Systematic review on the health effects of exposure to radiofrequency electromagnetic fields from mobile phone base stations

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Objective To review and evaluate the recent literature on the health effects of exposure to mobile phone base station (MPBS) radiation.
Methods We performed a systematic review of randomized human trials conducted in laboratory settings and of epidemiological studies that investigated the health effects of MPBS radiation in the everyday environment.
Findings We included in the analysis 17 articles that met our basic quality criteria: 5 randomized human laboratory trials and 12 epidemiological studies. The majority of the papers (14) examined self-reported non-specific symptoms of ill-health. Most of the randomized trials did not detect any association between MPBS radiation and the development of acute symptoms during or shortly after exposure. The sporadically observed associations did not show a consistent pattern with regard to symptoms or types of exposure. We also found that the more sophisticated the exposure assessment, the less likely it was that an effect would be reported. Studies on health effects other than non-specific symptoms and studies on MPBS exposure in children were scarce.
Conclusion The evidence for a missing relationship between MPBS exposure up to 10 volts per metre and acute symptom development can be considered strong because it is based on randomized, blinded human laboratory trials. At present, there is insufficient data to draw firm conclusions about health effects from long-term low-level exposure typically occurring in the everyday environment.

Une traduction en français de ce résumé figure à la fin de l'article. Al final del artículo se facilita una traducción al español. الترجمة العربية لهذه الخلاصة في نهاية النص الكامل لهذه المقالة.

Introduction

The introduction in the 1990s of mobile phones using the digital Global System for Mobile Communications (GSM) with bandwidths of 900 and 1800 megahertz and the subsequent introduction of the Universal Mobile Telecommunications System (UMTS) have led to widespread use of this technology and to a substantial increase in the number of mobile phone base stations (MPBS) all over the world. This development has raised public concerns and substantial controversy about the potential health effects of the radiofrequency electromagnetic field emissions of this technology.[1–3] A small proportion of the population attributes non-specific symptoms of ill-health, such as sleep disturbances or headache,[2,4] to exposure to electromagnetic fields. This phenomenon is described as electromagnetic hypersensitivity or "idiopathic environmental intolerance with attribution to electromagnetic fields."[5–8] Additionally, individuals who are hypersensitive to electromagnetic fields often claim to be able to perceive radiofrequency electromagnetic fields in their daily life.[6]

People are generally exposed to MPBS radiation under far-field conditions, i.e. radiation from a source located at a distance of more than one wavelength. This results in relatively homogenous whole-body exposure. MPBS exposure can occur continuously but the levels are considerably lower than the local maximum levels that occur when someone uses a mobile phone handset.[9] A recent study that measured personal exposure to radiofrequency electromagnetic fields in a Swiss population sample demonstrated that the average exposure contribution from MPBSs is relevant for cumulative long-term whole-body exposure to radiofrequency electromagnetic fields. However, as expected, it is of minor importance for cumulative exposure to the head of regular mobile phone users.[10](Personal exposure measurements assess the total radiation absorbed by the whole body, whereas spot measurements quantify short-term exposure in a single place, usually the bedroom.)

In 2005, the World Health Organization (WHO) organized a workshop on exposure to radiation from MPBSs and its health consequences and subsequently published a paper summarizing the state of knowledge on the matter.[11] At that time, studies about the health impact of MPBS emissions were scarce and of low quality because most of the previous research on the health effects of radiofrequency electromagnetic fields had focused on exposure to mobile phone handsets and on effects related to head exposure, such as brain tumours or changes in brain physiology. In the last four years, research efforts have increased in response to public complaints and to a Dutch study describing decreased well-being associated with UMTS base station exposure.[12] Acute effects have been investigated in healthy volunteers and in individuals with hypersensitivity to electromagnetic fields using randomized, blinded laboratory trials and field intervention studies. Further epidemiological research has been stimulated by the recent availability of personal exposure metres. The aim of this paper is to present a systematic review of the scientific literature concerning all the health effects of MPBS radiation that have been investigated to date.

Methods

Literature search

We conducted a systematic search of Medline, EMBASE, ISI Web of Knowledge and the Cochrane Library in March 2009 to identify all relevant peer-reviewed papers published before that date. Key and free-text words included "cellular phone,"

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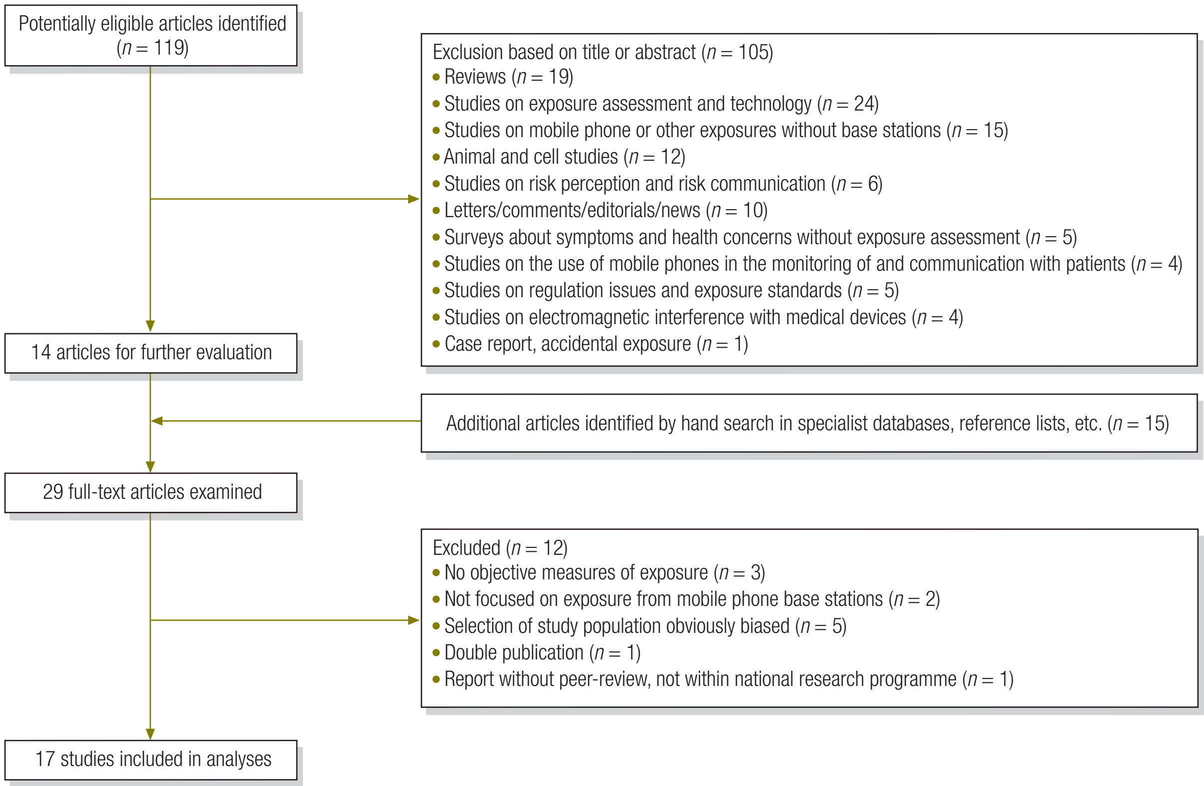
Fig. 1. **Flowchart showing the identification and selection of studies on the health effects of exposure to radiofrequency electromagnetic fields from mobile phone base stations**



"cellular," "phone," "mobile" and "mobile phone" in combination with "base station(s)." In addition, we examined references from the specialist databases ELMAR (http://www.elmar.unibas.ch) and EMF-Portal (http://www.emf-portal.de), reference lists in relevant publications and published reports from national electromagnetic field and mobile phone research programmes.

Inclusion and exclusion criteria

We included human laboratory trials and epidemiological studies, and we considered all the health effects that have been addressed so far. These include self-reported non-specific symptoms (e.g. headache, sleep disturbances, concentration difficulties), physiological measures (e.g. hormone levels, brain activity), cognitive functions, genotoxicity, cancer and various chronic diseases. In addition, we included randomized double-blind trials evaluating whether study participants were able to perceive radiofrequency electromagnetic fields. For a study to be eligible, far-field exposure from MPBSs had to be investigated – i.e. a relatively homogenous whole-body field in the GSM 900, GSM 1800 or UMTS frequency range – and the relationship between exposure and outcome had to be statistically quantified. In addition, basic quality criteria had to be fulfilled. Trials had to apply at least two different exposure conditions in a randomized and blinded manner. Epidemiological studies had to quantify exposure using objective measures (such as distance to the nearest MPBS, spot or personal exposure measurements, or modelling), possible confounders had to be considered and the selection of the study population had to be clearly free of bias in terms of exposure and outcomes

Data extraction

The data from each study were extracted independently by two researchers and recorded on one of two standardized forms. These forms, one for randomized trials and one for epidemiological studies, were developed using the CONSORT statement[13] for trials and the STROBE statement[14] for epidemiological studies. Extracted data included information about study participants, selection procedure, study design, exposure, analytic methods, results and quality aspects. Differences concerning data extraction were resolved by consensus.

Meta-analysis

All reported outcomes were checked for meta-analysis suitability. The only outcome with a sufficient number of comparable studies was the ability to perceive radiofrequency electromagnetic field exposure. To combine these study outcomes, for each study we calculated the difference between the number of observed correct answers (O) and the number of correct answers expected by chance (E), normalized by the number of correct answers expected by chance ([O-E]/E). Exact 95% confidence intervals (CIs) were calculated on the basis of binomial or Poisson data distribution, depending on the experimental design. In the absence of heterogeneity between studies ($I^2 = 0.0\%$; $P = 0.99$), we used fixed-effect models for pooling the study estimates. The detailed method is described in Röösli, 2008.[6]

Evidence rating

To rate the evidence for detrimental health effects from MPBSs, we assessed the risks of various types of bias for all included studies as proposed by the

Table 3. **Studies on mobile phone base station (MBPS) radiation and self-reported headache: results of a systematic review of studies conducted before March 2009**

Reference	Study design	Study population	Exposure source	Exposure levels of the exposed group(s)	Outcome measure	Results
Randomized human laboratory studies						
Regel 2006[17]	Crossover	33 EHS and 84 non-EHS adults	UMTS	1 and 10 V/m	Bulpitt quality-of-life questionnaire[23]	No exposure–outcome association: $P = 0.41$
Riddervold 2008[19]	Crossover	40 adults and 40 adolescents	UMTS	0.9 to 2.2 V/m	VAS[a]	Change of headache score during exposure: $P = 0.03$
Epidemiological studies						
Hutter 2006[24]	Cross-sectional	365 randomly selected participants living in the vicinity of MBPSs	GSM 900	> 0.43 V/m	Item of Von Zerssen symptom list[25]	RR = 3.1 (95% CI: 1.2 to 7.7)
Abdel-Rassoul 2007[27]	Cross-sectional	165 adults living/working near or far away from an MBPS	Not specified	Not reported	Questionnaire[a]	OR = 2.8 (95% CI: 1.1 to 7.4)
Heinrich 2007[28]	Field intervention	95 employees in an office building	UMTS	0.1 V/m	Questionnaire[a]	Mean score unexposed: 0.128 (SD = 0.588) Exposed: 0.152 (SD = 0.615)
Thomas 2008[31]	Cross-sectional	329 randomly selected adults	All[b]	0.21–0.58% of ICNIRP limit[c]	Freiburg symptom score[32]	OR = 1.2 (95% CI: 0.2 to 6.4)
	Longitudinal			0.19–0.56% (morning) 0.22–0.71% (afternoon) of ICNIRP limit[c]	Item of Von Zerssen symptom list[25]	Morning: OR = 0.6 (95% CI: 0.1 to 2.8) Afternoon: OR = 3.1 (95% CI: 0.8 to 12.6)
Berg-Beckhoff 2009[35]	Cross-sectional	1326 randomly selected adults	Base station (sum of GSM 900, GSM 1800 and UMTS)	> 0.1 V/m	HIT-6[36]	Score decrease in exposed individuals: −0.24 (95% CI: −1.57 to 1.08)
Kühnlein 2009[39]	Cross-sectional	1433 randomly selected children	All[b]	> 90th percentile (value not reported)	Item on Health Behaviour in School-aged Children questionnaire[40]	Headache: OR = 0.6 (95% CI: 0.3 to 1.0)

CI, confidence interval, EHS, electromagnetic hypersensitivity; GSM, Global System for Mobile Communications; HIT-6, Headache Impact Test; ICNIRP, International Commission on Non-Ionizing Radiation Protection; MHz, megahertz; OR, odds ratio; RR, relative risk; SD, standard deviation; UMTS, Universal Mobile Telecommunications System; VAS, visual analogue scale; V/m, volts per metre.
[a] No information about validation is given.
[b] Sum of GSM 900, GSM 1800, UMTS (up- and downlink), Digital Enhanced Cordless Telecommunications (DECT) and wireless local area networks (WLAN).
[c] The lower end of this range (0.21% of the ICNIRP limit) corresponds to 0.123 V/m at a frequency of 1800 MHz.

Cochrane handbook.[15] The final evidence rating was obtained according to the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach.[16]

Results

Selection of studies

In total, 134 potentially relevant publications were identified; 117 articles were excluded as they did not meet our inclusion criteria (Fig. 1). Of the 17 articles included in the analyses, 5 were randomized trials and 12 were epidemiological or field intervention studies. The majority of the studies examined non-specific symptoms.

Non-specific symptoms of ill-health

Acute effects of MPBS exposure on self-reported non-specific symptoms were investigated in four randomized double-blind human laboratory trials. The details of these studies are summarized in Table 1 (available at: http://www.who.int/bulletin/volumes/88/12/09-071852). Three trials used a UMTS antenna to create controlled exposure circumstances[17,19,20] and one study evaluated all three mobile phone frequency bands.[18] In total, 282 healthy adults, 40 healthy adolescents and 88 individuals with hypersensitivity to electromagnetic fields were included in these four studies. Exposure levels varied between 0.9 and 10 volts per metre (V/m).

We identified 10 epidemiological studies that investigated the effect of MPBS exposure in terms of self-reported non-specific symptoms (Table 2, available at: http://www.who.int/bulletin/volumes/88/12/09-071852). Most of these studies were cross-sectional, and the magnitude of the exposure was based on the distance between place of residence and the nearest MPBS,[1,27] or on spot measurements of MPBS radiation in the bedroom,[24,35] or on personal measurements of exposure to radiofrequency electromagnetic fields over a 24-hour period.[31,39] Four epidemiological studies applied an experimental approach (field intervention) in which exposure was modified either by turning on and off an MPBS[28,29] or by using shielding curtains.[30,33] Sample size ranged from 43 to 26 039 participants. The cut-off values differentiating exposed from unexposed persons varied between 0.1 and 0.43 V/m.

Of all non-specific symptoms, headache was most often investigated (Table 3). Two epidemiological studies[24,27] reported a statistically significant positive correlation between exposure level and headache score. In a Danish laboratory trial, when the data from 40 adults and 40 adolescents were pooled, a larger change in headache score was found under UMTS exposure than under sham exposure.[19] However, further analysis indicated that this change was due to a lower baseline score before UMTS exposure rather than to a higher score after exposure. The remaining four epidemiological studies[28,31,35,39] and one laboratory trial[17] did not indicate any association between MPBS exposure and headache.

With respect to self-reported sleep measures, only an Egyptian study[27] reported greater daytime fatigue in exposed individuals. None of the other studies found any association between MPBS exposure and fatigue or self-reported sleep disturbances (Table 4).[20,24,29–31,35,39]

Many other non-specific symptoms have been evaluated, such as concentration difficulties or dizziness. Generally, no association with exposure was observed (Table 1 and Table 2). One of the few exceptions was a laboratory trial that showed an increased arousal score among individuals with hypersensitivity to electromagnetic fields during UMTS exposure, which might be explained in part by the effect of order of exposure rather than by exposure itself.[18] One field intervention study observed a small increase in calmness under unshielded conditions compared with shielded conditions, but no effect on mood or alertness.[33] In an observational study from Egypt, several symptoms were more prevalent in 85 inhabitants or employees of a house near an MPBS compared with 80 employees considered unexposed.[27] In an Austrian study with 365 participants, a statistically significant association was found between 3 out of 14 symptoms (headache, cold hands and feet, concentration difficulties) and MPBS exposure.[24]

Some studies evaluated overall symptom scores obtained from standardized questionnaires such as the SF-36 Health Survey,[37] the Von Zerssen list[25] and the Frick symptom score[38] (Table 5). In a survey of 26 039 German residents, the Frick symptom score was significantly elevated for people living less than 500 m from an MPBS compared with those living further away.[1] However, subsequent improved dosimetric evaluations in 1326 randomly selected volunteers from this survey did not confirm a relationship between symptoms and measured MPBS radiation.[35] Three additional studies also failed to find any association between exposure and symptom scores.[17,18,28]

In summary, when data from all the randomized trials and epidemiological studies were considered together, no single symptom or symptom pattern was found to be consistently related to exposure. The cross-sectional epidemiological studies, however, showed a noteworthy pattern: studies with crude exposure assessments based on distance showed health effects, whereas studies based on more sophisticated exposure measurements rarely indicated any association.

Field perception

Four randomized double-blind trials addressed the ability to perceive the presence of a radiofrequency electromagnetic field. None of these trials[17–20] revealed a correct field detection rate better than expected by chance (Fig. 2) and there was no evidence that individuals who were hypersensitive to electromagnetic fields were more likely to determine correctly the presence or absence of exposure than individuals who were not hypersensitive ($P = 0.66$). In a German field intervention study,[28] a newly installed MPBS on top of an office building was randomly turned on and off over a period of 70 working days, and 95 employees assessed its operation status every evening. The most successful participant achieved 69% correct answers in 42 assessments. The likelihood of achieving a performance score that is good or better by chance is 1% for a given individual, but for one of 95 study participants to have achieved it can be explained by chance alone.

Cognitive functions

Exposure effects on cognitive functions were investigated in three trials[17,19,20] and two epidemiological studies.[24,27] All three trials investigated the effect of UMTS base station exposure but found no effect in a variety of cognitive tests. One epidemiological study produced inconsistent results,[27] whereas the other showed no exposure effects in several cognitive tests.[24]

Physiological measures

Three laboratory studies investigated different physiological responses. In one trial, no significant changes in blood volume pulse, skin conductance and heart rate were observed in 44 individuals with hypersensitivity to electromagnetic fields or in 115 individuals who were not hypersensitive after exposure to GSM 900, GSM 1800 or UMTS base station fields.[18] Likewise, autonomic nervous functions as measured by skin surface temperature, heart rate and local blood flow in the finger tip were not altered by UMTS base station exposure in a Japanese study.[20] In a third trial, polysomnographic electroencephalography (EEG) recordings from 13 study participants exposed to a GSM 1800 base station field for two nights did not differ significantly from recordings from two nights of sham exposure (Table 2).[41] In two field intervention studies, polysomnographic measures were not related to exposure.[29,30]

Chronic diseases

We identified no study that investigated an association between chronic diseases other than cancer and MPBS exposure. One observational study addressed the genotoxic effects of MPBS radiation. The investigators compared blood samples from 49 individuals employed by two Belgian mobile phone companies (38 radio field engineers and 11 administrative workers exposed at their workplace to radiofrequency antennas from sur-

Table 4. **Studies on mobile phone base station (MPBS) radiation, self-reported sleep measures and polysomnographic recordings: results of a systematic review of studies conducted before March 2009**

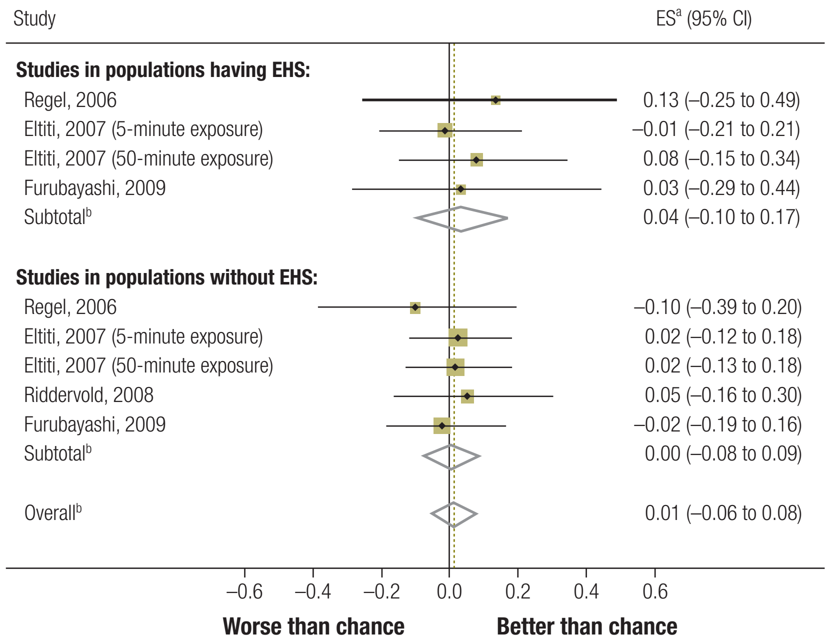
Reference	Study design	Study population	Exposure source	Exposure level of the exposed group(s)	Outcome measure	Results
Randomized human laboratory studies						
Hinrichs 2005[41]	Crossover	13 healthy volunteers	GSM 1800	30 V/m at subject's head	Polysomnography	No significant effects on classical sleep parameters
Furubayashi 2009[20]	Crossover	11 female EHS and 43 female controls	W-CDMA (2 140 MHz)	10 V/m at subject's head	POMS questionnaire[21]	Effect of condition: Fatigue ($P = 0.41$)
Epidemiological studies						
Hutter 2006[24]	Cross-sectional	365 randomly selected participants living in the vicinity of MPBSs	GSM 900	> 0.43 V/m	PSQI[26]	Sleep quality: $P = 0.24$ Sleep disturbances: $P = 0.34$ Global sleep score: $P = 0.28$
Abdel-Rassoul 2007[27]	Cross-sectional	165 adults living/working near or far away from an MPBS	Not specified	Not reported	Questionnaire	Sleep disturbances: OR = 2.8 (95% CI: 1.1 to 7.4)
Danker-Hopfe 2008[29]	Field intervention	397 adults from 10 German towns	GSM 900/ GSM 1 800 base station	0.1 V/m	Sleep diary and polysomnography	Sleep efficiency: $P = 0.84$ Time spent in bed: $P = 0.29$ Total sleep time: $P = 0.39$ Sleep latency: $P = 0.83$ Wake after sleep onset: $P = 0.88$ Restfulness: $P = 0.59$
Leitgeb 2008[30]	Cross-sectional	43 EHS volunteers from Germany and Austria	All sources	Unshielded condition: about 0.5% of ICNIRP limit	Written questionnaire on subjective sleep quality	Non-significant improvement of sleep score with increasing GSM-EMF at baseline ($P > 0.05$)
	Field intervention		Shielding of RF-EMF during 3 nights	Shielding	Polysomnography	No statistically significant effects on sleep parameters
Thomas 2008[31]	Cross-sectional	329 randomly selected adults	All[a]	0.21–0.58% of ICNIRP limit	Freiburg symptom score[32]	Sleeping disorders: OR = 1.1 (95% CI: 0.5 to 2.1) Fatigue: OR = 0.7 (95% CI: 0.3 to 1.8)
	Longitudinal (within one day)			0.19–0.56% (morning) 0.22–0.71% (afternoon) of ICNIRP limit	Fatigue (item of Von Zerssen symptom list)[25]	Morning: OR = 0.5 (95% CI: 0.2 to 1.1) Afternoon: OR = 0.5 (95% CI: 0.3 to 1.0)
Berg-Beckhoff 2009[35]	Cross-sectional	1326 randomly selected adults	Base station (sum of GSM 900, GSM 1800 and UMTS)	> 0.1 V/m	PSQI[26]	Score difference: –0.15 (95% CI: –0.69 to 0.38)
Kühnlein 2009[39]	Cross-sectional	1433 randomly selected children	All[a]	> 90th percentile (value not reported)	Items on Health Behaviour in School-aged Children questionnaire[40]	Sleeping problems: OR = 1.0 (95% CI: 0.6 to 1.5) Fatigue: OR = 0.8 (95% CI: 0.6 to 1.3)

CI, confidence interval; EHS, electromagnetic hypersensitivity; GSM, Global System for Mobile Communications; ICNIRP, International Commission on Non-Ionizing Radiation Protection; MHz, megahertz; OR, odds ratio; POMS, Profile of Mood States; PSQI, Pittsburgh Sleep Quality Index; RF-EMF, radiofrequency electromagnetic field; UMTS, Universal Mobile Telecommunications System; V/m, volts per metre; W-CDMA, Wideband Code Division Multiple Access.
[a] Sum of GSM 900, GSM 1800, UMTS (up- and downlink), Digital Enhanced Cordless Telecommunications (DECT) and wireless local area networks (WLAN).

rounding buildings) with samples from 25 subjects who were unrelated to the operators, had occupations that excluded exposure to sources of radiofrequency electromagnetic fields and did not use a mobile phone.[42] Overall, no differences were found among the three groups in chromosomal aberrations, DNA damage or sister chromatid exchange frequency. There was a tendency towards increased chromatid breaks for field engineers compared with administrative workers and controls.

An ecological study compared the cancer incidence among 177 428 persons living in 48 municipalities in Bavaria between 2002 and 2003 in relation to MPBS coverage.[43] Municipalities were classified on a crude three-level exposure scale based on the transmission duration of each MPBS and the proportion of the population living within 400 m of an MPBS. No indication of an overall increase in cancer incidence was found in municipalities belonging to the highest exposure class. The number of cases was too small for tumour-specific analysis.

Fig. 2. **Graphical representation of the results of field detection tests by means of randomized double-blind trials carried out in laboratory settings: results of a systematic review of studies conducted before March 2009**



CI, confidence interval; EHS, electromagnetic hypersensitivity; ES, effect size.

[a] Effect sizes refer to the relative difference between observed and expected correct answers.

[b] The edges of the diamonds show the 95% CIs of the pooled estimates (subtotals and overall).

Discussion

In response to public concerns, most studies dealing with exposure to electromagnetic fields from MPBSs have investigated non-specific symptoms of ill-health, including self-reported sleep disturbances. The majority of these studies have not shown any occurrence of acute symptoms after exposure to GSM 900, GSM 1800 or UMTS fields from MPBSs. The sporadically observed associations in randomized laboratory trials did not show a consistent pattern in terms of symptoms or types of exposure. In our review of epidemiological studies we found that the more sophisticated the exposure assessment, the less likely it was that an effect would be reported. We also found no evidence that individuals who are hypersensitive to electromagnetic fields are more susceptible to MPBS radiation than the rest of the population.

Our findings corroborate previous reviews on exposure to radiofrequency electromagnetic fields and self-reported non-specific symptoms,[6,7,11,44,45] while we included several more sophisticated recently published studies. Table 6 (available at: http://www.who.int/bulletin/volumes/88/12/09-071852) shows the risks of various types of bias for all studies included in the review. In general, the risk of bias was rare in double-blind randomized trials applying controlled exposure conditions in a laboratory. In epidemiological studies, exposure assessment is a challenge and random exposure misclassification is likely to have occurred in these studies. The corresponding bias probably diluted any exposure–response association, if one existed. None of the studies applied long-term exposure measurements. Cross-sectional studies may reveal effects of prolonged MPBS exposure if the applied measures do in fact represent the exposure level over a longer time period, which was reported to be the case in a Swiss study that measured personal exposure to radiofrequency electromagnetic fields.[10] Nevertheless, cross-sectional studies are by design limited in their ability to elucidate causal relationships. For self-reported outcomes, information bias could create spurious exposure–outcome associations if study participants are aware of their exposure status, which is to be expected if exposure is assessed on the basis of distance to a visible transmitter. Selection bias is also of concern, since people who believe that they can feel exposure may be more likely to participate in a study. In fact, objectively measured distance to an MPBS is only weakly correlated with actual exposure from that MPBS.[46,47] Interestingly, our review found the strongest symptomatic effects in two studies using measured distance,[1,27] which makes these findings arguable as well.

We excluded three epidemiological studies suggesting a link between cancer incidence and proximity to MPBSs[48–50] and three studies indicating an association with non-specific symptoms[51–53] because they did not fulfil our quality criteria. Data collection[48–50] or selection of study participants[51] was obviously related to exposure and outcome and therefore biased. Two studies used self-estimated distance, not objective distance, as an exposure measure,[52,53] which is problematic because it is likely to introduce bias, especially in combination with self-reported symptoms.

Exposure levels in human laboratory studies varied between 1 and 10 V/m. A homogeneous UMTS field of 1 V/m is estimated to yield an average whole-body specific absorption rate of 6 microwatts per kilogram (μW/kg) and a 1 gram (g) peak specific absorption rate in the brain of 73 μW/kg.[17] This is considerably lower than peak specific absorption rates caused by mobile phone handsets (about 1 to 2 W/kg).[54] Thus, a finding of acute brain-related effects (e.g. headaches or changes in brain physiology) would be expected in studies of mobile phone handset ex-

Table 5. **Studies on mobile phone base station radiation and symptom scores obtained from quality-of-life questionnaires: results of a systematic review of studies conducted before March 2009**

Reference	Study design	Study population	Exposure source	Exposure level of the exposed group(s)	Outcome measure	Results
Randomized human laboratory trials						
Regel 2006[17]	Crossover	33 EHS and 84 non-EHS adults	UMTS	1 and 10 V/m	Change of current disposition during exposure (CDdiff); current disposition after exposure (CDpost); adapted quality-of-life questionnaire (TNO)	No exposure–outcome association in EHS or non-EHS persons CDdiff: $P=0.95/P=0.95$ CDpost: $P=0.96/P=0.89$ TNO: $P=0.65/P=0.92$
Eltiti 2007[18]	Crossover	44 EHS and 115 non-EHS adults	GSM 900, GSM 1800 and UMTS	2 V/m	6 items on a visual analogue scale	GSM versus sham in EHS/non-EHS[a]: Total number of symptoms: $P=0.49/P=0.96$ Symptom score: $P=0.81/P=0.49$ UMTS versus sham in EHS/non-EHS[a]: Total number of symptoms: $P=0.10/P=0.41$ Symptom score: $P=0.12/P=0.87$
Epidemiological studies						
Heinrich 2007[28]	Field intervention	95 employees of an office building	UMTS	0.1 V/m	Questionnaire	During exposure: non-significant increase of symptom score ($P=0.08$) Cumulative exposure not associated with symptom score ($P=0.42$)
Blettner 2009[1]	Cross-sectional	26 039 German residents of a panel survey	Geo-coded distance to the closest mobile phone base station	Next base station < 500 m versus > 500 m	Frick symptom score[38]	Score difference: 0.34 (95% CI: 0.32 to 0.37)
Berg-Beckhoff 2009[35]	Cross-sectional	1326 randomly selected adults	Base station (sum of GSM 900, GSM 1800 and UMTS)	> 0.1 V/m	Von Zerssen symptom list,[25] SF-36[37]	Score differences: Von Zerssen: 0.55 (95% CI: –1.05 to 2.15) SF-36, physical: –0.14 (95% CI: –1.80 to 1.51) SF-36, mental: 0.37 (95% CI: –0.93 to 1.68)

CI, confidence interval; EHS, electromagnetic hypersensitivity; GSM, Global System for Mobile Communications; SF-36, Short Form (36) Health Survey; TNO, Netherlands Organization for Applied Scientific Research; UMTS, Universal Mobile Telecommunications System; V/m, volts per metre.

[a] *P*-values calculated from *F*- and *t*-values. Relevant *P*-value for significance after Bonferroni correction: $P < 0.003$.

posure rather than in studies mimicking MPBS exposure. Studies on mobile phone exposure suggest effects on EEG α-band activity during sleep,[55] with some evidence for a dose–response relationship,[56] but the results are inconsistent with regard to cognitive functions[57] and mostly negative for headache.[58,59]

Interestingly, persons classified as highly exposed in the epidemiological studies were actually exposed to rather low field levels. Exposure cut-off points for the highest exposed groups were below 0.5 V/m in all studies. This is much lower than the reference levels established by the International Commission on Non-Ionizing Radiation Protection, which range between 41 and 61 V/m for the frequency bands of MPBSs.[60] Since population exposure seems to be considerably lower than the reference levels, it is currently difficult to investigate the long-term health effects of exposure close to those levels.

In conclusion, our review does not indicate an association between any health outcome and radiofrequency electromagnetic field exposure from MPBSs at levels typically encountered in people's everyday environment. The evidence that no relationship exists between MPBS exposure and acute symptom development can be considered strong according to the GRADE approach[16] because it is based on randomized trials applying controlled exposure conditions in a laboratory.

Regarding long-term effects, data are scarce and the evidence for the absence of long-term effects is limited. Moreover, very little information on effects in children and adolescents is available and the question of potential risk for these age groups remains unresolved.

Where data are scarce, the absence of evidence of harm should not necessarily be interpreted as evidence that no harm exists. Further research should focus on long-term effects and should include children and adolescents. Additional cross-sectional studies would be of limited value, so future studies should apply a longitudinal design. Because there is no evidence that potential health effects would be restricted to MPBS frequency bands,[9] such studies should include an assessment of exposure to other sources of radiofrequency electromagnetic fields in daily life, such as mobile and cordless phones and wireless local area networks.[61] ■

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ملخص

مراجعة منهجية للتأثيرات الصحية للتعرض لحقول التردد الإشعاعي والكهربية المغناطيسية الصادرة عن محطات الهواتف المحمولة

الغرض: مراجعة وتقييم المؤلفات الحديثة عن التأثيرات الصحية المترتبة على التعرض للإشعاعات الصادرة عن محطات الهاتف المحمول.

الطريقة: أجرى الباحثون مراجعة منهجية للتجارب المختبرية البشرية المُعشَّاة والدراسات الوبائية التي تقصّت التأثيرات الصحية للإشعاعات الصادرة عن محطات الهاتف المحمول في البيئة اليومية.

الموجودات: ضم الباحثون في تحليلهم 17 مقالة لبت مواصفات الجودة الأساسية وتكونت من: 5 تجارب مختبرية بشرية مُعشَّاة، و 12 دراسة وبائية. وقد فحصت أغلبِ الأبحاث (14 بحثاً) الأعراض غير النوعية للاعتلال الصحي المبلغ عنها ذاتياً. ولم تكتشف أغلب التجارب المُعشَّاة أي ارتباط بين الإشعاعات الصادرة عن محطات الهاتف المحمول وظهور أعراض حادة أثناء التعرض أو بعد فترة وجيزة من التعرض. ولم تدل الارتباطات الفرادية التي لوحظت على وجود نمط ثابت للأعراض أو أنماط التعرض. كما اكتشف الباحثون أنه كلما كان قياس التعرض أكثر تعقيداً قل احتمال التبليغ عن التأثيرات الصحية. وكانت دراسات التأثيرات الصحية بعيداً عن الأعراض غير النوعية والدراسات عن التعرض للإشعاعات الصادرة عن محطات الهاتف المحمول بين الأطفال قليلة للغاية.

الاستنتاج: يمكن اعتبار الدليل على عدم وجود علاقة بين التعرض للإشعاعات الصادرة عن محطات الهاتف المحمول حتى مقدار 10 فولت لكل متر وظهور الأعراض الحادة دليلاً قوياً لأنه يرتكز على التجارب المختبرية البشرية المُعشَّاة والمُعَمَّاة. وحتى الآن لا توجد بيانات كافية للوصول إلى استنتاج قوي عن التأثيرات الصحية الناتجة عن التعرض طويل الأمد للمستويات المنخفضة كما يحدث تقليدياً في البيئة اليومية.

Resumé

Évaluation systématique des effets sanitaires de l’exposition aux champs électromagnétiques de fréquence radio des stations de base de la téléphonie mobile

Objectif Étudier et évaluer la documentation récente sur les effets sur la santé de l’exposition aux radiations des stations de base des téléphones portables.

Méthodes Nous avons réalisé une évaluation systématique des essais aléatoires menés en laboratoire sur des sujets humains et des études épidémiologiques examinant les effets sur la santé des radiations des stations de base de la téléphonie mobile dans l’environnement quotidien.

Résultats Nous avons inclus dans l’analyse 17 articles qui répondaient à nos critères de qualité élémentaires : 5 essais aléatoires en laboratoire réalisés sur l’Homme et 12 études épidémiologiques. La majorité des articles (14) examinaient les symptômes non spécifiques autodéclarés d’un mauvais état de santé. La plupart des essais aléatoires ne détectaient aucune association entre les radiations des stations de base des téléphones portables et le développement de symptômes aigus au cours de l’exposition ou peu de temps après. Les associations observées de façon sporadique ne montraient aucun modèle cohérent concernant les symptômes ou les types d’exposition. Nous avons également constaté que plus l’évaluation de l’exposition était sophistiquée, moins la probabilité de signalement d’un effet était importante. Les études sur les effets sanitaires autres que les symptômes non spécifiques et les études sur l’exposition aux stations de base des téléphones portables chez les enfants étaient peu nombreuses.

Conclusion La preuve d’absence de relation entre l’exposition aux stations de base de la téléphonie mobile jusqu’à 10 Volts/mètre et le développement de symptômes aigus peut être considérée comme solide car elle repose sur des essais aléatoires menés sur des sujets humains et à l’aveugle en laboratoire. Actuellement, nous ne disposons pas de données suffisantes pour tirer des conclusions définitives sur les effets sur la santé de l’exposition de faible intensité à long terme qui est présente dans l’environnement quotidien.

Resumen

Revisión sistemática sobre cómo afecta a la salud la exposición a los campos electromagnéticos de radiofrecuencia de las estaciones base de telefonía móvil

Objetivo Revisar y analizar la bibliografía reciente sobre cómo afecta a la salud la exposición a la radiación de las estaciones base de telefonía móvil (EBTM).

Métodos Se realizó una revisión sistemática de los ensayos aleatorizados en humanos realizados en laboratorio, así como de los estudios epidemiológicos que investigaron los efectos sobre la salud de la radiación EBTM en el entorno cotidiano.

Resultados En el análisis se incluyeron 17 artículos que cumplían nuestros criterios básicos de calidad: 5 ensayos de laboratorio aleatorizados y realizados en humanos y 12 estudios epidemiológicos. La mayoría de los artículos (14) examinados informaron sobre síntomas no específicos de enfermedad. La mayoría de los ensayos aleatorizados no detectó relación alguna entre la radiación EBTM y la aparición de síntomas agudos durante o poco después de la exposición. Las asociaciones observadas ocasionalmente no mostraron un patrón homogéneo en lo que respecta a los síntomas o a los tipos de exposición. También observamos que cuanto más compleja era la evaluación de la exposición, menos probable era que se constatara algún efecto. Se han realizado pocos estudios sobre los efectos en la salud más allá de los síntomas no específicos y sobre la exposición de los niños a las EBTM.

Conclusión Los resultados sobre la ausencia de una relación entre la exposición a las EBTM de hasta 10 voltios por metro y la aparición de síntomas agudos se pueden considerar consistentes, ya que se basan en ensayos de laboratorio llevados a cabo en humanos, aleatorizados y enmascarados. En la actualidad no hay datos suficientes para extraer conclusiones en firme acerca de los efectos sobre la salud de la exposición de baja intensidad y a largo plazo en el entorno cotidiano.

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Table 1. **Overview of randomized human laboratory trials included in a systematic review of studies of MPBS exposure and self-reported non-specific symptoms conducted before March 2009**

Reference	Study design	Study population	Inclusion/exclusion criteria	Outcome	Exposure assessment	Statistical model/covariables	Results (exposure versus sham/control)
Regel 2006[17]	Crossover	33 with EHS Mean age: 38 years Female: 58%	Inclusion: 20–60 years of age, right-handed, BMI between 19 and 30 kg/m^2 Exclusion: medical problems, implants, drug consumption	Questionnaires: CDdiff,[a] CDpost,[a] Bulpitt[b]	3 45-minute sessions with exposure to: (a) sham conditions (b) UMTS (2140 MHz), 1 V/m (c) UMTS (2140 MHz), 10 V/m Randomized, counter-balanced	Mixed linear models; circadian rhythm, smoking, exposure order, age, sex, BMI, caffeine intake, medication, menstruation-related complaints, sleep quality, and having a cold	No exposure–outcome association: CDdiff ($P=0.95$) CDpost ($P=0.96$) Bulpitt ($P=0.65$)
		84 without EHS Mean age: 38 years Female: 51%					No exposure–outcome association: CDdiff ($P=0.95$) CDpost ($P=0.89$) Bulpitt ($P=0.92$)
Eltiti 2007[18]	Crossover	44 with EHS Mean age: 46.1 years Female: 42.9%	Exclusion: brain injury, epilepsy, claustrophobia, pacemaker, mental disease, psychoactive medication within 4 months before testing	Rating of 6 items on a visual analogue scale every 5 minutes: anxiety, tension, arousal, relaxation, discomfort, fatigue	3 50-minute sessions with exposure to: (a) sham conditions (b) UMTS at 2020 MHz (c) GSM 900 and 1880 MHz combined; E-field: 2 V/m Randomized, not counter-balanced	ANOVA; condition, group[c]	GSM: anxiety ($P=0.06$); tension ($P=0.09$); arousal ($P=0.03$); inverse of relaxation ($P=0.46$); total number of symptoms ($P=0.49$); symptom score ($P=0.81$)[c] UMTS: anxiety ($P=0.005$); tension ($P=0.004$); arousal ($P=0.001$); inverse of relaxation ($P=0.03$); total number of symptoms ($P=0.10$); symptom score ($P=0.12$)[c]
		115 without EHS Mean: 54.5 years Female: 42.5%					GSM: anxiety ($P=0.53$); tension ($P=0.47$); arousal ($P=0.83$); inverse of relaxation ($P=0.25$); total number of symptoms ($P=0.96$); symptom score ($P=0.49$)[c] UMTS: anxiety ($P=0.04$); tension ($P=0.11$); arousal ($P=0.46$); inverse of relaxation ($P=0.04$); total number of symptoms ($P=0.41$); symptom score ($P=0.87$)[c]
Riddervold 2008[19]	Crossover	40 healthy adolescents Age range: 15–16 years Female: 58%	Exclusion: pregnancy, medical history of head injuries and/or neurological or psychiatric diseases, illiteracy	11 symptoms on a visual analogue scale: Primary outcome: change in headache during session, Secondary outcome: change in concentration difficulties during session	4 45-minute sessions with exposure to: (a) sham conditions (b) continuous wave at 2140 MHz (c) UMTS signal at 2140 MHz (d) UMTS signal at 2140 MHz with all control features E-field: 0.9–2.2 V/m Randomized, counterbalanced	Only exposure (UMTS with all control features) was considered. Standard crossover analysis technique based on Wilcoxon test; order of exposure	Concentration: no change ($P=0.88$) Headache: trend of increase ($P=0.09$)[d]
		40 healthy adults Age range: 25–40 years Female: 40%					Concentration: increase ($P=0.048$) Headache: trend of increase ($P=0.15$)[d]

Reference	Study design	Study population	Inclusion/exclusion criteria	Outcome	Exposure assessment	Statistical model/covariables	Results (exposure versus sham/control)
Furubayashi 2009[20]	Crossover	11 females with EHS Mean age: 37 years, 43 female controls Mean age: 38 years	Inclusion: 20–60 years Exclusion: Living too far from Tokyo, myocardial infarction, epilepsy, brain injury, pacemakers, hearing aids, pregnancy, medical treatment for psychiatric disorders	POMS questionnaire[21]: Change of 6 scales during session: tension-anxiety, depression, anger-hostility, vigour, fatigue and confusion. Discomfort was assessed every 5 minutes during exposure	4 30-minute sessions with W-CDMA exposure to: (a) continuous wave at 2 140 MHz (b) intermittent signal (turned on/off every 5 minutes), (c) sham with noise (d) sham without noise. E-field: 10 V/m at subject's head Randomized, counter-balanced	ANOVA; condition, sequence, group, time (before–after) (for discomfort: condition, group)	Effect of condition: Tension–anxiety ($P = 0.60$) Depression ($P = 0.78$) Anger-hostility ($P = 0.47$) Vigour ($P = 0.96$) Fatigue ($P = 0.41$) Confusion ($P = 0.77$) Discomfort ($P = 0.86$)

ANOVA, analysis of variance; BMI, body mass index; CDdiff, change of current disposition during exposure; CDpost, current disposition after exposure; EHS, electromagnetic hypersensitivity; GSM, Global System for Mobile Communications; MHz, megahertz; MPBS, mobile phone base station; POMS, Profile of Mood States; UMTS, Universal Mobile Telecommunications System; V/m, volts per metre; W-CDMA, Wideband Code Division Multiple Access.

[a] As measured by the short Questionnaire on Current Disposition.[22]

[b] Adapted Bulpitt symptom score as measured by a questionnaire developed to estimate quality of life during trials of an antihypertensive drug treatment.[23]

[c] *P*-values calculated from *F* and *t* values. Relevant *P*-value for significance after Bonferroni correction: $P < 0.003$.

[d] Pooled analyses of headache for adolescents and adults resulted in a significant change during exposure ($P = 0.027$).

Table 2. **Overview of epidemiological studies included in a systematic review of studies of MPBS exposure and self-reported non-specific symptoms conducted before March 2009**

Reference	Study design	Study population (participation rate)	Inclusion/exclusion criteria	Outcome	Exposure assessment	Statistical model/ covariables	Results
Hutter 2006[24]	Cross-sectional	365 subjects from Vienna and Carinthia in the vicinity of 10 base stations Mean age: 44 years (range: 18–91 years) Female: 59% (Participation rate: approximately 60% in Vienna, 68% in Carinthia)	Inclusion: age > 18 years, living in the present house for at least 1 year and staying there for a minimum of 8 hours a day on average	Von Zerssen complaint list,[25] PSQI[26]	Spot measurements in the bedroom Main source was GSM 900 3 exposure categories: < 0.19 V/m, 0.19–0.43 V/m, > 0.43 V/m	ANCOVA for PSQI, logistic regression for Von Zerssen complaint list; age, sex, region, regular use of mobile telephone and fear of adverse effects of the base station	Highest vs lowest exposure levels: Headache: RR = 3.1 (95% CI: 1.2 to 7.7) Cold hands or feet: RR = 2.6 (95% CI: 1.2 to 5.7) Difficulties in concentration: RR = 2.6 (95% CI: 1.1 to 6.1) Remaining 11 symptoms and sleep quality measures not associated with exposure.
Abdel-Rassoul 2007[27]	Cross-sectional	85 exposed inhabitants/employees (living near an MPBS) Mean age: 38.2 years Female: 57%; 80 unexposed employees (working 2 km from the MPBS) Mean age: 39.8 years Female: 59% (Participation rate not reported.)	Exclusion: epilepsy, psychiatric disorders, specific cause of headache	Prevalence of headache, irritability, memory changes, tremors, dizziness, blurred vision, depressive symptoms	Two sites with different distances to an MPBS; Frequency band not reported, no meaningful exposure measurements	χ^2 test, Student's *t*-test, ANCOVA; age, sex, occupation, education level, smoking and mobile phone use	Exposed vs unexposed: Headache: OR = 2.8 (95% CI: 1.1 to 7.4) Memory changes: OR = 7.5 (95% CI: 2.3 to 27.0) Dizziness: OR = 4.4 (95% CI: 1.3 to 16.5) Depressive symptoms: OR = 2.8 (95% CI: 1.0 to 8.0) Blurred vision: OR = 1.6 (95% CI: 0.7 to 3.9) Sleep disturbances: OR = 2.8 (95% CI: 1.1 to 7.4) Irritability: OR = 1.5 (95% CI: 0.7 to 3.3) Lack of concentration: OR = 1.8 (95% CI: 0.7 to 5.0)
Heinrich 2007[28]	Field intervention	95 employees of an office building in Bavaria (Germany) Median age 40 years (range: 26–62 years) Female: 30% (Participation rate: ca. 32%)	Not mentioned	Questionnaire with 21 symptoms: difference of the score between evening and morning	UMTS base station on the roof of the building randomly turned on/off during 1–3 consecutive days over a period of 70 days[a] E-field during exposure: maximum 0.53 V/m, mean 0.1 V/m	Mixed linear regression models with autocorrelation; sex, air pressure, day of week, self-reported EHS and ability to perceive EMF	During exposure non-significant increase of symptom score ($P = 0.08$). Cumulative exposure was not associated with symptom score ($P = 0.42$).
Danker-Hopfe 2008[29]	Field intervention	397 individuals of 10 German towns with no mobile phone coverage, only weak other RF-EMF sources and no emotional public debate about base station setting Mean age: 45 years Female: 51% (Participation rate: 17%)	Inclusion: place of residence < 500m from a base station, age > 17 years	Sleep diary and polysomnography	Transmission of GSM 900/ GSM 1800 base station during 5 consecutive nights on or off, randomized[a] E-field during exposure: 1 V/m to 6 V/m, mean: ca. 0.1 V/m	Student's *t*-test or Wilcoxon test	Exposed vs unexposed: Sleep efficiency ($P = 0.84$) Time spent in bed ($P = 0.29$) Total sleep time ($P = 0.39$) Sleep latency ($P = 0.83$) Wake after sleep onset ($P = 0.88$) Restfulness ($P = 0.59$)

Reference	Study design	Study population (participation rate)	Inclusion/exclusion criteria	Outcome	Exposure assessment	Statistical model/ covariables	Results
Leitgeb 2008[30]	Cross-sectional	43 EHS volunteers from Germany and Austria recruited by press release Mean age: 56 years Female: 61% (Participation rate: 44%)	Inclusion: EHS, Pittsburgh index > 5 Exclusion: neurological and psychological disorders, somatic reasons for sleep disorders, drug consumption, medical treatment	Written questionnaire on subjective sleep quality	3 control nights without shield. If unshielded: typical measured levels < 0.5% ICNIRP limit, maximum level: 3.5% of ICNIRP limit[b]	Linear regression	Non-significant improvement of sleep score with increasing GSM-EMF at baseline (*P* > 0.05)
	Field intervention				3 control nights without shield, 3 nights with sham shield and 3 nights with true shield; randomized, single-blind	MANOVA, Kolmogorov–Smirnov Z test or Mann–Whitney U test	3 participants with improvement by true shield; 6 participants with placebo effects (improvement by true and sham shield compared to control nights); 34 volunteers with no effects
				Polysomnography			2 participants with improvement by true shield; 6 participants with sleep impairment by true shield; 5 participants with mixed effects; 1 participant with placebo effects; 29 volunteers with no effects.
Thomas 2008[31]	Cross-sectional	329 randomly selected residents of 4 German towns Age range: 18–65 years Female: 53% (Participation rate: 30%)	Inclusion: age 18–65 years	Selection of items from Freiburg symptom score[32]: occurrence of symptom at least twice per month	Personal dosimetry of total RF-EMF[c] during waking hours of one day (in % of ICNIRP limit) Lowest quartile (reference): < 0.15% of ICNIRP limit Top quartile: 0.21–0.58% of ICNIRP limit[d]	Logistic regression; age, sex	Top quartile vs reference: Headache: OR = 1.2 (95% CI: 0.2 to 6.4) Neurological symptoms: OR = 0.6 (95% CI: 0.1 to 4.2) Cardiovascular symptoms: OR = 2.4 (95% CI: 0.6 to 9.9) Sleeping disorders: OR = 1.1 (95% CI: 0.5 to 2.1) Fatigue: OR = 0.7 (95% CI: 0.3 to 1.8)
	Longitudinal within one day			Selection of items from the Von Zerssen complaint list[25]: at least moderate symptom intensity			Morning/afternoon: Headache Morning: OR = 0.6 (95% CI: 0.1 to 2.8) Afternoon: OR = 3.1 (95% CI: 0.8 to 12.6) Neurological symptoms Morning: OR = 0.5 (95% CI: 0.2 to 1.3) Afternoon: OR = 0.4 (95% CI: 0.2 to 1.2) Fatigue Morning: OR = 0.5 (95% CI: 0.2 to 1.1) Afternoon: OR = 0.5 (95%CI: 0.3 to 1.0) Concentration problems Morning: OR = 0.3 (95% CI: 0.1 to 1.8) Afternoon: OR = 1.4 (95% CI: 0.4 to 4.7)

Reference	Study design	Study population (participation rate)	Inclusion/exclusion criteria	Outcome	Exposure assessment	Statistical model/ covariables	Results
Augner 2009[33]	Field intervention	57 volunteers; Mean age: 40.7 years, Female: 61%	Not mentioned	Standardized questionnaire on well-being (MDBF[34]) with 3 scales: mood, alertness, calmness	In a "field laboratory" three exposure levels were created by shielding devices (5 50-minute exposure sessions): Low = 0.04 V/m medium = 0.24 V/m high = 0.90 V/m; exposure originated predominantly from a GSM 900 antenna	ANOVA; age, sex and degree of possible EHS	Increase in calmness ($P = 0.042$) for participants in scenarios with high and medium exposure compared with low exposure. No effects for "good mood" and "alertness."
Berg-Beckhoff 2009[35]	Cross-sectional	1326 individuals from 8 urban German regions Age range: 15–71 years Female: 51% (Participation rate: 21%)	Participants in the panel survey by Blettner 2009[1]	5 symptom scales: sleep quality (PSQI),[26] headache (HIT-6)[36], symptom score (Von Zerssen list),[25] SF-36[37]	Sum of GSM 900, GSM 1800 and UMTS from a spot measurement in the bedroom, dichotomized at 90th percentile (i.e. > 0.1 V/m)	Linear regression model; age, sex, rural/urban, education level, mobile phone use, risk perception and stress	Score difference between subjects with high and low exposure: PSQI: –0.15 (95% CI: –0.69 to 0.38) HIT-6: –0.24 (95% CI: –1.57 to 1.08) Von Zerssen: 0.55 (95% CI: –1.05 to 2.15) SF-36, physical: –0.14 (95% CI: –1.80 to 1.51) SF-36, mental: 0.37 (95% CI: –0.93 to 1.68)
Blettner 2009[1]	Cross-sectional	26 039 German residents of a panel survey that is regularly carried out Age range: 14–69 years Female: 52% (Participation rate: 58.6%)	Not mentioned	Frick symptom score[38]	Geo-coded distance to the closest MPBS	Multiple linear regression model; age, sex, income, education, region, city inhabitants and concerns/ attribution	Difference in Frick score < 500 m vs > 500 m (95% CI: 0.32 to 0.37 (95% CI: 0.32 to 0.37) Worries were associated with self-reported distance but not with objectively geo-coded distance.
Kühnlein 2009[39]	Cross-sectional	1433 randomly selected children of 4 German towns Age range: 8–12 years (Participation rate: 53%)	Inclusion: age 8–12 years, German nationality, only 1 participant per household	Computer-assisted personal interview: questions on chronic symptoms during the last 6 months	Personal dosimetry of total RF-EMF[c] over 24 hours (in % of ICNIRP limit); mean exposure dichotomized at 90th percentile (value of cut-off not reported)	Multiple logistic regression models; age, sex, parents' level of education, parents' environmental worries, mobile phone use, DECT use, estimated distance to next MPBS and study site	> 90th percentile vs < 90th percentile: Headache: OR = 0.6 (95% CI: 0.3 to 1.0) Irritation: OR = 1.0 (95% CI: 0.6 to 1.5) Nervousness: OR = 0.8 (95% CI: 0.5 to 1.4) Dizziness: OR = 1.1 (95% CI: 0.5 to 2.4) Fear: OR = 0.6 (95% CI: 0.2 to 2.0) Sleeping problems: OR = 1.0 (95% CI: 0.6 to 1.5) Fatigue: OR = 0.8 (95% CI: 0.6 to 1.3)

ANCOVA, analysis of covariance; CI, confidence interval; DECT, Digital Enhanced Cordless Telecommunications; EHS, electromagnetic hypersensitivity; EMF, Electromagnetic field; GSM, Global System for Mobile Communications; HIT-6, Headache Impact Test; ICNIRP, International Commission on Non-Ionizing Radiation Protection; MANOVA, multivariate analysis of variances; MDBF, Mehrdimensionale Befindlichkeitsfragebogen [Multidimensional Mood State Questionnaire]; MHz, megahertz; MPBS, mobile phone base station; OR, odds ratio; PSQI, Pittsburgh Sleep Quality Index; RF, radiofrequency; RR, relative risk; SF-36, Short Form (36) Health Survey; UMTS, Universal Mobile Telecommunications System; V/m, volts per metre; WLAN, wireless local area network.

[a] Transmission status of base station was not detectable by mobile phone.

[b] The maximum level (3.5% of the ICNIRP limit) corresponds to 2 V/m at a frequency of 1800 MHz.

[c] Total RF-EMF: sum of GSM 900, GSM 1800, UMTS (up- and downlink), DECT and WLAN.

[d] The lower end of this range (0.21% of the ICNIRP limit) corresponds to 0.123 V/m at a frequency of 1800 MHz.

Table 6. **Risk of various types of bias[a] in studies included in a systematic review of MPBS exposure and self-reported non-specific symptoms conducted before March 2009[b]**

Study	Exposure assessment bias	Selection bias	Randomization bias	Confounding	Other bias
Randomized human laboratory trials					
Hinrichs 2005[41]	Low	Low	Low	↕ Medium: sequence of exposure not considered	↓ Medium: Low statistical power ($n=13$)
Regel 2006[17]	Low	Low	Low	Low	No
Eltiti 2007[18]	Low	Low	↑ High: exposure conditions were not counterbalanced	↑ Medium: sequence of exposure not considered	↓ Medium: conservative multiple endpoint adjustment (Bonferroni)
Riddervold 2008[19]	Low	↑ Medium: unequal headache score at baseline of various exposure conditions	Low	Low	↕ Medium: selective reporting: only results from one out of three exposure conditions reported
Furubayashi 2009[20]	Low	Low	Low	Low	↓Medium: Low statistical power for EHS analysis ($n=11$)
Field intervention epidemiological studies					
Heinrich 2007[28]	↓ Medium: small exposure contrasts and no individual exposure assessment	Low	Low	Low	No
Danker-Hopfe 2008[29]	↓ Medium: small exposure contrasts and no individual exposure assessment	Low	Low	↕ Medium: sequence of exposure not considered	↓ Medium: data analyses based on weekly average instead of single nights
Leitgeb 2008[5]	↓ Medium: small exposure differences, no individual exposure assessment	Low	Low	↑ High: day of week not considered	↕ Medium: only individual based data analysis, no comparison of group averages
Augner 2009[33]	Low	↑ Medium: unclear criteria for combining the results from various exposure conditions	Low	↑ High: only adjusted for age	↕ Medium: small control group ($n=9$)
Observational epidemiological studies					
Hutter 2006[24]	↓ Medium: small exposure contrasts	↑ Medium: affected people close to base station may be more likely to participate	Low	Low	↑ No multiple endpoint correction
Maes 2006[42]	↕ Medium: no exposure measurements	Low	Low	↕ Medium: few confounders tested (results not shown)	No
Meyer 2006[43]	↓ High: crude exposure assessment	Low	Low	↕ Medium: only age and sex considered	↓ Medium: small number of cases

Study	Exposure assessment bias	Selection bias	Randomization bias	Confounding	Other bias
Abdel-Rassoul 2007[27]	↑ High: crude exposure assessment, no measurements	↕ High: unclear how participants were recruited and selected; workers are compared with general population	↑ High: participants must be aware of their exposure status	↕ Medium: few confounders considered	No
Thomas 2008[31]	↓ Medium: small exposure contrasts ↕ Medium: no differentiation between base station and handset exposure ↑ Medium: personal measurements might be manipulated	↑ Medium: affected people who are highly exposed may be more likely to participate	Low	↕ Medium: only age and sex considered	No
Berg-Beckhoff 2009[35]	↓ Medium: small exposure contrasts	↑ Medium: agreeing to participate in measurement study may not be random	Low	Low	No
Blettner 2009[1]	↕ High: crude exposure assessment	↑ Medium: affected people living close to base station may be more likely to participate	↑ Medium: people may be aware of distance to closest MPBS	Low	No
Kühnlein 2009[39]	↓ Medium: small exposure contrasts ↕ Medium: no differentiation between base station and handset exposure ↑ Medium: personal measurements might be manipulated	↑ Medium: affected people who are highly exposed may be more likely to participate	Low	Low	No

EHS, electromagnetic hypersensitivity; MPBS, mobile phone base station.

[a] Risk of bias classified into the categories low, medium and high. For medium and high risk of bias, the direction is indicated with arrows: ↓ refers to an underestimation of the exposure effect association (false negative); ↑ refers to an overestimation of the association (false positive) and ↕ indicates that the direction of the bias is not clear.

[b] Blinding was also assessed: all randomized human laboratory trials were double-blind. In field intervention studies and in observational epidemiological studies, it is impossible to ensure blinding with regard to exposure.