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Does Acute Exposure to Mobile Phones Affect Human Attention?

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Recent studies have indicated that acute exposure to low level radiofrequency (RF) electromagnetic fields generated by mobile phones affects human cognition. However, the relatively small samples used in addition to methodological problems make the outcomes of these studies difficult to interpret. In our study we tested a large sample of volunteers (168) using a series of cognitive tasks apparently sensitive to RF exposure (a simple reaction task, a vigilance task (VT), and a subtraction task). Participants performed those tasks twice, in two different sessions. In one session they were exposed to RF's, with half of subjects were exposed to GSM signals and the other half was exposed to CW signals, while in the other session they were exposed to sham signals. No significant effects of RF exposure on performance for either GSM nor CW were found, independent of whether the phone was positioned on the left or on the right side. Bioelectromagnetics 00:1–6, 2005. © 2005 Wiley-Liss, Inc.

Key words: GSM; RF; cognitive tests; behavioral effects

INTRODUCTION

Mobile telephone antennae emit low level radiofrequency (RF) electromagnetic fields with wavelength frequency bands starting from about 900 MHz. These fields may exert a force on the electric charges of body tissues located close to the emitting source, which, while not significantly increasing the temperature of biological tissues, could in principle exert an action that may affect the normal functioning of brain tissue [e.g., Cleary, 1995]. Hence, it has been suggested that acute exposure to RF fields generated by mobile phones could affect human cognition.

Recent studies have suggested that exposure to RF fields generated by either analogue or global system for mobile communication (GSM) mobile phones positively affect performance in memory and attention tasks [Preece et al., 1999; Koivisto et al., 2000a,b; Edelstyn and Oldershaw, 2002; Lee et al., 2003; Smythe and Costall, 2003; Curcio et al., 2004]. However, a serious question concerns whether the observed effects are genuine. In one study [Preece et al., 1999], 36 volunteers performed a series of cognitive tests while exposed to RF fields generated by analogue and GSM phones operating at about 900 MHz, as well as to a control condition without RF exposure. When exposed to the RF fields generated by analogue cellular phones, but not by GSM digital phones, people were faster in a two-choice reaction time task (CRT) compared to the control condition. No significant difference between exposure and control conditions occurred in any of the other cognitive tasks used. Similarly, another study [Koivisto et al., 2000b] found that, in a battery of about a dozen cognitive tests, there was a significant difference in performance between the exposure to GSM mobile phones condition and the control condition only in three tests, that is, a simple reaction time task (SRT), a subtraction task, and a vigilance task (VT). However, it is possible that these findings might reflect a statistical artifact, since the probability of wrongly rejecting a true null hypothesis in the family of statistical tests performed within each of the above studies was relatively high (i.e., >0.05). Moreover, in other studies

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the significant results obtained may have reflected poor matching of the baseline performance between control and exposure conditions [Edelstyn and Oldershaw, 2002; Lee et al., 2003]; type I statistical error [Smythe and Costall, 2003; Curcio et al., 2004]; small sample size with no attempt to replicate the original findings; or a speed-accuracy trade-off [Koivisto et al., 2000a]. Only two studies found no significant effect of RF field exposure on any of the cognitive tasks used [Haarala et al., 2003, 2004].

Given the widespread and increasing use of mobile phone technology around the world, it is vital to determine whether the RF fields emitted by these phones are indeed having a significant impact on human cognitive functions. It is, however, very difficult to draw firm conclusions on this question, since none of the studies which found significant findings, apart from Curcio et al. [2004], used a double blind design in administering RF exposure and control conditions. Hence, it is possible that a non-optimal administration of the independent variable may have led to spurious significant findings [cf. Haarala et al., 2003, 2004]. Thus, the evidence suggesting that exposure to RF fields emitted by mobile phones, either GSM or analogue, might affect performance in cognitive tasks remains unclear.

The aim of the present research was to overcome the limitations of previous studies in order to provide a thorough evaluation of the impact of the use of GSM and analogue continuous wave (CW) unmodulated signal mobile phones on attention in adults. To maximize the chance of detecting a significant effect of acute exposure to RF fields, we selected some of the tasks that previous studies [e.g., Koivisto et al., 2000b; Curcio et al., 2004] found were affected by RF exposure, that is, a SRT, a subtraction task, and a VT. To ensure high statistical power 168 volunteers were tested. Assuming that RF exposure (irrespectively of this being associated to GSM or CW signals, and whether or not the exposure was primarily applied to the left or the right side of the head) may have a small effect on cognitive performance, that is, effect size, $d = 0.3$, with 168 participants we had a statistical power of about 0.97 to reject a false null hypothesis about the RF exposure effect. Hence, given the large power of the present study, any failure to reject the null hypothesis cannot be attributed to a lack of statistical sensitivity. Moreover, to assess if there is any differential effect of GSM modulated versus CW unmodulated signals, half of the participants were exposed to an 888 MHz CW signal and the remaining half were exposed to an 888 MHz GSM signal. Importantly, RF exposure was administered under fully double blind conditions. Furthermore, half of the participants were tested with the mobile phone positioned on their left ear, and the remaining half had the phone positioned on the right ear. This potential lateralized effect has not been examined in any previous study.

MATERIALS AND METHODS

Participants

One hundred and sixty-eight healthy volunteers (99 women, 69 men; average age = 23.5 years; range 17–41) with normal or corrected-to-normal vision were tested in two different sessions, 1 week apart; each subject attended the two sessions at the same time of the day. Participants were students of the University of Essex recruited through advertisements in the campus; each participant was paid 10 Pounds Sterling. In one session participants were exposed to RF fields: a random half of the participants to GSM modulated signal and the other half to CW unmodulated signal, both at 888 MHz; the phones (discontinuous transmission was disabled). In the other session there was no exposure. In that case the power, either in GSM or CW, was actually diverted to an internal load of the phone. Half of the participants were exposed to RF on the first session with the no-exposure condition on the second session, and vice-versa for the other half. Both participants and experimenters were blind to the on-off exposure condition. Of all participants, 4% were not mobile phone users, 35% did use a mobile phone for about 5 min or less on average per day, and the remaining 61% used a mobile phone for more than 5 min per day.

Materials

A mobile phone was fixed on a "cage/cap" that was mounted on the head of each participant. The handset device was positioned on the head so that the telephone microphone was close to the mouth and the antenna was touching or very close to the head, above and slightly behind the ear. The mobile phone was on the left side of the head for half participants and on the right for the other half, irrespective of the handedness of participants.

The mobile phone 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) in the present study was the same for both CW and GSM signals with SAR within the International Commission on Non-Ionizing 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 no exposure 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 (http://www.mthr.org.uk/meetings/nov_2002/summaries/human_exposure.htm) in the UK. The measurements were made in a phantom head over a 36 by 17 measurement grid with 5 mm spacing, using the standard CENELEC (The European Committee for Electrotecnhical Standardization) device position and measurement procedures. The phantom headshell used for the dosimetric assessments was constructed by vacuum injection moulding of reinforced fiberglass resin using inner and outer moulds. The shell thickness was 2.0 ± 0.2 mm over the sides of the head.

Procedure

Participants were asked not to use any mobile telephone for at least 1 h before each session. At the beginning (and at the end) of each session, participants completed a questionnaire to rate a series of subjective symptoms. Then the mobile phone set was mounted on the head of each participant and activated. After that, participants had to complete a subsection of Raven's matrices (10 matrices in total) for a maximum of 10 min. This was simply done to allow the mobile phone to ''warm up'' after being switched on.

Four different tasks were administered in a counterbalanced order. In all the experiments visual stimuli were displayed on a computer screen and participants had to give, depending on the task, either a verbal response to a microphone in front of them or a key response on the computer keyboard. The reaction times (RT) for each response were then recorded. Each task was preceded by both verbal and written instructions, and by a variable number of practice trials (in order to familiarize participants with the task and to reach a stable performance).

In the SRT participants were presented with the letter ''O'' and asked to press the space bar on the computer keyboard as soon the letter appeared. The letter display lasted until the participant gave the response. The subsequent stimulus display was presented after a random interval ranging from 1 to 4 s. Each participant was presented with 40 trials.

In the *10-choice reaction time task* (10-CRT) participants had to read aloud into a microphone a one-digit number (any number from 0 to 9) randomly displayed. The number disappeared as soon as the response was given and the next number appeared 1 s after the verbal answer. After practice (i.e., 10 trials), a block of 80 trials was presented. In the *subtraction task* (ST) participants were presented with subtractions (one for each display), in which a one-digit number had to be subtracted from the number 9 (e.g., $9-5=?$). They had to say aloud the solution into a microphone.[1] The display with the subtraction disappeared as soon as an answer was given and the next display appeared after 1 s. This task always followed the 10-CRT task. Eighty trials were randomly presented.

In the VT a single capital letter from a pool of 15 different letters was presented for 200 ms. Each participant had to press the space bar on the computer keyboard as soon as one of the target letters (L, M, or Y) appeared, while no response had to be given when any other letter appeared. The inter-stimulus interval randomly varied from 500 to 3000 ms. Each participant was presented with 360 trials of which 72 (20%) were target trials.

Once the experimental tasks were completed, the phone set was removed and participants were once again given the questionnaire on subjective symptoms; the data on subjective symptoms and mobile phone use will be reported in a future study; each session lasted about 50 min. However participants were actually exposed to RFs for about 35–40 min. The order of the on- or off-exposure conditions and the order of presentation of the experimental tasks were counterbalanced across participants. The procedures used in this study complied with the relevant safeguards and regulations in place for studies testing human participants at the University of Essex and the study was approved by the University of Essex Ethics Committee.

Statistical Analysis

All participants were exposed to both ON and OFF (sham) conditions (in counterbalanced order). In the ON condition, 84 participants were exposed to GSM signals and 84 to CW signals. For each group, 42 subjects had the phone positioned on the left side of the head and 42 on the right side. Data were analyzed with a mixed factorial ANOVA, where the factors were Type of signal (CW and GSM, between subject factor),

[1]Note that in Koivisto et al. [2000b] responses in the 10CRT and ST tasks were given by pressing keys in the computer keyboard. We believe that for RTs measured on the verbal answers, when several options are available (as in our experiments), there is less variability both within and between participants. In fact, not only a manual response is normally less automatic (because less practiced) than a verbal one, but also individual ability with the keyboard can vary extensively, thus affecting RTs. We also believe that practice would affect more a manual response than a verbal one, and, therefore, because ST was always performed after 10CRT, RTs would reflect the time taken to give the actual answer (relative to the time taken to mentally process the stimulus and the answer) more in the 10CRT than in the ST, when a manual response is given.

RF exposure (On vs. Off, within subject factor), and Position (left vs. right, between subject factor). Supplementary analyses were conducted to assess any effect of practice and on differential effects of the On vs. Off variable on sex. This analysis was conducted to assess the extent to which the Smythe and Costall [2003] findings, of a differential impact of the On/Off variable on women versus men could be replicated using attentional tasks.

RESULTS

Table 1 provides the mean of the median RTs for each participant in each of the tasks used. RTs of incorrect responses were removed. A series of 2 (type of signal: CW vs. GSM) $\times$ 2 (position of the phone: Left vs. Right) $\times$ 2 (RF exposure: On vs. Off) mixed factorial ANOVAs were performed on the median, the log transformed median, the arithmetic, and the geometric mean of the performance of each participant in each condition. The results of these analyses were comparable, so only those carried out on medians are reported. A summary of the analyses carried out on each task follows.

Effects of RF/Sham Exposure

Simple reaction time task. None of the main effects was significant [Fs (1, 164) $<$ 1.21], none of the two-way interactions [Fs (1, 164) $<$ 1.1], nor the three-way interaction was significant [F (1, 164) $=$ 3.26, $P >$ .05]. Participants did not make any errors in this task.

Vigilance task. None of the main effects was significant [Fs (1, 164) $<$ 1.26], none of the two-way interactions [Fs (1, 164) $<$ 2.82], nor the three-way interaction was significant [F (1, 164) $<$ 1].

The proportion of missed targets across conditions ranged from 0.022 to 0.041. A mixed factorial ANOVA on these error data did not show any significant effect [Fs (1, 164) $<$ 2.07, $P >$ .15], indicating that there was not a speed-accuracy trade-off.

Ten CRT and subtraction tasks. Mixed factorial ANOVAs on the RTs obtained both in the 10 choice and in the subtraction task showed that none of the main effects nor interaction were significant [Fs (1, 164) $<$ 1.31]. Moreover, the 10CRT performance could be considered a baseline for the subtraction task. Hence, by

TABLE 1. Reaction Times in ms (RT) in the Attentional Tasks Used

Task[a]	Type of signal[b]	Phone position[c]	Exposure[d] ON	Exposure[d] OFF	P-value[e]
	CW	Left	315	316	>.82
		Right	323	321	>.64
SRT	GSM	Left	311	307	>.23
		Right	313	323	>.06
	CW	Left	286	284	>.51
		Right	300	295	>.32
VT	GSM	Left	294	299	>.25
		Right	300	295	>.55
	CW	Left	461	467	>.40
		Right	474	469	>.51
10CRT	GSM	Left	474	475	>.82
		Right	483	485	>.79
	CW	Left	732	736	>.79
		Right	750	751	>.95
ST	GSM	Left	770	767	>.77
		Right	737	754	>.37
	CW	Left	271	269	>.87
		Right	276	282	>.76
ST−10CRT	GSM	Left	297	292	>.72
		Right	253	269	>.40

[a]Simple reaction time task (SRT) vigilance task (VT), 10choice reaction time task (10CRT) subtraction task (ST) and on the RT difference between ST and 10CRT.
[b]Type of signal (unmodulated vs. modulated, i.e., CW vs. GSM).
[c]Position of the phone (Left vs. Right; number of subjects in parenthesis).
[d]RF exposure (On vs. Off).
[e]The P-values refer to the test of the ON vs. OFF variable. $N = 42$ participants per group.

removing the RTs obtained in the 10CRT task from the RTs obtained in the subtraction task we can obtain an estimate of the net time required to perform arithmetic subtractions. A mixed ANOVA on the RTs obtained by subtracting the RTs in the 10CRT from the subtraction task did not show any significant effect [Fs $(1, 164) < 1$].

The proportion of errors across conditions ranged from 0.025 to 0.044. A mixed factorial ANOVA on these error data did not show any significant effect [Fs $(1, 164) < 2.0$, $P > .15$], indicating that there was no a speed-accuracy trade-off.

RF/Sham Exposure in Session 1 and Session 2

To control the presence of practice effects on performance, we did an ANOVA where On and Off performances were compared separately for the first session and the second session. No significant differences between On and Off RTs were found for the first session nor for the second session. Average RTs and p-values for t-tests are shown in Table 2.

RF/Sham Exposure and Gender

To examine possible interactions between gender and On/Off exposure, we performed an ANOVA with RF exposure (On vs. Off, within subject factor) and Gender (male female, between subject factor) as factors. No significant interactions were found between On-Off exposure and gender (see Table 3).

DISCUSSION AND CONCLUSION

We found that when a large sample of participants is tested and exposure to RF fields is administered in a double blind manner, then RF emitted by mobile phones does not appear to significantly affect performance in a series of attentional tasks. It is important to note that these are the same tasks that previous, less powerful, studies have shown were affected by exposure to RF fields. There are some methodological discrepancies in response modality and number of trials between two of our experiments, and those conducted by Koivisto et al. [2000b]. However, we believe that our methodological changes were unlikely to interfere with attentional processing. In fact, we would argue that they should improve the chances of detecting possible effects (if any) of RFs on human attention. Moreover, in our study whether RF exposure originated from the right or the left, or whether the RF signal was modulated or unmodulated, made little difference to any of the cognitive tests. Finally, RF exposure effects were not modulated by gender in any of the tasks.

TABLE 2. RTs (in ms) for Each Attentional Task, According to the Session (Session 1 and Session 2) and to Whether the Phone was On (RF Exposure) or Off (Sham Exposure)

	RTs ON	RTs OFF	P-value[a]
SRT			
Session 1	312	314	>.82
Session 2	318	319	>.95
VT			
Session 1	293	303	>.24
Session 2	297	288	>.27
10CRT			
Session 1	466	476	>.37
Session 2	480	473	>.49
ST			
Session 1	765	771	>.84
Session 2	730	733	>.87
ST−10CRT			
Session 1	299	295	>.88
Session 2	250	261	>.59

[a]P-values resulting from the statistical analysis where, for each session, On RTs were compared with Off RTs.

The study of the effect of exposure to RF fields on behavior and health parameters is a highly controversial field of science with significant public interest and concern. Research to date suggests that it is unlikely that any effect on biological systems induced by the use of mobile phone can be ascribed to thermal effects. While there is public concern about non-thermal effects, there seems to be no viable theoretical basis to understand the possible non-thermal effects that microwave fields might have on biological systems [e.g., Maier et al., 2000]. In this theoretical vacuum, it is of some concern that research reports demonstrating an effect of RF fields generated by mobile phones on behavioral or on health parameters have not been subsequently replicated, especially when more sophisticated methodologies have been implemented [e.g., Repacholi, 1997; Krause et al., 2000, 2003; Utteridge et al., 2002].

In summary, the results we obtained do not, of course, preclude the possibility that exposure to RF

TABLE 3. Mean and P-values of the Interactions Between Gender and RF Exposure for Each of the Tasks Used

		Female	Male	P-value
SRT	On	315	317	>.29
	Off	314	321	
VT	On	299	289	>.52
	Off	300	288	
10CRT	On	478	466	>.33
	Off	480	465	
ST	On	774	709	>.78
	Off	783	708	
ST−10CRT	On	296	244	>.64
	Off	302	243	

fields generated by mobile phones may affect other aspects of cognitive functions that were not measured by the tasks we used. However, the present study highlights the need for replicable patterns of results using adequately powered studies in order to provide a sound empirical foundation for any theoretical understanding of how RF fields might affect cognitive functioning.

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