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Interactions between radiofrequencies signals and living organisms

Sense and sensibility in the context of radiofrequency electromagnetic field exposure

Mesure et perception des champs électromagnétiques radiofréquences : une étude de cohorte sur l'hypersensibilité électromagnétique

Martin Röösli [a,b,*], Evelyn Mohler [a,b], Patrizia Frei [a,b]

[a] *Swiss Tropical and Public Health Institute Basel, Socinstrasse 59, CH-4002 Basel, Switzerland*
[b] *University of Basel, Petersplatz 1, CH-4003 Basel, Switzerland*

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ABSTRACT

The association between radiofrequency exposure (RF-EMF) and non-specific health complaints in electromagnetic hypersensitive (EHS) individuals was investigated in a prospective cohort study conducted between 2008 and 2009 in Switzerland. Exposure to environmental far-field RF-EMF sources was modelled and cordless and mobile phone use was also considered in the analyses. About 8% ($n = 130$) of the study population declared to be EHS. Health disturbances were considerably more prevalent in the EHS group compared to the rest of the study population. However, we did not find evidence that health disturbances of EHS individuals were associated with RF-EMF exposure.

RÉSUMÉ

L'association entre l'exposition aux champs électromagnétiques radiofréquences (RF-EMF) et les troubles non-spécifiques de la santé dont se plaignent les sujets souffrant d'hypersensibilité électromagnétique (EHS) a été étudiée dans le cadre d'une étude de cohorte prospective menée entre 2008 et 2009 en Suisse. L'exposition environnementale à des sources radiofréquences en champ lointain a été modélisée et l'usage de téléphones sans fil ou mobiles a été pris en compte dans l'analyse. Les troubles de la santé étaient considérablement plus fréquents dans le groupe des personnes EHS en comparaison avec le reste de la population étudiée. Néanmoins, nous n'avons pas mis en évidence d'association entre le niveau d'exposition aux RF-EMF et les troubles de la santé des sujets EHS.

1. Introduction

Nowadays, the use of wireless communication devices has become very common in our everyday lives. Wireless communication devices and stationary transmitters such as mobile phone base stations emit electromagnetic fields (EMF) in the radiofrequency (RF) range. This has raised public concerns about potential health effects [1–3]. Some individuals even attribute non-specific symptoms of ill health such as sleep disturbance or headaches to EMF exposure [2,4]. This phenomenon

* Corresponding author at: Swiss TPH, Socinstrasse 59, CH-4002 Basel, Switzerland.
E-mail address: martin.roosli@unibas.ch (M. Röösli).

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is described as electromagnetic hypersensitivity (EHS) or idiopathic environmental illness with attribution to electromagnetic fields (IEI-EMF) [5–8]. No objective diagnostic criteria for EHS has been revealed so far and little is known about effective treatment of such patients [8]. Thus, EHS status is a self-declaration based on own experience. Various definitions for EHS have been used in population based surveys to estimate the prevalence of EHS yielding prevalences of 1.5% in Sweden [9], 3.2% in California [10], 4% in the UK [11], 5% in Switzerland [2], and 8–10% in Germany [12].

A substantial part of EHS individuals (e.g. 56% in Switzerland [4]) claims to be able to perceive RF-EMF or to suffer from RF-EMF exposure immediately, or within a few minutes after exposure. This phenomenon has been investigated in a number of double-blind, randomized provocation studies by applying well-controlled exposure circumstances in a laboratory. A recent review concluded that neither perception nor development of acute symptoms was related to real RF-EMF exposure under blinded conditions [13]. Several provocation studies supported, however, the role of the nocebo effect, which means the development of adverse symptoms due to expectations (e.g. due to concerns). However, it is still not clear whether the health of EHS individuals is affected by RF-EMF exposure in the long term, i.e. after prolonged exposure to RF-EMF. To our knowledge, no epidemiological study has investigated the association between RF-EMF exposure of a few months and symptoms of ill health in an EHS collective.

We used data from a prospective cohort study on health related quality of life and radio frequency electromagnetic field exposure (QUALIFEX) to investigate the following topics:

- To compare the self-declared EHS status at baseline with the respective judgement one year later;
- To compare the socio-demography, RF-EMF exposure situation and health status of EHS individuals with the rest of the study population;
- To investigate the association between RF-EMF exposure and symptoms of ill health in an EHS collective.

2. Methods

2.1. Study population

In May 2008 we sent out questionnaires entitled “environment and health” to 4000 randomly selected residents from the region of Basel, Switzerland, aged between 30 and 60 years. To minimize non-eligibility due to language difficulties, only Swiss residents or people living in Switzerland for at least five years were selected. After one year, in May 2009, a follow-up enquiry was conducted with the respondents of the baseline survey. Ethical approval for the study was received from the Ethical Commission of Basel on March 19th, 2007 (EK: 38/07).

2.2. Written questionnaire

In the written questionnaire we asked about the general health status, about non-specific symptoms of ill health, about socio-demographic factors (e.g. age, gender) and about exposure relevant characteristics and behaviours. With regard to EHS, we asked the participants: “Are you electrohypersensitive?” Those answering “yes” to this question are considered electromagnetic hypersensitive (EHS). We also asked: “Do you think that you develop detrimental health symptoms due to electromagnetic pollution in everyday life?” Those answering “yes” to this questions but not declaring to be hypersensitive are called “attributers” in this paper. In the absence of a common internationally used classification scheme for EHS, we hypothesized that these two questions correspond to a different degree of involvement in the EMF topic. The term EHS is not very common in Switzerland and thus may be mainly known by persons who are already informed about EMF and health issues, whereas attributing symptoms may be associated with less prejudice towards EMF exposure. Thus, we wanted to explore whether these two groups differed in terms of sociodemographic factors, exposure situation or health status.

2.3. Health outcomes

We measured various somatic complaints including headache, daytime sleepiness, sleep disturbance and tinnitus by means of questionnaires.

General health problems were determined by using a question from the European Health Interview Survey (EHIS) Questionnaire about the general health status. Study participants who rated their general health as fair, bad or very bad were considered to suffer from general health problems in contrast to participants rating their health as good or very good.

To assess somatic complaints the *von Zerssen* somatic complaint list was used. This list consists of 24 different items covering a broad range of non-specific symptoms [14]. Severity of each symptom is assessed on a four point Likert scale (not at all, rarely, fair, heavy) resulting in a score ranging from 0 (no complaints) to 72 (severe complaints).

Severity of headache was assessed using the Headache Impact Test (*HIT-6*) [15]. HIT-6 consists of six questions using a five point Likert scale. The HIT-6 score ranges from 36 (no impact) to 78 (severe impact).

Daytime sleepiness was determined by seven items from the Epworth Sleepiness Scale (ESS) ranging from 0 (no daytime sleepiness) to 21 (very excessive daytime sleepiness) [16]. For data presentation we created a binary variable according to a previous study on insomnia [17] indicating *excessive daytime sleepiness* if the ESS score was above 10.

The presence of *sleep disturbances* was assessed using four standardised questions from the Swiss Health Survey 2007 assessing the frequency of badly falling asleep, fitful sleeping, waking phases during night and awaking too early in the morning [18]. A binary sleep quality score was calculated by adding up all items (ranging from 0 to 12) and defining a score of eight or higher as having *sleep disturbances*.

We also asked study participants whether they suffered from *tinnitus* at the time of the survey.

2.4. Exposure assessment

We assessed exposure to environmental far-field sources (e.g. mobile phone base station) as well as exposure from sources operating in close proximity to the body (e.g, mobile phone handset). Regarding exposure to environmental far-field sources, we predicted total environmental far-field RF-EMF exposure and exposure from fixed site transmitters at home separately. The latter includes exposure from mobile phone base stations and broadcast transmitters. It was modelled by means of a geospatial propagation model which had been developed and validated for the study region [19,20]. Total environmental far-field RF-EMF was obtained from a predictive exposure assessment model that was developed based on weekly personal RF-EMF measurements from 166 residents of the study area who were not part of the cohort study [21,22]. The exposure assessment model considers the following relevant exposure predictors: the modelled residential exposure from fixed site transmitters [19], modified by the type of house wall and window frames, the ownership of communication devices (W-LAN, mobile and cordless phones) and behavioural characteristics (amount of time spent in public transport vehicles or cars, percent full-time equivalent).

Regarding close to body sources we enquired the study participants about their typical use of mobile and cordless phones. In addition, we asked for informed consent to obtain operator data of their mobile phone use covering the period of the previous six month of each survey. Obviously, individuals who stated not to own a mobile phone could not provide operator data. Thus, their operator recorded use of mobile phone was set to 0 (9 EHS individuals and 9 attributers).

In order to evaluate the occurrence of information bias or a nocebo effect, we assessed self-estimated exposure to RF-EMF in comparison to the average Swiss population in the questionnaire.

2.5. Statistical analyses

The prevalence of EHS for the whole study region was calculated using direct adjustments, with weights for age and gender derived from the 2008 population data of the study region by means of the survey module of STATA 10.0. Confidence intervals were calculated using the Wilson score method based on quadratic equations [23]. Comparisons between the three groups (nonsensitive individuals, attributers and EHS individuals) were done with chi-square tests in the case of binomial variables or Kruskal–Wallis tests in the case of scored or ranked data.

The association between RF-EMF exposure and health complaints was separately examined in attributers and in EHS individuals. We conducted a cohort and change analysis. In the cohort analysis, we aimed to investigate effects occurring with a latency of one year. We evaluated the association between exposure level at baseline and the change in health status between the baseline and follow-up survey. Two exposure categories were defined: exposure above median vs. exposure at median or below (reference). In the change analysis, we examined whether a change in exposure between baseline and follow-up resulted in a change of the health outcomes. We compared the study participants with the 20% largest decrease and increase in RF-EMF exposure with the remaining 60% who experienced a smaller or no change of exposure during the course of one year. For the linear outcome variables (von Zerssen-, HIT-6-, ESS- and sleep disturbance score) multiple linear regression models were calculated. For tinnitus (binary) a logistic regression model was used.

All models were adjusted for age, sex, body mass index, stress, physical activity, smoking habits, alcohol consumption, education, marital status, urban/suburban, nightshift work, use of sleeping drugs, general attitude towards the environment and whether they have moved between baseline and follow-up. Missing values in the confounder variables at baseline were replaced with the information of the follow-up and vice versa. If values were missing for both, baseline and follow-up, they were replaced with values of either the most common category (categorical variables) or with the mean value (linear variables). In all models for environmental far-field exposure sources, we included (self-reported) use of mobile and cordless phones as co-exposures. Similarly, total far-field exposure was used as co-exposure variable in all models for mobile and cordless phone use.

3. Results

3.1. EHS prevalence

In total, 1375 persons participated in the baseline survey in 2008. This corresponds to 37% of 3763 eligible individuals invited for participation. Participation rate for the follow-up was 82% resulting in 1122 returned questionnaires. Table 1 shows the distribution of the EHS status in 2008 and 2009. Almost 70 percent of the participants stated neither to be EHS nor to attribute own symptoms to RF-EMF exposure in both surveys (defined as nonsensitive individuals). The attributer group consisted of 219 individuals (baseline and follow-up combined), and 130 study participants stated to be electromagnetic hypersensitive either in 2008 or in 2009 (EHS group). This EHS self-declaration was not very persistent: 40% stated to

Table 1
Overview about the EHS (electromagnetic hypersensitivity) status of the study participants in 2008 and 2009.

		EHS status 2009			
		nonsensitive	attributer[a]	EHS[b]	Total
EHS status 2008					
nonsensitive	*n*	773	85[c]	23[d]	881
	(proportion)	(68.9%)	(7.6%)	(2.0%)	(78.5%)
attributer[a]	*n*	74[c]	60[c]	11[d]	145
	(proportion)	(6.6%)	(5.3%)	(1.0%)	(12.9%)
EHS[b]	*n*	28[d]	16[d]	52[d]	96
	(proportion)	(2.5%)	(1.4%)	(4.6%)	(8.6%)
Total		875	161	86	1122
		(78.0%)	(14.3%)	(7.7%)	(100%)

[a] Attributes own symptoms to RF-EMF exposure.
[b] Declares to be EHS.
[c] In the following defined as attributers ($n = 219$).
[d] In the following defined as EHS individuals ($n = 130$).

Table 2
Comparison of the socio-demographic factors as well as self-estimated RF-EMF exposure in the three study groups.

	Nonsensitive individuals *n* (%)	Attributers *n* (%)	EHS individuals *n* (%)	*p*-value
Age (years)				
30–39	219 *(28.3)*	61 *(27.9)*	33 *(25.4)*	0.58
40–49	266 *(34.4)*	82 *(37.4)*	54 *(41.5)*	
50–60	288 *(37.3)*	76 *(34.7)*	43 *(33.1)*	
Sex				
female	451 *(58.3)*	133 *(60.7)*	94 *(72.3)*	0.01
male	322 *(41.7)*	86 *(39.3)*	36 *(27.7)*	
Urbanity				
suburban	487 *(63.0)*	132 *(60.3)*	83 *(63.8)*	0.72
urban	286 *(37.0)*	87 *(39.7)*	47 *(36.2)*	
Educational level				
none	29 *(3.8)*	20 *(9.1)*	5 *(3.8)*	< 0.01
apprenticeship	369 *(47.7)*	120 *(54.8)*	76 *(58.5)*	
higher education	375 *(48.5)*	79 *(36.1)*	49 *(37.7)*	
Self-estimated RF-EMF exposure in 2008[a]				
lower	241 *(31.2)*	61 *(27.9)*	33 *(25.4)*	< 0.01
equal	504 *(65.2)*	133 *(60.7)*	72 *(55.4)*	
higher	28 *(3.6)*	25 *(11.4)*	25 *(19.2)*	

[a] Compared to the Swiss population.

be EHS in both surveys, 34% only in 2008 and 26% only in 2009. Of the attributers only 27% attributed own symptoms to EMF in both surveys, the remaining individuals attributed symptoms to EMF either in 2008 (34%) or in 2009 (39%) only.

Estimated EHS prevalence in our study area in the age group of the 30–60 year old persons was 8.1% (95%-CI: 6.6% to 9.8%) in 2008 and 7.3% (95%-CI: 5.9% to 9.0%) in 2009. EHS prevalence was higher in women (8.9% in 2009) than in men (5.7% in 2009). Estimated prevalence of attributers was 13.0% (95%-CI: 11.2–15.1%) in 2008 and 14.3% (95%-CI: 12.4–16.5) in 2009.

3.2. Demographic characteristics of EHS individuals

In Table 2, socio-demographic factors of EHS individuals are compared with the attributers and nonsensitive people. There were no differences between the three groups regarding the age distribution and the urbanity of their place of residence. However, the proportion of females is higher in EHS individuals than in nonsensitive persons or attributers. Nonsensitive persons are more likely to have a higher education than attributers and EHS individuals. Self-estimated exposure differed significantly between the three groups. The proportion of individuals who believed to be more exposed than the Swiss average population was 19% among EHS individuals, 11% among attributers and 4% among nonsensitive persons.

3.3. Exposure situation

Fig. 1 depicts the proportion of persons owning a mobile phone, a cordless phone or a W-LAN for the three groups. There was no substantial difference between the nonsensitive and the attributer group. However, the proportion of individuals owning wireless communication devices was by trend lower in EHS individuals. This difference was most pronounced for cordless phones. Few statistical differences were observed regarding amount of use of wireless communication devices

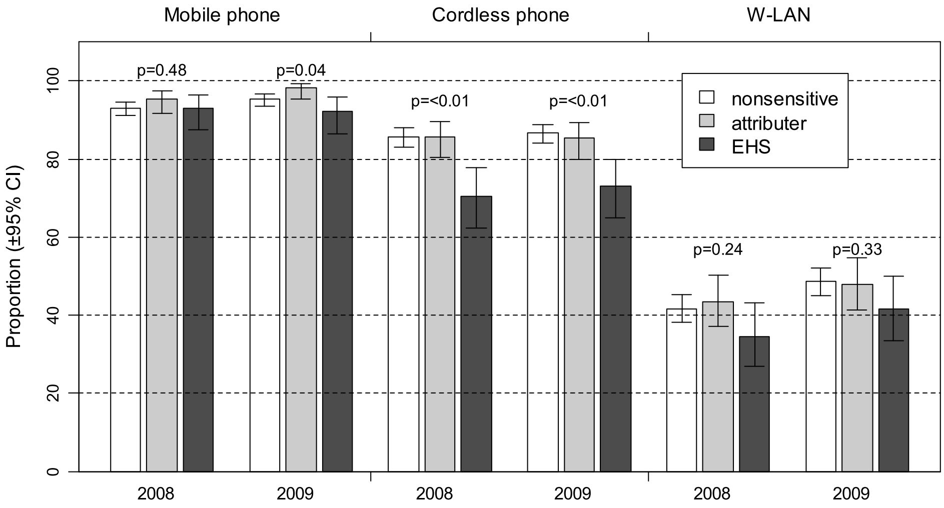

Fig. 1. Comparison of wireless communication device ownership between the three study groups in 2008 and 2009.

Table 3
Comparison of the exposure situation between the three study groups in 2008 and 2009.

Year	*n*	Nonsensitive individuals mean	(95%-CI)	Attributers mean	(95%-CI)	EHS individuals mean	(95%-CI)	*p*-value
Distance to the closest mobile phone base station [m]								
2008	1122	290	[276; 303]	273	[247; 299]	273	[241; 305]	0.31
2009	1122	294	[279; 310]	286	[256; 316]	269	[237; 301]	0.39
Predicted residential exposure to fixed site transmitters [mW/m^2]								
2008	1122	0.020	[0.017, 0.024]	0.033	[0.017, 0.049]	0.015	[0.011, 0.019]	0.29
2009	1122	0.020	[0.016, 0.024]	0.037	[0.020, 0.055]	0.017	[0.011, 0.022]	0.13
Predicted total environmental far-field exposure (all sources) [mW/m^2]								
2008	1122	0.120	[0.117; 0.123]	0.126	[0.118; 0.134]	0.114	[0.107; 0.121]	0.42
2009	1122	0.125	[0.122; 0.128]	0.134	[0.126; 0.141]	0.116	[0.108; 0.123]	0.02
Self-reported use of mobile phone [min/week]								
2008	1119	62.9	[52.4; 73.3]	81.1	[58.8; 103.3]	55.8	[35.3; 76.31]	0.40
2009	1113	62.5	[52.1; 72.8]	90.0	[64.8; 115.1]	61.6	[38.4; 84.7]	0.01
Operator registered use of mobile phone [min/week]								
2008	458	24.3	[19.3; 29.3]	34.1	[19.0; 49.2]	44.0	[21.0; 67.0]	0.28
2009	423	17.7	[14.0; 21.4]	29.0	[17.2; 40.8]	26.9	[13.7; 40.2]	0.07
Self-reported use of cordless phone [min/week]								
2008	1119	74.5	[66.9; 82.1]	79.6	[62.3; 96.9]	69.8	[49.8; 89.8]	0.16
2009	1110	77.6	[69.0; 86.3]	79.5	[62.9; 96.1]	65.9	[47.7; 84.0]	0.10

(Table 3). In tendency, EHS and nonsensitive individuals showed a similar usage pattern, whereas attributers tended to use wireless communication devices more often. Distance of residency to the closest base station as well as predicted residential exposure from fixed site transmitters was not different between the three groups. Predicted total far-field exposure from all sources was somewhat lower for the EHS group.

The 34 study participants who became EHS between 2008 and 2009 tended to reduce their use of wireless communication devices between baseline and follow-up (mobile phone: −4.3 min [95%-CI: −24.6, 16.0 min], cordless phones: −2.4 min [95%-CI: −27.7, 22.9 min]). In contrast, 44 study participants who lost the EHS status between 2008 and 2009 tended to increase their use of wireless communication devices (mobile phone: +10.7 min [95%-CI: −8.7, 30.0 min], cordless phones: +2.4 min [95%-CI: −27.0, 31.9 min]).

3.4. Health status

General health problems and sleep disturbances were least frequent in the nonsensitive group and most frequent in the EHS group (Fig. 2). Frequency of tinnitus was also somewhat higher among EHS, although not statistically significant. Regarding excessive daytime sleepiness, little differences between the three groups were observed. A substantial difference in the von Zerssen and the HIT-6 score was observed between the three groups. In 2009, mean von Zerssen score was 12.4 [95%-CI: 11.8, 13.1] in the nonsensitive group, 13.7 [95%-CI: 12.4, 15.0] in the attributer group, and 17.2 [95%-CI: 15.3, 19.1] in the EHS group. In 2009, mean HIT-6 score was 44.8 [95%-CI: 44.2, 45.3] in the nonsensitive group, 47.1 [95%-CI: 45.9,

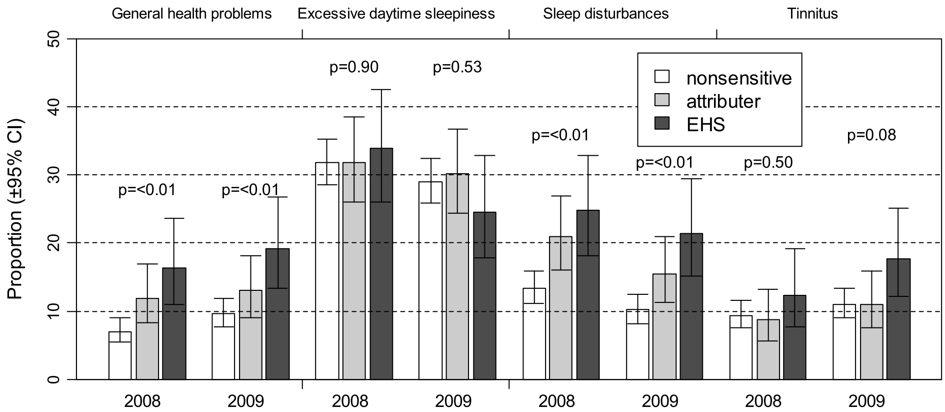

Fig. 2. Frequency of various health problems in the three study groups in 2008 and 2009.

Table 4
The association between the von Zerssen score and various exposure surrogates for the EHS group ($n = 130$). The table shows the change of the von Zerssen score (including 95% confidence interval) for various exposure groups compared to the reference group. The cohort analyses refer to the exposure at baseline (i.e. one year latency), the change analyses refer to the exposure change between baseline and follow-up.

	Cohort analysis		Change analysis		
	⩽median (reference)	>median (95%-CI)	Exposure decrease (95%-CI)	No change (reference)	Exposure increase (95%-CI)
Environmental far-field exposure					
Total environmental far-field exposure	0	−0.50 [−4.12; 3.11]	3.61 [−0.32; 7.53]	0	2.90 [−1.15; 6.95]
Residential exposure to fixed site transmitters	0	−2.04 [−5.06; 0.97]	**−5.65 [−9.66; −1.65]**	0	−0.03 [−4.19; 4.13]
Close to body exposure					
Mobile phone use (self-reported)	0	1.64 [−1.95; 5.23]	−1.37 [−5.46; 2.73]	0	2.39 [−1.52; 6.29]
Mobile phone use[a] (operator data)	0	1.75 [−3.28; 6.77]	−0.65 [−6.73; 5.44]	0	1.94 [−5.68; 9.56]
Cordless phone use (self-reported)	0	0.16 [−2.94; 3.26]	0.87 [−3.22; 4.95]	0	0.37 [−4.53; 5.27]

All regression coefficients are adjusted for: age, sex, body mass index, stress, physical activity, smoking habits, alcohol consumption, education, marital status, urban/suburban, nightshift work, use of sleeping drugs, general attitude towards the environment and moving between baseline and follow-up.
[a] Operator data were obtained for 50 EHS individuals at baseline (cohort analysis) and for 36 EHS individuals for both surveys (change analysis).

48.2] in the attributer group, and 48.1 [95%-CI: 46.4, 49.8] in the EHS group. Change of the EHS status was associated with a corresponding change of the health scores. For instance, the von Zerssen score increased by 3.5 units [95%-CI: 1.0, 6.0] for those becoming EHS and decreased by 3.3 unit [95%-CI −5.8, −0.9] for those losing the EHS status between 2008 and 2009. The corresponding changes of the HIT-6 score were +1.75 [95%-CI: −0.25, 3.75] and −0.7 [95%-CI: −3.5, 2.0], respectively.

3.5. Association between exposure and health

Table 4 shows the association between the von Zerssen score and various exposure proxies in the EHS group. All coefficients were statistically non-significant except a drop of the von Zerssen score by 5.5 units in the EHS individuals with the 20% largest reduction of residential RF-EMF exposure from fixed site transmitters between 2008 and 2009. However, an increase of fixed site transmitter exposure between 2008 and 2009 was not related to an increase in the von Zerssen score (regression coefficient: −0.03) and also being in the high exposure group at baseline (>median) was not followed by an increase in the von Zerssen score, but rather by a decrease of the score by 2.0 units [95%-CI: −5.1; 1.0]. Self-estimated exposure was not associated with the von Zerssen score (data not shown).

The same analyses as presented in Table 4 were done for the HIT-6, the ESS and the sleep disturbance score (data not shown). Out of these 45 additional regression models, five statistically significant regression coefficients were observed. However, these significant effects referred to different outcomes and different exposure measures: an increase in the ESS score in relation to an increase of the total far-field exposure, a decrease of the ESS score in relation to a decrease of the residential fixed site transmitter exposure, an increase in the sleep disturbance score in relation to a decrease in self-reported as well as recorded mobile phone use, and a decrease of the HIT-6 score in relation to be a heavy cordless phone user at baseline.

All analyses were repeated for the attributers resulting in three significant regression coefficients out of 60 models. (This concerned a decrease of the von Zerssen score with a decrease in the operator recorded mobile phone use between 2008 and 2009; a decrease of the ESS score in those attributers who were heavy cordless phone user at baseline; and an increase in the sleep disturbance score for the 20% attributers who reported the largest increase of cordless phone use between 2008 and 2009.)

A pooled analysis of the EHS and the attributer group did not yield substantially different results (data not shown) and also analyses restricted to the 52 participants, who stated to be EHS in both surveys, did not provide support for an exposure effect. Tinnitus was not related to any of the considered exposure metrics, neither in the EHS nor in the attributer group (data not shown).

4. Discussion

About 7–8% of our study population declared to be EHS in 2008 and 2009 and about 13–14% attributed own symptoms to RF-EMF exposure but did not declare to be hypersensitive (attributers). However, only a minority of the EHS individuals and the attributers made the same declaration in 2008 and 2009. The RF-EMF exposure situation of EHS individuals was comparable to the rest of the population except ownership of cordless phones. Health disturbances were considerably more prevalent in the EHS group than in the attributer group and even more than in the rest of the population. Most importantly, we did not find evidence that various symptom scores were associated with RF-EMF exposure in the EHS group.

4.1. Strengths and limitations

To our knowledge, this is the first epidemiological study investigating the association between health related quality of life and RF-EMF exposure in an EHS collective. Due to the cohort design we were able to capture health effects with a one year latency. Our previous measurement study demonstrated that the average weekly personal RF-EMF exposure remains relatively stable over several months [22]. Thus, this cohort study allowed investigating health effects of considerable longer exposure duration than in human experimental studies. We considered both, exposure to environmental far-field sources as well as exposure to sources close to the body. For both types of exposure, we used objective data. The elaborate prediction model for the total far-field exposure includes all relevant RF-EMF exposure sources in everyday life in the frequency range of 88–2500 MHz. The prediction model is based on a geospatial propagation model, which uses accurate parameters from all fixed site transmitters of the study region. In addition, the prediction model considers also exposure relevant behaviours that were identified in a previous study by personal exposure measurements and subsequently asked in the health study by questionnaire. The feasibility and reproducibility of the prediction model as well as of the geospatial propagation model was demonstrated [19,21]. For those who consented to provide the mobile phone operator data, we collected traffic records of all ingoing and outgoing calls of the previous six months of each survey from the mobile phone operators, which has, to our knowledge, not been done in previous studies investigating the effect of mobile phone use on the development of non-specific symptoms. Although self-reported, the subjective symptoms that we assessed were based on standardized questions.

A limitation was the rather low participation rate of 37% in the baseline survey. As a consequence, our estimated EHS prevalence is uncertain. One might assume that study participants may be generally more concerned or affected by EMF than non-responders resulting in an overestimation of the EHS prevalence. Interestingly, this was not confirmed in a non-responder survey that we conducted with 665 non-responders of the baseline survey by phone. In this non-responder survey, EHS prevalence was 15.9%. Thus, it is difficult to know at present, whether the estimated EHS prevalence of 7–8% is an over- or underestimation of the true EHS prevalence of the 30–60 year old people living in the study region. In 2004, a representative Swiss telephone survey concluded that EHS prevalence was 5% among people older than 14 years [2]. The low participation rate of the baseline survey is less of a problem for the cohort and change analysis because participation rate was high in the follow-up (82%).

Another limitation is the relatively small sample size. The EHS group consisted of 130 individuals and the attributer group of 219 persons. Thus, the power of the study was relatively low and subtle effects may have been missed.

Exposure levels were low in our study and we observed only small exposure differences between baseline and follow-up. This represents the current RF-EMF exposure situation in the everyday environment. This implies that our study is informative for exposure levels that are experienced nowadays. However, we cannot draw conclusions about health consequences for EHS individuals at levels close to the exposure limits, which are much higher.

4.2. Interpretation

Observational research in EHS individuals is limited if one assumes that EHS individuals tend to avoid EMF exposure. If such an intentionally achieved exposure reduction results in a better health status, it could either be mediated by a biophysical mechanism or by a pure nocebo mechanism. Interestingly, four out of six significant EHS effects concerned the exposure reduction in the change analyses. Thus, the question arises whether exposure avoidance behaviour is relevant for these findings. We observed a decrease of wireless communication usage for individuals that became EHS during the course of the study and an increase in exposure for those who lost the EHS status. These trends were weak and not statistically significant. We did not find such trends for the distance between the closest mobile phone base station and place of residence, nor for the modelled residential exposure to fixed site transmitters. Thus, EHS individuals seem not to have moved due to the presence of a mobile phone base station during the course of the study. Overall the exposure situation of EHS individuals differed not much from the rest of the study population (except ownership of cordless phones) suggesting that exposure avoidance behaviour is not pronounced.

In order to identify the potentially most sensitive individuals we asked about two different aspects in this context: (i) to attribute own symptoms to EMF (attributers); and (ii) to declare to be EHS. We hypothesized that attributers have a less prejudiced attitude to EMF than persons who declare to be EHS because the term EHS is not very common in Switzerland. A less prejudiced attitude to EMF may be associated with less exposure avoidance behaviour and thus, if there is any health effect at all, there might be a higher chance to detect such an effect in this group by means of an observational study. In fact, in none of the two groups we found evidence for health effects from EMF, however, we found differences between these two groups with respect to socio-demography, to RF-EMF exposure and to health status. This suggests that the methods of EHS classification matters and these should be considered in future studies, in risk communication or in the management of patients. Also a German interview based study observed considerably heterogeneity within the EHS group in terms of significance and coping with the perceived sensitivity in their daily life [24] and a Scandinavian study observed differences between people with symptoms related to mobile phone and people with general EHS [25]. Potentially one could use biological measures to differentiate between various EHS subgroups. For instance, altered cortical excitability [26], different heart rate variability [27,28], altered skin conductance [29], or different electrodermal activity [28] were observed in EHS individuals compared to the rest of the population. These parameters were not related to EMF exposure but may indicate that EHS individuals suffer from a general higher genuine vulnerability to physical and psychosocial environmental stressors.

Of note is the relatively small overlap between the EHS declaration in 2008 and 2009. This suggests that for most of the EHS individuals the perceived impairment is relatively subtle and only a small minority feels heavily affected by RF-EMF exposure. This corresponds to our experience with a medical helpdesk for EHS patients in Switzerland. During two years, only about 150 patients contacted the helpdesk for advice and thereof only about 50 patients were subsequently sent to a medical doctor. The generally low affliction may explain why the exposure situation of EHS individuals was not markedly different from the rest of the population. Only ownership of cordless phones was significantly lower in the EHS group. The attributer group tended to use wireless communication devices even more often than the rest of the population.

Regarding the association between symptoms and RF-EMF exposure, we observed only few statistically significant effects, which were not consistent with respect to exposure source or health effects. Some of the observed exposure effects were even positive for health. Given the numerous analyses we performed, a few statistically significant effects can be expected by chance. We conducted numerous analyses because in the absence of a known biological mechanism in the low dose range, it was unclear which aspect of exposure might be relevant for health disturbances, if any at all. In our analyses, we did not apply a formal multiple endpoint correction (e.g. Bonferroni correction). Instead we checked the consistency and biological plausibility of similar analyses. We hypothesized prior to the conduct of the analyses that exposure at the head, mainly caused by mobile and cordless phones, is most relevant for headache; total environmental far-field exposure is particularly relevant for the von Zerssen somatic symptom score; and residential exposure from fixed site transmitters, which also occurs during night, may play a role for ESS and sleep disturbances. However, none of these associations were observed. We neither observed similar results for one specific outcome from similar acting exposure measures (e.g. similar effects from mobile and cordless phone use) nor from similar models (e.g. cohort and change analysis). Thus, we conclude that the observed statistically significant effects occurred by chance and our study provides little evidence for detrimental health effects due to RF-EMF exposure for EHS individuals. Nevertheless, we cannot completely exclude that one or some of the observed patterns are real, even if formal significance criteria are not met. However, this has to be confirmed in an independent study.

Inherently, the absence of a phenomenon cannot be proven with empirical research. Thus, we cannot completely rule out that there exist a small minority who are particularly sensitive to EMF exposure. However, such individuals have not yet been identified [6] and our study demonstrates clearly that, as a group, EHS individuals are not more vulnerable to RF-EMF exposure than the rest of the population.

The observed lack of association between RF-EMF exposure and health symptoms is in line with the results from provocation studies investigating the acute development of symptoms in EHS individuals [13]. Interestingly, our previous measurement study demonstrated that self-estimated RF-EMF exposure is not related to actual RF-EMF exposure [30]. On one hand this means that our study participants are actually blinded to their exposure status which prevented our analyses from information bias. On the other hand comparing self-estimated exposure with health scores allows evaluating potential nocebo effects. EHS individuals tended to believe that their exposure was higher than the rest of the population, but their self-estimated exposure was not associated to various health disturbances. Thus, nocebo seems to play a minor role in our data. This is in contradiction to provocation studies where nocebo played a relevant role for the development of acute health problems [13].

In conclusion, our study could not confirm an association between RF-EMF exposure in the everyday environment and health disturbances for EHS individuals or for people attributing own symptoms to RF-EMF exposure. This study has captured an exposure duration of one year and is in line with the results from provocation studies that have investigated acute effects of RF-EMF exposure in EHS individuals.

5. Conflict of interests

The authors declare that they have no competing financial interests.

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