Exposure to Mobile Phone Electromagnetic Fields and Subjective Symptoms: A Double-Blind Study

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Objectives: The objective of this study was to examine whether acute exposure to radio frequency electromagnetic fields (REFs) emitted by mobile phone may affect subjective symptoms. **Methods:** Three large groups of volunteers (total 496) were exposed to REFs emitted by mobile phones in one session and sham signals in a different session. REF and sham exposure sessions were counterbalanced and double blinded. Participants were exposed to either Global System for Mobile Communication (GSM) or unmodulated signals, and the mobile phone was positioned either on the left or on the right side of the head. Before and after REF and sham exposure participants completed a questionnaire to rate five symptoms. Any changes in the severity of the symptoms after REF exposure were compared with changes after sham exposure. **Results:** For one group of participants ($N = 160$), it was found that dizziness was affected by GSM exposure, but this was not consistently found with the other two groups of participants. No other significant effects were found. **Conclusions:** We did not find consistent evidence suggesting that exposure to mobile phone REFs affect subjective symptoms. Even though we acknowledge that more research is needed, we believe that our results give an important contribution to the research on mobile phone use and subjective symptoms. **Key words:** radio frequency electromagnetic fields, REF exposure, subjective symptoms, mobile phones.

REF = radio frequency electromagnetic field; **GSM** = Global System for Mobile Communication; **CW** = continuous wave; **SAR** = specific energy absorption rate; **SD** = standard deviation.

INTRODUCTION

The use of mobile phones has often been associated with particular subjective symptoms such as headache, fatigue, rash, or warmth sensations on the skin (particularly in the area around the ear). Thus, in recent years, scientists have been trying to establish whether symptoms such as these can be triggered specifically by the radio frequency electromagnetic fields (REFs) emitted by mobile phones (1). As it is often the case with studies on the effects of electromagnetic fields on human health, this is a very controversial area of research and there are no conclusive studies as yet (2). A way of investigating this issue is by examining symptoms or sensations experienced by mobile phone users (3–5). Hocking (5) interviewed 40 mobile phone users and found that the majority (88%) suffered of cranial symptoms such as heat or dull pain on temple, ear or occiput when using a mobile phone. Typically symptoms started a few minutes after commencing a call. Other symptoms frequently reported were transient effects on vision, such as blurring (31%) and sensation of nausea or dizziness (43%). The same symptoms did not occur when using ordinary handsets. In a more recent survey, Balikci et al. (3) compared symptoms reported by mobile phone users and nonusers and found that the use of mobile phone may increase the severity of symptoms such as headache, irritation, clicking sounds in ears and others. While studies examining the symptoms of mobile users in everyday life are essential to reveal effects related to prolonged daily exposure to mobile phones, a) they do not necessarily reveal an association between subjective symptoms and REFs exposure, b) they may lack accurate experimental control, as in those kind of studies it is very difficult to have control of variables other than REFs that can trigger particular symptoms, and c) volunteers can be biased when judging the severity of the symptoms related to mobile phone use. An alternative way of testing whether or not mobile phones REFs produce subjective symptoms is by exposing individuals, under strict experimental control and under double-blind conditions (i.e., when both participants and experimenter are unaware of the exposure condition) to REFs and sham signals, in different sessions, for a given period of time, and then ask them to report about particular symptoms they are experiencing (6). Hietanen et al. conducted a study using a similar method (7). They recruited a group of volunteers who reported themselves as being sensitive to cellular phones. In several sessions, participants were exposed to either REFs or sham signals and were then questioned about any particular symptoms. The symptoms reported were not aggravated by REFs exposure. The study also investigated whether participants were able to sense mobile phone REF emission and it was found that no one could distinguish between exposure conditions. Recently, other studies have shown no relations at all between exposure to mobile phone REFs and subjective symptoms (6,8,9), not even those studies that have focused on individuals claiming to be hypersensitive to REFs.

Even though some scientists came to the conclusions that nocebo effects (8) or psychological factors (9) may affect reports of symptoms, generally it is acknowledge that more research is needed (10).

In the present study, we investigated whether exposure to mobile phone REFs can affect five symptoms (headache, dizziness, fatigue, itching or tingling of skin, and sensation of warmth on skin). The choice of symptoms was based on what has been previously reported in the literature. In two different sessions, volunteers were exposed to active REF and sham signals, and asked to rate the above symptoms. Exposure conditions (real exposure and sham exposure) were double blinded. Testing under double-blind conditions seems important since many effects reported under single-blind conditions

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have not stood up to the test of replication under double-blind REF exposure (11–13). The large sample included in the study and the very high standards of the experimental method used make our study an important and valuable contribution to the research on the effects of electromagnetic fields on public health.

METHOD

Four hundred ninety-six volunteers took part in the study (330 were female; average age was 23 years, with SD = 4.4, minimum age = 18 years and maximum age = 42 years), between March 2003 and September 2005. All were studying or working at the University of Essex, United Kingdom. Volunteers were originally recruited to participate in one of three different groups of experiments (studies 1, 2, and 3), whose main aim was to test possible effects of exposure to mobile phone REF on cognitive functions (attention, memory, and auditory perception). In addition to performing their cognitive tasks, participants were asked to evaluate a group of symptoms both before and after REF and sham exposure. Details of the three studies are shown in (13,14). In each study, participants were tested in two sessions (about 1 week apart): in one session they were exposed to REF signals, whereas in the other session exposure was sham (the order of REF and sham sessions was counterbalanced between participants). REF and sham conditions were double blinded. In both conditions, exposure lasted for about 40 minutes. During exposure, participants had to perform a series of cognitive tasks. Although the nature of the tasks performed was different in the three studies, REF and sham exposure conditions were identical. Half of participants were exposed to Global System for Mobile Communication (GSM) signal and half to continuous waves (CW) unmodulated signals. The phone was attached to a cap that was then positioned on participant's head. Its position was adjusted so that the antenna of the phone was slightly behind and above the ear. For half of participants, the mobile phone was mounted on the left side of the head, and on the right side for the other half. The mobile phone used could emit GSM modulated and CW unmodulated signals at 888 MHz as well as a sham signal. The level of specific energy absorption rate (SAR) was the same for both CW and GSM signals (with SAR within the International Commission on NonIonising Radiation Protection guidelines). The average SAR in both modes was 1.4 W/Kg (±30%). For the GSM mode, the peak SAR was 11.2 W/Kg (CW does not have a peak). The SAR in the sham condition was less than 0.002 W/Kg. The above features correspond to the approved exposure system made for the Mobile Telecommunication and Health Research Programme (see http://www.mthr.org.uk/meetings/nov_2002/summaries/human_exposure.htm) in the United Kingdom.

In each session, participants were given the same questionnaire where they rated five particular sensations or symptoms experienced at that very moment, as shown in Table 1. Each symptom was assessed on a scale ranging from 1 (no sensation) to 5 (strong sensation). The questionnaire was given both at the beginning (before positioning the phone on the head) and at the end of the session (once the phone was removed). Therefore, each participant completed the same questionnaire four times.

The procedures used in the three studies complied with the relevant safeguards and regulations in place for studies testing human participants at the University of Essex and the Ethics Committee of the University of Essex approved the study.

Participants were briefed about the nature of the study and made aware that they could withdraw at any time, if they wish.

TABLE 1. Symptom Questionnaire Completed by the Participants of Our Study

Could you, please, rate the strength of the sensations or symptoms, reported below, you are experiencing at the moment?					
In the scale, next to each symptom/sensation, 1 = no sensation, 5 =strong sensation					
a) Headache	1	2	3	4	5
b) Dizziness	1	2	3	4	5
c) Fatigue	1	2	3	4	5
d) Itching or tingling of skin	1	2	3	4	5
e) Sensation of warmth on skin	1	2	3	4	5
If you are experiencing any of the sensations in d) or e), could you please specify exactly where (e.g., back of the head, temple regions, ear, face, etc.):					
d)					
e)					
Report if you have any other symptom/sensation (with rate)					

RESULTS

In the analysis of the data, changes in symptom ratings after real REF exposure were compared with changes after sham exposure. The number of participants was 168 in studies 1 and 3, and 160 in study 2*. The data of the three studies were initially separately analyzed, as the tasks performed during REF exposure were different. In a second analysis, the data of the three studies were analyzed together to test possible differential effects of REF exposure due to the type of task performed.

In the first analysis, for each symptom and each study, a separate mixed factorial analysis of variance was performed with the following four factors: type of exposure (REF versus sham; within subjects), when symptom was rated (before versus after exposure; within subjects), mode (GSM versus CW; between subjects), and side of exposure (left versus right; between subjects). To evaluate possible effects of exposure to mobile phone REFs, the most critical factors were whether REF exposure was real or sham and whether a symptom was rated before or after exposure. Significant interactions of the two factors may suggest an effect of REF exposure on particular symptoms. Mean ratings of each symptom are shown in Table 2. Since the statistical analyses were conducted per each symptom in each experiment, the α level for each set of statistical analyses for each symptom was set at 0.01 to control for type I statistical errors within each experiment.

In all studies each symptom worsened at the end of the session (all F values >9), independently of any other factor.

In study 1 and study 2, there were no significant interactions involving the two relevant factors† [in study 1 all F values$(1,163) < 5.5$; in study 2 all F values$(1,155) < 3.7$].

In study 3, we found that for dizziness there was a significant interaction between type of exposure and when symptom

*Note, however, that in each study, a few participants were discarded before data analysis because of errors in data recording or missing data. Therefore, in study 1, $N = 167$; in study 2, $N = 159$; and in study 3, $N = 160$.

†With a less stringent α level at .05, in study 1, there was a significant interaction for fatigue between type of exposure and when symptom was rated [$F(1,163) = 5.5$, $p = 0.02$; see Table 2]. However, note that the symptom worsened more at the end of the sham session. A three-way significant interaction was found for symptom "itching or tingling of skin" between type of exposure, when symptom was rated, and which side the phone was positioned: when on the left, the difference between before and after exposure ratings was 0.1 with REF exposure and 0.3 with sham exposure, whereas when the phone was on the right, the differences were 0.3 and 0.2, respectively [$F(1,163) = 4.7$, $p = 0.03$]. These results were not replicated in studies 2 and 3, hence, more importantly, it is likely to reflect a type I statistical error. We also estimated the effect size and found that it was very small: $d = 0.18$, for study 1, and $d = 0.02$, for all three studies.

TABLE 2. Mean Ratings of the Five Symptoms in Studies 1–3

	Study 1 (N = 167)			Study 2 (N = 159)			Study 3 (N = 160)		
	Before	After	p	Before	After	p	Before	After	p
Headache									
REF	1.25 (0.58)	1.58 (0.85)	0.9	1.25 (0.5)	1.89 (0.95)	0.06	1.19 (0.58)	1.61 (0.95)	0.3
Sham	1.23 (0.52)	1.54 (0.87)		1.25 (0.54)	1.75 (0.95)		1.2 (0.55)	1.52 (0.85)	
Dizziness									
REF	1.19 (0.5)	1.59 (0.85)	0.3	1.11 (0.39)	1.59 (0.84)	0.8	1.12 (0.36)	1.66 (1.0)	0.001[a]
Sham	1.16 (0.41)	1.62 (0.84)		1.13 (0.44)	1.6 (0.89)		1.16 (0.46)	1.49 (0.81)	
Fatigue									
REF	1.66 (0.85)	1.88 (0.94)	0.02	1.72 (0.84)	2.33 (1.12)	0.3	1.5 (0.72)	2.25 (1.12)	0.6
Sham	1.58 (0.79)	1.96 (1.06)		1.66 (0.83)	2.18 (1.09)		1.48 (0.74)	2.19 (1.16)	
Itching/tingling of skin									
REF	1.15 (0.43)	1.34 (0.78)	0.5	1.09 (0.35)	1.17 (0.5)	0.06	1.14 (0.46)	1.29 (0.69)	0.6
Sham	1.13 (0.48)	1.37 (0.82)		1.1 (0.34)	1.31 (0.7)		1.13 (0.39)	1.25 (0.68)	
Sensation of warmth on skin									
REF	1.43 (0.85)	1.93 (1.18)	0.7	1.36 (0.75)	1.81 (1.1)	0.7	1.34 (0.67)	1.84 (1.19)	0.8
Sham	1.43 (0.79)	1.97 (1.14)		1.4 (0.8)	1.92 (1.19)		1.39 (0.74)	1.71 (1.07)	

[a] Statistically significant at α level = 0.01.

SDs are reported in parenthesis. Ratings are reported according to whether participants were exposed to REF or sham signals, and according to when symptoms were rated (before or after exposure); p-values are reported for the interactions between the two factors (when symptom was rated and type of exposure) in the ANOVA (α level applied = 0.01).

was assessed [$F(1,156) = 11.1$, $p < .001$]. The difference between before and after exposure ratings was 0.6 with REF exposure and 0.3 when exposure was sham. No other significant interactions were found [all F values <3.3].

The data from the three studies were also analyzed together. One significant interaction only was found for dizziness [$F(1,474) = 5.5$, $p < .01$] showing that while in studies 1 and 2 differences between before and after exposure ratings remained constant with both types of exposures (0.5), in study 3 that difference decreased when exposure was sham (0.6 with REF exposure and 0.3 with sham exposure).

In a further analysis, suggested by an anonymous reviewer, we analyzed the data of the three studies for possible gender effects. A significant interaction of Exposure by When by Gender occurred for the symptom of dizziness [$F(1,457) = 6.6$, $p = .01$; ratings are shown in Table 3]. Inspecting Table 3 it appears that the significant interaction was due to a relatively higher score of males at the end of the REF exposure session. However, for the remaining four symptoms none of the exposure by when-symptom-was-rated interactions were modulated by gender factor [all F values <2].

TABLE 3. Ratings for Dizziness According to Gender (p = .01).

Gender	Exposure	When	Mean
Female	REF	Before	1.13
		After	1.52
	Sham	Before	1.18
		After	1.58
Male	REF	Before	1.15
		After	1.84
	Sham	Before	1.11
		After	1.58

In the symptom questionnaire, participants were also asked to report any other symptom or sensation they were experiencing other than those listed. The most frequently reported symptom was "strained or tired eyes." Among the 23 volunteers reporting the symptom, 11 reported the symptom at the end of the REF exposure session, 8 reported the symptom at the end of the sham session, 3 at the end of both sessions, and 1 at the beginning of the sham session. Other symptoms were reported, but with a very low frequency: "difficulty in concentrations" (2 participants), "tension in neck or shoulder" (7 participants), earache (4 participants), and sleepiness (1 participant). There were not relevant differences between REF and sham sessions.

DISCUSSION AND CONCLUSIONS

In the present study, we investigated possible effects of mobile phone REF exposure on subjective symptoms. Under double-blind conditions, participants were exposed, in two different sessions, to active REF mobile phone signals and sham signals and, in both sessions, they had to rate five subjective symptoms before and after being exposed to the signals. All symptoms significantly worsened at the end of the sessions, probably because of the difficulty of the tasks performed during exposure. Of all symptoms examined, headache, fatigue, itching or tingling of skin, and sensations of warmth on skin were not found to be related to mobile phone exposure, in any of our three studies. This is consistent with recent studies (6,8,9). Participants in study 3 showed a larger increase in sensation of dizziness after REF exposure, compared with sham. However, this was not found in study 1 (where levels of dizziness were numerically higher after sham exposure) and study 2 (where levels of dizziness were almost identical in both exposures), and, when the data from all three studies were analyzed together, the increase in dizziness at

the end of the session did not significantly vary in the two exposure conditions. This pattern of results is quite puzzling as REF and sham exposure conditions were identical in the three studies, including the duration of exposure. What changed from one study to the others was the kind of cognitive tasks performed during exposure—they were typical cognitive tasks assessing either attention or memory, where participants have to respond to stimuli shortly presented on a computer screen (details of tasks are in Refs. 13,14,15). There are no reasons to believe that REF effects may depend on the particular tasks in which participants are involved during exposure. Because recent studies gave no evidence of dizziness being affected by exposure to mobile phones (3,6), we suggest that our results may simply reflect type I statistical errors. However, to further understand the nature of the significant effect we found on dizziness, we estimated the effect size (as in Ref. 16) and found that $d = 0.25$, when considering study 3 only, and $d = 0.06$, when considering the data from all three studies, which suggests that the effect is indeed very small and further support our view that there are no real effects of REF on dizziness.

On a post-hoc analysis we also assessed gender effects. Some modulation occurred for dizziness where a slight increment in dizziness occurred among males after REF exposure. It is to be noted that this modulation was not detected for any of the other symptoms. Hence, this outcome may simply reflect a type I statistical error.

The present study does not provide consistent evidence that active exposure to mobile phone REFs can affect subjective symptoms. The results not only provide reliable evidence but are also consistent with recent studies (6–9). However, we do not consider our study to be conclusive, as only a small number of symptoms were examined and participants were not asked to rate other symptoms that in the literature have been reported as being affected by REFs (3) (note however that, in the present study, participants were encouraged to report any other symptom not listed in the questionnaire). Moreover, for our study we did not select volunteers who reported to be hypersensitive to electromagnetic fields, and this group might show effects to REF exposure—even though a recent review has shown that this might not be the case (1). Also, in our study, exposure duration was about 40 minutes, which is certainly longer than the duration of typical phone calls. However, the possibility that frequent daily REF exposure might have real effects on subjective symptoms cannot be ruled out. Even though we believe that our results give a much-needed contribution to the research on mobile phone use and subjective symptoms, we acknowledge that more research has to be done. In particular, we believe that there should be more studies on effects of long-term exposure and effects on children.

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