for the syndrom label is the patient's belief in the adverse effect of nearby electric appliances (see also Hillert further in this proceedings).

A statistical analysis of the general population (313 women, 283 men) showed a significant correlation of the self classification of the individual EHS with the measured perception threshold of directly applied electric 50 Hz-currents. This supports the approach to characterize EHS by this parameter.

Apart from some gender dependent differences it could be shown that higher sensitivity was reported by people with worse general behaviour, increased weather sensitivity and health awareness (indicated by less alcohol and cigarette consumption and increased sports activity). Investigations at 47 panic patients which are known to have a significantly increased degree of self observation showed that this aspect does not influence the degree of EHS.

The comparison of the results of 42 CEHS showed the expected higher degree of frequency and intensity of health complaints but no characteristic differences to the general population in other parameters. It is worth to mention that the degree of self classified sensitivity of female CEHS was not correlated with the measured perception threshold. This again does not support the assumption that their symptoms are caused by electromagnetic fields /17/.

## 4 Conclusion

The term electromagnetic hypersensitivity deserves clarification: It is necessary to differentiate between its use

- a) to coin a medical syndrom irrespective an established causal realtionship to characterize individuals who attribute their adverse health symptoms to nearby electrical appliances (CEHS);
- b) to address the ability of persons to react to EMFs at significantly lower levels than normal (EHS) without necessarily developing health symptoms in a daily life exposure situation.

It has to be acknowledged that there are people with even severe health symtoms of unknown origin that deserve help.

Existing studies tend to support rather than falsify the existence of EHS.

So far there is no convincing scientific evidence neither to conclude that exposure to EMFs plays a causal role in causing symptoms in persons claiming to be electromagnetic hypersensitive (CEHS), nor for the contrary.

There are only little data on the possible role of radio frequency EMFs.

Experience shows, that CEHS develop symptoms on the basis of their belief rather than the true exposure situation.

The possible role of EMFs as causal factor or possible cofactor at CEHS and the question whether EHS deserves consideration in the discussion of exposure limits warrant further research.

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## **Hypersensitivity to Electricity: Management and Intervention Programs**

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### ***Background***

Many people report hypersensitivity to electricity. Patients coined this syndrome label. There is no available medically evaluated diagnostic test, and we also lack diagnostic criteria or consistent objective markers to support the use of the syndrome label.

The presented symptoms are varied and non-specific. Similar symptoms can occur both in known medical diseases and as physiological reactions in healthy human beings. So in all the cases, the basis for the syndrome label is the patients' belief in the cause of their suffering. In their experience, symptoms are triggered or aggravated in proximity to electrical appliances and other sources of electromagnetic fields (EMFs). Although a specific cause is unknown, the suffering of these patients is real and motivates actions aimed at prevention, early interventions, and treatment. It is important that we use our present knowledge and avoid focusing solely on yet unanswered questions.

No single treatment or preventive action has been proven superior to other interventions. It is also hard to distinguish positive results of different actions, including thorough investigations and reassuring information, from spontaneous improvement. The rationale for the program presented below is an appraisal of the present knowledge, taken together, from scientific studies and experience from clinical treatment of patients with hypersensitivity to electricity at centers of occupational and environmental medicine as well as occupational health services, primarily in Sweden. Support material that backs up the presented approach are:

- Alternative contributing factors have been indicated in different studies; today, the cause of the syndrome is thought to be multifactorial (1, 2).
- Lack of any established relation between EMFs and hypersensitivity to electricity (1, 2, 3).
  - Indications that a certain situation/appliance, such as a visual display unit (VDU), might act as a conditioned stimuli, for example, symptoms are triggered in open but not in blind provocation (4).
  - Symptoms can appear in the absence of EMF (for example, during sham exposures in provocation studies (5)) and might be manifestations of organic disease, that is, EMF is not a necessary cause for the symptoms.

- EMF (*nota bene* that this conclusion is restricted to the aspects of EMF thus far investigated) does not always provoke symptoms during provocation studies, that is, EMF is not a sufficient cause of the symptoms (4, 5).
- Improvement in health has been shown to occur, although EMFs and/or VDU work were not avoided (6, 7).
- Alternative explanatory factors, both medical and environmental, are found in a substantial number of cases with hypersensitivity to electricity (Table 1.).
- Different treatments and actions have been shown to offer help, which indicates the importance of individualized choices of actions (table 2.).

Contributing factors indicated in studies of skin symptoms among VDU workers (S) or hypersensitivity to electricity (HE) are:

- High work load (S)(8)
- Lack of social support from co-workers (S)(9)
- High temperature and/or low relative humidity indoors (S)(10)
- Electric fields that represent the general environment in the room (S)(8)
- Individual factors, such as gender (more common in women) and age (neurovegetative symptoms are more pronounced in older persons with hypersensitivity to electricity) (HE)(11)

Project leader/author(s)	Investigated group	Proportion of patients where possible alternative medical causes of symptoms were found
Hillert et al (7)	63 patients referred to a centre of occupational medicine	16% somatic diagnosis, 17 % psychological conditions of importance
Harlacher (12)	80 patients referred to a department of dermatology	56% received a diagnose of a skin diseases (in 66% not previously diagnosed)
Ahlborg et al (13)	65 patients referred to a centre of environmental sensitivity at a centre for occupational and environmental medicine	14% somatic diagnosis and 5% psychiatric diagnosis

Table 1. Medical diagnosis in patients referred to specialists because of hypersensitivity to electricity.

There are also indications of physiological differences among persons who suffer from hypersensitivity to electricity and healthy controls. These differences include:

- Levels of stress-sensitive hormones during VDU work (14)
- Heart rate (15) and difference in skin temperature of left and right cheek at rest (16)
- Pupil reactions to light (15)
- EEG registrations and visual evoked potential (VEP) during exposure to modulated (flickering) light (17, 18)

So far, exposure to EMF has not been shown to produce altered reactions in people with hypersensitivity to electricity—as compared to controls. The observed differences in

reactions might be in agreement with the hypothesis that persons with environmental hypersensitivities might have different reactions in the central and the autonomic nervous system, possibly due to a sympathetic predominance. If this is shown to be true, various treatments are possible, both pharmacologically and psychologically oriented.

<b>Project leader/ author(s)</b>	<b>Patients</b>	<b>Therapy/action</b>	<b>Follow- up time</b>	<b>Results</b>
Gustavsson P, Ekenwall L (22)	24	Investigation by an occupational medicine specialist	4-33 months	11/24 improved; 6/24 gone back to VDU-work (reduced VDU- work time seemed to facilitate)
Hillert L (23)	18	Investigation by an occupational medicine specialist	25 months (mean)	10/18 improved, all but one with some avoidance behaviour
Lidén S et al (24)	220	Company-based occupational health service multi- disciplinary intervention program	About two years	60% had no symptoms (in full- time VDU work), 30% improved
Harlacher U (12)	80	Investigation by a dermatologist; extra time given at consultation and special interest given to psycho-social factors	0-26 months	30/80 recovered
Andersson B et al (5)	17; 9 treated and 8 controls	Cognitive behavioural therapy	22 weeks (mean), incl. therapy	Significant reduction of subjective ratings of disability in the treated group
Harlacher U (12)	26; 13 pairs; 13 patients initially in waiting group	Cognitive behavioural therapy	9-12 months, incl. 3-5 months treatment	50% improved or recovered; significant reduction of complaints after therapy as compared to control group
Hillert et al (7)	22; 10 treated & 12 controls	Cognitive behavioural therapy	12 months, incl. 2-5 months treatment	Significant reduction of symptoms in both groups; significant reduction of complaints from HE in the treated group; no significant group differences
Arnetz B et al (25)	20; 13 deep & 7 super- ficial	Acupuncture	6 months after treatment	Significant reduction of symptoms in both groups; no significant group differences
Eliasch C (personal communication)	36	Shiatsu, offered to persons on sick leave because of HE	12-18 months	78% were very satisfied 12 months after treatment, 47% in work

*Table 2. Follow-up results from different handling and treatments in groups with hypersensitivity to electricity (HE). (Adapted from Swedish National Board of Health and Welfare, Message No. 22/97) (26).*

Physical factors might interact with psychological factors and a susceptibility of the individual to develop a certain clinical picture. It is possible that the contributing factors might differ from person to person. *Individual response stereotypy* may account for specific and individual reactions to different stressors, i.e. similar physiological reactions are triggered by different factors at different times (19). The reactions may differ among

individuals; one person might experience mainly skin sensations and another palpitations and dizziness. A multifactorial etiology is not unique to hypersensitivity to electricity. Different factors are known to influence almost all medical disorders. The less we know about the background of a syndrome, the greater the need for a thorough broad investigation.

Actions aimed at reducing EMF exposure are often the prime concern of the patients. There is no controlled study of *EMF clean-ups*. In Sweden, there are two retrospective investigations of the experience of electrosensitive persons after alterations either at work (29 persons) (20) or at home (36 persons) (21). Neither study had a control group. The actions taken showed a great diversity (from single measures, such as replacement of fluorescent lighting to light bulbs, to very extensive actions) and the results are difficult to appraise. Generally, the interviewed reported an experience of reduced symptoms but not full recovery. Neither investigation allowed any evaluation of the effects of separate measurements or change in work ability. But 8 of 14 persons, previously living elsewhere, were able to move back to their homes.

The heterogeneity of the group of persons reporting hypersensitivity to electricity makes it very hard to compare the results of different studies and treatment. Early treatment, for example, has been associated with better prognosis (12, 13). To facilitate comparisons of results, studies should include information on reported symptoms, duration of symptoms, attribution, triggering factors, and behaviour, which includes work ability. An additional problem in evaluating results is that different actions are often taken simultaneously. For example, does electromagnetic clean-ups often involve other changes, including other physical and psychosocial alterations.

### ***Managing hypersensitivity to electricity***

The program presented here is in agreement with:

- Swedish National Board of Health and Welfare (3), *Guidelines*
- Programs at local centers of occupational and environmental medicine in Sweden (26)
- Norwegian Board of Health (27) *Recommendations*
- *Report* from the European group of experts to the European Commission, DG V (2)

Due to different presentations of hypersensitivity of electricity in different countries and varied structures of health-care systems, local modifications of the program are motivated.



### ***Prevention of hypersensitivity to electricity***

Prevention should focus on

- *Information* (readily available to the general public and target groups) on:
  - Electromagnetic fields (EMFs); existence and characteristics of established and suspected health risks, present standards, and recommendations.
  - Present knowledge of hypersensitivity to electricity; possible causes and presentation of the syndrome, and prognosis (good in the majority of cases, especially in early treatment, and no established long-term effects).
- *Elimination or reduction* of risk factors known to cause health problems similar to the ones in hypersensitivity to electricity. Factors of importance might be indoor climate, air pollution, work load, psychosocial factors, ergonomics, vision ergonomics and lighting.

#### Workplace

In Sweden, preventive programs have been launched mainly at places of work because 90% of the cases present themselves through VDU-related skin symptoms at work. Large companies in particular, where the problem was growing quickly at the end of the 1980s and the start of the 1990s, have developed strategies based on a broad approach to the problem. The programs include:

- Optimizing, for example, the previously mentioned factors
- Introducing an openness about the problem and a readiness to respond to the problem

The actions are not primarily aimed at reducing EMF. But ensuring that electrical equipment and EMFs meet present standards and recommendations is often part of the programs. New VDUs must meet requirements for the TCO '92 and the TCO '95 certifications. The requirements and test methods for environmental labeling of display units were set by TCO (the Swedish Confederation of Professional Employees) in cooperation with the Swedish Society for Nature Conservation, the National Board for Industrial and Technical Development in Sweden (NUTEC), and SEMCO.

TCO '92 mainly includes requirements for low electric and magnetic fields and automatic display power down. TCO '95 specifications integrate requirements for computers covering both the ecological and working environments. But note that the recommendations regarding EMFs were based on prudent avoidance and what was technically achievable, and not on established medical effects.

The preventive programs have been very effective and the number of new cases dropped significantly (24, 28). But the general approach makes it impossible to evaluate the effect of separate actions taken. Besides the previously mentioned factors, providing means for taking breaks from VDU work, or alternating VDU work with other tasks, probably has a preventive effect on developing skin symptoms.

#### General environment

So far in Sweden, there are no preventive programs aimed at the general population - regarding hypersensitivity to electricity. In 1996, five Swedish authorities issued guidance for decision-makers regarding low-frequency electrical and magnetic fields: the National

Board of Occupational Safety and Health, the National Board of Housing, Building and Planning, the National Electrical Safety Board, the National Board of Health and Welfare, and the Radiation Protection Institute (29).

The authorities recommend a precautionary principle based primarily on non-discountable cancer risks. The document stated that similar precautionary principles should also be applied to other suspected effects on health. But at the same time, the document stated that, due to insufficient knowledge, the authorities currently refrain from issuing any joint, general recommendations regarding electrical hypersensitivity.

The precautionary principle states that

“if measures generally reducing exposure can be taken at reasonable expense and with reasonable consequences in all other respects, an effort should be made to reduce fields radically deviating from what could be deemed normal in the environment concerned. Where new electrical installations and buildings are concerned, efforts should be made already at the planning stage to design and position them in such a way that exposure is limited.”

The recommendation of a precautionary principle by the Swedish national authorities has been viewed as a good example of how to handle a situation of public concern but without sufficient scientific knowledge for exposure limits. However, there has been criticism pointing out that the precautionary principle, by its own existence, can induce fear of a risk where no risk is yet proven.

More readily available information material for the public and different target groups is warranted to balance alarm articles in the media. It is of utmost importance that professionals and authorities send the same message. It would probably also be of interest to improve the knowledge of the population at large of psychobiophysiological interplay and models. A situation of crisis, for example, when struck by ill health, is not the optimal time to introduce radically new concepts of possible mechanisms in illness.

Environmental factors of importance might, for example, be air pollution from different sources and noise.

#### Early intervention

Early handling of symptoms attributed to VDU work or hypersensitivity to electricity is important to prevent aggravation of symptoms and increasing functional handicap. There are indications that early handling leads to a better prognosis (12, 13). The aim of the evaluation is primarily to exclude diseases that require specific medical therapy and environmental factors of importance other than EMFs and not to establish hypersensitivity to electricity. Correct and balanced information is an important cornerstone in early handling.

Actions taken should include:

- A thorough *medical investigation* based on symptoms and signs
  - Patient evaluation including
  - A comprehensive history of the problem

- A review of past medical records (diagnosis, laboratory evaluation and clinical investigations, treatments)
- A physical examination with specific attention given to the affected organ systems.

The investigation should be individualized, based on symptom and signs, but standard baseline tests might be helpful. Extensive testing, if not medically motivated, should be avoided. Hypersensitivity to electricity has not been associated with abnormal test results, and the medical investigation is typically unremarkable if no other illness is present.

Referrals to specialists should be liberal when based on medical concern. But it is important that the patient establishes one main medical contact that, in case of continuing illness, can follow the patient—providing support and a possibility to reconsider if and when new investigations are called for. In a lot of cases, somatic diseases are diagnosed, for example, thyroid dysfunction, anemia, diabetes, inflammatory diseases, migraine and in rare cases, cancer.

- *Information on different possible etiologies of present symptoms and ill health, EMF, and hypersensitivity to electricity.*

See the “Prevention” section. Special attention should be given to the overall good prognosis, especially in early handling, and assurance of no established long-term effects. The discussion should include information on possible interplay between psychological and somatic reactions and symptoms.

- *Investigation of environmental factors* at work or at other specific locations where symptoms are triggered or aggravated.  
Investigation by an industrial hygienist of environmental factors known to cause or influence the symptoms presented by the patient, for example, those listed under prevention. With concern to EMF, see the following discussion.
- *Investigation of psychosocial factors* of importance by a psychologist/psychotherapist.  
The initial focus will be on the patient's situation at the time of the initial presentation of symptoms and consequences brought on by the symptoms.
- *Prompt actions* aimed at any identified suboptimal condition, both medical and environmental.  
Stress reduction measurements might be tried. Alternative work tasks may be considered in case of VDU-related symptoms.
- Establishing a *plan of action*, which must be followed up.

The investigations and actions are preferably done in close cooperation with a physician, an industrial hygienist/safety engineer, and a psychologist/psychotherapist. This will ensure broad coverage of all possible aspects in a minimum amount of time. All actions should be taken in close cooperation with the patient.

In most cases, the first medical contact for patients with hypersensitivity to electricity is a general practitioner (GP) or company-based occupational health services. The Swedish national Board of Health and Welfare stated in their guidelines issued in March 1998 ("Handling of patients relating symptoms to amalgam and electricity") (3) that in most cases, treatment should be done by the primary care system. A general practitioner can provide continuous contact, enabling the doctor to follow the clinical presentation of the health problem, and if it is altered, reconsider if new medical investigations are motivated, and offer caring support. It would probably be of additional value to have collaborating teams of GPs and psychologists (or medical social workers). This has been tried in Sweden and has been very helpful in many situations of adverse life events (for example, traumatic experiences like loss of a relative, falling ill with a serious disease or just too many stressful events adding up). In these cases, the patients usually do not meet criteria for psychiatric disease, but may profit from caring support or short-term therapy.

If symptoms are work related, early contact with the occupational health service (or if the place of work does not provide that, a centre of occupational medicine) is recommended.

Information on the state of the art concerning electromagnetic fields and hypersensitivity to electricity should be made readily available to doctors, especially general practitioners. Patients often seek information themselves, and it is necessary for the investigating doctor to have a good knowledge of the syndrome to give the patient correct and balanced information.

Medical certificates, for example, for sick leave, should be based on a broad evaluation of the patients illness and disability. Hypersensitivity to electricity is not a diagnosis. In Sweden, we use symptom diagnosis in these cases, but add the information that the patient interprets the symptoms as hypersensitivity to electricity. The latter information is of great importance for treatment and prognosis.

Patients demand to be taken seriously and to be given the time to provide a full account of their suffering. Priority should be given to:

- Allow the patient enough time and/or enable repeated visits
- Ensure follow-up and continuity in medical contact
- Establish a working relation and trust between both parties in difficult situations concerning a syndrome surrounded by uncertainties and controversy
- Apply a non-judgmental and supportive approach, but inform the patient of your professional opinion about the problem
- Avoid becoming provoked by the fact that the patients often are dissatisfied with the general medical community
- Convince the patient that both of you have the same ambition, that is, her improvement, and together you will explore different possible actions
- Focus on reducing disability and improving quality of life, rather than, after the initial thorough investigation, pursuing a search for a specific causal factor

### ***Treatment of individuals with persisting symptoms***

If symptoms persist despite the previously listed interventions, individual support and programs are necessary. The ill health motivates actions regardless of the lack of knowledge of a specific causal factor. There is no standard treatment, but the choice should be based on an broad view of the patients' situations—taking their own preferences into consideration. Approaches that have been proven effective in chronic diseases or treating other illnesses of unknown etiology might be considered. Focus should be on reduction of symptoms and disability.

Beneficial effects have been reported for cognitive therapy and a treatment package that included acupuncture (both deep and a placebo treatment of only superficially inserted needles). Treatments such as shiatsu, hypnosis, medication with low doses of antidepressant drugs (especially when anxiety, depression, or chronic pain is part of the clinical picture), antioxidants, and reduction of EMF exposure have also been suggested—and by some people, reported successful. Relaxation training might facilitate decrease in autonomic symptoms. Hypnosis might be tried in some cases if the patient is motivated for it.

Cognitive behavioural therapy has been evaluated in several studies, see Table 1. The goals are set by the patient in collaboration with the therapist. The therapy often initially focuses on helping the patient find alternative and better ways to cope with the symptoms, thus reducing disability. Many patients interpret the symptoms as warning signals of even worse health disturbances or disease as a result of EMF exposure. Alternative mechanisms behind symptoms and interpretations, including the possibility of confirmation bias favoring information that supports a suspected specific causal relationship, are discussed. Home assignments are used to test different actions and reactions, as well as evidence in support of suggested causal factors. Relaxation techniques may be used. Most therapist, who have worked with this group of patients, contend that an individual approach is necessary. The patient may benefit from the therapy even if he remains convinced of suffering from hypersensitivity to electricity.

The patient must understand that the introduction of psychological approaches to the problem is not equivalent to a diagnosis of the symptoms as only psychological or imaginary. The condition might be regarded as a psychobiological phenomenon (30). Body and soul are two complementary and interacting parts of a person. Reactions and changes in one necessarily leads to reactions in the other. One obvious example of this is the suffering and practical problems that hypersensitivity to electricity leads to, in severe cases, regardless of the initial causal factor. Both somatic and psychological approaches may be applied. Drugs, physical training, and psychological therapies can all influence the psychobiological balance.

Perhaps the success of different treatments, and sometimes also placebo, illustrates that the caring environment is more important than a specific treatment. The choice of therapy or other action should be based on the clinical presentation of the syndrome as well as the patient's responsiveness.

It is easy to understand that the so-called causal treatments often offered by the self-aid groups and therapists in complementary medicine might seem more attractive to the patient than the therapies aimed at reduction of disability presented by the medical doctor. The medical doctor should accept that the patient might want to try actions other than the ones offered by the medical community—to reduce the suffering. Such choices of the patient must not lead to a discontinuation of an established medical contact.

### **Electric and magnetic fields**

Self-aid groups in Sweden often claim that to prevent increased illness, it is necessary to avoid EMF exposure and particularly VDU work. Because the etiology of hypersensitivity to electricity is still unknown, we cannot say that we have scientific proof neither to support nor discard this belief in all cases. But our clinical work has repeatedly shown that avoidance by no means is a necessity for improvement (7). A follow-up study has also shown that the group of VDU workers, who got well or who are significantly relieved of skin symptoms, continued working with VDU to a higher degree than the group with persisting skin symptoms (6).

One conclusion from these examples is that if all persons who report hypersensitivity to electricity immediately should change their lifestyles and start avoiding EMF and VDU work, this would, at least in several cases, be unnecessary. This conclusion is a strong argument for trying other actions and treatments first. The non-specific symptoms, which might be provoked by many previously discussed factors, and the ubiquity of EMFs (which might lead to severe isolation if avoidance of EMFs is sought), constitutes additional arguments for refraining from an increasing avoidance of EMFs.

To measure EMFs and to take action to reduce exposure to electric and/or magnetic fields, in cases of hypersensitivity to electricity, are controversial issues. But it is very important that the situation and possible outcomes are carefully considered before measurements and actions are taken. Before starting EMF measurements, it's advantageous to ensure that everyone agrees on what types of results will motivate further initiatives. Advantages and disadvantages must be considered in all cases. This includes considering both the person with hypersensitivity to electricity and others who will be affected by the actions taken, for example, colleagues, employers, and family members. The advantage of responding to the concern of the patient must be balanced against possible risks of downplaying other factors of importance and inducing fear of danger in other persons. The European group of experts presented arguments for and against actions directed toward EMFs; see Table 3.

### **Prognosis**

The prognosis very much depends on how far the syndrome has progressed; see Figure 1. In Sweden, there is much evidence to support a distinction between temporary VDU-related skin symptoms and reported hypersensitivity to electricity in general (2). Although most cases of hypersensitivity to electricity start with VDU-related skin symptoms, the majority of the latter group experiences a recovery or an improvement, and do not experience a disabling progress. It would be of great value to be able to distinguish persons at risk for worsening of symptoms as early as possible. But today, we have no secure objective indicators. In our experience from clinical work, it seems

that the risk for progress is increased in cases with more suboptimal conditions (for example, medical disease as well as problems at work and at home).

Cases with long histories of illness and prolonged sick leaves or even disability pensions usually have a need for a prolonged rehabilitation period. In many cases, we find that we must start by offering these people supportive therapy to improve their daily lives.

Arguments for	Arguments against
<p><b>—measuring fields:</b> Ensure that levels of exposure of EMF meet existing standards and recommendations.</p> <p>May provide a basis for possible actions to be taken by the individual to reduce exposure.</p> <p>To respond to the concerns of the individual.</p> <p>If measured levels are low this may have a reassuring effect.</p> <p>By using dosimeters and symptom records, the hypothesis of an association between symptoms and exposure levels in the individual case might be investigated.</p> <p><b>—reducing fields:</b> As part of a prudent avoidance strategy.</p> <p>To respond to the concerns of the individual.</p> <p>May have a placebo effect in reducing symptoms</p>	<p><b>—measuring fields:</b> A causal relationship has not been proven, and taking measurements might be interpreted as an indication that a hazard exists.</p> <p>Lack of knowledge of possible exposure parameter of relevance and consequently lack of relevant guidelines or protocols for measurements of such parameters.</p> <p>The absence of dose-response relationship.</p> <p>Might draw attention away from other factors that might be more relevant.</p> <p><b>—reducing fields:</b> No medical or scientific basis on which to reduce exposure to levels lower than those limits that already exists.</p> <p>In view of the ubiquitous nature of EMFs, reducing the levels in a particular location may not contribute significantly to a reduction in the individual's total exposure.</p> <p>May create unnecessary anxiety among others.</p>

Table 3. Arguments for and against actions concerning electric or magnetic field exposures in situations where individuals with hypersensitivity to electricity exist (Adapted from Possible health implication of subjective and electromagnetic fields; A report prepared by a European group of experts for the European Commission, DG V) (2).

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<b>Goals:</b>	Complete rehabilitation	Reduce symptoms	Improve daily life
<b>Means</b>	Information, explanations	alternative For example, cognitive therapy	Supportive therapy
<b>Prognosis</b>	Good	Varies	Poor

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*Figure 1. A time axis of symptoms, attributions, treatments, and prognosis during hypersensitivity to electricity (31).*

### **Recommended action**

*Government agencies and institutions, occupational health services, employers, electric companies, mobile phone manufacturers, and network providers:*

- Provide information on EMF and hypersensitivity to electricity for the general population and target groups.
- Optimize environmental factor.

*Government agencies and institutions:*

- Train medical staff, especially GPs, in treating electrosensitive patients.
- Facilitate treatment in multidisciplinary teams or in close cooperation among different professionals.
- Establish specialist centers for referrals and update information made available for both medical staff and general public.
- Increase public awareness of psychophysiological models of importance for illness/disease.

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## **Non-Specific Health Symptoms Attributed to ELF and RF Field Sources: Clinical Data**

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Few years after the experimental demonstration by Hertz, of the Maxwell's laws about electromagnetic fields, in 1893 d'Arsonval was the first who used electromagnetic radiation as therapeutic mean in human medicine. By this, he showed that electromagnetic waves had a physiological effect. However, in this time only the thermal effect was used.

In industrial as well as in domestic areas the more and more extensive use of electricity and the exponential development of telecommunications pose the problem of concerns about their possible physiological or even pathological effect.

Classically, the absorption by tissues of the energy carried by electromagnetic fields leads to induced currents at low frequencies, and increase of internal temperature of tissues at radiofrequencies. However, it seems that these effects are not the only ones to act on man's physiology.

Indeed, various reports alleged non-specific symptoms in relation with long term exposure to low power density electromagnetic fields. But their results were not validated and a conclusive evaluation was not possible on the basis of the present level of knowledge.

We plan to analyse various documents published on this topic:

The first clinical study concerning the biological effects of electromagnetic fields on men was published in 1957, in an occupational medicine revue of the former USSR by Piscounova and coll who exposed 128 workers to electromagnetic fields of 300 kHz, 20 and 75 MHz.

So far, various reports have supported the early Russian work (Sazonova ; Danilin ; Gordon; Vialov; Asanova and Rakov ; Fole; Deroche; Miro), while others did not (Barron and Banaff, Kouwenhoven; Strumza; Malbysson; Robinette; Knave; Baroncelli)

According to a synthesis of the clinical observations of the first group, in some people long time exposure of man to low power density electromagnetic fields could lead to disorders the more frequent of which are:

- physical asthenia with muscular tiredness particularly in legs,
- myalgias of the extremities
- psychological asthenia with recent difficulty of the thought elaboration,
- apathy contrasting with recent irritability and emotional disturbances

- loss of memory
- anxiety
- headaches generally with pulsations
- modifications of nyctemeral cycle and sleep disturbances
- unstableness, dizziness, loss of consciousness, sometimes with nausea
- thermoregulation disturbances, with sudden increase of temperature generally moderated but unexplained, shivers and fits of sweat
- dysesthetic sensations of extremities

Until now all these symptoms are reported to be regressive in more or less time.

In general the clinical examination is found to be normal. At the very most, a slight tachycardia is possible, but it is generally related to patient's anxiety.

All these symptoms are non-specific and can be triggered by various other causes. Consequently, the problem is to investigate the causality of electromagnetic field exposure of the patient on these non-specific symptoms.

To solve it, it is necessary to make not only personal but also familiar, social and occupational inquiries.

Paraclinical tests were made by several teams:

- EEG showed an increase of slow waves in exposure people compared with the control group. An increase of the reaction time to the periodic light stimulation, with disturbance of the response was also reported.
- In 79% of the people exposed to electromagnetic fields blood tests showed the presence of punctuated red cells with basophile granulations. In another publication, an important increase of red cell membrane resistance to hypotonic saline solutions was found: Normally the final hemolysis rate is from 3,5 to 3,1 g of ClNa p 1000, while in exposed people, values below 2 g of ClNa p 1000 are reached.

A more detailed analysis of these studies shows that only a part of the people exposed to electromagnetic fields presents these symptoms. In the first work of Piscounova about 128 people were exposed, 30 had no clinical symptoms and only 77 complains with neurovegetative disturbances. In a clinical and epidemiological study we made, where all people were exposed to electromagnetic fields with the same conditions, 60% of them had no clinical symptoms, 30% complains with one or some neurovegetative symptoms and only 10% presented a clinical syndrome justifying an examination in a hospital. In other words, it seems that the individual sensibility to electromagnetic fields is variable in dependence on personal and external factors.

One of them is the temperature of the environment of the exposed people. A study made by Losak on the workers of UHF stations of the Aeroflot Company shows that the neurovegetative syndrome is more frequently found in stations situated in meridional areas than

in stations of north or temperated areas. This fact seems to be supported by the results of our clinical and epidemiological study made in the North Africa area.

Furthermore, skin symptoms were reported in relation with electromagnetic fields induced by visual display units (VDU). Subjective symptoms such as pain, itching, burning are noted with or not mild objectives signs as rashes, redness, sometimes erythema. or seborrhoeic eczema. Generaly these skin symptoms are transient, often being reduced after work or over weekends.

The conclusion of the report prepared for DG V about "Possible health implications of subjectives symptoms and electromagnetic fields" is : " While skin symptoms appear to be associated with VDU work, this appears less certain for skin disorders. Regarding objective signs, no conclusion appears possible. Some results suggest that normal explanations for these problems such as a low relative humidity or a high air temperature, as well as stress situations may be major explanatory factors for these skin problems also in VDU Work situations."

Finally, various endocrinologic disturbances particularly concerning the thyroid gland were reported. However, if these one were validated biologically after acute overexposure to electromagnetic fields during an accident, they are not validated for chronical exposures.

In conclusions there are very few clinical data linked with chronical electromagnetic field exposures. The symptoms reported are essentially neuro vegetative and non-specific. In a population globally exposed to electromagnetic fields, they appear only on a small percentage and with a variable importance for the function of each person.

In this connection, can we speak about "Hypersensibility" ? The problem is that untill today, we have no clinical or paraclinical test to determine if a person is "Hypersensiative" or not even if we take into account the symptoms allegeded.

It seems to me interesting to analayse the results of medical observations of persons accidentally exposed to elcctromagnetic fieds during their work.

With our network of occupational medicine , now we have some typical observations of accidental exposures including the conditions and the level of exposure, the results of the first medical examination , the paramedical tests asked and the followup of the patients.

We found 3 persons exposed in the near field of a radar emitter with a relative low average power. During the exposure no symptom was noted, but during the days following the exposure variouys symptoms appeared such as pulsatiles headaches, loss of memory, sleep disturbances, unstableness, thermoregulation disturbances and anxiety. A brain scintigraphy with amino-acids was made and showed a disturbance of local brain circulation and areas of loss of radio nuclide binding, in relation with a metabolic brain disturbance.

In another case, where the head was accidentally exposed to radiofrequency emission, we found very important disturbances of hormonal tests, coresponding to a loss of the ovarian cycle and also the same modifications at its brain scintigraphy.

Thus, it seems that this nuclear medical test could be interesting to validate subjective symptoms.

Perhaps, this technique could allow us to medically support persons who allege non-specific health symptoms attributed to electromagnetic field exposure.

# **Non-Specific Health Symptoms Attributed to Electromagnetic Sources: A Review of Epidemiological and Experimental Studies**

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## **1. Scope of this review**

This review will attempt to describe currently available data concerning the relationships - if any - between various non-specific health symptoms (NSHS) and electric or magnetic field (EMF) sources. The data used are derived from formal epidemiological or experimental studies. I will also discuss in some details terms and conceptual models for use in the evaluation of them.

The review is interrelated to other talks presented at this meeting. I will not dwell on clinical observations since they have already been described by Prof Miro. Nonspecific health symptoms in relation to the use of mobile phones will be covered by Dr Mild, and sleep disorders - especially in relation to RF field sources - by Dr Rösche. Parts of the material which is presented here have also been presented earlier, see e.g. a report prepared for the European Commission on Electromagnetic Hypersensitivity (11), a talk given at an earlier ICNIRP meeting (10), and an earlier review on RF epidemiology (9).

## **2. Some methodological considerations**

### *2.1 The nature of non-specific health symptoms*

In this review, non-specific health symptoms (NSHS) are taken as symptoms of adverse health (with "health" in the broad, WHO sense) obtained without reference to a diagnosed disorder in the individual concerned, usually by questionnaires. Thus, while some symptoms may be etiologically related to disorders, others may result from other processes. An example is given by eye discomfort, which could arise as a consequence of disorder, as a consequence of normal physiological aging, or as a consequence of exertion or adverse visual ergonomic conditions such as glare. This broad definition of NSHS carries with it some methodological problems because of possible attribution processes - see further discussion in an earlier paper (10).

In the EC report (11), descriptions of symptoms that have been attributed to EMF sources by individuals were solicited from centers for occupational medicine and from self-aid groups. The replies were categorized into the following categories:



- Nervous system symptoms (such as sleep disturbances, decreased arousal and fatigue, neurasthenia, stress/irritation, anxiety and headaches); 95 replies,
  - Skin symptoms and signs (such as facial pricking, burning sensation, irritation and rashes); 25 replies,
  - Various body symptoms (pain and ache in muscles or joints etc.); 10 replies,
  - Eye symptoms and non-specified disorders (burning sensations, "problems" etc.); 10 replies,
  - Less common symptom categories were cardiovascular symptoms (5 replies), ear, nose and throat problems (5 replies, e.g. tinnitus), hormonal/ metabolic dysfunctions (3) and non-specified allergy (2). Cancer (3), reproductive or pregnancy (2), digestive disorders (1) and interference with pacemakers (1 reply) were also mentioned.
- (The number of replies refers to the number of specific symptoms reported.)

The review will concentrate on the first two groups of symptoms mentioned above (i.e. those related to the nervous system or the skin). The attribution of eye symptoms and to some degree also of muscle/joint pain and ache with EMF sources is often interrelated with work with visual display units (VDUs) - and for which other factor than the EMF exposure found in such work situations appear to be primarily involved.

## *2.2 Different situations and exposures*

In the same EC report (11), information on attributed source situations for health problems was also solicited. The responses can be subdivided into sources for ELF, intermediate and high frequency fields - with some sources emitting in several different frequency bands. Examples of high frequency field sources often quoted as problem sources were broadcasting stations, TV towers or telecommunication masts, microwave ovens and mobile phones, with somewhat less attention given to induction heaters or plastic welding and radar stations. For extremely low frequencies (ELF), sources quoted were power lines and transformer stations as well as electrical wiring or appliances at home, followed to a lesser degree by electric railways. Sources of mixed frequency field exposures or miscellaneous sources that were most commonly mentioned were VDUs, followed to a lesser degree by light sources, medical equipment (e.g. NMR) and heavy machinery. As described in some details in the EC report (11), these attributed sources (and the symptoms) varied substantially between countries.

It is often pointed out that the characterisation of the actual EMF exposure is fraught with difficulty in epidemiological research, and the exposure procedure has also been criticized in some experimental studies. In these attribution situations, a further complication is that the attribution should be seen as being linked to a situation - not an exposure (more or less well-defined). The VDU work situation is a good example, with:

- The same order of magnitude exposure to ELF electric and magnetic fields as the general office environment, but with some differences in terms of precise frequencies and waveforms (of unknown importance).
- Low level exposure to fields of intermediate frequencies.
- Depending on the relative humidity etc., substantial electrostatic fields.
- A more difficult visual ergonomic situation compared to non-VDU work.
- A heat source, with possible implications also for relative humidity.

- A concentration on the physical data entry work task, with a high degree of monotonous and repetitive movements.
- For some workers, a less mobile and more monotonous work situation.
- Changes in work tasks and work roles compared to other jobs, in several such work situations these changes can be classified as "stressful".

Attribution of a health problem to this situation does not - *a priori* - identify the explicit factor(s) that could be responsible. Thus, the separation of an effect of e.g. an EMF emission from that of a stressful work situation, a temperature problem or glare is not self-evident, but requires careful consideration.

### 2.3 *The identity of investigated individuals*

For many reasons, it is imperative that the source population for a study (epidemiological or experimental) is clearly defined and understood. In this review, a distinction is made between studies recruiting among the general (or general working) population, and studies recruiting among individuals with a particular sensitivity (as in electromagnetic hypersensitivity). This distinction may be important in order to avoid false negative results.

Attempts at identification of specifically sensitive individuals in terms of EMF (electromagnetic hypersensitives) have been made in several ways, such as by an individual's detection of fields or currents. Some data exist, see e.g. the presentation by Prof Leitgeb. In other investigations, however, the definition of sensitive individuals is often based on a judgement process by the individual (47).

Another point concerning the identity of such a "sensitivity" is whether it is specific to EMF or general. Data have recently appeared that suggest that some individuals (in Sweden) suffering from (self-defined) electromagnetic hypersensitivity may in fact be sensitive to other stimuli, especially modulated light (40, 48) and investigations in terms of e.g. autonomic system instability among these individuals have therefore been initiated (K Hansson Mild, presentation at the NIEHS EMF Rapid review (31)).

### 2.4 *The mechanism under investigation*

Evaluation of study results (and indeed also the design of studies) is strongly dependent on the type of relationships between (e.g.) EMF exposure and an NSHS that is envisioned. It should be noted that an association could be due to:

- a/ a physical causal process, where the NSHS are - in principle - independent of awareness of the field exposure.
- b/ a psychosomatic dependent process, where the causal relationship between exposure and effect depends on the awareness of exposure.

Of course, a relationship could be due to a combination of a/ and b/. In addition, the association could c/ be spurious, where none of the two processes above (a/ or b/) is present, due to the presence of confounding factors or other methodological problems.

Both process a/ (physical) and process b/ (psychosomatic) should be seen as real since they both describe a way by which a disadvantageous situation arises for an individual due to the presence (or perceived presence) of EMF exposure. This contrasts with c/ which is an artefact of a study. Of course, differentiating between process a/ and b/ is

needed as well, since prevention activities strongly differ. The possibility to differentiate between these processes is clearly dependent on the design of the study.

### *2.5 Experimental vs epidemiological approaches*

An experimental (double blind) study should ideally be able to differentiate between process a/ and b/ above. The ability to eliminate c/ should also be high, by accurate control of "other" conditions. One approach taken in some provocation studies (3, 23) is that of first performing an "open" provocation session, where individuals capable of reacting according to a/ or b/ are identified, followed by a "closed" (double blind) session with those individuals, where awareness of the exposure is eliminated. If the association persists, a strong indication of process a/ is achieved. If not, (weaker) indications of process b/ are obtained.

In contrast, epidemiological studies are in principle susceptible to all three possibilities (a/--c/), and differentiating between them depends on additional information in subsequent analyses. Findings that a substantial part of the public hold misconceptions about "levels, characteristics, and potential health effects of exposure to electric and magnetic fields" (2) suggest that process a/ and b/ could be separated by careful epidemiological approaches, as not all individuals who are exposed (at a certain level) would consider themselves exposed, and vice versa. See also a discussion by Beale et al. (8). On the other hand, epidemiological studies have the advantage that data derived from them - in principle - would include also other factors. If a symptom depends not only on the EMF factor, but also on other (unknown) co-factors, this could be detectable by epidemiological studies provided that the co-factor is present for a sufficient number of (exposed) individuals - it may not even have to be identified. Experimental studies may cause false negative results if a co-factor necessary for the reaction is inadvertently absent. The "open"/ "closed" procedure described above, is one way of reducing this problem, as the positive reaction in the open session would confirm the presence of necessary co-factors (external or individual) for at least one mechanism.

Thus, experimental studies would be primarily suitable to detect sufficient causes, whereas epidemiological studies would be more suitable for detecting whether a factor is a necessary (but not sufficient) or is a contributory cause - especially if co-factors are unknown. On a practical approach, data from both type of studies should be useful for the study of NSHS and EMF, particularly when results from one type of study (e.g. co-factor identification in epidemiological studies) are used for the design of the other (e.g. inclusion of such co-factors). In the reviewed studies, this has seldom been done.

## **3. Extremely low frequency (ELF) fields**

### *3.1 Experimental studies on individuals recruited from the general population*

In a recent evaluation by the NIEHS EMF Rapid program (31), experimental studies on humans were reviewed. Heart rate variability, sleep processes, melatonin and electromagnetic hypersensitivity were considered to be of more relevance for risk assessment and hazard identification re EMF than the other topics. Indications that heart rate variability may be influenced by fairly strong (20 µT) 60 Hz magnetic fields have been seen in studies from one laboratory (41). In another recent study, 16 individuals were exposed

during night sleep to 50 Hz, 1  $\mu$ T magnetic field. Compared to nights without exposure, the time spent in slow wave sleep was reduced, and the sleep was reported as less deep (49). Somewhat similar results have also been obtained after exposure to higher magnetic field levels (60 Hz, 28  $\mu$ T) by another laboratory (21). The NIEHS evaluation pointed out that none of the findings on heart rate variability and sleep parameters was robust enough to form a basis for hazard evaluation - but they should be further examined as verification of such effects may have implications for health and well-being, e.g. in terms of cardiac diseases or worker safety etc. (31). The NIEHS evaluation (31) found little robust indications in a number of experimental human studies that exposure to EMF would influence nocturnal melatonin blood levels, but a few epidemiological investigations on urinary excretion of melatonin metabolites have suggested some effects of situations involving various occupational and residential exposures, e.g. in railway workers exposed to 16 2/3 Hz fields (36) or in power industry workers (16). In summary, the NIEHS evaluation did not consider current melatonin results on humans robust enough to form a basis for hazard evaluation. For further review, see also (11, 26, 27).

Hypothetically, several of these results could - if verified - have bearing on different NSHS discussed here, apart from the suggested implications of some of them also on clinical diagnosed disorders. For example, some electromagnetic hypersensitives report - among other symptoms - fatigue, sleep disturbances and various cardiac symptoms. On the other hand, the paucity of robust experimental results preclude conclusions concerning a role of EMF in electromagnetic hypersensitivity based on these studies.

### *3.2 Epidemiological studies on general populations living in the vicinity of power lines*

Three studies have investigated the occurrence of headaches (migraine or non-migraine) in the vicinity of power lines. In two of them (30, 37), no associations between power line proximity and headaches were found. In the third by Dowson et al. (19), some suggested associations between proximity and headaches were seen, but the results did not suggest a dose-response relationship. In addition, analysis limitations and low response rates reduce the credibility of this one positive finding.

Concerning depressive symptoms, data are more suggestive. A study by Poole and coworkers (37) found an association between proximity to power line and depression, also after adjusting for attitudes and concern for the power line. Some further support for this was also found by some earlier studies (19, 35) - even if these latter studies suffer methodological shortcomings, such as insufficient confounder analysis. In contrast, McMahan et al. (29) failed to find any associations, neither with proximity to power lines nor with measured ELF magnetic field levels, whereas worry about the powerline was strongly associated with symptoms (30). Somewhat similar results - reduced associations between exposure and depression when adjustments were made for perception processes - were also noted by Beale et al. (8). The discrepancy between some of these studies have been discussed in terms of the selection of populations under study, and the strong stratification of populations in terms of social classes that can often be found around powerlines (11, 18, 34). It appears difficult at the moment to fully clarify the impact of either worry/perception and/or social class on the possible link between exposure to ELF fields from power lines and depressive symptoms.

Anxiety was also associated with measures of prolonged magnetic field exposure in the study by Beale et al. (8). Again, including perception parameters reduced the direct association between the exposure and the effect. The study by McMahan and coworkers failed to find associations between poor appetite, sleep problems or lack of concentration with exposure. It should be noted that irritability and sleep problems were observed in some earlier Russian studies as being associated with exposure (4, 43). A few older studies have suggested a link between estimated (38) or measured (35) ELF field levels and suicide occurrence among dwellers, whereas McDowell did not (28). Again, the positive studies have been criticized for limitations in their methodology.

### *3.3 Epidemiological studies on general working populations*

Three occupational studies have examined headaches, without finding relationships with measured or estimated field levels (15, 20, 45). In a study of electrical workers by Savitz et al. (42), no overall differences between "electrical" and "non-electrical" workers as to depressive symptoms were found, even if some associations for e.g. concentration problems were found among some subgroups (electricians). Other studies have failed to note associations between measured fields or electrical worker groups with depression (7, 15, 17, 20, 24, 45).

A lack of associations between symptoms such as anxiety, sleep problems and tiredness and exposure (measured or estimated) were reported in several studies on power line workers (7, 15, 17, 20, 24). The one exception was in the study by Törnqvist et al. (45), where increased risks of developing neurasthenia (concentration difficulties, irritation, anxiety, etc.) were found to be related to increasing levels of magnetic field exposure. The authors noted that this effect remained after adjustment for a number of confounders (including worry about work problems), but cautioned that insufficient data on workrelated worry and concern may have played a limiting role in this analysis. Concerning suicide, Baris and coworkers reported some weak indications for an association with prolonged exposure to electric fields among blue-collar power line workers. They pointed out that the results are however statistically rather uncertain and there is a lack of dose-response. No associations with magnetic field exposure were noted (5, 6).

## **4. Intermediate frequency fields**

Data from situations where intermediate frequency fields occur are essentially limited to VDU work situations. It should be noted that these situations also involve exposure to ELF electric and magnetic fields and sometimes also electrostatic fields.

### *4.1 Provocation studies of individuals with health problems*

A fairly large number of provocation studies have been performed, mostly in Sweden, where individuals with health problems attributed to VDU work or to other EMF sources have been exposed to ELF and intermediate frequency fields (static electric and high frequency fields were also included in a few of them). The field sources were either a VDU, or coils and electrically charged plates by which similar or somewhat stronger field situations were created. In all, some 255 individuals have been tested. The overall results demonstrated that these individuals were generally unable to detect the fields to which

they were exposed, nor were their symptoms associated with the field "on" situation when tested in double blind situations. In the two "open"/"closed" studies (3, 23), an association between field awareness (even if wrong) and symptoms was found. For a more detailed review, see (11) or the NIEHS report (31).

#### *4.2 Epidemiological and interventions studies of individuals with health problems*

A few intervention studies have been carried out in Norway, where VDU workers with skin problems were blindly tested by reductions of electrostatic/electric field levels. In one of them (32), a significant reduction in tingling/pricking sensations was noted when fields were reduced by a filter placed in front of the VDU (with grounding connection in "on" vs in "off" states). A replication study by the same authors failed, however, to verify this finding (33). In another study (44), reducing electrostatic and electric field exposures by various methods did reduce skin complaints among the tested individuals, but only in situations where a high dust level was present in the office environment.

In a nested case-control study in Sweden of individuals with self-declared electromagnetic hypersensitivity, symptoms among the cases on a certain day were examined in relation to various physical exposure conditions measured at the same day. Relationships were noted between some climate factors (especially relative humidity) or lighting factors (dark rooms, flicker) and certain symptoms. For ELF and intermediate frequency field levels, associations between ELF electric fields and tingling sensations were found. No associations were found with magnetic field levels for any symptom, nor with electric fields with other symptoms apart from tinglings (46). Finally, in a case description of 27 individuals with self-proclaimed electromagnetic hypersensitivity (1), various actions involving reduction of EMF exposure at VDU work places resulted in reduced discomforts. However, these actions (e.g. reduced VDU work) also involved changes in other factors, making identification of specific factors impossible. Six of these patients participated in a substudy, where exposure to ELF magnetic fields were recorded during one week by use of a logger. No temporal associations between magnetic field exposure and concurrent symptom registration were found.

#### *4.3 Epidemiological studies of individuals recruited from the general population*

Several studies have examined - in studies based on the general population - the possibility of an association between VDU work and various skin problems. By and large, associations have been found for complaints derived from questionnaires and signs such as non-specific erythema with extent of VDU work, and in some studies also with indications of stressful work. Indications for a role of various climate factors (temperature, humidity) have been made in some but not all of the studies. Associations between diagnosed skin disorders (or their manifestations) and VDU work have not been consistently found, however, even if a case could be made for seborrhoeic eczema. For further review, see the EC report (11).

Two of these studies have examined relationships between measured levels of electrostatic as well as ELF and intermediate electric and magnetic field exposure levels. In the cohort study by Bergqvist et al. (12, 13), no associations were found between any field measures and skin problems. The case-control study by Sandström and coworkers (39) likewise failed to find significant associations between exposure levels at the VDU

work stations and skin complaints. However, this latter study did detect a significant association between ELF electric field levels recorded in the office in general and skin symptoms, especially for women. (This latter field exposure parameter was not investigated by Bergqvist et. al.) Both studies agreed to the association between VDU work and stressful conditions with skin symptoms as already described above.

## **5.High frequency ("radiofrequency") fields**

### *5.1 Epidemiological studies of individuals with high exposure to various RF sources*

A number of studies have examined possible health outcomes related to situations which include exposure - or potential exposure - to high frequency fields. The studies were based on radar workers, "microwave workers" (non-specified), electric utility workers, plastic welders, physiotherapists and radio ("ham") operators as well as populations living close to RF sources. The method of exposure assessment varied substantially, from occupational categories, to - in some studies - individual measurements. Effects under study included cancer, lens opacities, neurasthenia, upper limb paresthesia and various other disorders including heart problems (for a review, see 9).

Findings of neurasthenia, upper limb paresthesia and heart disorder are of interest in this review. In most studies, no association between neurasthenia or heart problems with RF exposure or presumed exposure could be verified, however (9). In the study by Kolmodin-Hedman and coworkers (22, 25) on 62 female plastic welders and 23 referents, where actual determination of RF exposure levels were made at the work-places, levels were found to be substantial; the level exceed  $100 \text{ W/m}^2$  at least in one position - usually the hand - for 62% of the measured work positions, normally at 27 MHz. The following endpoints were examined; upper-limb paresthesia, neuropathy, eye discomforts, headache, tiredness and neurasthenia. A significant difference between the plastic welders and the sewing machine operator controls was found for paresthesia, a finding also noted - in brief - by Bini et. al. (14). Apart from this, most discomforts appear similar between exposed and referents (22). An increased use of medication for headaches was noted in the Swedish study, even if headache occurrence was similar (22, 25). Whether this is related to a different intensity of headaches, and - if so - on the physical characteristics of the work (including RF fields) or the increased reported "stress" level among the plastic welders can not be determined from the available data.

By and large, these (mostly) older studies have, with exception of paresthesia, failed to find evidence of endpoints of interest for NSHS. The studies where some suggestions of associations with health parameters were noted - be they NSHS related or not - were all conducted in situations where occupational exposure guidelines (national or international) appear to be - or could potentially be - exceeded.

### *5.2 Other studies*

Some more recent observations are available on other endpoints and other situations of higher frequency field exposure than those reviewed above; experimental and observational studies on sleep problems, studies on individuals complaining of NSHS while

using mobile phones, and clinical studies of individuals subjected to industrial overexposures. These topics are reviewed by other authors at this symposium.

## 6. Discussion and summary

I will here concentrate on ELF and intermediate frequency fields, as fields of higher frequencies are primarily treated by others. Despite the rather substantial number of papers reviewed here - or in companion reviews - the results are rather meagre. In addition, it is often difficult to summarize different study results because of differences or unclear definitions concerning:

- endpoints studied (e.g. neurasthenia, worry, anxiety etc.),
- exposure characterisation (both for EMF and other factors),
- populations from which participants were recruited,
- whether other factors have been considered, and
- differences in conceptual models.

Nevertheless, a few suggestive areas emerge from this review. First of all, there are some indications of a complex interrelationship between endpoints such as depressive symptoms, neurasthenia, anxiety and worry on one hand, and exposure situations involving ELF magnetic fields on the other. However, it is at present not possible to differentiate between a role for the awareness of EMF exposure and a role for the field exposure as such. Clearly, factors such as worry or perceptions are closely related to these endpoints - but whether a mechanism exist by which fields (independent of awareness of fields) can assert an influence is at present not clear - indications for this are currently rather limited. Experimental studies on various "objective" outcomes that may be relevant to this offer - at the moment - little conclusive support. Experimental studies on symptoms are largely restricted to special sensitive groups, and currently fail to support the existence of such a mechanism.

Secondly, some suggestions have appeared for an effect of electric (or electrostatic) fields on skin symptoms, especially tinglings. It can at least be hypothesized that these findings are related to the well known such effect of strong electric fields (above some 10 kV). A possibility is that either some studies have recruited individuals with an extreme sensitivity to this, and/or that the electric field situations (admittedly difficult to measure) may actually include spots of substantially higher levels than those recorded.

In conclusion, I would like to emphasize that while the area of non-specific health symptoms and ELF electric and magnetic field exposure is an important area for research, current data are unable to give a definite positive identification of such relationships. Improved methodological design of future studies, and better coordination between studies, would likely improve the situation. Whether this will result in identification of causal relationships between EMF fields and symptoms which are independent of awareness of the fields, remains to be seen.

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## **Mobile Telephones and Non-Specific Health Symptoms**

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Public concern about the health hazards of electromagnetic fields from mobile phones (MP) has increased. Specifically, there is concern that, as the handsets deployed in the new generation of personal telecommunications systems are brought close to the head, there may be either a thermal insult produced by power deposition in tissue (acute effects) or other (long-term) effects. A large body of literature exists on the biological effects of radiofrequency and microwave radiation. However, only a few studies have considered exposure specifically from MPs. There have been reports that people occupationally exposed to microwave radiation have complained of heavy feeling in their heads, headaches, fatigue, drowsiness in the daytime, irritability, poor memory, nausea, vertigo, and sleep disturbances more often than control groups (Marha et al, 1971; Baranski and Czerski, 1976). The overall symptoms have often been described as neurasthenic syndrome. Also among operators of plastic welding machines neurasthenic symptoms have been reported more often than among the controls, and the consumption of headache pills was significantly higher in the plastic welding group (Kolmodin-Hedman et al., 1988). The problems regarding the neurasthenic syndrome have not been solved. The question has not been addressed since the mid-1970s, when it was dismissed because of lack of control of confounding factors.

Most previous studies of mobile phone users have been focused on cancer but in recent years a few studies have been done that have relevance to non-specific health problem, and some of these will be further discussed below.

### **Studies of mobile phone users and subjective symptoms**

The question of subjective disorders linked with the use of radiotelephone handsets has recently been raised. Users have contacted manufacturers, sales organizations and research institutes. The problem has been raised in Sweden, Norway (Oftedahl, 1996), UK (Cox, 1996), Australia (Hocking, 1996), and USA (Lotz, 1996) – all references refer to personal communications to Hansson Mild. Complaints are usually about headaches, difficulties in concentrating, nausea, and sometimes also a stinging sensation and a feeling of heat in the facial skin that appear to be similar in some respects to the neurasthenic syndrome mentioned above. A majority of the callers were using the new digital system; they had recently changed from an analogue to a digital phone or were new subscribers.

Hansson Mild et al (1998) set up an epidemiological study in 1996 where the main hypothesis was that the users of GSM MPs experienced more symptoms than did NMT

users. To find out if there was a difference between the prevalence of symptoms in the two groups, a comparison was made between the users of the different transmitter systems, and the NMT users were used as reference category. For most symptoms there were no statistically significant differences between the prevalence of symptoms with regard to the different transmitter systems. The hypothesis was therefore falsified. However, both in Norway and in Sweden the study indicated a statistically significant lower risk for warmth sensation on and behind ear for GSM-users compared to NMT-users. The same trend was also seen in the Swedish data for headache and fatigue. The effect of transmitter system and *number of calls* or *calling time per day* was analyzed by using the category with the lowest number of calls/the shortest calling time irrespectively of transmitter system as the reference category.

Increased risk was observed for most symptoms for groups with longer calling times and higher number of calls per day. The effect was particularly pronounced for the warmth sensation variables, where odds ratios (OR) up to 10 -50 were seen with the longest calling times >60 min/day. Among the vegetative symptoms the most pronounced effects were seen for headache and fatigue, and here ORs in the range 3-6 were found for the highest category of calling time.

Hocking (1998) interviewed 40 persons with symptoms they associated with their use of MPs. They reported similar symptoms as described by Hansson Mild et al (1998). No distinction was made between digital and analogue phones.

### **Exposure factors and MP use**

The technical details of analogue and digital systems used for MPs have been described in detail (McKinlay et al, 1996, Bach Andersen et al, 1995) and only a short background is given here. The NMT systems operate at 900 MHz with a continuous carrier wave. The maximum output from the handheld NMT900 phones is 1 W, but earlier models had up to 6 W of output power. The NMT phones have their output power regulated through the base station in two levels, 0.1 or 1 W; the closer to the station the lower is the output power.

In the digital GSM system the information is sent in pulses with a repetition rate of 217 Hz. The pulse length and repetition frequency give a duty cycle of 1/8. The maximum output power is 2 W and this leads to a mean value of 0.25 W maximum. The GSM system also provides a battery saving function, which can change the repetition frequency to 2 Hz when the user is just listening. If one listens as much as one talks this would practically turn down the output power to half of the maximum. The output power is also regulated from the base station, from a maximum of 2 W down to a minimum of 20 mW (with the phones sold today an even lower value of 5 mW is used). The mean output power is, thus normally well below 0.1 W.

Different phones have different design for the antenna position and physical dimensions, for instance, a dipole antenna or a helical antenna. Recently Kuster (1997) measured 16 different European digital phones, and he found a very wide variation in the SAR-values. The phone giving the lowest value, when averaged over 10 g tissue, had a SAR of 0.28 W/kg and the one with the highest value had 1.33 W/kg; all normalized to an antenna

input power of 0.25 W, which is the maximal value for a GSM phone. If the averaging was done over 1 g tissue the span was from a low of 0.42 W/kg to a high of 2.0 W/kg.

Generally the GSM phones have a lower output power than the NMT900 phones. The antenna systems used are similar for the two systems, and the SAR values, thus, are slightly higher for the NMT900 users.

The SAR- measurements were done under normal user conditions. However, when the phone is slightly tilted towards the head of the user Kuster (1997) exemplifies that the value can go from 0.2 to 3.5 W/kg. Thus, for different phones under maximal output, we have a factor of about 5 between the extremes, and to this, the personal handling of the phone gives a factor of tenfold or more.

It should be noted that all given values are maximum SAR values found regardless of the anatomical localization. An equal weight is put to the value regardless if it is obtained on the external ear, middle or inner ear, or behind the ear. In the future, it will be necessary to make the comparison at the same anatomical localization. Presumably, then the values as given by Kuster (1997) might differ even more.

Taken together we have a rather large uncertainty in the actual SAR determination for a specific situation, with a factor of 100 from the nearness to the base station and at least a factor 10-50 depending on make and model and personal style of use.

The currents from battery also gives rise to magnetic fields near the phone. For GSM phones magnetic flux densities of a few  $\mu\text{T}$  near the phone have been measured (Bach Andersen et al., 1995; Linde and Hansson Mild, 1995). The fields are pulsed DC fields with a frequency of 217 Hz. For the NMT phones the magnetic field from the battery current is to be regarded as pure DC fields.

It is difficult to see how the actual exposure (if measured as SAR) can be proxied by "billing record", a procedure that would only give the total time for outgoing calls, not showing incoming calls, nor the powersettings of the phone.

The ability for microwaves to cause a skin sensation of warmth have been known for decades, but only recently have this been measured under standardized laboratory conditions (Blick et al., 1997). The threshold for detection decreased monotonically with frequency and at the lowest tested frequency, 2.45 GHz, the threshold was  $630 \text{ W/m}^2$ . From the data it can be extrapolated that at 900 MHz the threshold would be of the order of  $1000 \text{ W/m}^2$ , and thus it is not possible to obtain any RF heating sensations from the mobile phones with the power outputs used.

### **The phone gets warm.**

When using a MP for a longer continuous period of time, the phone gets rather warm due to the heating from the current drawn from the battery. For some of the early models of NMT it was not possible to hold the phone in the same hand throughout a long phone call due to excess heating. This factor may thus be of importance for the occurrence of the warmth sensations, at least among the NMT users.

Törnevik et al. (1998) measured maximum temperature increases on some phones of 15 to 19 °C in the area of the ear piece when the phone had been operating at maximum output for 30 minutes. They also examined temperature increase around the ear on human volunteers holding the phone in a normal talking position. The maximum temperature readings ranged between 37 and 41 °C for analogue phones and between 36 and 39 °C for the GSM phones.

If the amount of absorbed radio frequency energy or heated phones are responsible for the observed difference in prevalence of warmth sensation between NMT and GSM users, one would expect that longer phone calls would cause a higher prevalence of these phenomena. In particular, one would expect this to be the case for NMT users. In fact, for warmth sensation as well as for several of the listed vegetative symptoms Hansson Mild et al (1998) found an increase in ORs with respect to *Calling time* and *Number of calls*, but they found about the same tendencies for GSM as for NMT users. Because the SAR-values as well as the phone heat are lower from GSM phones than from NMT phones, the influence of factors such as modulation and low frequency magnetic fields can not be excluded.

### **Blood brain barrier**

Some studies of interest for the present study indicated a potential effect of radio frequency exposure at low level. Allan Frey did research on microwave hearing in the 1960s using intensities below 10 W/m<sup>2</sup>. The experiments were discontinued because he himself and some of the volunteers were reporting headache in connection with the experiment. This was recently reported in an overview article by Frey (1998) where he also points to the blood-brain-barrier-experiments (BBB) showing that electromagnetic energy with characteristics similar to present day cell phone emission resulted in the breakdown of the BBB. This is a critical regulatory interface that controls what gets into the brain from the blood, and it may very well be involved in headaches.

Studies by Salford et al (1993) showed effects on the BBB in rats with both continuous and pulse modulated microwave fields at 915 MHz and with SAR-values well below 1 W/kg. In a follow up study Persson, Salford and Brun (1997) reports effects on the BBB at SAR-values as low as in the mW/kg -range. The effect is more pronounced with continuous radiation than when using pulsed fields.

### **Blood pressure**

Recently Braune et al (1998) measured the blood pressure on human volunteers after 35 minutes of exposure to GSM 900 MHz, 2 W peak, 217 Hz repetition rate, and they found an increase of both systolic and diastolic pressure compared to control conditions. They also during exposure noted a significant reduction in heart rate and a more pronounced vaso-constrictions of the capillaries as measured with infrared plethysmograph on the right hand.

### **Sleep disturbances**

Several studies have been published on effects on sleep in connection with exposure to



low level radio frequency radiation (Altpeter et al., 1995, Reite et al., 1994, Pasche et al., 1990). Mann and Röschke (1996) studied the effect of fields from a GSM phones placed near a person during night and they found a REM suppressive effect with reduction of duration and percentage of REM sleep. Wagner et al. (1998) could not confirm this. In the latter experiment they used a circularly polarized field at lower intensity than previously (0.2 vs. 0.5 W/m<sup>2</sup>), and the authors state that the failure to confirm the results may be due to dose-dependent effects of the fields on the human sleep profile.

### **Other studies**

Johansson (1995) carried out a study with twelve people claiming sensitivity to MPs. He exposed them to MPs contained in a bag. It is reported that one person out of the twelve could correctly tell in nine out of nine trials if the telephones were on or off. The study is presented as an institutional report and lacks details regarding exposure. The results were inconclusive.

The effects of radiotelephone radiation exposure on endocrine and electrophysiological parameters are being investigated by de Seze et al (1996). Following 4 weeks of exposure for 2 hours per day over 5 days per week a slight decrease in the pituitary hormone, TSH, was found. This finding needs to be confirmed in future studies. Electrophysiological and neuropsychological recordings in human volunteers are being carried out by Spittler. So far, no significant electrophysiological and neuropsychological differences have been detected between microwave radiation and sham-exposed human subjects at SARs typical of radiotelephone use.

### **Discussion**

Although none of the studies performed today clearly shows any health effect from MP use, there are several that indicate that the use of the phones may lead to subjective symptoms as well as measurable changes in physiological parameters related to the autonomic nervous system. Whether extent these effects are related to the absorption of microwaves or to other factors such as a heated phone is too early to say, and further research is needed to clarify these issues.

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## **Sleep Disorders, EEG Disturbances, and EMF Exposure: A Review**

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### **Abstract**

Several groups of investigators have assessed the impact of electromagnetic fields (EMF) on sleep and its disorders, waking electroencephalography (EEG), and the neuroendocrine system. These studies evaluated the effects of both mobile and non-mobile telephone EMF exposure in humans and animals. The results of these studies are summarized and discussed in this article.

### **1. Mobile Telephone EMF Exposure**

#### ***1.1 Effects on Sleep***

A study by Mann and Röschke (1996) used a 900 MHz GSM cellular telephone signal at a distance of 40 cm to each of 14 subjects (21 - 34 years) versus an inactive telephone in a randomized cross-over design, studied for 3 consecutive 8-hour nights (1 adaptation night, 2 experimental nights) in the laboratory. Sleep latency (i.e., the time from lights out to sleep onset) was significantly reduced from 12.25 to 9.50 minutes with EMF exposure. A non-significant increase was observed in REM sleep latency, but there was a significant decrease in REM sleep percentages, from 17.07 to 13.91%. In addition, there was an increase of the mean power density in all frequency bands (especially the  $\alpha_1$ , 7.5 - 12.5 Hz, and  $\alpha_2$ , 12.5 - 15 Hz, frequency bands), during REM sleep with EMF exposure, while other sleep stages showed a decrease. Subjectively, no significant impairment of sleep perception was observed.

The investigators observed that their experimental approach was limited because EMF inhomogeneities could not be sufficiently controlled and the actual applied EMF power flux density could only be indirectly measured. To compensate for these limitations, these investigators conducted a follow-up study (Wagner et al., 1998) in which the 900 MHz GSM cellular telephone signal was emitted from a circular polarized antenna in a sleeping chamber lined with absorbing material custom designed to improve the homogeneity of the field. Twenty-four healthy male subjects (18 - 37 years) were studied in a cross-over design experiment over three consecutive nights, with or without 8 hours of EMF exposure. Although there were trends for decreased sleep latencies ( $15.9 \pm 9.0$  to  $15.3 \pm 7.5$  minutes), prolonged REM sleep latencies ( $60.6 \pm 21.5$  to  $76.0 \pm 32.9$

minutes), and decreased REM sleep ( $100.5 \pm 19.0$  to  $95.0 \pm 18.8$  minutes), contrary to the earlier study, none of these findings were statistically significant. Similarly, no significant difference of spectral power was found with EMF exposure. The investigators attributed the discrepancies in the two studies to the following reasons: (1) the circular polarized field (compared to the linear polarized field used in the prior study); and (2) a lower average power flux density of  $0.2 \text{ W/m}^2$  (compared to the  $0.5 \text{ W/m}^2$  used in the prior study). The investigators speculated that the linear polarized field inhomogeneity and the largely uncontrolled external reflections may have resulted in the enhanced EMG local power density of the prior study.

### ***1.2 Effects on Waking EEG Activity***

The group of investigators who performed the experiments described in the prior section (Röschke and Mann, 1997) studied 34 male subjects (21 - 35 years) in a single-blind cross-over design experiment. The subjects were exposed to 3.5 minutes of either a 900 MHz GSM cellular telephone signal at a distance of 40 cm or an inactive telephone, and an awake EEG with eyes closed was obtained from each subject. No statistical differences in the spectral power densities in separate frequency bands between the two experimental conditions were observed. The investigators emphasized that the EEG is only one aspect of cerebral function, and stated that their results could not be generalized to longer EMF exposures, other physiological states than alert wakefulness with eyes closed, or individuals other than healthy young volunteers.

Similarly, other investigators reported no significant EEG changes with EMF exposure. A study with 10 male volunteers exposed to cellular telephones revealed no EEG changes, although a slight statistical difference was found in short latency auditory evoked potentials between individuals in the telephone on versus telephone off conditions (Kim et al., 1998). Hietanen and colleagues (1997) studied 10 men (28 - 48 years) and 9 women (32 - 57 years) with 3 analog (NMT) and 2 digital (GSM and PCN) mobile telephones placed against the right ear while their EEG was recorded during 6 trials, each lasting 30 minutes (20-minute EMF exposure, 5-minute sham control period before and after each exposure). No clinically significant differences were observed in actual versus sham EMF exposure for the subjects. EEG analysis plus neuropsychologic testing were conducted on 52 volunteers (20 - 38 years) with and without EMF exposure (Calabrese et al., 1997; Spittler et al., 1996; 1997). Twenty-five of the subjects were exposed to a GSM-type signal for 10 minutes of a 30-minute EEG recording, the remaining 27 subjects served as controls without EMF exposure. No significant differences were found in EEG or cognitive performance either between the exposed and non-exposed subjects or between the signal-on versus signal-off periods of the exposed subjects. Thimonier and colleagues (1995) studied the auditory brainstem responses (ABR) and auditory distortion products (ADP) of 10 male and 10 female volunteers (20 - 30 years) using GSM mobile telephones. No clinically significant differences were obtained between pre- and post-exposure recordings for the studied ABR and ADP parameters.

A few studies reported changes in EEG frequencies with EMF exposure, although the clinical significance of these changes is unclear. A study using 17 subjects (20 - 29 years) exposed to a GSM-type pulsed 150 MHz signal at a power density lower than 1

$\mu\text{W}/\text{cm}^2$  revealed an increase in the 10 Hz frequency band; the significance of this observed phenomenon is unknown (von Klitzing, 1995). Reiser, Dimpfel, and Schober (1995) conducted a single-blind, cross-over designed study on 36 volunteers (18 men, 18 women) using a 902.4 MHz signal with a GSM-type pulse modulation pattern. An increase in EEG power in the higher frequency bands ( $\alpha_2$ ,  $\beta_1$ , and  $\beta_2$ ) were observed, but the significance of this finding is also unclear. Lastly, Dec and colleagues (1997) observed EEG power variations in the alpha and theta frequencies of 5 subjects (24 - 26 years) with cellular telephone exposure versus 5 subjects without exposure. Thuróczy and colleagues (1994) studied the effects of microwave irradiation on brain electrical activity and cerebral circulation in rats, using electroencephalograms (EEG), rheoencephalograms (REG) (as a marker for cerebral blood flow), brain tissue DC impedance and temperature, and electrocardiograms (ECG). Two weeks following surgery, the rats were either exposed to: (1) whole body 2450 MHz EMF for 10 minutes at specific absorption rates (SARs) of 0.2, 2.3, and 6.9 mW/g and brain tissue SARs of 0.8, 8.3, and 25.1 mW/g, or (2) brain-targeted 4000 MHz EMF at SARs of 8.4, 16.8, and 42 mW/g. The total power of EEG spectra and cerebral blood flow increased following whole body 25 mW/g SAR 2450 MHz exposure for 10 minutes. The power of the EEG delta (0.5 - 4 Hz) frequency band and cerebral blood flow increased following 42 mW/g SAR exposure. An increased power of EEG beta (14.5 - 30 Hz) frequencies were observed with amplitude modulation at 16.8 and 42 mW/g SAR, but changes in cerebral blood flow were not observed. Continuous wave EMG at 8.4 mW/g SAR increased cerebral blood flow, but did not change EEG spectra. This group of investigators also recently extended their studies to humans (Thuróczy et al., 1997), by studying 45 women ( $48.7 \pm 10.5$  years) and 31 men ( $41 \pm 12.8$  years) with GSM mobile telephones switched on twice for 7.5 minutes. Using EEG, REG, ECG, and blood pressure measures, these investigators observed that the level of measured psychophysiologic changes did not exceed normal physiological responses following EMF exposure. They did observe spectral power changes in the EEG alpha frequency band (without a significant peak frequency shift) and a simultaneous slight decrease in cerebral blood flow during the first exposure period. There were also observed changes in the level of anxiety and blood pressure.

### **1.3 Effects on the Neuroendocrine System**

In an effort to explain the EMF effects on sleep observed in their earlier studies, the team of Mann and colleagues (1998) studied EMF effects on 4 sleep-related hormones. The hormones chosen and the rationale for their selection were: (1) Growth hormone (GH) random, pulsatile secretions are distributed throughout the day, but there is a sleep-onset peak associated with the first NREM episode independent of the circadian rhythm. (2) Cortisol secretions are strongly associated with the circadian rhythm and are maximal in the early morning, and have an ultradian rhythm during sleep with a 150-minute period length. (3) Luteinizing hormone (LH) pulsatile secretions are associated with REM periods. (4) Melatonin secretions are dependent on light-dark cycles and are maximal at night. They studied 24 healthy male volunteers (18 - 37 years) exposed to either no EMF exposure or a 900 MHz GSM cellular telephone signal emitted from a circular polarized antenna in a sleeping chamber lined with absorbing material custom

designed to improve the homogeneity of the field. The subjects were exposed to the EMF field for 8 hours per night across 3 consecutive nights. Blood samples for hormonal analysis were drawn every 20 minutes over the 8-hour recording period each night. A slight, transient elevation in the cortisol serum level was observed immediately after EMF exposure; this elevation persisted for one hour. No significant effects were found for GH, LH, or melatonin secretion in the EMF versus control conditions. Similar to the later studies by this same group of investigators, a non-significant trend to a REM suppressive effect was observed. The investigators concluded that weak high-frequency EMF exposure has no effect on nocturnal hormone secretion, with the exception of a slight, transient elevation in cortisol secretion, which may reflect a non-clinically relevant adaptive response to the EMF exposure.

There is a lack of studies examining the effects of mobile telephone EMF exposure on the neuroendocrine system. However, no statistical differences were found in melatonin secretion of 19 male volunteers (20 - 32 years) following exposure to GSM and DCS mobile telephones (de Seze et al., 1997). The subjects used GSM or DCS cellular telephones 2 hours per day, 5 days per week, for 4 weeks at a carrier frequency of 900 or 1800 MHz and a maximal peak power of 2 watts. This corresponded to a peak SAR in the temporal lobe of the brain of approximately 0.1 W/kg. Blood samples for melatonin were collected every hour from 10 p.m. to 10 a.m. and every 3 hours from 10 a.m. to 10 p.m..

## **2. Non-Mobile Telephone EMF Exposure**

### ***2.1 Effects on Sleep and Insomnia***

A comprehensive study (Altpeter et al., 1995) analyzed the population in proximity of the shortwave radio transmitter station of Schwarzenburg (Canton of Berne, Switzerland). Although there was no substantial increase of any chronic disease in the exposed population, nervousness, restlessness, insomnia, general weakness and tiredness, and limb pains were more frequent in the vicinity of the transmitter. Sleep interruptions showed a dose-dependent association with the electromagnetic field strength of the transmitter, and sleep quality improved following interruption of transmission activities. Urinary levels of 6-hydroxy-melatonin-sulfate did not correlate with the electromagnetic field strength of the transmitter or with the sleep problems. Lastly, the graduation rate from primary to secondary school since the 1950's was lower in the exposed area compared to a control school, and transmitter exposure was offered as a possible explanation; however, the authors reported that socioeconomic factors could not be excluded.

A series of papers by a group of investigators (Reite et al., 1994; Lebet et al., 1996; Pasche et al., 1996) studied low energy emission therapy (LEET) as a treatment of chronic psychophysiological insomnia. LEET is a method of delivering a 27.12 MHz RF signal, with signal amplitude controlled by a microprocessor. A modulation frequency bandwidth of 0.1 Hz to 10 kHz is delivered to the patient by an electrically-conducting "spoon-shaped mouthpiece" positioned between the tongue and the palate and in direct contact with the oral mucosa. Fifteen- to twenty-minute LEET sessions were given three times a week for up to 4 weeks. Significant increases in total sleep time ( $76.0 \pm 11.1$  minutes,  $p = 0.0001$ ) measured by polysomnography were observed between baseline

and post-treatment values. Sleep latency was significantly decreased ( $-21.6 \pm 5.9$  minutes,  $p = 0.0006$ ) between baseline and post-treatment values. LEET also resulted in a significant 30% increase in the number of sleep cycles per night. Interestingly, discontinuation of LEET did not result in rebound insomnia, which is characteristic of many sleep-inducing medications. The SAR, as noted by the investigators, was less than 10 W/kg in the oral mucosa and 0.1 to 100 mW/kg in brain tissue, roughly a thousand times lower than the SAR generated during an MRI examination (Magin, Liburdy, Persson, 1992). The investigators further state that although the specific mechanism of action of LEET is unknown, animal studies have shown that low EMF levels affects calcium release from neural cells (Adey and Sheppard, 1987; Blackman, 1992; Adey, Bawin, and Lawrence, 1982), GABA release (Kaczmarek and Adey, 1973), cerebral benzodiazepine receptor concentrations (Lai et al., 1992), and melatonin release (Reiter, 1993).

## ***2.2 Effects on Waking EEG Activity***

A pilot study by Bise (1978) revealed temporary changes in EEG and behavior in 5 men and 5 women (18 - 48 years) with exposure to continuous wave 200, 350, 360, and 365 MHz, and pulse-modulated wave 9,100 and 9,150 MHz. This EMF exposure at these frequencies were reported to cause increased alpha wave amplitudes, increased slow wave index, and EEG desynchronizations. EMF exposure to continuous wave 130 to 960 MHz frequencies reportedly caused decreased alpha wave amplitudes, increased slow wave index, and EEG desynchronizations. Mental and behavioral changes, including short-term memory impairment followed by concentration inhibition and irritability, apprehension, and mental and physical sluggishness, were reported. The EEG abnormalities almost immediately reverted to normal patterns when the generator frequency was altered or stopped. A later article by Stocklin and Stocklin (1981) proposes support for the study of Bise by physics and neural hypotheses.

A study by Sinczuk-Walczak and Izycki (1981) evaluated the occupational exposure of heat sealer operators to dielectric heaters operating at 27 - 30 MHz for about 1 hour per day at a field intensity of up to 1 mW/cm<sup>2</sup>. No significant differences were found between the heat sealer operators versus controls in emotional lability, headache, dizziness, sleep disorders, fatigue, tremors of the hands and eyelids, dermatographism, excessive sweating, or heightened reflexes. The incidence of these symptoms were not correlated with exposure duration, and no occupational-related organic brain damage was detected by objective examination. No significant differences were observed in EEG analysis for the heat sealer operators versus controls, except that heat sealer operators showed decreased alpha wave activity.

Abnormal EEG recordings were observed in 29% of employees operating radio and television installations (3,000 - 7,000 MHz having an average power density ranging from 0.1 to 2.0 W/m<sup>2</sup>) and 70% of workers using furniture gluing machines (4 - 18 MHz) in Poland (Bielski, 1994). These abnormalities consisted of nearly flat or low-voltage alpha EEG frequency waves as well as numerous series of slow theta waves and single sharp waves irregularly distributed, sometimes with phase opposition. These workers also complained of nonspecific symptoms such as excessive irritability, increased perspiration, headaches, dizziness, chest pains, discomfort, and sleep disturbances.





### 3. Conclusions

Mobile telephone EMF exposure may reduce sleep latency and suppress REM sleep in normal, healthy subjects, and low-energy emission therapy may be effective in the treatment of patients with chronic psychophysiological insomnia. The effects of mobile telephone EMF exposure on human waking EEG activity appears to be minimal, a few studies have reported EEG power changes primarily in the alpha frequency band following EMF exposure. No clinically significant changes have been observed in studies examining the effect of mobile telephone EMF exposure on neuroendocrine function. A few studies described EEG frequency changes and subjective complaints, including sleep disruption, with non-mobile telephone EMF exposure; however, the limited sample sizes and lack of adequate controls limit the generalizability of the results. In the few cases where EMF exposure has been shown to affect sleep or waking EEG activity, the mechanism and extent of this association are unknown; future investigations will hopefully provide more insight into these questions.

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# **The Effects of Digital Mobile Radio Telephones on the Electroencephalogram of Humans**

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## **1. Introduction**

The discussion about the effects of electromagnetic fields on the human organism has recently been stimulated by the introduction of digital mobile radio telephones. These new communication systems are operated on the base of pulsed high-frequency electromagnetic fields in the lower microwave range. Power density of digital mobile radio telephones is usually too small to produce thermal effects. Nevertheless, for many years, people have searched for interactions between low-level microwaves and biological systems, but few effects have appeared that are clearly reproducible and physiologically significant, other than effects that are likely to be thermal in origin. However, few effects have been reliably demonstrated at power levels that are insufficient to produce significant heating (Bawin et al., 1975; Arber and Lin, 1985; Adey, 1990; Kullnick, 1992; Reite et al., 1994). The findings are quite heterogenous and comparisons are difficult due to the wide range of different physical and biological experimental conditions.

Increasingly in recent years experimental investigations were carried out in order to elucidate the interaction between nonionizing electromagnetic fields and biological systems. For a comprehensive review of the variety of findings see Polk and Postow (1986) and Michaelson and Lin (1987). However, the reported phenomena are very heterogenous. Results from various studies can only be compared to a limited extent because of very different physical and biological experimental conditions. Most investigations were performed in cellular model systems or small laboratory animals. Fundamental problems in this area of research are the extrapolation of those results to man and the assessment of observed effects as a potential health hazard.

In principle, one has to distinguish between thermal effects which are caused by heating the tissue through absorption of radiation energy and nonthermal direct radiation effects. Regarding the thermal effects of electromagnetic fields, knowledge has increased considerably. These effects can be estimated quantitatively and can be well controlled by keeping a safe distance. Increasing interest is focused now on the nonthermal effects of weak nonionizing radiation. But there is still a great lack of available data, especially in man, and the fundamental mechanisms of the interaction with biological systems are not yet understood in detail.

The purpose of our research was to illuminate putative effects of electromagnetic fields emitted by digital mobile radio telephones (GSM-systems) on the electroencephalogram of humans. In fact we investigated the awake EEG (Röschke and Mann, 1997) during a

realistic exposure period of nearly 3.5 minutes and the sleep EEG (Mann and Röschke, 1996) when subjects were exposed to the EMF for 8 hours.

## **2 No short-term effects of digital mobile radio telephones on the awake human electroencephalogram**

### **2.1 Subjects**

34 healthy male volunteers, aged 21 to 35 years (mean = 27 years, SD = 4 years), participated in the study. In order to rule out physical or mental illness, all subjects underwent a detailed history, physical and neurological examinations and a psychiatric exploration. In addition ECG, EEG and routine laboratory parameters were required to be normal. All subjects were non-smokers and were not taking any drugs. Consumption of alcohol and caffeine was forbidden during the last four days preceding the EEG recordings.

### **2.2 Methods**

The experimental sessions took place in a soundproofed electrophysiological laboratory of the Department of Psychiatry at the University of Mainz. In all cases, the investigation time was in the morning between 9 a.m. and 12 a.m. For each subject, two consecutive EEG registrations of about 10 minutes duration each were performed, interrupted by a break of 30 minutes, meanwhile the subjects were allowed to walk around. Each EEG registration was subdivided into 3 successive parts, each consisting of 80 sweeps at 2.55s duration. The first and the third segments served as a control of vigilance. During these parts, the electromagnetic field was always turned off. For the registration of the electroencephalic activity during the middle segments, the digital mobile radio telephone was active during one registration session and inactive during the other registration session. The order of application of the external field was randomized (in half of the subjects the aerial was active in the first experiment and vice versa), unrecognizable for the subjects under investigation (single blind condition).

The electromagnetic field was emitted by the aerial of a digital mobile radio telephone (GSM system) positioned at a distance of 40 cm from the vertex of the subjects and, therefore, comparable with normal use. It was a 900 MHz electromagnetic field pulsed with a frequency of 217 Hz and a pulse width of 580 ms. The radiated peak power of the aerial was 8 W, revealing an estimated power density of  $0.05 \text{ mW/cm}^2$  at a distance of 40 cm. The telephone was operated from an adjacent room by help of an extension lead, so the subjects were not informed about the experimental condition. The operation mode of the telephone (on/off) was controlled via a receiving aerial in a distance of 2 m from the telephone and an additionally used oscilloscope

The EEG recordings were performed in a prone position, during relaxed but alert wakefulness, with eyes closed. The monopolar EEG derivations were measured with Ag/AgCl surface electrodes fixed at the positions  $C_3$ ,  $C_4$  and ipsilateral mastoids ( $A_1$ ,  $A_2$ ) according to the international 10-20 system [Jasper, 1958]. Electrode impedances were below 5 KOhms. The ground electrode was positioned at the forehead.

After preamplification, the EEG signals were recorded on a Nihon Kohden EEG machine (50 Hz low pass filter, 0.3 s time constant) standing in the central unit. Either EEG channels were continuously drawn on paper. For further computer analysis, after

additional 45 Hz low-pass filtering (48 dB/octave) to avoid aliasing, the signals were sampled with a frequency of 100 Hz and digitized by a 12 bit analog- digital converter. The data were stored on the disc of a Hewlett-Packard A-900 digital computer in successive sweeps each consisting of 256 data points according to time segments of 2.55 s duration. During on-line registration, artifacts due to eye or body movements, were automatically eliminated by discarding those sweeps where the amplitude of one of the signals exceeded previously defined voltage thresholds. EEG registration was continued until a number of 80 artifact-free sweeps was achieved for each third of the registration periods. After the first and second third of the experiment, the data acquisition was interrupted for nearly 15 s to activate or inactivate the digital mobile radio telephone (unrecognizable for the subject under study). Thus, the complete EEG registration contained two times 240 sweeps.

Further computer analysis was performed off-line. For each sweep, the spectral power density was calculated via Fast Fourier Transform (FFT). Afterwards, the spectra of all 80 sweeps of each single third were averaged in the frequency domain. Thus, for each subject, the EEG recording was characterized segment by segment by an averaged spectral power density. For quantitative assessment of these spectra, the mean spectral power density was calculated in distinct frequency ranges [Herrmann et al., 1989]: delta (1-3-5 Hz), theta (3.5-7.5 Hz), alpha (7.5-12.5 Hz), beta (12.5-18 Hz). Further statistical analysis was based on these spectral parameters. Pairwise comparisons between the two experimental conditions (with and without electromagnetic field) was performed by applying the distribution-free Wilcoxon test for paired samples. Differences were considered statistically significant with a p-value of  $p < 0.05$ .

## 2.3 Results

The results of the evaluation of the mean spectral power densities in the previously defined frequency bands for the middle registration segment (sweeps 81-160) are summarized in Table 1.

	C3/A1		C4/A2	
Frequency range	Without field	With field	Without field	With field
Delta (1-3.5 Hz)	3.89±1.5	3.79±1.56	3.61±1.73	3.42±1.73
Theta (3.5-7.5 Hz)	0.70±1.97	0.62±1.82	0.70±1.86	0.36±1.82
Alpha 7.5-12.5 Hz	0.94±3.06	1.04±2.73	0.97±3.06	0.86±3.12
Beta 12.5-18 Hz	-5.12±2.72	-4.99±2.11	-4.47±2.49	-5.64±2.16

*Table 1. Mean spectral power densities (dB) in certain frequency bands for the middle EEG recording segment without and with electromagnetic field exposure (mean ± standard deviation, n=34, left: C<sub>3</sub>/A<sub>1</sub>, right: C<sub>4</sub>/A<sub>2</sub>). No statistically significant differences between the two experimental conditions could be detected.*

The mean values and standard deviations of the averaged spectral power densities in dB (0 dB equivalent to 1  $\mu\text{V}^2/\text{Hz}$ ) for the 34 subjects under the two experimental conditions. Pairwise statistical comparison of the data with and without exposure to the

electromagnetic field revealed no significant difference, neither for the frequency bands nor the EEG derivations. No difference between left and right hemisphere could be observed during active (field on) nor during inactive (field off) conditions. Moreover, it should be emphasized that the averaged spectra of the first, second, and last third of the EEG recordings were stable in time. There was no indication for an alteration of vigilance, i.e., we could not detect any decrease of the EEG alpha and beta activity nor an increase in the delta and theta range (Koella, 1982; Kugler, 1984).

## **2.4 Discussion**

In summary, studying the effect of pulsed high-frequency electromagnetic fields, emitted from the aerial of a digital mobile radio telephone, on the waking EEG, the statistical comparison of the spectral power densities in distinct frequency bands revealed no differences between the experimental conditions, with and without exposure to the field. Moreover, there was no indication to a bimodal distribution of the EEG alterations as would be expected in case of a differentiation between field sensitive and field insensitive individuals.

In fact, no alteration of the spontaneous ongoing EEG during a time period of nearly 3 ½ minutes of an active digital mobile radio telephone could be shown. However, this finding does not exclude any possible influences on brain function under exposure to the electromagnetic field. In recent years, at the cellular level several effects on biological systems induced by electromagnetic fields were described. Besides disturbances of the diffusion of calcium ions (Bawin et al. 1975; Carson et al. 1990; Dutta et al. 1989), there are some indications for alterations of information processing in the nervous system (Arber and Lin 1985, Kullnick 1992). Taking into account these effects, one has always to keep in mind that the EEG is only one aspect of cerebral function. Possible alterations of brain function are only partly reflected by the EEG, which is a well-known fact in clinical electroencephalography.

Several limitations must be considered in interpreting our results. They are only valid for the given experimental set-up. In order to avoid relevant alterations of vigilance, we only studied the short-term effect with an exposure time of nearly 3 1/2 minutes. We cannot make a statement concerning longer exposure times. Our results are based on the spontaneous EEG activity under the condition of alert wakefulness with eyes closed. They cannot be extended to other physiological states, as under the influence of sensory inputs or under mental tasks.

## **3. Effects of pulsed high frequency electromagnetic fields on human sleep**

### **3.1 Justification**

In this investigation we studied the effects of the electromagnetic field, irradiated by the aerial of a digital mobile radio telephone, on the sleep of normal subjects. In our design the intensity is weak, not leading to thermal effects. Sleep appears to be an appropriate physiological process to be studied in this area of research. On the one hand, sleep is a very complex biological process, controlled by the central nervous system and reacting



very sensitively to external influences. And although the exact biological mechanisms are not known in detail yet, the regular sequences of waking and sleeping states as well as the physiological microstructure of sleep are necessary requirements for correct information processing of the brain, metabolic homeostasis and intact immune function (Hobson, 1990). On the other hand, sleep is a well-defined biological condition, excluding to a large extent other external influences and stressors. Moreover, exposure can be of relevance due to possible time-integrating interaction mechanisms.

### 3.2 Methods

14 healthy subjects 21-34 years old (mean age  $27.3 \pm 4.2$ ), participated in the study. Each subject spent 3 successive nights in the sleep laboratory. Following an adaption night, two polysomnographies were performed. EEG signals were measured with Ag/AgCl surface electrodes fixed at the positions  $F_z$ ,  $C_z$ ,  $C_3$ ,  $P_4$ ,  $P_z$  and the mastoid, according to the international 10-20 system. All electrode impedances were below 5 k $\Omega$ . Unipolar EEG derivations (vs. mastoid electrode interconnected by two 5 k $\Omega$  resistors) as well as EOG, EMG of the m. mentalis and ECG were recorded.

A digital mobile radio telephone (Motorola, GSM system) was positioned at the head of the bed at a distance of 40 cm to the vertex of the subject. The device was operated from the neighboring room using an extension lead. The telephone aerial emitted a 900 MHz electromagnetic field pulsed with a frequency of 217 Hz and a pulse width of 580  $\mu$ s. The radiated peak power of the aerial was 8 W, resulting in an estimated average power density of 0.05 mW/cm<sup>2</sup> at a distance of 40 cm.

The subjects had not been allowed to fall asleep until the lights were switched off at 11 p.m. Polysomnographies were performed over 8h, the registration started at 11 p.m. and finished at 7 a.m. when the subjects were woken up. In one night, an exposure to the electromagnetic field for each subject occurred from 11 p.m. until 7 a.m., i.e. over a duration of 8 h, in the other night the transmitting aerial was turned off. The order of application was randomized and the subjects were not informed about the experimental condition. In six subjects, the first polysomnography was performed under exposure to the field and the second without application of the field, while for the other 6 subjects the sequence was vice versa.

Rating scales for measuring subjective perception of sleep quality and well-being during the following day (VIS-M, VIS-A) were filled out by each subject in the morning and in the evening of the day following the sleep laboratory investigations (Collegium International Psychiatria Sclorum, 1986). In addition, side effects were assessed by brief non-standardized interviews.

All signals were recorded using a Nihon Kohden EEG machine (0.3 s time constant and 50 Hz dB/octave low-pass filter for EEG signals). The sleep EEGs were scored visually by one experienced rater who was blind with respect to the experimental condition. Sleep stages were defined according to the criteria of Rechtschaffen and Kales (1968): wakefulness (predominating alpha activity), stage I (low voltage, mixed frequency EEG without rapid eye movements), stage II (background EEG similar to stage I, but additionally sleep spindles and K complexes), slow wave sleep (SW, stage III and IV,

characterized by high amplitude, slow wave activity), stage REM (characterized by rapid eye movements and low amplitude EMG).

For further computer analysis, additional 45-Hz low-pass filtering (48 dB/octave) was carried out to avoid aliasing effects. The EEG signal derived from Cz was sampled at a rate of 100 Hz and digitized by a 12-bit analog-digital converter. The data were stored continuously on the disc of a Hewlett-Packard A-900 digital computer in 1440 successive time intervals, each consisting of 2048 data points. Off-line power density spectra of the EEG signal were calculated applying FFT to each of the 1440 time intervals. Afterwards all spectra of a single night, unambiguously corresponding to one of the classical sleep stages, were averaged.

Statistical comparison of the classical sleep EEG parameters (table 1) and of the subjective parameters (table 4) was performed applying Wilcoxon test for paired samples (two-sided). For assessment of EEG power spectra, distinct frequency ranges were defined and the mean value of the spectral power density in these frequency bands was calculated. Statistical analysis was performed applying a two-way ANOVA model with sleep stage (awake, stage I, stage II, slow-wave-sleep, REM) and field exposure (without field, with field) as within-subject factors for distinct frequency ranges. Before, normal distribution was proven by the Kolmogoroff-Smirnoff test. Differences were considered statistically significant with a p value <0.05.

### 3.3 Results

The results of the classical sleep analysis according to the criterial of Rechtschaffen and Kales (1968) are summarized in Table 2. The sleep efficiency index was identical under both experimental conditions. Sleep onset latency was significantly reduced after exposure to the electromagnetic field ( $p < 0.005$ ). REM latency showed a tendency to increase. However, the difference in REM latency did not reach statistical significance. Regarding sleep architecture, in the exposure night a significant decrease of the percentage of REM sleep could be observed ( $p < 0.05$ ), while the other sleep stages were not significantly affected.

	Without fields	with field	
Sleep onset latency, min	12.25±5.96	9.50**±	4.44
Total sleep time, min	470.04±14.11	473.38±12.80	
Sleep efficiency index,%	0.95±0.03	0.95±0.03	
Number of awakenings	5.17±5.51	4.58±2.61	
Awake, %SPT	2.99±3.45	2.95±2.71	
Stage I, %SPT	22±2.20	10.22±3.06	
Stage II, %SPT	52.98±5.33	54.14±7.03	
Slow wave sleep, %SPT	15.70±3.30	16.69±5.86	
REM, %SPT	17.07±3.23	13.91*±2.88	
REM latency, min	84.96±22.69	93.17±27.87	

SPT = Sleep period time. \* $p < 0.05$ ; \*\* $p < 0.005$ .

Table 2. Classical sleep EEG parameters (mean  $\pm$  standard deviation 12 subjects)

For assessment of the EEG power spectra, first the entire frequency range from 1 to 20 Hz was taken as a basis. Table 3 shows the mean power density of the averaged spectra for each sleep stage. Analysis by a two-way ANOVA (Table 4) with sleep stage and field exposure as within-subject factors revealed, besides a significant main effect of the factor sleep stage which is evident ( $p < 0.001$ ), a significant interaction between sleep stages and field exposure ( $p < 0.05$ ). Pairwise comparison of the experimental conditions without and with field in the individual sleep stages revealed an increase of the mean power density during REM sleep ( $p < 0.05$ ), while a decreasing tendency of the mean power density was observed in the sleep stages I, II, slow wave sleep and in the waking state. For a more detailed analysis, smaller frequency bands were defined: delta = 1-3.5 Hz, theta = 3.5-7.5 Hz,  $\alpha_1$  = 7.5-12.5 Hz,  $\alpha_2$  = 12.5-15 Hz, beta = 15-20 Hz. During REM sleep, an increase of the mean power density under field exposure was found in all frequency bands, whereas the other sleep stages showed again a decreasing tendency for all frequency bands (table 3) revealed significant interactions between sleep stages and field exposure for the  $\alpha_1$  band ( $p < 0.01$ ) and the  $\alpha_2$  band ( $p < 0.01$ ).

	Without fields	with field
Awake	-5.846 $\pm$ 1.809	-6.563 $\pm$ 1.524
Stage I	-8.109 $\pm$ 1.323	-8.717 $\pm$ 1.121
Stage II	-6.909 $\pm$ 1.574	-7.134 $\pm$ 1.438
Slow-wave sleep	-6.703 $\pm$ 1.828	-7.131 $\pm$ 1.827
REM	-10.133 $\pm$ 1.431	-9.595 $\pm$ 1.606

0 dB correspond to 1 ( $\mu V$ )<sup>2</sup>/Hz. \* $p < 0.05$

Table 3. Mean power density (dB) of the averaged power spectra of different sleep stages in the frequency range from 1 to 20 Hz (mean  $\pm$  standard deviation of 12 subjects)

	Sleep stage	Field	Sleep stage x Field
Total	37.99***	1.76	3.58*
Delta	162.43***	0.41	1.35
Theta	71.83***	0.43	1.83
Alpha1	37.35***	2.40	3.80**
Alpha 2	36.69***	4.29	4.34**
Beta	83.91***	1.71	1.50

\* $p < 0.05$ ; \*\* $p < 0.01$ ; \*\*\* $p < 0.001$

Table 4. F-values of the ANOVA procedures with sleep stage and field exposure as within-subject factors applied to the mean power densities in the given frequency ranges.

None of the subjects reported any side effects during the investigation nights or the following days. Regarding subjective sleep quality and alertness in the morning, no significant effects could be observed. Also, the subjective sleep efficiency parameters sleep latency, number of awakenings and sleep period showed no significant alteration, but the changes were concordant with the corresponding objective sleep EEG parameters. During the day following nocturnal exposure to the electromagnetic field, the subjects felt significantly more calm ( $p < 0.05$ ) and reported a higher energy level ( $p = 0.055$ ) compared to the night without application of the field.

### 3.4 Discussion

Besides a hypnotic effect with significantly reduced sleep onset latency, exposure to the electromagnetic field induced an alteration of REM sleep, quantitatively as well as qualitatively. The significant decrease in the duration and the percentage of REM sleep, together with the trend towards an increase of REM latency, points to a REM-suppressive effect of the field. Moreover, spectral analysis revealed a specific alteration of the EEG signal during REM sleep with an increased spectral power density, which was not observed in the other sleep stages and in the waking state. Here the alpha frequency range was mainly affected. Regarding the reports of the subjects, no significant impairment of sleep perception was observed, well-being during the following day was affected in the sense of increased calmness. The results indicate a specific alteration of sleep regulation. To our knowledge, comparable investigations do not exist to date. In accordance with our findings, Reite et al. (1994), however, also reported a hypnotic effect during waking EEG registrations in healthy subjects. Exposure to a 27.12-MHz radiofrequency electromagnetic field amplitude-modulated (sine wave) at 42.7 Hz and applied over a 15-min time period resulted in a shortening of sleep latency, an increase in the duration of sleep stages, and the subjects reached a deeper stage of sleep compared to the placebo treatment. As in our study, no appreciable sensations were experienced by the subjects. Direct quantitative comparison of the results (sleep latency, duration of sleep stages) is not possible due to methodological differences. Besides different carrier frequency and modulation conditions, an older classification of sleep stages was used by Reite et al. (1994), based on the Loomis criteria. With regard to sleep architecture, no conclusion can be drawn, because the EEG registrations performed by Reite et al. (1994) were restricted to 15-min only. Moreover, the underlying interaction mechanisms might be different in the two studies. Although several reports indicate that pulsed microwaves, as used in our study, are more effective than continuous-wave radiation, at present it is an open question whether the two waveforms might elicit different biological effects at the same average power density. However, the occurrence of thermoelastic phenomena in biological tissue is generally accepted in the case of pulsed electromagnetic fields (Polk and Postow, 1986), possibly contributing to the observed effects in our study.

Regarding the observed alterations of sleep architecture, some support of our results comes from a clinical study performed by Sandyk et al. (1992), although only a very limited comparison can be made due to the greatly varied experimental conditions. In neurological patients exposed to a magnetic field, behavioral effects could be produced which paralleled those observed in REM sleep-deprived subjects. Therefore, the authors

hypothesize that the behavioral effects of treatment with magnetic fields may be mediated via REM sleep deprivation. However, no sleep EEG registrations were performed in this study.

The interaction mechanism of the electromagnetic field and the sleep regulation system is unknown. Until now, no comprehensive theory exists which could provide a satisfactory explanation of the variety of reported effects in biological systems under exposure to electromagnetic fields. However, in recent years several hypotheses have been developed based on experimental findings and theoretical considerations (for an overview see Polk and Postow, 1986; Michaelson and Lin, 1987; Taylor, 1981). It now appears quite certain that weak nonionizing radiation, not leading to a heating of tissue, is able to cause biological effects. According to theoretical considerations by Weaver and Astumian (1990), macromolecules are sensitive to very weak external electrical fields due to conformational transitions that involve intramolecular movements of charge or changes in dipole moments. Such field-induced conformational changes could for instance modulate enzyme activities. Considering the time-integrating mechanisms of enzymes-catalyzed membrane-associated reactions, field intensities become relevant which are below the thermal noise due to random fluctuations in the transmembrane potential.

Several studies have identified the cell membranes as the primary site of interaction with electromagnetic fields (Adey, 1988, 1990; Lawrence and Adey, 1982; Grundler, 1992). There is strong evidence for internal nonlinear, non-equilibrium processes, induced by the fields, modifying the coupling of humoral stimuli from surface receptor sites to the cell interior, such as neurotransmitters and hormones. Intramembranous protein particles which form pathways for signaling and energy transfer play a key role, as well as alterations of calcium-ion binding along the membrane surface. Thus, by modulating the inward and outward signal streams through the cell membrane, electromagnetic fields can lead to alterations of intracellular processes as well as intercellular communication.

On the cellular level, a number of phenomena induced by electromagnetic fields in biological systems have been described, which in principle can modify the function of the central nervous system and thus could be accountable for our findings. Especially a disturbance of the calcium homeostasis could be proven, which is important for a multitude of both basic cellular and complex neuronal processes, such as neural excitation, regulating neurotransmitter secretion and hormone molecule binding at membrane receptor sites (Bawin et al., 1975; Carson et al., 1990; Dutta et al., 1989). There are also indications for modifications of information processing in the nervous system. Arber and Lin (1985) reported inhibitory as well as excitatory influences of high-frequency electromagnetic fields depending on the kind of signal modulation. Kullnick (1992) observed alterations of the membrane potential of central nervous in form of hyperpolarization under exposure to weak non-ionizing radiation. Additionally the threshold of excitation was changed. Moreover, effects on upper physiological levels must be discussed, such as alterations of endocrine systems. Here, especially melatonin has received attention (Schneider and Semm, 1992; Yaga et al., 1993). Also, in several investigations, influences on neurotransmitters were found (reviewed in Michaelson and Lin, 1987), such as serotonin, noradrenaline and dopamine, which are well known to play an important role in the sleep-wake regulation; but in these studies probably hyperthermia was predominantly responsible rather than direct radiation effects.

The relevance of our results concerning possible health hazards cannot be assessed yet. Although a complete understanding of the physiological function of the different sleep stages is still missing, some principal points concerning their functional meaning have become obvious. While slow wave sleep seems to be associated with recovery processes (Horne, 1993), REM sleep plays a special physiological role for information processing in the brain. Here selecting, sorting and consolidating of new experiences received during the waking state were performed as well as linking them together with old experiences (Koukkou and Lehmann, 1983). For this reason, modification of REM sleep parameters induced by the electromagnetic field may be associated with an alteration of mnemonic functions and learning processes. But because cognitive functions were not assessed in the present study, no conclusions can be drawn about this from our results.

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# Brain Activity and the Role of Weak Electromagnetic Fields

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## 1. Introduction

Looking for neurophysiological signals suitable to evaluate biological effects of electromagnetic fields (EMF) there are basically three parameters generally accepted for routine applications:

- Spontaneous electroencephalogram (EEG),
- Evoked potentials (EP) of various modalities
- Event related potentials (ERP) of various modalities

All these measures reflect electrical potentials originating from intra-neuronal electrical currents and from synaptic processes. According to basic physical laws their magnetic counterparts can also be observed (magnetencephalogram (MEG), evoked magnetic fields (EF), event related magnetic fields (ERF)) although the necessary device (magnetencephalograph (MEG)) requires huge technical and financial investment. It is extremely susceptible to external electromagnetic fields. Therefore till now no MEG-EMF study has been published.

All of these signals reflect ensemble activities of nervous cells and thereby are candidates for EMF interaction via various basic cellular and biochemical EMF-effects reported by various authors. Some keywords are: Membrane effects (Adey, 1996),  $\text{Ca}^{++}$ -efflux (Bawn et al. 1975), blood brain barrier (Fritze et al., 1997). None of the before mentioned effects - if valid at all - could explain any potential EEG-/EP-/ERP-effects in terms of a sound comprehensive model of signal generation. However, on the other hand, all these mechanisms are known to be involved in the complex electrical brain activity and thus might lead to an overall sensitivity of neurophysiological parameters with respect to EMF.

## 2. Basic Signal Properties

### Electroencephalogramm (EEG)

Clinically the EEG is interpreted as a sensitive indicator for global brain function. Intraindividual topographical and/or spectral EEG-changes are found under a large variety of neurological and psychiatric symptoms and diseases but may also occur under varying stages of consciousness or after application of cerebroactive drugs. In order get

physiologically meaningful results routine-EEG are usually recorded while the subject is relaxed and awake, keeping its eyes closed. The EEG is one of the standard parameters for estimating sleep stages. In contrast to its sensitivity with respect to global brain function it clearly lacks the ability to provide specific information about functional deficits if any. If this is needed it may be derived with other methods like EP or ERP (see below).

Technically the normal EEG is characterized by amplitudes in the range of some 10  $\mu$ V, bandwidth of about 0 ... 50 Hz, dominant rhythm near 10 Hz and noise level below 2  $\mu$ V<sub>p-p</sub>. Electrodes (usually made of Ag/AgCl, gold or steel) are fixed on the subjects head thus coupling it to the EEG-amplifier. Usually up to 32 (even more under research condition) channels of EEG originating from different scalp regions are recorded simultaneously in order to cope with its complex topographical structure.

### Evoked potentials (EP)

EP represent the brain's electrical response to external physical stimuli of various modalities, such as acoustic clicks (->acoustically evoked potentials (AEP)), sequentially inverting chess board pattern presented on a display (->visually evoked potentials VEP)), electric pulses applied via electrodes (->somatosensory evoked potentials (SEP)). EPs are usually a compound of some partly overlaying subsequent half waves ('components') with well defined peak latencies and amplitudes. Some of these components but not all of them can be attributed to distinct stages of perceptual processing in distinct anatomic regions. An intact EP indicates that the corresponding sensory pathway from the stimulation on to the cortex is intact and vice versa. EPs exhibit a large intraindividual amplitude-variability (up to 50%, Jørg and Hielscher, 1984).

Surface recorded EP-amplitudes are an order of magnitude below the spontaneous EEG or even smaller, depending on the type of EP. Therefore they can only be observed after averaging a sequence of stimulus-related EEG epochs. Its spectrum covers a range from about 20Hz for late (appr. 100...1000ms) components up to 2 KHz for early AEP (appr.1...10 ms). EP exhibit a modality specific topographical distribution. However, in contrast to the EEG only a few (1...3) channels are needed for a sufficient characterization of the EP (Jørg and Hielscher, 1984). Intracerebral EP may be recorded directly, i.e. without averaging, if measured in the generating neural structure.

### Event related potentials (ERP)

ERP are specific brain-potentials elicited by internal mental or cognitive processes. In order to provoke them the subject has to perform a predefined task while appropriate stimuli are presented (e.g. Heinze and Mangun, 1995). Example: A sequence of frequent standard and rare target tones are binaurally presented. The subject has to press a button on detection of a target stimulus on the left side. By careful analysis ERP allow for a differential temporal and topographical analysis of all the sub-processes involved. Clinical applications include the examination of memory processes, visual attention etc. Many of them though not all can be linked to well known anatomical structures.

Technically ERP are similar to EP: Stimulus related averaging is needed to extract these

low-amplitude signal (some  $\mu V$ ) from the spontaneous EEG. However like the EEG, ERP need to be recorded from a large number of electrodes simultaneously because the topographic distribution of these potentials carries considerable information.

### 3. Error Sources

As known from clinical drug studies several types of errors or distortions may occur if some basic experimental rules are violated:

- Vigilance must be controlled, especially in case of longer ( $>10$  min) recording sessions
- With respect to vigilance it is preferable to randomize the sequence of measurement conditions (e.g. field on/off).
- Artifacts, i.e. technically or biologically generated signal distortions, must be detected and rejected from quantitative evaluation.
- Subjects should not know about the actual application of the EMF ('blind' condition).
- The amplifier must comply with electromagnetic compatibility demands, especially regarding frequency response.
- An appropriately designed measurement cabin with a homogeneous spatial EMF-distribution increases the validity of the results.

### 4. Reported Studies

#### 4.1 Overview

In the past concerns have been raised about potential health risks caused by (i) nuclear magnetic resonance tomography (NMR) with its extremely high magnetic field strength (papers on that will not be addressed here because the focus of this communication is on weak EMF), (ii) high frequency fields of radio and television (TV) stations and (iii) various kinds of low frequency EMF including 50/60 Hz fields originating in residential environments from arbitrary electrical equipment. Recently with the increasing popularity of cellular phone networks pulsed EMF entered the focus of interest pushed by users and by political pressure groups. Studies on humans and experiments applying animal models have been performed, the latter concentrating on hippocampal structures either in vivo or in vitro. Faltenberg-Blank and Perevalov (1977) have shown that this neural structure together with the hypothalamus is most sensitive with respect to EMF.

Lots of studies have been focussing on the impact of low frequency EMF-components on brain function because these fields are estimated most likely to influence brain function (Adey et al., 1992). According to Adey, high frequency EMF below 1 GHz do not affect central nervous system (CNS) unless they are amplitude modulated or pulsed at extremely low frequencies in the spectrum below or not much higher than 100 Hz.

Recently two papers were published (Schienle et al. 1996, Schienle et al. 1997) dealing with EEG and psychological fluctuations under the influence of sferics which are a kind of naturally EMF. Sferics are electromagnetic Impulses with frequencies between 1-100

kHz which are emitted during thunderstorms. During their propagation over long distances (>1000 km) sferics undergo pronounced changes in field strength and spectral structure.

In contrast to potential health hazards EMF were also evaluated with respect to potential therapeutic effects. However, none of these, if any, has gained general acceptance so far.

#### **4.2 Low frequency EMF and low frequency modulated EMF**

Bell et al. (1992) exposed rabbits to magnetic fields (0.1 mT, 5Hz) and simultaneously recorded the animal's EEG. They found changes in EEG power spectra in most but not all cases. This effect vanished if the frequency was set beyond 20 Hz.

In another experiment Bell et al. (1994b) found a decreased 10-Hz human EEG-activity under the influence of a 10 Hz magnetic field (0.1 mT).

The same author (Bell et al. 1994a) observed an unsystematic interaction between 1.5/10 Hz magnetic fields (0.04 mT) and human brain activity at these frequencies.

Persinger et al. (1997) observed a driving effect, i.e. an enhancement of certain signal frequencies according to the external field, of their EEG upon application of complex low frequency magnetic fields (1 mT) over some minutes. The signal-evaluation is not quite clear from the paper but the results are to some extent in line with those derived by Bell et al. (1994a) but not with Bell (1994b).

Similar effects, although derived under long term exposition (4 hr) were reported by Gavalas et al. (1970): Monkey hippocampal EEG records showed a slow increment in spectral activity at the field frequency (7Hz) after exposition with a 7 Hz electrical field (2.8 V/m).

Bawin et al., (1973), observed an enhancement of spontaneous EEG rhythm in cats following a 147 MHz radiofrequency field ( $1 \text{ mW/cm}^2$ ) exposition (20 sec bursts) modulated at frequencies close to the biologically dominant frequency.

Even more complex results are found in a paper of Thuroczy et al. (1994): Some EEG spectral band power values increased after exposition of rats to 2.45 GHz microwave field with 4 Hz amplitude modulation at an EMF flux of  $30 \text{ mW/cm}^2$ .

Recently Bawin et al. (1996) conducted an experiment with magnetic fields (5.6/56/560  $\mu\text{T}$ ) in the spectral range 1..100 Hz acting on rat hippocampal slices in vitro. As a result, induced slow rhythmic activity (similar to those observed during memory processes in vivo) were destabilized by 1Hz and 60 Hz field frequency. Therefore, Bawin and colleagues argue that this kind of fields might interfere with functional brain states.

Both EEG and acoustically evoked potential (AEP) were examined by Lyskov et al. (1993) regarding changes induced by an 1 hour exposition of normal humans to a 45 Hz magnetic field (1.3mT). They found an increase of Alpha (8...14 Hz) and Beta (14-20Hz) power in frontal areas and of total power in occipital regions. Changes in late AEP were observed for late components (100 ms) but not for the early ones.

Dowman et al. (1989) monitored macaques by means of three different EP-modalities (AEP, VEP, SEP) under different EMF conditions (60 Hz; 3kV/m/.01mT, 10kV/m/.03mT, 30kV/m/.09mT ) plus control. No changes occurred except for late SEP components exhibiting an amplitude decrease at high field strength.

Vorobyov et al. (1997) measured the EEG of rat brain during a 10 min exposure to 945 MHz radiofrequency field ( $0.2 \text{ mW/cm}^2$ ), amplitude modulated at 4Hz. They found a significant hemispheric asymmetry in the 10...14 Hz band power values as compared to control condition. The authors refer this finding as most likely to an asymmetrical neurochemical status. However, this assumption is not supported by any other EMF-study.

## Summary

The large number of different experiments both with humans and animals exhibit a large variety of partly contradictory effects. This missing convergence to some extent may be attributed to the fact that many of these studies are not sufficiently controlled (especially excluding potential confounders) in the sense of clinical studies. In addition none of the experiments can serve as a replication for any other one. Therefore not more than hypotheses can be formulated from these findings regarding possible interference of low frequency EMF with spontaneous EEG and EP. Well designed, well controlled and well conducted studies with a clear and simple hypotheses are urgently needed to get sound insight into the basic mechanisms of interaction.

### 4.3 Brain function under exposition of GSM-EMF and other high frequency fields.

#### 4.3.1 Spontaneous EEG of awake subjects

Several studies on potential influence of GSM-like high frequency fields have been presented so far, all of them except one for 900 MHz and 217 Hz pulse frequency.

R'schke and Mann (1997) conducted a study on normal subjects being exposed to a GSM-field (217 Hz,  $0.05 \text{ mW/cm}^2$  at the brain surface) for a few minutes. The study was performed under blind condition with randomized order of active (i.e. field on) and control condition. Compared to the intraindividual control condition EEG spectral parameters did not exhibit any changes under exposition.

Spittler et al (1997) used a similar experimental design (same field parameters, comparable exposition time). They also did not observe any EEG changes.

Thuroczy et al. (1996) applied a modified experimental setup by adding a second exposition phase, however without randomizing the order of active/control conditions. They reported a significant difference between second active phase and its preceding control-EEG (increase of alpha activity (8..12 Hz)). This effect did not occur during the first active phase. A comment on artifact and vigilance control is missing.

Reiser et al. (1996) also evaluated possible GSM-induced spectral EEG variations. In addition to a regular control condition they recorded a third session with a so called 'therapy instrument' operating at 150 MHz with a mostly magnetic field (400 pT) pulsed at 9.6 Hz. The GSM field was comparable to the studies mentioned before. Reiser and colleagues found a sudden increase in all frequency bands but delta (1..5Hz) and theta (5..7 Hz) after the onset of the 150 MHz source. This activation persisted over several minutes after field cessation. The GSM field exhibited a mild version of this effect in just two electrodes located closest to the antenna: 15 min after field cessation a significant increase in beta1 (13...19 Hz) activity was observed. Taking into account the large number of simultaneous statistical test, this observation should not be estimated as a standing result but serve as a hypothesis which could be confirmed in a second study.

Von Klitzing (1975) reported from a similar study, this time however following a fixed sequence of control and active phases coming out with approximately one hour of EEG recording without any break. He applied a magnetic 150 MHz-field ( $10^{-8}$  T) pulsed with 217 Hz. Following the paper, a decrease in alpha-activity was observed during both active phases as compared to their preceeding control phase. The paper does not specify the way and quality of vigilance control, a statistical evaluation is also missing. Also the large variation of the EEG spectra over the whole experimental session is unusual for normal subjects.

#### 4.3.2 Sleep studies

In a first study Mann and R'schke (1996) demonstrated a sleep inducing effect with shortening of sleep onset latency and reduction of REM-pahse under the influence of a GSM- 900MHz field (217 Hz pulse frequency,  $0,2 \text{ W/m}^2$ ) on healthy subjects. These findings however were no longer statistically significant when the experiment was repeated with a slightly modified experimental setup (Wagner et al. 1998). Details will be presented elsewhere in this workshop.

Yet another study was conducted by Hinrichs and Heinze. (1998) with application of GSM like EMF (1800 MHz,  $2\text{W/m}^2$ , far field characteristic). They also lacked finding any EMF-induced effects on sleep dynamics. Spectral analysis also did not show any systematic variations (in line with Wagner et al., 1998).

#### 4.4 Sferics and brain function

Schienze et al. (1996) and Schienze et al. (1997) described an experiment with simulated sferics (magnetic field peak strength 50 nT). Sferics are a kind of natural EMF. Normal subjects were exposed to these randomly triggered pulses over 10 min. In the first study an decrease in alpha and beta power was observed during application of the EMF. In their second paper however the authors mention an increase of the same parameters, persisting even after the field was switched off. The authors relate this contradictory results to different classes of subjects as revealed by psychological test scores. Both these studies lack any information regarding vigilance control. In addition it remains unclear whether the subjects knew about the application of the sferics fields (i.e. if the

experiment was designed with blind condition.)

#### **4.5 EMF as a therapeutic method**

In a couple of papers sleep inducing effects of a short term treatment with a so called 'low energy emission therapy' device was reported (Reite et al., 1994, Pasche et al., 1996). This device generates 27.12 MHz electromagnetic signals with amplitude modulation at 42,7 Hz (specification in one paper) or according to more complex scheme as mentioned in the second paper. These signals are fed into the subjects head via an special mouthpiece being placed on the tongue. Following the papers, several classical sleep parameters are significantly influenced under this therapy indicating an improved sleep quality. Taking into account the significantly deviating experimental design and the completely different field characteristic a comparison with other sleep studies is not reasonable. Results derived with this instrument have been presented only by this group.

A couple of case reports indicate that various symptoms of several neurological diseases might be reduced under EMF treatment:

After repeated administration of 1:T complex pulsed magnetic fields Baker-Price et al. (1996) observed in four patients an improvement of psychological depression in the course of acute brain injury .

In a variety of different papers Sandyk (1998a, 1998b, 1998c, 1997a, 1997b, 1997c, 1997d, 1997e, 1997f) described, how the course of several diseases may benefit from EMF. Some of them are: Normalization of VEP in multiple sclerosis (MS), improvement of cognitive dysfunction in MS, general improvement in the long term course of MS, reduction of various symptoms in patients suffering from Parkinson's disease, reduction of symptoms in patients with Tourette syndrom. None of these observations has been validated by standardized controlled clinical studies.

### **5. Discussion and Conclusions**

Comparing the studies on low frequency EMF-effects to those conducted with GSM-like fields, the widely varying and to some extent contradictory results are obvious. Therefore at present none of the various effects can be claimed to be a standing fact. Not all studies match the demands of a sound clinical study keeping out or randomize as many confounding factors as possible. On the other hand there seem to be some hints of possible effects which need further investigation. A common set of hypotheses and a standardized experimental approach could help to elucidate potential biological effects of low frequency EMF.

Most of the studies on GSM-field-applications have lacked to show any significant neurophysiological effect, however some minor hints might indicate that there could exist at least some susceptibility of man's brain to high frequency fields. However, even if these would turn out to be definite the interpretation in terms of pathology would remain

an open question taking into account that in other fields of applications similar EMF-effects are accepted as positive therapeutic effects.

No study was published so far dealing with ERP and EMF. The reason might be that ERP measurements are much more demanding regarding experimental technique and need special experience. On the other hand these experiments could provide information about potential impact of EMF on cognitive processes like attention, memory, motor control etc.. Statements about these issues would have much more practical relevance.

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## **Effects of Extremely-Low Frequency Electric and Magnetic Fields on Physiological Sleep Parameters and Sleep Quality in Humans**

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### **Abstract**

The Electrical Hypersensitivity Syndrom (EHS) is a very complex problem with a variety of non-specific health symptoms. The difficulty in finding a correlation between electric and magnetic fields and effects in humans stands in contrast to the rising numbers of case studies from people suffering from EHS.

In many case reports sleep disturbances such as multiple awakenings, problems with falling asleep, long waking hours during the night and early awakening in the morning are frequently reported. These case reports have to be considered as forerunners to scientific studies and therefore have to be taken seriously. This review is a summary of the research done on the effects of extremely-low frequency electric and magnetic fields on sleep in humans and presents preliminary results of a study (Project NEMESIS) that is currently underway investigating the effect of EMF on sleep in volunteers suffering from EHS.

### **1 Sleep and sleep parameters**

In almost every living creature we can find circadian rhythms in organic functions, humans are no exception to the rule. Even if environmental influences are eliminated, the cycles of circulatory and metabolic functions, body temperature and brain-activity are sustained, although the length of a period may extend to more than 24 hours. The functional changes seem to be triggered endogeneously (biological clock) [1]. The endogenous rhythms are synchronized - under natural conditions - by external „zeitgebers“ to the 24-hour period of the day. In humans, the synchronization is dominated by social factors, mainly by the periodicity of social activity, while terrestrial zeitgebers such as light-dark-cycles play only a secondary role. The endogenous control mechanisms for sleep-wake-cycles are also subject to these external zeitgebers.

The physiological parameters which are used to characterize human sleep (i.e. brain activity, heart-rate, respiration and movements) are also called sleep parameters. If sleep parameters are influenced by external or internal stimuli, subjective sleep quality could, as a consequence, be affected either positively or negatively. This hypothesis can be extended to the effect of extremely-low frequency EMF: The effect of EMF on sleep quality is caused by changes in sleep parameters.

#### *1.1 Sleep stages*

Sleep is generally regarded as a state, but it is, nevertheless, a behavior [2]. Active brain mechanisms cause us to engage in the behavior of sleep. Brain-wave recordings (EEG) are used to study the activity of the brain during the night. From these recordings, five stages can be distinguished, apart from waking state. Stages 1-4 are classified by differences in amplitude and frequency of the brain-activity. Stage 1 is the first stage after the onset of sleep followed by stages 2 - 4. Stages 3 and 4 are called slow-wave sleep because of the dominance of low frequency brain-waves ( $< 3.5\text{Hz}$ ). The fifth stage is called REM-sleep. During REM-sleep rapid eye movements (REM) occur as well as a low muscle tonus and dreaming (narrative type of dreams) [2]. Sleep stages alternate between periods of REM- and slow-wave sleep. The duration of one cycle is approximately 90 minutes. With each cycle the slow-wave activity gets shorter while REM-sleep lasts longer.

### *1.2 Objective and subjective sleep measures*

Reliable research in human sleep is conducted in a sleep laboratory. Several electrophysiologic measurements are applied to characterize human sleep. The physiological parameters of sleep are brain-wave activity (EEG), heart-rate (ECG), eye movements (EOG), muscle tonus at the chin (EMG), respiration (ECG, induction-plethysmography, air-flow-sensors at the nostrils), movements (Actigraphy), body temperature and skin conductivity. The combined methods are also known under the expression polysomnography. The polysomnography is an objective sleep measure, the parameters cannot be influenced voluntarily by the subject.

Data on sleep quality is more difficult to obtain. Sleep quality is a subjective measure, which reflects the subjective estimation of one's sleep. It is - as a rule - dependent on the individual perception. Results from polysomnographic sleep studies and sleep quality questionnaires do not necessarily have to be correlated.

### *1.3 Sleep disorders and other influences on sleep quality*

Insomnia is a problem that affects at least 20 per cent of the population at some time [3], but unfortunately, little is known about its causes. There is no single definition of insomnia that can apply to all people. The amount of sleep that individuals require is quite variable. A short sleeper may feel fine with five hours, a long sleeper may still feel unrefreshed after 10 hours of sleep. Although many people do believe that they do not get as much sleep as they would like, insomnia must be defined in relation to a persons's particular sleep needs [2]. Insomnia is not a disease. It can be caused by depression, pain, illness, stress or even anticipation of a pleasurable event.

Sleep disturbances can be defined as changes in either physiological or subjective parameters of sleep. This implicitly includes effects in the body that are not consciously perceived by the sleeping person. Events which affect the subjective estimation of sleep (sleep quality) are perceived sleep disturbances.

## **2 Effects of extremely-low frequency electric and magnetic fields on sleep**

A literature research was conducted searching the following databases: MEDLINE, INSPEC, CC (Current Contents), BA (Biological Abstracts), Sociofile, Sigle (grey literature). The results from the query are listed in table 1 below. The keywords used were: electric, magnetic, electromagnetic, field, EMF, ELF, extremely-low, non-ionizing, sleep, melatonin, circadian rhythm, polysomnography, physiological, psychological,

neurasthenic, neurovegetative, brain, respiration, heart-rate, pulse, heart rate variability, interbeat interval. The keywords were selected with regard to their relevance in the context of EMF effects on sleep and were compiled in the search string in order to optimize the search results.

*In short, no studies exclusively dealing with the effect of extremely-low frequency (ELF) electric or magnetic fields on sleep in humans have been found.* However, the search produced three different papers which report either physiological or endocrinological effects of ELF EMF that are related to sleep parameters or sleep in general [11,16,19] and one paper which reports an effect of weak EMF on circadian rhythms [4]. Two papers not listed in table 1 dealing with the effect of ELF EMF on sleep quality in humans will be discussed in chapter 2.2. There is a small number of papers on high-frequency EMF and sleep [16] that have been taken into account only in part because they have not been the object of the search. Nevertheless, they produced important findings with respect to sleep in humans.

Database	Year	Number of References Papers	
MEDLINE	1966 - 6/98	5	Wever [4]; Selmaoui et al. [11]; Reite et al. [14], Sandyk et al. [18], Sastre et al. [19]
INSPEC	1969 - 6/98	2	Reite et al. [14]; Sastre et al. [19]
CC (Current Contents)	1996 - 6/98	3	Selmaoui et al. [11]; Reite et al. [14]; Sastre et al. [19]
BA (Biological Abstracts)	1980 - 3/98	1	Selmaoui et al. [11]
SIGLE (grey literature)	1980 - 12/97	none	
Sociofile	1974 - 4/98	none	

Table 1: Results of the literature research using CD-ROM-databases (SilverPlatterâ)

The findings of the literature search stand in contrast to the growing numbers of case reports from people suffering from EHS. Therefore, it is obvious that the effects of extremely-low frequency electric and magnetic fields on sleep in humans still need to be investigated further in order to prove or dismiss a correlation between EMF and sleep disturbances in people and especially in those suffering from EHS.

### 2.1 Circadian rhythms, melatonin and extremely-low frequency EMFs

Wever [4] reported that the free-running circadian periods in humans in the absence of all external cues are influenced by weak square-wave 10Hz electric field of 2.5 V/m. Constant field exposure results in a significant shortening of free-running periods, while a periodically switched field can even act as a zeitgeber and thus synchronize the circadian rhythms. The fields used in Wever's study were the weakest ever to produce a significant biological effect in humans. Due to the special experimental setup (total isolation of the subjects from all external stimuli) it is not clear, whether this effect is still relevant under normal environmental conditions, where far stronger zeitgebers act upon human beings. Sleep is stimulated by excretion of large quantities of melatonin mainly from the pineal gland during the dark period of the day. Light inhibits the production of melatonin but does not stop it altogether [5]. In recent years, melatonin has gained widespread

attention not only in frequent-flyer-communities because of the supposed synchronization effect on circadian rhythms (a remedy for jet-lag). As hypotheses, a decrease of nighttime melatonin could promote cancer (by reduced scavenging of radicals) or even have effects on human sleep (by alteration of circadian rhythms).

The effect of extremely-low frequency electric and magnetic fields on melatonin has been discussed in many studies. Evidence from animal studies show an alteration of circadian melatonin-rhythms whereas human studies failed to reproduce this effect [6]. However, a link between EMF and melatonin production, levels or decomposition in humans has to be proven first.

Lambrozo et al. [7] summarized the current knowledge concerning animal or human experiments with regard to melatonin and low frequency EMF finding a reduction in pineal melatonin production or an increase of melatonin degradation in four studies on rodents. Although one study failed to confirm these findings. The field levels varied between 2 and 65 kV/m. A number of magnetic field experiments with rodents showed a decrease in nighttime melatonin (field strengths from 0.02 to 100 $\mu$ T), whereas some other studies failed to find an effect. In addition, there is a lack of evidence for a dose-response relationship (where dose = field strength), even noted in some of the studies with positive findings. Two studies performed on non-rodent mammals failed to show an effect.

Human studies with regard to melatonin have been conducted by Graham et al. (60Hz magnetic field, 1 - 20 $\mu$ T) [8, 9] and Selmaoui et al. (50Hz magnetic field, 10 $\mu$ T) [10, 11]. The studies failed to find overall changes in nocturnal melatonin related to nighttime magnetic field exposures.

## *2.2 Studies on extremely-low frequency EMF and sleep*

There are extremely-low frequency (ELF) electric and magnetic fields and ELF-pulsed high-frequency (HF) electromagnetic fields. HF-EMF are absorbed by the tissue and may cause heating, whereas ELF-EMF penetrate the body undisturbed and therefore may act through excitation of nerve and muscle cells. ELF-EMF may also influence physiologic processes which work in a similar frequency band (e.g. brain-wave activity).

Abelin et al. [12] conducted a study on health effects of the shortwave transmitter station in Schwarzenburg, Switzerland. The study focused further on the effects of the shortwave electromagnetic field (EMF) in the frequency range between 6.1 and 21.8 MHz on nighttime melatonin and sleep quality of people living near the radio station. Sleep disturbances and sleep quality were studied in two subsequent surveys by means of interviews and health diaries.

As a result from the first survey, sleep disturbances were significantly more frequent with increasing field strength. The odds ratio per 10mA/m was 1.13 (95% CI: 1.04 - 1.23). In the second survey, all broadcasting activities were interrupted in order to verify the results from the first survey. The shut-down resulted in a statistically significant improvement of sleep quality as recorded in the health diaries after a 1-day delay. Furthermore, the differences between people with either high or low field exposure, as observed in preceding sub-studies, were confirmed.

The melatonin study was conducted during a 10-day experimental period, where morning urine samples were collected from 65 subjects taken from the participants of the second survey. Melatonin levels showed to be independent of the magnetic field strength of the transmitter. The interruption of the broadcasting activities did not result in a change in melatonin levels. The hypothesis of an effect of EMF on melatonin metabolism and, as a

consequence, on sleep quality could not be confirmed for the frequencies and field strengths encountered in the surroundings of the transmitter in Schwarzenburg.

In conclusion, Abelin et al. stated that the EMF from the transmitter station were linked to a marked deterioration of sleep quality in the highly exposed group which amounted to a considerable adverse effect on well-being. It has to be noted, that the study could not be conducted in a double-blind setting. It is therefore not clear whether the effect observed is caused directly by the EMF or rather by the activity of the transmitter station in general (music on the telephone, „speaking gutters“ etc.).

Bonhomme-Faivre et al. [13] investigated human neurovegetative and hematological effects of 50Hz magnetic fields from transformers. The 13 subjects which worked near a transformer or near high tension cables with field strengths ranging from 0.2 to 6.6 $\mu$ T were matched with 13 controls. The results show a significant increase in degree of certain neurovegetative disorders (i.e. physical fatigue, psychical asthenia, lipothymia, decreased libido, melancholy, depressive tendency and irritability) and a significant decrease in blood parameters such as total lymphocytes, CD4, CD3 and CD2 lymphocytes as well as a rise in NK cells. In addition, leukopenia and neutropenia (reduction of leucocytes and neutrophile leucocytes) were observed in two subjects permanently exposed to 1.2 - 6.6 $\mu$ T. The disorders dissappeared when exposure stopped and reappeared on reexposure.

The neurovegetative parameters were recorded using self-rating questionnaires. The results were compared between the exposed group and the controls with a  $\chi^2$ -test. Besides the significant effects on neurovegetative disorders, there is a tendency to an increase of multiple awakenings, sleep disturbances in general, insomnia and also of sleep duration.

Reite et al. [14] reported a significant decrease in sleep latency to stage B2 ( $p=0.013$ ) and an increase of total duration of stage B2 ( $p=0.0008$ ) after treatment with a Low Energy Emission Therapy (LEET) device. LEET consists of a 27.12 MHz amplitude modulated (42.7 Hz) EMF. The estimated local peak SAR was less than 10 W/kg in the oral mucosa and 0.1 to 100 mW/kg in brain tissue. Active treatment consisted of an intermittent exposure (3s on/1s off) for 15 minutes. The effects were investigated in a double-blind cross-over study performed on 52 healthy subjects. Reite et al. concluded, that a 27.12 MHz EMF, intermittently amplitude-modulated at 42.7 Hz, results in a significant sleep inducing effect in healthy subjects. In the same experiment, Lebet et al. [15] found EEG changes after LEET consistent with shorter sleep latencies, longer sleep duration and deeper sleep.

### *2.3 Effects on brain activity and physiological factors during sleep*

The literature reviewed in the following chapter does not deal directly with the subject of extremely-low frequency EMF and sleep. The parameters discussed in the following papers are also measured in sleep studies and are therefore of interest considering possible effects of EMF on physiologic processes in humans.

Schienze et al. [16] studied the effects of 10kHz-sferics (electromagnetic impulses of natural origin that are typical for thunderstorms in close vicinity (<100km)). The impulse with a duration of 0.5ms and a maximum magnetic component of 50nT was applied to 20 subjects with a pulse repetition rate statistically varying between 7 and 20Hz. The



exposure duration was 10 minutes which was followed by a 20-minute period without exposure. This design had been chosen in order to test for prolonged effects of sferics exposure on electrocortical activity. The exposure to the sferics provoked changes in EEG during the treatment in form of an alpha (7.6-13.9Hz) and beta (14.2-20Hz) power enhancement and also induced effects that continued within the following 10 minutes after the sferics-stimulation had been stopped. The control group, which received no treatment, showed the opposite response tendency with a reduction of alpha and beta power in the first half of the experiment and an increase in the second half.

Increases in EEG power within the alpha and beta band have also been observed by Lyskov et al. [17]. Two groups of ten volunteers each were exposed to either continuous or intermittent (1s on/off) sinusoidal 45Hz-field with a field strength of 1.26mT for one hour. Each subject received one real and one sham exposure. Measurements of EEG, omega potentials and reaction time were performed before and after the exposure. An increase of alpha activity and a decrease of delta activity (1.5-3.9Hz) were observed. Beta waves increased in the frontal derivations as did the total power in occipital derivations. No direct effects on reaction time were observed.

The findings from Schienle et al., Lyskov et al. and Lebet et al. (chapter 2.2) show changes in brain-wave activity or in sleep latency following either pulsed high-frequency or extremely-low frequency EMF exposure. The increase of alpha waves and the decrease of delta activity may indicate, as a hypothesis, an increased relaxation following magnetic field exposure. Some changes, however, are not consistent with these findings. The increase of beta activity, for instance, may indicate mental or psychomotor activation.

Sandyk et. al [18] studied the effects of weak magnetic fields (pico-Tesla range) in two subjects, one with parkinson's disease, the other with multiple sclerosis. The treatment with 7.5 pT magnetic fields with a frequency of 2Hz produced behavioral effects which paralleled those observed in REM-sleep deprived animals and humans. The behavioral effects of REM-sleep deprivation include the enhancement of motivational and drive-related behaviors such as increase in appetite, sexual behavior, aggressiveness and locomotor activity. Sandyk's hypothesis is based on sELF-reported effects in two subjects. Further studies are necessary in order to validate these findings.

Sastre et al. [19] studied the effects of a 60Hz, 20 $\mu$ T magnetic field on heart-rate variability (HRV). HRV results from the action of neuronal and cardiovascular reflexes, including those involved in the control of temperature, blood pressure and respiration. The scientists used the quantitative spectral analysis method (digital Fourier transform technique) to study alterations in HRV, which proved to be useful indicators of beat-to-beat variations in sympathetic and parasympathetic nerve activity. Previous studies showed changes in mean heart-rate by exposure to power frequency electric and magnetic fields, while the study from Sastre et al. examined effects of exposure on HRV. The results from Sastre et al. showed that an intermittent (15s on/off) 20 $\mu$ T magnetic field significantly reduced HRV in the spectral band associated with blood-pressure and temperature control mechanisms ( $P=0.02$  and  $P=0.035$ ). The magnetic field also led to a significant increase of variability in the spectral band associated with respiration ( $P=0.06$  and  $P=0.008$ ). The changes reported in the study resembled those reported in stage 2-sleep. This hypothesis of increased stage 2-sleep induced by intermittent magnetic field exposure could not be confirmed since no encephalographic data was recorded during this experiment.

Although sleep is a period during which we do not respond very much to the environment, it is incorrect to refer to sleep as a state of unconsciousness. During sleep, our consciousness is certainly different from consciousness during waking. Changes in physiological parameters might result in sleep disturbances in people who are hypersensitive to electricity. This hypothesis takes into account the numerous case reports on people suffering from EHS-symptoms including sleep disturbances. At the Institute for Hygiene and Applied Physiology of the Swiss Federal Institute of Technology (ETH) in Zurich, a project is underway to investigate the effect of weak 50Hz electric and magnetic fields on physiological sleep parameters and sleep quality in volunteers who claim to be hypersensitive to electricity [20].

### 3. Project NEMESIS

(Non-ionizing electric and magnetic fields and electrical hypersensitivity syndrome in Switzerland)

It seems that there is an increasing number of people suffering from EHS. Or it may be simply because more and more people dare to report their health problems to their relatives, to their doctors or to the authorities due to the growing media attention focusing on negative effects of electric and magnetic fields. Case studies of people who claimed to have experienced a remarkable increase in well-being and in quality of life after carrying out field mitigation measures in their homes drew the attention of the authorities to the electrical hypersensitivity syndrome. Whatever the reasons of the improvements are, case studies and reports from affected people have to be considered as indicators for an effect of electric and magnetic fields, even if no conclusive evidence for a direct effect has been found so far. The Swiss Federal Environmental Protection Agency (BUWAL) initiated a research project to study the effects of weak electric and magnetic power-frequency fields on humans in order to confirm the reported ill-effects on well-being or the improvements of the same after carrying out mitigation measures. The study is supported mainly by the BUWAL and the Association of Swiss Electric Power Companies (VSE).

#### 3.1 Methods

The heart of the study is a double-blind provocation experiment with 50 subjects considering themselves as hypersensitive to electricity, who have actively changed their exposure conditions at home. The experiment focuses on objective sleep parameters and on subjective sleep quality. By recruiting volunteers from the group of people claiming to suffer from EHS, the chances to find at least one subject who shows a reaction to the field provocation is increased substantially (Based on surveys and laboratory experiments, Leitgeb [21] estimated that maybe 2% of the population could be more sensitive to electric and magnetic fields than the rest). The experiment is carried out in the homes of the subjects, exposing them to a 50Hz electric or magnetic field of approximately 100V/m or 2 $\mu$ T respectively. The provocation takes place at night for a period of 25 days, during which the field characteristics are changed according to a double-blind schedule. The electric and magnetic field is switched on either combined or separately for continuous (4 hours per night) or intermittent (4 hours per night, 10 minutes on/off) exposure or is switched off for sham exposure.

Testing the subjects in a familiar setting offers the advantage, that the subject's sleep is not disturbed by new and unfamiliar surroundings and environmental factors. In addition,

the results from such an experiment are practical and allow an assessment of field effects relevant to environmental exposure.

### *3.1.1 Recruitment of the subjects*

Information on the planned project was disseminated via the media (radio, television, newspapers) and on the occasion of a public seminar on Electrical Hypersensitivity at the ETH Zurich. People with EHS volunteering for the project then had to send in a case report of their present situation and experiences concerning the syndrome. The case reports were used to select the subjects for the study (people who claimed to have suffered from EHS or still do and who are in good health). Currently there are 50 subjects in the study group, 27 females and 23 males. The subjects are 18 to 75 years old (mean 49.2y) with the major part in the age-group of 45 to 60 years.

After the selection process, every subject was interviewed personally. The interview yielded all the necessary information for the programming of the exposure schedule (i.e. sleeping schedule, habits) and was used to pass on further information about the project. Every subject was asked to participate in an additional survey, where each of the volunteers had to fill in a personality test (Freiburger Persönlichkeits Inventar, FPI-R), a questionnaire on somatoform disorders (SOMS) and a test for magical ideation (MI-scale). These psychological tests were used to investigate whether the subjects selected for the experiment showed any differences if compared with the average population or with patients with psychosomatic disorders.

### *3.1.2 Measurement of sleep parameters using indirect actimetry*

Sleep parameters are measured during the night using a new measuring device. The so-called Dormograph® consists of four sensors that are placed under the bedposts or under other weight-bearing parts of the bed. The placement of the sensors under the bed allows the measurement of heart-rate, respiration and movements without touching the person. This technique has the advantage, that the sleeping subjects are not disturbed by any kind of sensors or devices being attached to the body. Furthermore it does not require any time or highly qualified personnel for preparation before going to bed and the subjects do not have to change their habits or adjust to sleeping with electrodes attached to their body (which would interfere with the sensitive subjects' sleep and thus affect the results).

Parallel to sleep parameters, the environmental factors noise, temperature, humidity and light are recorded by a separate sensor. These factors are important confounders in this study because of the potentially very small effects from the electric and magnetic fields on sleep, if there are any at all.

### *3.1.3 Assessment of sleep quality and well-being*

The quality of sleep is assessed by means of a diary. The diary is made up of two different questionnaires, one to be filled in every evening shortly before bedtime, the other to be filled in shortly after waking up in the morning. The evening-questionnaire focuses on the well-being perceived during the day whereas the morning-questionnaire is designed to study the effects of the nightly field provocation on the subjective sleep quality. Possible confounders of the night's sleep, such as alcohol, nicotine, caffeine and drugs, are also investigated in the evening-questionnaire. For every evening and morning there is a section with contrasting wordpairs which are evaluated for differences in the pleasure-arousal-dominance system (PAD). Alterations in this measure for emotional status could indicate an effect of the provocation field on the well-being of the subjects.

#### 4. Conclusions

Only a couple of studies concentrated on the effects of extremely-low frequency electric and magnetic fields on sleep in humans. This stands in contrast with the growing numbers of complaints issued forth by people suffering from electrical hypersensitivity. Sleep disturbance is a very frequently named symptom in EHS-patients.

Recent studies by Abelin et al. [12] and Bonhomme-Faivre et al. [13] on sleep quality using health diaries and sELF-rating questionnaires, showed an effect on subjective parameters. Alterations in sleep quality and in well-being in general are indicators for a direct effect of weak electric and magnetic fields on human-beings, even though the relevant physiological mechanisms are still shrouded in mystery. Wever [4] could show an effect of weak electric fields on circadian rhythms. Although it remains unclear whether such weak fields as used in his study can have an effect in natural conditions, where external zeitgebers act much stronger on humans.

Changes in physiological parameters could have an effect on sleep in humans as well. The role of the pineal hormone melatonin in synchronizing circadian rhythms and supporting sleep during the night has been investigated in a number of studies: While some of the studies on rodents showed a significant decrease in melatonin levels or increase in melatonin degradation, human studies failed to show such an effect.

Other physiological parameters such as heart-rate or heart-rate variability could be indicators for an effect of weak EMF on sleep. The changes in heart-rate variability (HRV) reported in the study of Sastre et al. [18] resembled those of stage 2-sleep. In other words, weak magnetic fields of 20 $\mu$ T altered HRV to show the same characteristic as in stage 2-sleep. Effects of weak EMF on sleep stages could also be derived from the findings of Schienle et al [14] and Lyskov et al. [15], where alterations in brain-wave activity occurred. The increase of alpha waves and the decrease of delta activity could be interpreted as an increased relaxation following magnetic field exposure. The increase of beta activity, however, is an indicator for mental activation, which is not consistent with a relaxing effect. On the other hand, the study by Reite et al. [16] on LEET (42.7 Hz-pulsed high-frequency EMF) showed a significant sleep inducing effect in healthy subjects.

The literature research on effects of extremely-low frequency EMF on sleep in humans revealed, that further investigations are necessary. So far, there are only a few studies which focused on sleep, even though sleep disturbances are a very common symptom in people suffering from electrical hypersensitivity.

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