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Effects of mobile phone electromagnetic fields on an auditory order threshold task

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The effect of acute exposure to radio frequency electromagnetic fields (REF) generated by mobile phones on an auditory threshold task was investigated. 168 participants performed the task while exposed to REF in one testing session (either GSM -Global System for Mobile Communication- or unmodulated signals) while in a separate session participants were exposed to sham signals. Lateralisation effects were tested by exposing participants either on the left side or on the right side of the head. No significant effect of exposure to REF was detected, suggesting that acute exposure to REFs does not affect performance in the order threshold task.

In recent years, the number of studies investigating the effects of exposure to low-level radio frequency electromagnetic fields (REF) emitted by mobile telephones has constantly increased. Some studies of human cognitive functioning have shown that exposure to electromagnetic fields of the type emitted by mobile phones can affect cerebral functions (e.g., Hamblin *et al*., 2004) as well as the behavioral performance of exposed volunteers (e.g., Keetley *et al*., 2006; Koivisto *et al*., 2000). Other studies, however, have found no significant effects either on human behaviour (Russo *et al.*, 2006; Haarala *et al*., 2004), or on brain processes (e.g., Krause *et al*., 2003).

Since the area around the ear receives the highest exposure to mobile phone REF, a limited number of studies have examined the effects of mobile phone REF on auditory perception. Curcio *et al.* (2004) found that, after being exposed to REF for a minimum of 25 minutes the tympanic temperature of human participants increased. Moreover, participants were also faster to respond in an acoustic simple reaction-time task. In contrast, however, Maier and colleagues (2004), in a pilot study with human participants, found that performance in an auditory discrimination task was *impaired* after REF exposure of 50 minutes. In the experiment, participants were presented with two consecutive identical sounds, one on the left and the other on the right ear, and they had to decide on which side the first sound of each pair was presented. Gradually, the interval between the two sounds was decreased and until an order threshold (i.e., the minimum interval between the two sounds needed to detect the order of their presentation) for each participant was found. In Maier and colleagues' study, participants performed the auditory discrimination task in two sessions under double-blind conditions. In both

sessions they performed the same task twice, with a 50 minutes resting interval between the first and second time. In one session participants were exposed to REF during the resting interval, while they were not exposed in the other session. Maier and colleagues then compared performance of the two sessions after the resting interval and found that the order threshold increased after REF exposure in 8 out of 11 participants. This is an important pattern of results, but given the low sample size it needed to be replicated.

The present study provides such a replication of Maier *et al*.'s order threshold experiment (2004) with a much larger sample of participants (168 participants). This sample size provides sufficient statistical power to allow us to confidently reject the null hypothesis, which was not the case in the Maier *et al* (2004) study. The 168 participants (114 female, 54 male; average age: 23 years, range 18-42) were tested in two sessions, with the REF/sham condition double-blinded. In each session the order threshold task was performed twice: the first time at the beginning of the session and the second time at the end of the session, after an interval of about 40 minutes. During the 40 minutes interval, participants were exposed to mobile phone REF in one session, while in the other session they were exposed to sham signals[1]. Participants listened to two identical sounds (300Hz) from stereo headphones. The two sounds were presented sequentially, one to the left ear and the other to the right ear. The task was to decide on which side the first sound of each pair was presented (left-to-right and right-to-left presentations were random). The sound length was 40ms. The initial interval between the two sounds of each pair was 240ms; then the interval was decreased if the response was correct, increased if it was incorrect. The amount by which the interval was decreased or increased depended on the magnitude of the interval. Larger intervals were modified by a larger amount and vice versa for shorter intervals. Intervals were reduced/increased by a minimum of 1 ms to a maximum of 10 ms. However, an interval was never smaller than 5ms. Moreover, for a given interval, the amount of decrement if the response

[1] The order threshold task was part of a study that investigated the effects of REF exposure on visual attention and memory. It included three other tasks (a visual search task, a memory task and a Stroop task, described in Cinel, Boldini, Fox and Russo [submitted]) which were performed during the 40 minutes interval.

was correct was smaller than the amount of increment when the response was incorrect. Participants were asked to guess when they did not know the answer.

The mobile phone used for this study 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-Ionising 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 (see http://www.mthr.org.uk/meetings/nov_2002/summaries/human_exposure.htm) in the UK.

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 Ethics Committee of the University of Essex.

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

To asses if there was any differential effect of GSM modulated vs. CW unmodulated signals, half of the participants (84 out of 168) were exposed to an 888 MHz CW signal, the other half to an 888 MHz GSM signal. For each group, 42 participants were tested with the mobile phone positioned on their left ear, and the remaining 42 had the phone on the right ear. This manipulation was designed to test any potential lateralised effect.

For each task performed, the order threshold was the minimum interval necessary for each participant to achieve an accuracy score of at least 60%. In particular, for each participant the moving average for accuracy and stimulus intervals (SOA) was individually calculated for groups of ten trials. Then the minimum average interval amongst those corresponding to the moving averages of accuracy at 60% was chosen to be the order threshold. Data were analysed with a mixed factorial ANOVA where the factors were: REF exposure (On vs. Off – within subject factor), Type of Signal (GSM vs. CW – between subject factor), Side of Exposure (Left vs. Right – between subject factor), When Task was

performed (Beginning vs. End of session – within subject factor). REF exposure effects were assessed by examining whether any difference between thresholds obtained at the beginning and at the end of each session was dependent on the On-Off condition. Therefore, the most critical statistical analyses were those including REF exposure and the When Task was performed factors. There was a significant main effect of when the task was performed [$F(1,149) = 6.2$, $p < 0.05$] [2]: the order threshold was smaller when the task was performed at the beginning of the session (48ms), compared to when performed at the end of a session (52ms). However, this difference was independent of whether participants were exposed or not to REF: in the sessions with sham exposure the average threshold was 47ms at the beginning of the session and 50ms and at the end; when there was REF exposure the threshold was 49ms and 53ms respectively [F, $1,149 < 0.2$, $p > 0.7$). No other main effects or interactions were significant [$Fs < 2$, $p > 0.1$] (see Table 1 for the results of 3-way and 4-way interactions).

In a second analysis the criterion of accuracy considered to calculate the average thresholds was 70%. The results obtained using this alternative level of accuracy were comparable to those obtained when using 60% of accuracy level. There was a significant main effect of when the task was performed with a threshold of 47ms at the beginning of the session and 52 ms at the end [$F(1,149) = 16.1$, $p < 0.01$], but no other effects were statistically significant [$Fs < 2$, $p > 0.1$] (see Table 1).

As indicated above, the present study was designed to provide sufficient statistical power to allow us to confidently reject the null hypothesis. Making the conservative assumption that REF exposure has a small effect on the task used (i.e. effect size, $d = 0.3$) then with 150 participants we had a statistical power greater than 0.95 to reject a false null hypothesis about the effect of REF exposure. Hence, if the result obtained by Maier and colleagues (2004), who tested 11 participants, were replicable we should have comfortably rejected the null hypothesis in the present study. We can therefore quite safely conclude that exposure to REF emitted by a mobile phone for a 40 minute period does not affect performance in the order threshold task**.**

[2] Note that degrees of freedom are = 149 (despite the total number of participants being 168), because some of the participants were discarded due to errors in data recording.

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Table 1. Auditory order thresholds (in milliseconds) in the different conditions, when calculated according to (a) 60% level of accuracy and (b) 70% of accuracy. The most critical analyses were those involving, amongst other factors, the REF exposure factor and When Task was performed factor. The results of the ANOVA for 3-way or 4-way interactions were as follows. For 60% of accuracy: REF exposure × When Task was performed × Side [$F(1,149) < 1$, $p > 0.9$], REF exposure × When Task was performed × Type of Signal [$F(1,149) < 1$, $p > 0.7$], REF exposure × When Task was performed × Side X Type of Signal [$F(1,149) < 1$, $p > 0.4$]. For 70% of accuracy: REF exposure × When Task was performed × Side [$F(1,149) < 1$, $p > 0.4$], REF exposure × When Task was performed × Type of Signal [$F(1,149) < 1$, $p > 0.8$], REF exposure × When Task was performed × Side × Type of Signal [$F(1,149) < 2$, $p > 0.1$].

a) 60% of accuracy (in ms)		Left		Right	
		Beginning	End	Beginning	End
GSM	On	47	52	53	56
	Off	48	50	48	54
CW	On	48	51	47	53
	Off	42	45	49	51
b) 70% of accuracy (in ms)		Left		Right	
		Before	After	Before	After
GSM	On	39	52	53	58
	Off	47	51	47	54
CW	On	49	53	47	54
	Off	43	45	49	52