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Sleep Disturbances in the Vicinity of the Short-Wave Broadcast Transmitter Schwarzenburg

Schlafstörungen in der Umgebung des Kurzwellensenders Schwarzenburg

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Summary

Objectives The studies reported here investigated the association between health complaints and the vicinity to the short wave transmitter Schwarzenburg, and looked for evidence for a relationship between magnetic field exposure and sleep disturbances.
Subjects and Methods Between 1992 and 1998 two cross-sectional and two panel studies were performed in the area of Schwarzenburg. In each cross-sectional survey about 400 adults living in differently exposed areas were asked about somatic and psycho-vegetative symptoms including sleep disturbances as well as possible confounding factors. Exposure was estimated based on 2621 measurements of magnetic field strength made in 56 locations. In the panel studies, sleep quality and melatonin excretion was studied when the transmission was interrupted or definitively shut down, respectively.
Results In both surveys, prevalence of difficulties of falling asleep and in particular, maintaining sleep, increased with increasing radio frequency electromagnetic field exposure (RF-EMF). Sleep quality improved after interruption of exposure. A chronic change of melatonin excretion following RF-EMF exposure could not be shown, but a parallel study of salivary samples in cows showed a temporary increase after a short latency period following interruption of exposure.
Conclusions The series of studies gives strong evidence of a causal relationship between operation of a short-wave radio transmitter and sleep disturbances in the surrounding population, but there is insufficient evidence to distinguish clearly between a biological and a psychological effect.

Keywords radio frequency – sleep disturbance – insomnia – melatonin – psycho-vegetative symptoms – field study – epidemiology

Zusammenfassung

Fragestellung Die vorliegenden Studien untersuchten den Zusammenhang zwischen gesundheitlichen Klagen und der Nähe zum Kurzwellensender Schwarzenburg, sowie die Beziehung zwischen der Exposition gegenüber elektromagnetischen Feldern und Schlafstörungen.
Untersuchungsbevölkerung und Methoden Zwischen 1992 und 1998 wurden in der Gegend von Schwarzenburg zwei Querschnittstudien und zwei Longitudinalstudien durchgeführt. In jeder Querschnittstudie wurden rund 400 in unterschiedlicher Entfernung vom Sender lebende Erwachsene über somatische und psycho-vegetative Symptome, sowie über mögliche Störfaktoren befragt. Die Schätzung der Exposition erfolgte aufgrund 2621 Messungen der magnetischen Feldstärke an 56 Messstellen. In den longitudinalen Studien wurden die Schlafqualität und die Melatoninexkretion untersucht – je einmal nach vorübergehender Unterbrechung und endgültiger Beendung des Sendebetriebs.

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Resultate In beiden Erhebungen nahm die Prävalenz von Einschlaf- und namentlich Durchschlafstörungen mit zunehmender Hochfrequenz Strahlungsexposition zu. Die Schlafqualität verbesserte sich nach Unterbruch der Exposition. Eine chronische Veränderung der Melatoninexkretion nach Hochfrequenz Strahlungsexposition konnte nicht gezeigt werden, aber in einer parallel durchgeführten Studie bei Kühen fand sich nach Expositionsunterbrechung eine vorübergehende Zunahme.
Schlussfolgerungen Die Reihe von Studien ergibt deutliche Evidenz für einen Kausalzusammenhang zwischen dem Betrieb eines Kurzwellenradiosenders und Schlafstörungen in der umgebenden Bevölkerung, aber es liegt ungenügende Evidenz vor, um klar zwischen einer biologischen und einer psychologischen Wirkung zu unterscheiden.

Schlussfolgerungen Hochfrequenzstrahlung – Schlafstörung – Insomnie – Melatonin – Psycho-vegetative Beschwerden – Feldstudie – Epidemiologie

Introduction

Although psycho-vegetative symptoms are often reported from populations exposed to radio frequency electromagnetic fields (e.g. [2, 3, 5]), these have not been studied with scientific rigor so far. Nevertheless, in the context of the mobile phone health risk debate, increasing attention is paid to such symptoms. In this paper, results from a series of population studies around a short-wave radio transmitter will be reported.

In 1990, a petition addressed to the Swiss government drew attention to the fact that large numbers of residents living near the transmitter complained about symptoms such as nervousness, headache, sleep disturbance and loss of energy, and that the transmitter was blamed for what was perceived as an accumulation of cases of cancer and other chronic disease. The government agreed to study the situation under the supervision of a panel of scientists convened by the Federal Department of Energy, and our group was charged with designing and conducting appropriate studies. The focus was on psycho-vegetative symptoms, as the study population was too small for studying rare diseases such as cancer. On the basis of the results from the first studies, follow-up studies were designed, leading to a sequence of studies, mostly in the human population surrounding the transmitter, but partly also in cattle:

(1) A first cross-sectional survey in 1992, when little had been published on electromagnetic field (EMF) and psycho-vegetative symptoms. There was no particular focus on sleep disturbances.
(2) An interruption study in 1993, with temporary interruption of exposure and melatonin determination in morning urine in humans, and in two-hourly night salivary samples in cows.
(3) A second cross sectional survey in 1996 with 39 % new participants from an additional exposed zone and use of an extended questionnaire on possible correlates of sleep disturbance.
(4) A shut-down study with monitoring of sleep quality and salivary melatonin excretion before and after the final shut-down of the transmitter in 1998.

Results were published only in a governmental report [1] and a doctoral thesis [4], but with one exception [6] not yet in the scientific literature. The purpose of this publication is to give an overview of these studies. For methodological details reference is made to other sources. Results from the shut-down study will be published elsewhere.

Methodology

The setting is the Swiss national short-wave radio transmitter of Schwarzenburg, about 20 km south of the Swiss Capital city of Berne. Constructed during the pre-World War 2 period, it served to transmit information worldwide since 1939. It operated at frequencies of 3 to 30 MHz, with a maximum power of two times 150 kW. The direction of the transmission beam changed about every two hours according to the local time in the target areas around the world (America, Asia, Africa, Australia). The beam was elevated by 11 degrees against the horizontal axis to reach its target by repeated reflexion between the stratosphere and the ground.

First cross sectional interview survey of 1992

A first study was addressed at all adult persons living up to 1500 meters from the transmitter (exposed) and a simple random sample of persons in comparable areas at 3000 to 5000 meters (assumed unexposed). The exposed area was divided into an inner circle (zone A, up to 900 meters) and an outer circle (zone B). The area assumed to be unexposed was called zone C. 404 persons or 60 % of those invited responded to a structured interview by trained student interviewers. Participation rates were 73.7 %, 55.0 % and 56.3 % in zones A, B and C respectively. The questions concerned frequency of symptoms regardless of a possible relationship with the transmitter, and aspects of working conditions and lifestyle as possible confounders. Prevalence rates of symptoms were compared between the three zones.

A total of 2621 exposure measurements were conducted during day and night time at 56 locations of zones A, B and C.

After an initial analysis showed correlations of several symptoms with distance from the transmitter, a multivariate analysis with graphical modelling was applied to distinguish between direct and indirect correlations with exposure.

Panel studies of 1993 and 1998

In 1993, sleep quality diaries were completed by stratified random sampling with replacement of subjects from the first survey. One hundred and two individuals had to be contacted in order to obtain participation by 65 with approximately equal distribution in terms of exposure zones and presence of sleep complaints. 6-hydroxy-melatonin-sulfate concentration was determined in morning urine during 10 days. After 3 days of baseline measurements the operation of the transmitter was stopped for three days, after which usual exposure was reinstated and measurements were continued for another four days. The results of a parallel study of cows have been published elsewhere [6]. When the transmitter was permanently shut down in March 1998, a convenience sample of 54 volunteers were followed for one week before and one week following shut-down (sleep quality diaries; salivary melatonin excretion) and retested for sleep quality after six months. Fifty-one of these had already participated in the second cross-sectional survey of 1996 (see below). 25 of the 54 participants reported sleep disturbances at the beginning of the shut-down study, of which 17 had reported sleep disturbances in the 1996 survey already.

Second cross-sectional survey of 1996

Local activists criticized the first study for not having included a small exposed mountain farming population in the commune of Rueggisberg to the east of the transmitter ("zone R") and claimed that the omission was in order to weaken the study results. The reason for not including this area in the first survey was however the exceptional situation of zone R. It is an isolated mountain farming area, where medical drug consumption is generally low and other lifestyle characteristics including smoking habits also differ from all other zones. Against the opinion of the supervisory body, we decided to conduct a second cross sectional interview survey using our own resources. This permitted to adapt the interview by deleting questions of no further interest and adding more detailed questions related to sleep disturbances.

399 subjects were fully interviewed, including 244 of the participants from the first survey who could still be located, and 155 subjects from the previously excluded zone R. Participation rate for the full interview among those located was 77 percent. Among 45 persons refusing an interviewer visit, telephone interviews with a few crucial questions were conducted.

As five repeated twenty-four hour exposure measurements in zones A and B showed good correspondence with those of the first survey, previous exposure estimates were used again. Additional measurements were conducted in five locations of the newly added zone R.

The same methods of statistical analysis were applied as in survey 1.

Results

Magnetic field exposure

An emission period lasted generally 2 hours per day due to the changing transmission direction. During the emission period field levels at the participants home from zone A varied from 14 to 41 mA/m (median: 28 mA/m), in zone B from 3 to 37 mA/m (median: 21 mA/m), in zone C from 1–2 mA/m (median 1 mA/m). In zone R a few spot measurements performed in 1996 yielded field levels up to 10 mA/m. The highest values in zone A were close to but did not exceed IRPA exposure limits (73 mA/m). 24 h average were approximately 20 times lower (figure 1). In general,

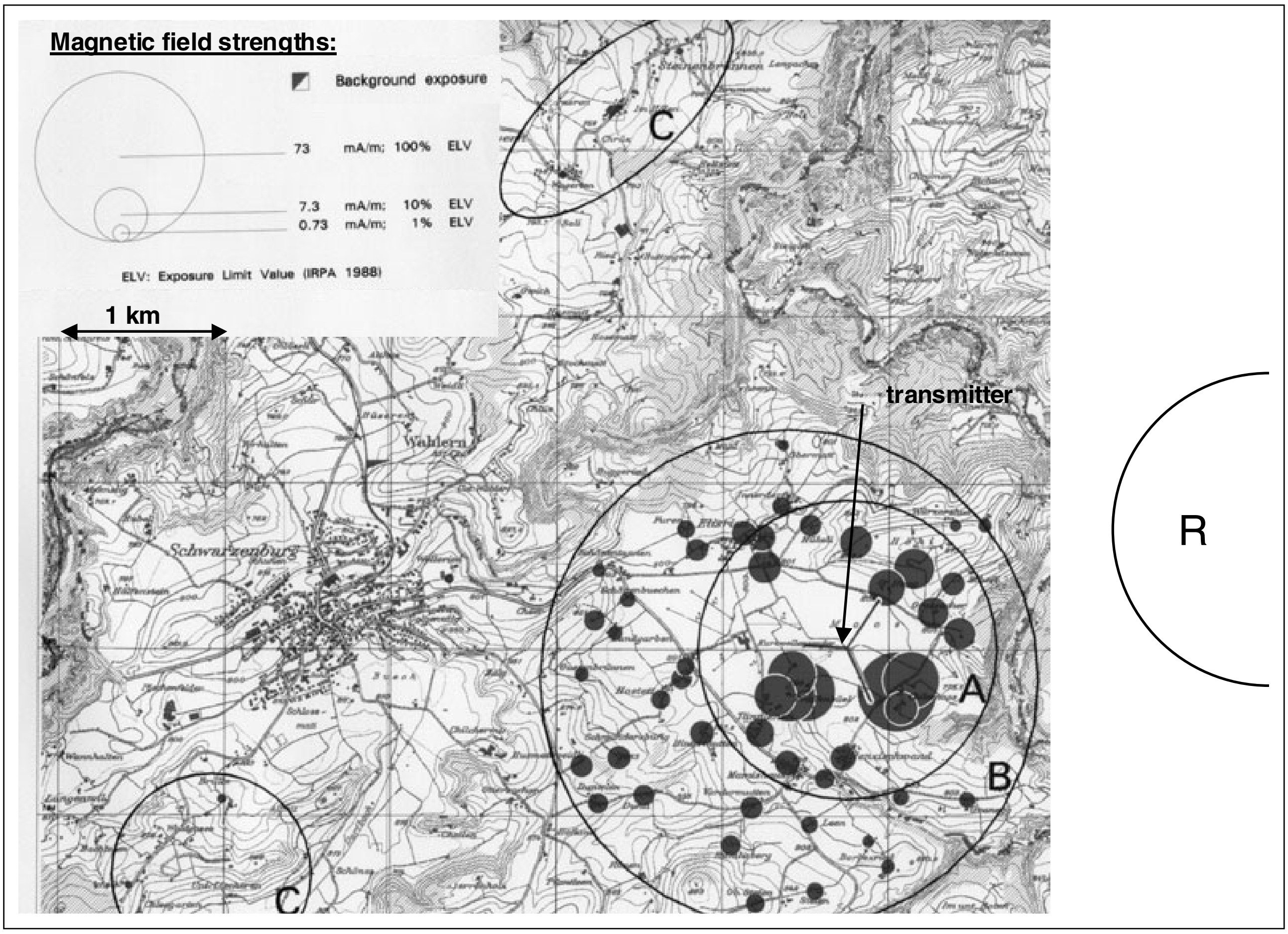

Figure 1. Map of the Schwarzenburg area showing the location of the transmitter, the H-field measurement points and the location of the zones A, B, C and R. The diameters of the circles around the measurement points indicate the 24 hour average magnetic field strengths, as measured between August 1992 and August 1993. (Reproduced with approval from swisstopo (BA046633.))

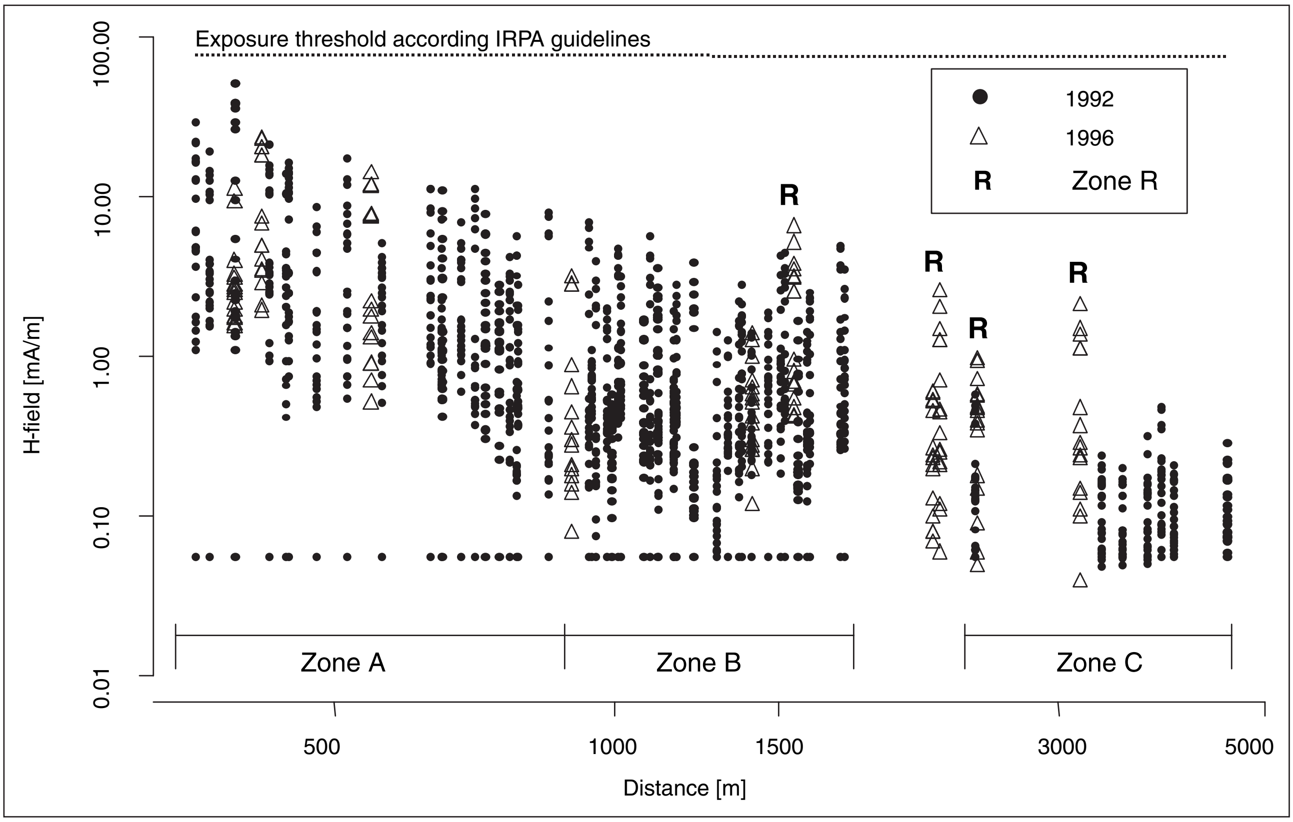

Figure 2. Measured H-field strengths from 56 locations in 1992 and 10 locations in 1996, in relation to distance from transmitter in meters. Each dot represents a mean value over an emission period at a particular location. Measurements of 1996 at or above 1500 meters are from zone R.

exposure increased steadily with decreasing distance from the transmitter (figures 2 and 3). Zone R had higher exposure levels than expected from distance alone, mainly because of its elevated location on a slope facing the transmitter.

The relationship between EMF exposure and psycho-vegetative symptoms

Table 1 shows the prevalence rates of symptoms based on interview responses in relation to distance from the transmitter. Where available, results from surveys 1 and 2 are shown. The p-values are unadjusted. Age is a strong independent risk factor for sleep disturbances, but adjustment for age, gender and education did not affect significance

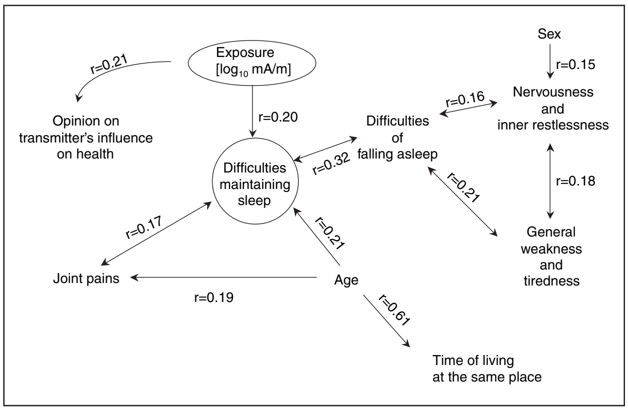

Figure 3. Graph of direct and indirect relationships of measured magnetic field strength with symptoms and personal characteristics of subjects, based on multivariate analysis (graphical model). All variables were correlated with each other, taking into account all other variables. Arrows are only drawn where significant correlations were found. Based on 1992 survey.

[1, 4]. Based on survey 1, prevalence rates of reported sleep disturbances are highest in zone A and lowest in zone C (control zone), with intermediary values in zone B. Although several other symptoms including nervousness, restlessness, limb pains, etc. show the same gradient, that for sleep disturbance is the most striking. Results from survey 2 confirm those of survey 1 and strengthen them, because in accordance with the observed EMF field strengths, the prevalence of reported sleep disturbance for zone R lies between those of zones B and C. The prevalence rates of reported difficulties of maintaining sleep were considerably higher in the second than in the first survey despite using the same sleep questions, but the gradients are similar in studies 1 and 2.

Logistic regression yielded an increase in prevalence odds by a factor of 3.2 (95 % confidence limits 1.84 to 5.52) for difficulties falling asleep and by a factor of 3.4 (95 % confidence limits 1.9 to 6.0) respectively for difficulties staying asleep with each increase of field strength by a factor of 10.

Behaviour related to sleep disturbance

In the second survey a number of additional questions on habits possibly related to suffering from sleep disturbance were added. As shown in table 1, the proportion of such habits (e.g. taking sleep drugs, coffee consumption in the evening etc.) was higher in the exposed area. Individuals from farming zone R are probably less comparable to the rest of the study population.

Interrelationship of magnetic field strength, psycho-vegetative symptoms and personal characteristics

Identical multivariate analyses were performed on the results from 1992 and 1996. Figure 2 shows the resulting graphical

Table 1. Prevalence of symptoms and other characteristics of respondents in surveys 1 (1992) and 2 (1996) by zones of different RF-EMF immission.

	Survey	No. respondents	Prevalence Zone A	Prevalence Zone B	Prevalence Zone R	Prevalence Zone C	p-value
No. respondents	1	404	105	119	–	180	–
	2	400	70	83	155	92	–
*Sleep disturbance**			%	%	%	%	
Difficulties in falling asleep	1	404	25.0	18.0	–	7.0	0.000
	2	400	28.7	15.6	14.2	8.7	0.006
Difficulties in maintaining sleep	1	404	32.4	18.5	–	8.9	0.000
	2	400	58.9	43.4	36.8	29.4	0.001
General weakness and tiredness	1	404	22.0	13.0	–	6.0	0.000
	2	399	24.3	17.1	13.6	12.0	0.138
*Other symptoms**			%	%	%	%	
Nervousness, restlessness	1	404	25.0	18.0	–	7.0	0.000
	2	399	30.0	28.6	20.0	13.0	0.024
Limb pain	1	404	14.3	6.7	–	3.3	0.003
	2	400	20.0	15.7	21.3	12.0	0.268
Joint pain	1	404	22.9	10.1	–	10.0	0.004
	2	400	24.3	19.3	23.9	18.5	0.671
Neck and shoulder pain	1	404	17.1	15.1	–	10.0	0.182
Back pain	1	404	7.6	10.1	–	6.7	0.566
Personal characteristics and behaviour			%	%		%	
Believe in transmitter's influence on health at up to 1500 meters distance	1	404	12.4	16.0	–	5.0	0.006
Spare time mainly away from home	1	404	41.9	34.4	5.6	5.0	0.000
Sleep much better/better away from home	2	399	36.2	28.9	24.8	7.8	0.000
Drug use to fall asleep (1/month or more)	2	445**	17.6	14.6	4.3	8.4	0.004
Drug use to maintain sleep	2	442**	8.2	10.1	3.7	6.7	0.135
Coffee before bedtime	2	401	2.9	6.0	3.9	14.1	0.006
Main meal in the evening	2	393	1.4	7.1	9.2	16.1	0.014
Sociodemographic characteristics			%	%	%	%	
Proportion female	1	404	61.9	52.1	–	58.9	–
	2	445**	64.9	53.8	46.6	62.5	–
Age median age	1	404	44	44	–	46	–
	2	446**	53.5	48	44	49.5	–
Education Compulsory only	1	403	39.0	30.3	–	28.5	–
	2	400	41.4	27.7	23.9	23.9	–

*Always or often
**incl. respondents with short telephone interview

model for 1992. The model based on the 1996 data is very similar (and thus not shown), in spite of the fact that almost 40 % of the respondents came from a different exposure group, and although prevalence of reported sleep disturbance was higher in 1996. "Difficulties maintaining sleep" is the only symptom directly related to EMF field strength (1992 data) or distance from the transmitter (1996 data), whereas all other symptoms and personal characteristics show significant correlations with field strength only indirectly through the association with "difficulties staying asleep". For 1992 there is also a correlation between exposure and "believing in health effects of EMF", whereas the correlation between this variable and "difficulties staying asleep" is not significant and therefore not shown in the model.

Sleep disturbance and salivary melatonin after interruption of transmitter activity

In the experimental study of 1993 with 65 human subjects, a decrease of awakenings during the second night after interruption of exposure was correlated to the extent of previous exposure. Urinary 6-hydroxy-melatonin-sulfate levels showed neither a chronic effect between exposure groups nor acute changes after interruption or reinstatement of exposure [1]. In cows, no chronic effect was observed either, but there was a statistically significant temporary increase of salivary melatonin three days after transmitter shut-down [6]. The permanent shut-down of the transmitter in 1998 was followed by improved sleep quality. Morning freshness as an indicator of sleep quality was rated every morning on a visual analogue scale ranging from 0 (=very fresh) to 100 (=very tired). Rating of freshness improved after shut down in the exposed group (24 h average H field >1mA/m) by 11.6 units (95 %-CI: 6.7 to 16.5) whereas in the low exposed group (24 h average H field <1mA/m) only minor improvement was observed: mean = 3.2 units (95 %-CI: −0.8 to 7.2). The improvement persisted in a follow up six months later.

Discussion

In the situation of the short-wave radio transmitter of Schwarzenburg, it was possible to study rather large samples of around 400 persons living at different distances from the transmitter, thus allowing for differentiated analyses of dose-effect relationships. When survey 1 was conducted, there had not been much communication between residents about types of symptoms. To our knowledge the hypothesis that sleep disturbance would become the predominant outcome variable had not been voiced before, and the literature available at that time had not led us to a special interest in sleep disturbance. Therefore suggestion as a mechanism is unlikely to have been responsible for the results of survey 1. This was different in survey 2, because the participants of study 1 had been informed that sleep disturbance was the primary outcome symptom. This, together with an increased age of the subjects may explain the higher prevalence of difficulties of maintaining sleep in study 2, while the consistent correlation between sleep disturbance and EMF exposure cannot be explained by confounding factors. The direct correlation of sleeping disturbance with magnetic field strength in multivariate analysis and the pattern of secondary behaviour (consumption of sleeping pills, avoidance of coffee and large meals in the evening, sleeping better when away from home) further strengthen the hypothesis of a real increase of prevalence of sleep disturbance with increasing exposure to RF-EMF.

Several difficulties have to be considered in the study of "soft" effects of electromagnetic fields, including sleep disturbances. These symptoms are rather prevalent in all populations, requiring comparison of prevalence rates between subgroups with different exposure. Many of these symptoms, in particular sleep disturbances can be caused or aggravated by anxiety, including fear of effects from EMF exposure. Soft outcomes cannot be measured objectively in this large number of subjects, but are based on subjective reporting. Thus, blinding in terms of exposure would be desirable, but persons living close to radio stations are experienced in recognizing transmitter activity through physical effects such as resonance phenomena from household appliances (e.g. radio sound from washing machine).

The cross-sectional approach was chosen by necessity in this situation of long-term exposure. Its value is limited for drawing conclusions on causal association, but this was compensated partially by longitudinal observation of morning freshness as an indicator of sleep quality immediately and six months following the shut-down of the transmitter. As no information about non-responders is available, selection bias cannot be ruled out, in particular in the second survey when the public was more aware of the objective of the study. In the first survey decisive selection bias was ruled out, when rates of disturbed sleep maintenance remained statistically significant even when computed under the assumption that all persons experiencing sleep disturbance had participated in the study.

The main strengths of our studies are the detailed exposure measurements and the large numbers of subjects allowing for differentiated data analysis. Two instances of interruption of exposure (of which one, in 1993, without previous information of the subjects) led to improvement of sleep quality as reported in detailed sleep diaries.

How can the study results be interpreted? The series of studies successively revealed consistent evidence of a close association between operation of the Schwarzenburg transmitter and health relevant sleeping disturbances. Believing in negative health effects of the radio transmitter explained only a small part of the association between magnetic field strength and difficulties maintaining sleep. But also, the search for a causal mechanism mediated by melatonin was unsuccessful, except for an isolated observation in cows [6], which can hardly have been influenced by psychological factors. Therefore, further research in humans with longer observation periods is desirable to replicate this observation.

In practical terms, a governmental scientific advisory group examined our results and recognized a causal relationship between operation of the transmitter and sleep disturbances – but left open whether the mechanism was biological or by suggestion. In either case, the population would be suffering and remedial action was thought to be indicated. But generalization and consideration in adjusting general exposure standard limits would only be justified, if more evidence was available for a biological effect.

What is the significance for mobile phone studies? The measured field levels in the vicinity of the short-wave transmitter correspond roughly to maximal but in practice rarely observed field levels close to mobile phone base station. As frequency and signal characteristics are not identical, results cannot directly be transferred. Nevertheless, some of the open questions are comparable, and when psycho-vegetative symptoms including sleep disturbance are suspected as a health consequence, similar study designs, interview constructions and approaches to data analysis might be indicated. Laboratory studies allow to study exposure effects under well controlled conditions using sophisticated measurement devices. However, sufficiently large observation periods, which are relevant to study latency periods, can hardly be achieved in the laboratory. Epidemiologic field studies may therefore be a valuable complement.

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