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Wireless communication fields and non-specific symptoms of ill health: a literature review

Martin Röösli and **Kerstin Hug**

Swiss Tropical and Public Health Institute, Basel, Switzerland, and University of Basel, Basel, Switzerland

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Hochfrequente elektromagnetische Wellen und unspezifische Gesundheitsbeschwerden: eine Literaturübersicht

Zusammenfassung. Dieser Artikel aktualisiert eine frühere systematische Literaturübersicht (1) zu den Auswirkungen hochfrequenter elektromagnetischer Felder (RF-EMF) auf die gesundheitsbezogene Lebensqualität. Zwischen August 2007 und November 2010 sind zur Exposition gegenüber Nahfeldquellen wie Mobil- und Schnurlostelefonen neun randomisierte experimentelle Studien und zwei beobachtende Studien erschienen. Die Fernfeldexposition, wie sie beispielsweise in der Umgebung von Mobilfunkbasisstationen auftritt, wurde in sechs experimentellen und acht beobachtenden Studien untersucht. Die meisten Experimente zeigten keinen Zusammenhang zwischen der Hochfrequenzbelastung und dem Auftreten von unspezifischen Symptomen wie Kopfschmerzen, Schwindel oder Konzentrationsstörungen. Die sporadisch beobachteten Assoziationen ergaben kein einheitliches Muster, weder bezüglich der Symptomform noch bezüglich der Effektrichtung (Zu- oder Abnahme). Auch in den beobachtenden Studien bestanden grösstenteils keine Zusammenhänge zwischen der RF-EMF-Belastung und dem Auftreten von Beschwerden. Die Aussagekraft dieser Studien wird allerdings dadurch eingeschränkt, dass die Expositionskontraste in den Kollektiven gering waren und Fehler in der Expositionsabschätzung nicht ausgeschlossen werden können. Ausserdem fehlen Studien über einen längeren Beobachtungszeitraum, und es gibt noch kaum Untersuchungen an Kindern und Jugendlichen.

Insgesamt weisen die aktuellen Studien nicht auf einen Zusammenhang zwischen der alltäglichen Hochfrequenzbelastung und dem Auftreten von unspezifischen Symptomen hin. Sie zeigen auch nicht, dass Personen, die sich selbst als hypersensibel bezeichnen, empfindlicher auf RF-EMF reagieren als der Rest der Bevölkerung. Da sich die Technik der Mobilkommunikation rasch weiter entwickelt und die alltägliche Exposition in Zukunft voraussichtlich ansteigen wird, sind aber longitudinale Studien zur Untersuchung eventueller Langzeiteffekte erforderlich. Wegen der weiten Verbreitung der drahtlosen Kommunikationstechnik hätten schädliche Auswirkungen eine grosse Public Health-Relevanz.

Schlüsselwörter: Hochfrequenzstrahlung, unspezifische Symptome, Beschwerden, gesundheitsbezogene Lebensqualität, elektromagnetische Hypersensibilität, idiopathische Intoleranz gegenüber EMF

Summary. This is an update of a previous systematic review on the association between radiofrequency electromagnetic field (RF-EMF) exposure and health-related quality of life that included studies published before August 2007 [1].

Since then, nine randomized trials addressed short-term exposures from close-to-body RF-EMF sources such as mobile phones, and two observational studies investigated the effects of mobile phone use on health-related quality of life. Six randomized trials addressed short-term far-field exposure arising, for instance, from mobile phone base stations, and eight studies evaluated the effects of environmental far-field RF-EMF exposure.

In most of the randomized trials, no exposure-response association was observed. The sporadically reported associations did not show a consistent pattern regarding the type of symptoms or the direction of the effects (increase/decrease). Similarly, most of the recent observational studies did not show associations between RF-EMF exposure and non-specific symptoms. However, the exposure gradients were small and possible exposure misclassification is a limitation of these studies. Longitudinal studies as well as studies in children and adolescents are scarce.

In summary, recent research did not indicate health-related quality of life to be affected by RF-EMF exposure in our everyday environment. Furthermore, none of the studies showed that individuals with self-reported electromagnetic hypersensitivity (EHS) were more susceptible to RF-EMF than the rest of the population. Nevertheless, the rapid technological development and anticipated increase in exposure levels warrant the conduct of further longitudinal studies. Due to the widespread use of wireless communication technologies potential adverse health effects would have major public health consequences.

Key words: Radiofrequency electromagnetic fields, non-specific symptoms, health-related quality of life, electromagnetic hypersensitivity (EHS), idiopathic environmental intolerance attributed to electromagnetic fields (IEI-EMF)

Correspondence: *Martin Röösli, PhD*, Swiss Tropical and Public Health Institute, Basel, Associated Institute of the University of Basel, Socinstraße 59, 4002 Basel, Switzerland.
Fax: ++41-61-284 8101, E-mail: martin.roosli@unibas.ch

Introduction

Electromagnetic fields (EMF) are ubiquitously distributed in our everyday environment. In particular, radiofrequency (RF) EMF exposure has considerably been increasing in the last two decades due to the widespread application of wireless communication technologies. Parts of the population complain that RF-EMF exposure causes health disturbances such as sleeping problems, headache or nervousness [2–4]. These individuals also often claim to be able to perceive RF-EMF in their daily life [5]. The attribution of non-specific symptoms to EMF exposure is described as "electromagnetic hypersensitivity" (EHS) or "idiopathic environmental intolerance attributed to electromagnetic fields" (IEI-EMF) [6–8].

In principle, two types of RF-EMF exposure have to be differentiated in our daily life: near-field and far-field exposure situations. Near-field exposure occurs while using communication devices such as mobile or cordless phones close to the body (<10 to 30 cm). More distant RF-EMF sources such as mobile phone base stations or W-LAN access points result in far-field exposures. In the latter case, the exposure of the whole body is relatively homogenous and the levels are considerably lower than the local maximum levels that occur by using a mobile phone [9]. In addition, far-field exposures usually are prolonged and can also occur during the night. Far-field exposure is less controllable than exposure from near-field sources, which can be turned on and off by the users. This may explain why most people are more concerned about health disturbances caused by mobile phone base stations than by mobile phones [4].

The association between RF-EMF exposure and non-specific symptoms has been investigated either by experimental or by observational studies. Both approaches have their merits and limitations. Experimental studies allow the application of well-defined exposure conditions in a randomized and blinded way, which minimizes the impact of bias. According to the GRADE approach (Grading of Recommendations Assessment, Development and Evaluation) [10] double-blind randomized trials provide the highest degree of evidence. However, only short-term effects in relatively small collectives can be investigated. Furthermore, subtle effects on well-being may be missed in a stressful experimental setting in an unfamiliar environment. These limitations can be avoided by observational research. However, observational studies are prone to biases such as exposure misclassification, participation bias, and confounding. With regard to non-specific symptoms, selective outcome reporting is an additional source of bias.

A previous systematic review evaluated all studies on RF-EMF exposure and non-specific symptoms of ill health published prior to August 2007 [1]. On the basis of eight randomized trials investigating 194 EHS and 346 non-EHS individuals in a laboratory setting, there was little evidence that short-term exposure to mobile phones or base stations caused non-specific symptoms. Some of the trials provided evidence for the occurrence of nocebo effects indicating that the participants developed symptoms when they believed to be exposed to RF-EMF. At that time, only a few observational studies were available: in most of these studies health effects were reported. However, these studies did not allow to differentiate between biophysical and nocebo effects as they were mostly conducted in the vicinity of large transmitters (e.g. short-wave transmitters).

Since the publication of the previous review [1], numerous studies on non-specific symptoms have been published. The aim of this paper is to update the previous systematic review with the most recent research and to evaluate the evidence for a relationship between RF-EMF exposure and health-related quality of life. In particular, we aimed to elucidate whether there are indications that EHS individuals are more susceptible to RF-EMF than the rest of the population.

Methods

For this narrative review we considered studies published between August 2007 and November 2010 investigating the effects of RF-EMF on health-related quality of life. This includes studies on self-reported non-specific symptoms and the ability to perceive low-level RF-EMF exposure. We did not consider studies merely investigating physiologic effects such as changes in the electroencephalogram (EEG) or the cognitive functions. The reason for that is that the importance of these outcomes for health-related quality of life is unknown. In terms of exposure we included all studies that addressed RF-EMF sources in the frequency range of a few MHz up to 10 GHz. These include frequency modulated (FM) radio broadcasting (88–108 MHz), TV broadcasting transmitters (174–223 and 470–830 MHz), TETRA (380–470 MHz), GSM900 (uplink [transmission from handset to base station]: 880–915 MHz, downlink [transmission from base station to handset]: 925–960 MHz), GSM1800 (uplink: 1710–1785 MHz, downlink: 1805–1880 MHz), DECT

Tab. 1: *Experimental* studies of exposure to *close to body sources* (handsets) addressing well-being, symptoms or "on"/"off" judgment

Reference	Study design	Collective	Exposure	Exposure duration	Intensity	Significant association	Non-significant association
Cinel [12]	Randomized double-blind crossover	167 volunteers Age: 18–42 y	GSM 900	2 × 40 min	SAR: 1.4 W/kg		Headache, dizziness, fatigue, itching/tingling of skin, sensation of warmth on skin
		159 volunteers Age: 18–42 y					Headache, dizziness, fatigue, itching/tingling of skin, sensation of warmth on skin
		160 volunteers Age: 18–42 y				↑Dizziness	Headache, fatigue, itching/tingling of skin, sensation of warmth on skin
Hillert [13]	Double-blind crossover	71 volunteers (thereof 38 reporting symptoms in relation to mobile phone use) Age: 18–45 y	GSM 900	2 × 3 h	Spatial peak $SAR_{10\,g}$ of all head tissues: 1.4 W/kg Tissue averaged SAR: Grey matter: 0.20 W/kg White matter: 0.18 W/kg Thalamus: 0.18 W/kg	↑Headache, Nocebo effect (believing to be exposed was related to symptoms)	Fatigue, nausea, vertigo, difficulties concentrating, feeling low-spirited, temporary vision problems, sensation of the face being swollen, itching, reddening of the skin, heat sensation, stinging pain or tingling, stress, and "on"/"off" judgment
Johansson [31]	Randomized single-blind crossover	15 patients with atopic dermatitis and 15 volunteers without atopic dermatitis Mean age: 31 y/29 y	GSM 900	2 × 30 min	SAR_{1g}: 1 W/kg		Substance P (SP), tumor necrosis factor receptor 1 (TNF R1), brain derived neurotrophic factor (BDNF)
Kleinlogel [32]	Randomized double-blind crossover	15 healthy subjects Age: 20–35 y	GSM 900, UMTS	4 × 33 min	Spatial peak SAR_{10g}: 0.1 and 1 W/kg		Symptom score (von Zerssen)
Kwon [29]	Randomized double-blind crossover	84 healthy volunteers Mean age: 24 y	GSM 900	6 trials with 100 × 5 s	SAR_{1g}: 1.2 W/kg SAR_{10g}: 0.86 W/kg	"On"/"off" judgment of 2 participants in one trial[1]	"On"/"off" judgment of 82 participants in all six trials
Nam [33]	Randomized single-blind crossover	18 EHS Mean age: 26 y	CDMA (800 + 1900 MHz)	2 × 30 min	SAR_{1g}: 1.22 W/kg		Skin temperature, heart rate, respiratory rate, heart rate variability, redness, itching, warmth, fatigue, headache, dizziness, nausea, palpitation, indigestion, "on"/"off" judgment
		19 non-EHS Mean age: 25 y					Skin temperature, heart rate, respiratory rate, heart rate variability, redness, itching, warmth, fatigue, headache, dizziness, nausea, palpitation, indigestion, "on"/"off" judgment

Lowden [30]	Double-blind crossover	48 volunteers (thereof 23 reporting mobile phone-related symptoms) Age: 18–44 y	GSM 900	2 × 3 h (prior to sleep)	Spatial peak $SAR_{10\,g}$ of all head tissues: 1.4 W/kg Tissue averaged SAR: Grey matter: 0.20 W/kg White matter: 0.18 W/kg Thalamus: 0.18 W/kg		Sleepiness, mental fatigue, arousal (across the experimental evening) Self-reported sleep quality (morning rating)
Nieto Hernandez [14]	Randomized single-blind crossover	60 non-EHS regular TETRA users Mean age: 38 y	Continuous wave (CW) and TETRA (both 385 MHz)	3 × 50 min	SAR_{10g}: 1.3 W/kg		Headache, fatigue, dizziness, nausea, sensations of warmth or burning of skin, skin itching, tingling, stinging or numbness, feeling irritable or anxious or depressed, difficulty concentrating or thinking
		60 EHS regular TETRA users Mean age: 36 y				↓Skin itching (with CW)	Headache, fatigue, dizziness, nausea, sensations of warmth or burning on skin, tingling, stinging or numbness, feeling irritable or anxious or depressed, difficulty concentrating or thinking
Riddervold [34]	Randomized double-blind crossover	53 volunteers Mean age: 36 y	TETRA hand-set (420 MHz)	2 × 45 min	SAR_{10g}: 2 W/kg		Headache, concentration difficulties, tingling, pain, nausea, dizziness, sleepiness, freezing, sweating, breathlessness, “on”/“off” judgment

Arrows indicate the direction of the association: ↑ indicates a positive correlation; ↓ a negative correlation.
[1] Replication experiment failed.

Tab. 2: *Observational* studies of exposure to *close to body sources* (mobile or cordless phone use) addressing well-being and symptoms

Reference	Study design	Collective	Type of exposure	Exposure assessment	Exposure values	Significant association	Non-significant association
Schüz [15]	Registry-based cohort study	Mobile phone subscribers compared to the Danish population, hospital contacts followed through 2003	Being a mobile phone subscriber during 1982–1995	Operator records	Private mobile phone subscriptions of 420 095 persons	↑Migraine, ↑Vertigo	
Mohler [16]	Cross-sectional	1212 adults (453 with operator data) Age range: 30–60 y (participation rate: 37%)	Mobile and cordless phone use	Self reported use and operator data	Average mobile phone use: 47 min/week, average cordless phone use: 75 min/week		Sleep disturbances, excessive daytime sleepiness

Arrows indicate the direction of the association: ↑ indicates a positive correlation.

cordless phones [1880–1900 MHz], UMTS (uplink: 1920–1980 MHz, downlink: 2110–2170 MHz [note that GSM900 and GSM1800 bands can also be used for UMTS) and W-LAN/WIFI (2400–2485 MHz and 5150–5850 MHz).

We did not consider studies exclusively based on self-reported exposure data, since this is particularly prone to bias in connection with self-reported symptoms [11].

Relevant studies were identified in literature data bases such as Medline, EMBASE, ISI Web of Knowledge, and the Cochrane Library in November 2010. We also examined references from the specialist databases ELMAR (http://www.elmar.unibas.ch) and EMF-Portal (http://www.emfportal.de) as well as reference lists of the relevant papers.

Results

Exposure to close to body sources

Since August 2007, nine experimental studies investigated associations between exposure from close to body sources and non-specific symptoms in laboratory settings using a crossover design (Tab. 1). In total, 790 non-EHS volunteers and 139 EHS volunteers were included in these studies. GSM900 mobile phones were addressed in six studies, TETRA handsets in two studies, and UMTS phones in one study. Another study investigated exposure to CDMA (code division multiple access) phones at 800 and 1900 MHz.

The trials revealed almost no increase in any symptom during exposure. Among the few exceptions were an increase in dizziness during GSM900 exposure in one out of three collectives [12], an increased headache score during GSM900 exposure [13], and a reduction in skin itching when being exposed to a continuous wave signal at 385 MHz [14]. In one study, two out of 82 participants had exceptionally high correct "on"/"off" judgments in one trial consisting of 100 ratings but both participants failed to replicate their performance one month later. Hillert et al. [13] observed nocebo effects, i.e. the belief that RF-EMF exposure had been active was associated with increased sensations of the face being swollen, skin reddening or feeling of heat, stinging pain and/or tingling in the skin, and pain in the left ear region.

Two observational studies addressed health-related quality of life in connection with mobile or cordless phone use by analyzing objective exposure data (Tab. 2). In the Danish subscriber cohort study, early mobile phone subscribers were more likely to get hospitalized with migraine (standardized hospitalization ratio (SHR) = 1.2; 95% CI: 1.1–1.3) or vertigo (SHR-1.1; 95% CI: 1.1–1.2) compared to the rest of the Danish population [15]. In a Swiss cross-sectional study of 1212 adults, neither sleep disturbances nor excess daytime sleepiness was related to operator recorded and self-reported use of mobile phones or self-reported use of cordless phones [16]. In that study, operator data of all ingoing and outgoing call covering a six-month period prior to the survey was obtained from 453 study participants.

Far-field RF-EMF exposure

Table 3 summarizes six experimental studies investigating the effects of far-field sources on health-related quality of life either in a laboratory setting (3 studies [17–19]) or in everyday environments (3 studies). Two of these field intervention studies assessed the application of RF-EMF shielding [20, 21], the third was based on randomly turning on and off a temporary constructed mobile phone base station [22]. In total, 709 non-EHS individuals and 102 EHS individuals were included in these six trials. Mostly, no association between RF-EMF exposure and symptoms was found. In one trial, the change in a headache score was larger under UMTS exposure than under sham exposure, when the data from 40 adults and 40 adolescents were pooled [19].

In another study with 57 volunteers, RF-EMF exposure increased the ratings of the participants concerning their calmness [20]. Leitgeb et al. [21] applied three exposure conditions (true shield, sham-shield, and control) to a collective of 43 EHS individuals during three nights each. Besides recordings of polysomnography, subjective sleep quality was inquired. By analyzing each individual separately, the authors identified two individuals reporting an improvement in sleep quality during the true shield condition compared to the sham-shield, which would be indicative of an EMF effect. On the other hand, six participants experienced improved sleep quality by any type of shielding, which rather indicates placebo effects. In the pooled analyses, RF-EMF exposure was not related to sleep quality.

In the laboratory trial conducted by Wallace et al. [18], EHS individuals reported more severe symptoms when they were informed that they were exposed to a TETRA mobile phone base station (open provocation). A similar tendency was observed in the non-EHS collective, however, to a lower extent. Subsequent double-blind tests did not reveal any exposure effects, neither in the EHS nor in the non-EHS group.

Tab. 3: *Experimental* studies of exposure to *far-field* RF-EMF addressing well-being, symptoms or “on”/“off” judgment

Reference	Study design	Collective	Exposure	Exposure duration	Intensity	Significant association	Non-significant association
Leitgeb [21]	Field intervention (randomized crossover)	43 EHS volunteers Mean age: 56 y	Shielding of RF-EMF	3 × 3 nights (true shield/sham shield/ without shielding)	If unshielded: typically measured levels < 0.5% of ICNIRP limit, maximum level: 3.5% of ICNIRP limit[1]	2 Participants with improvement of subjective sleep quality/efficiency by true shielding 6 Participants with placebo effects	Subjective sleep quality, subjective awakening quality and subjective sleep efficiency was not affected in 34 volunteers No association in pooled analyses
Riddervold [19]	Randomized double-blind crossover	40 adults Age: 25–40 y and 40 adolescents Age: 15–16 y	UMTS base station, 2140 MHz, with all control features	2 × 45 min	0.9–2.2 V/m	↑Headache[2] ↑Concentration difficulties (adults)	Concentration difficulties (adolescents)
Augner [20]	Field intervention (randomized double-blind parallel group)	57 volunteers Mean age: 40.7 y	Shielding of a base station (mainly GSM 900)	5 × 50 min (various levels)	0.04–0.9 V/m	↑Calmness	“Good mood" and "alertness”
Furubayashi [17]	Randomized double-blind crossover	11 EHS Mean age: 37 y 43 controls Mean age: 38 y	W-CDMA base station (2140 MHz)	4 × 30 min (in combination with noise)	10 V/m (at subject’s head)		Tension-anxiety, depression, anger-hostility, vigor, fatigue, confusion, discomfort, “on”/“off” judgment
Wallace [18]	Randomized double-blind crossover	48 EHS Mean age: 42y 132 healthy volunteers Mean age: 41y	TETRA base station	2 × 50 min	10 mW/m² (≈2 V/m), 271 μW/kg	Nocebo effect (open provocation)	Heart rate, skin conductance, blood pressure, anxiety, tension, arousal, discomfort, fatigue, relaxation, field perception Heart rate, skin conductance, blood pressure, anxiety, tension, arousal, discomfort, fatigue, relaxation, “on”/”off” judgment
Danker-Hopfe [22]	Field intervention (randomized crossover)	397 individuals Mean age: 45 y (participation rate: 17%)	GSM 900/GSM 1800 base station	2 × 5 consecutive nights, base station was turned on or off[3]	1 mV/m to 6 V/m, mean: ca. 0.1 V/m		Sleep efficiency, time spent in bed, total sleep time, sleep latency, wake after sleep onset, restfulness

Arrows indicate the direction of the association: ↑ indicates a positive correlation.
[1] 3.5% of ICNIRP limit corresponds to 2 V/m at a frequency of 1800 MHz.
[2] when pooling data from adults and adolescents.
[3] Transmission status of base station was not detectable by mobile phone.

Tab. 4: *Observational* studies of exposure to *far-field* RF-EMF addressing well-being and symptoms

Reference	Study design	Collective	Type of exposure	Exposure assessment	Exposure values	Significant association	Non-significant association
Leitgeb [21]	Cross-sectional	43 EHS volunteers Mean age: 56 y	RF-EMF	Measurements during 3 control nights without shielding	If unshielded: typically measured levels <0.5% of ICNIRP limit, maximum level: 3.5% of ICNIRP limit[1]		Sleep score
Thomas [35]	Cross-sectional	329 randomly selected residents of 4 German towns Age: 18–65 y (participation rate: 30%)	Sum of GSM 900, GSM 1800, UMTS (up- and downlink), DECT and WLAN	Personal dosimetry of total RF-EMF during waking hours of one day	<0.15% of ICNIRP limit Top quartile: 0.21 to 0.58% of ICNIRP limit[2]		Headache, neurologic symptoms, cardiovascular symptoms, sleeping disorders, fatigue
	Longitudinal (within 1 day)						Headache, neurologic symptoms, fatigue, concentration problems
Blettner [23]	Cross-sectional	26,039 German residents within a panel survey carried out regularly Age: 14–69 y (participation rate: 58.6%)	Distance between residence and next base station	Geocoded distance to the closest mobile phone base station	<500 m *vs.* >500 m	↑Frick symptom score	
Berg-Beckhoff [24]	Cross-sectional	1326 individuals from 8 urban German regions Age: 15–71 y (participation rate: 21%)	Sum of GSM 900, GSM 1800 and UMTS base stations	Spot measurements in the bedrooms	Two categories, dichotomized at the 90th percentile (i.e. >0.1 V/m)		Sleep quality (PSQ), headache (HIT-6) symptom score (von Zerssen, SF-36-physical, SF-36-mental)
Eger [25]	Cross-sectional	251 residents of a German municipality (participation rate: 23%)	Mobile phone base station radiation	Spot measurements	Two categories[3]: high (0.7–1.17 V/m) *vs.* low (0.18 V/m)	↑Sleep disturbances, ↑depression, ↑cerebral affection, ↑joint pain, ↑infections, ↑skin changes, ↑circulatory disturbances, ↑balance disturbances, ↑impaired vision, ↑hormonal changes, ↑gastro-intestinal disturbances	Headache, thinking problems, tooth ache, dizziness, nosebleed, weight gain, weight loss, bedwetting
Heinrich [36]	Cross-sectional	1484 children (8–12 y) and 1508 adolescents (13–17 y) (participation rate: 53%)	Sum of GSM 900, GSM 1800, UMTS (up- and downlink), DECT and WLAN	Personal dosimetry of total RF-EMF over 24 h	Quartiles (in % of ICNIRP limit): Children: 0.15%, 0.17%, 0.20%, adolescents: 0.15%, 0.17%, 0.21%[2] Sensitivity analyses using the 90th percentile as cut-off (children: >0.92%, adolescents: >0.78%)		Headache, irritation, nervousness, dizziness, fear, sleeping problems, fatigue

Mohler [16]	Cross-sectional	1212 adults Age: 30–60 y (participation rate: 37%)	Total RF-EMF, night time EMF exposure, EMF from fixed site transmitters	Modeling	Three categories (<median, 50–90th, >90th percentile): Total RF-EMF: <0.18, 0.18–0.21, 0.21–0.33 V/m. Night time EMF: <0.02, 0.02–0.09,0.09–0.33 V/m, Fixed-site transmitters: <0.04, 0.04–0.12, 0.12–0.62 V/m		Sleep disturbances, excessive daytime sleepiness
Thomas [26]	Cross-sectional	1498 children (8–12 y) and 1524 adolescents (13–17 y) (participation rate: 52%)	Sum of GSM 900, GSM 1800, UMTS (up- and downlink), DECT and WLAN	Personal dosimetry of total RF-EMF over 24 h	Quartiles (in % of ICNIRP reference value): children: 0.15%, 0.17%, 0.20% adolescents: 0.15%, 0.17%, 0.21%[2]	↑Overall behavioral problems, (adolescents), ↑conduct problems (adolescents and children)	Overall behavioral problems (children), emotional symptoms, hyperactivity, peer relationship problems (children and adolescents)

Arrows indicate the direction of the association: ↑ indicates a positive correlation.
[1] 3.5% of ICNIRP limit corresponds to 2 V/m at a frequency of 1800 MHz.
[2] 0.21% of ICNIRP limit corresponds to 0.123 V/m at a frequency of 1800 MHz.
[3] Additional analyses comparing 1.17 V/m to 0.7 V/m (most symptoms significantly higher at 1.17 V/m).

As presented in Tab. 4, eight observational studies investigated associations between far-field RF-EMF exposure in the everyday environment and health-related quality of life by means of cross-sectional analyses. Three of these studies reported statistically significant associations. In a German survey of 26,039 residents, the Frick symptom score of persons living within 500 m of a mobile phone base station was 0.34 (95% CI: 0.32–0.37) units higher than that of the rest of the participants [23]. However, subsequent dosimetric evaluations with measurements in the bedrooms of 1326 randomly selected volunteers from this survey did not confirm a relationship between measured mobile phone base station radiation and subjective symptoms [24]. In a small German questionnaire survey with 251 participants, numerous symptoms were more prevalent in participants living within 400 m of a base station compared to a control group living further apart and also within the 400 m radius, symptoms were strongly correlated with distance to the base station [25]. In another German study, Thomas et al. [26] observed an association between personal RF-EMF exposure recorded during one day and behavioral problems in adolescents (4th *vs.* 1 st quartile of exposure: OR = 2.2; 95% CI: 1.1–4.5) but not in children (OR = 1.3; 95% CI: 0.7–2.6). Further analyses of the subscales revealed an increased risk for conduct problems (OR = 3.7; 95% CI: 1.6–8.4) and a tendency of an increased risk for hyperactivity (OR = 2.1; 95% CI: 0.9–4.8).

Discussion

In experimental studies, few associations between near-field or far-field RF-EMF exposure and acute non-specific symptoms were observed. None of the studies indicated that EHS individuals were more susceptible to RF-EMF than the rest of the population. Two studies addressing nocebo effects found evidence for this phenomenon. Overall, the recent experimental research confirms the conclusion of the previous systematic review [1] that short-term exposure to RF-EMF is unlikely to impair health-related quality of life. With respect to observational research, the number of studies has considerably increased since 2007. Interestingly, the more recent studies were less likely to report associations than the earlier studies.

For a balanced discussion of the available evidence the possibility of false positive as well as of false negative results has to be considered. Regarding studies reporting an association, systematic errors are of particular concern as they may introduce a bias, whereas for studies reporting no association, non-differential misclassifications of outcome or exposure are of concern as this would dilute any type of association. Furthermore, statistical significance usually means that the likelihood of a false positive result is less than 5% but it does not completely exclude chance findings. Particularly when considering many results from numerous studies, false positive associations have to be expected in about one out of 20 analyses. On the other hand, true effects may be missed due to insufficient statistical power (in particular when applying conservative multi-testing corrections).

For some of the observed associations bias may indeed be an explanation although this cannot finally be proven. In one study indicating an increased headache score during exposure [13], two participants reported to hear a faint sound during the true exposure condition, which was confirmed by a co-worker. This technical flaw was fixed but may nevertheless have affected data of additional participants. In another randomized trial [19], further analyses indicated that the observed increase in headache score during UMTS mobile phone base station exposure was due to a lower baseline score before the exposure rather than to a higher score afterwards.

The increased hospitalization rates for migraine and vertigo observed in the cohort of early Danish mobile phone subscribers may be explained by differences in socioeconomic status and lifestyle aspects of this collective compared to the Danish population [15]. This explanation is supported by the observation of lower rates of brain tumors and neurodegenerative diseases in these subscribers [27]. The association between personal RF-EMF exposure and behavioral problems in adolescents reported by a German study [26] might be due to reverse causality. Behavioral abnormalities may result in an increased use of mobile phones and other wireless communication devices. If so, these behavioral problems cause an increase in personal RF-EMF exposure [28] and not vice versa.

The Selbitz study [25] was conducted in the vicinity of one single mobile phone base station. In the paper, it is not explained why exactly this study area was selected. If there had already been public concerns about health risks caused by this base station that could have led to selection bias and could have heavily affected the study results. The strong decrease in the participation rates with increasing distance from the base station is supportive for such an explanation (participation rate <100 m: 36%; 300–400 m: 14%, control group: 28%). In addition to selection bias, no confounding factors were considered, the statistical methods were inappropriate and the selection criteria for the control group are not described.

Since the sporadic associations observed in 4 further studies point into different directions they may have occurred by chance: There were two beneficial exposure effects [14, 20] and two detrimental effects [12, 23]. Chance is, however, not a plausible explanation for the exceptional accurate "on"/"off" judgment of two participants in one trial because the *p*-values were below 10^{-21} [29]. The probability of achieving such a performance by chance is as low as achieving six correct hits in a lottery (6 out of 49) three times in a row. Nevertheless, the two participants could not confirm their performance in a replication experiment, which makes this finding arguable and a temporary unblinding during the first trials might be a possible explanation.

Regarding the bulk of experimental studies with non-significant exposure-response associations, non-differential misclassification is not an issue in these studies as exposure conditions are well defined. A lack of statistical power may, however, be relevant in studies with small samples (e. g. <20 participants) or conservative adjustment for multiple testing. Since some studies had quite large samples, a relevant effect should have been detected in these studies. More subtle effects could be revealed by meta-analytic pooling of study results. However, the wide variety of study methods and outcome measures is a challenge for any meta-analysis and to the best of our knowledge no attempt to pool these results has been undertaken so far. Furthermore, we found no indication that the non-significant associations pointed preferable in the same direction. Rather, increased as well as decreased symptom scores in relation to RF-EMF exposure were found. In addition, the nocebo effects detected in two experimental studies indicate that the trials were sensitive enough to reveal detrimental effects of reasonable magnitude if they existed.

The most striking finding is the lack of associations in the majority of the recent observational studies, whereas until 2007 five out of six papers reported an association. Most of the old findings were related to residents in the vicinity of short-wave broadcast transmitters. On the one hand, this situation results in a relatively high exposure gradient, on the other hand, cluster studies investigating one single source of RF-EMF exposure are particularly prone to bias. Nocebo effects could also play a role since residents are aware of the exposure source and public concerns may have actually initiated the conduct of the study. Interestingly, also among the recent studies, the most pronounced exposure-response associations were reported by a cluster study conducted in the vicinity of a mobile phone base station [25]. The exposure gradients reported in that study are much higher than in another German study comprising eight urban regions [24], and the authors assign the differing results to these discrepancies in exposure. However, no explanation is given why the exposure gradients produced by this particular base station would be much higher than those of other base stations. Possibly, the divergent exposure gradients are merely due to the different methods used to determine the exposure levels.

In observational research, the assessment of RF-EMF exposure is a major challenge as many field sources are involved resulting in a high degree of temporal variation and small-scale spatial heterogeneity. Measurement studies have shown that the distance to the next mobile phone base station is actually not correlated with personal RF-EMF exposure and also short-term measurements in the bedroom are only moderately correlated with it [28]. In the absence of a biologic mechanism it is also not known which exposure measure might be most relevant for health effects and how to combine near and far-field sources to one single dose measure. Thus, the amount of exposure misclassification in observational studies is expected to be substantial and could dilute any true exposure-response association. Notably, the persons classified as highly exposed in the observational studies addressing far-field RF-EMF were actually exposed to rather low-field levels. The cut-off points for the highest exposure categories were below 0.5 V/m in all studies except the Selbitz study [25]. This reflects the situation in our everyday environment but is much lower than the reference levels established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), which range between 28 and 61 V/m for the RF-EMF frequency range. Since the population exposure is considerably lower than that, it is currently difficult to investigate long-term health effects of RF-EMF exposure close to those levels.

In conclusion, this review including 15 randomized trials published between 2008 and 2010 revealed little evidence that short-term RF-EMF exposure causes non-specific symptoms and impairs health-related quality of life. This does not exclude other acute RF-EMF effects. For instance, Lowden et al. [30] observed EEG changes during sleep although the rating of subjective sleep quality was not affected. In order to improve epidemiologic research on long-term effects of far-field RF-EMF exposure, a sophisticated exposure monitoring is needed to enhance our knowledge of the population exposure. This may reveal populations with larger exposure contrasts where potential health effects can be investigated by means of longitudinal studies. Such studies are urgently needed given the worldwide rapidly ongoing development and application of wireless communication technologies. Because of the almost universal distribution of RF-EMF exposure, the public health impact of adverse effects would be substantial, even if only a very small proportion would be affected.

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Conflict of interests

The authors declare no conflict of interests.

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