Effects of 902 MHz electromagnetic field emitted by cellular telephones on response times in humans

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The present study examined possible influences of a 902 MHz electromagnetic field emitted by cellular telephones on cognitive functioning in 48 healthy humans. A battery of 12 reaction time tasks was performed twice by each participant in a counterbalanced order: once with and once without the exposure to the field. The results showed that the exposure to the electromagnetic field speeded up response times in simple reaction time and vigilance tasks and that the cognitive time needed in a mental arithmetics task was decreased. The results suggest that exposure to the electromagnetic field emitted by cellular telephones may have a facilitatory effect on brain functioning, especially in tasks requiring attention and manipulation of information in working memory. *NeuroReport* 11:413–415 © 2000 Lippincott Williams & Wilkins.

Key words: Cellular telephones; Cognition; Electromagnetic field; GSM; Mobile phones; Response times

INTRODUCTION

The growing use of GSM (global system for mobile communication) telephones has raised discussion about the possible health risks associated with cellular telephones. Cellular telephones emit radio waves usually in the frequency range from 100 to 2000 MHz, GSM telephones typically in the frequency around 900 MHz. Part of such radiofrequency electromagnetic fields (RFs) is absorbed by the user's brain. In principle, it is possible that the absorbed field may influence normal brain function.

Although one study reported that exposure to 900 MHz RF had an effect on spontaneous electroencephalogram (EEG) pattern while the subjects were sleeping [1], further studies could not confirm this finding when the subjects were either asleep [2] or awake [3]. However, there are now some indications that an exposure to RF may alter brain activity during cognitive tasks. Eulitz *et al.* [4] found that high-frequency brain responses to task-relevant stimuli were modulated by RF exposure. Freude *et al*. [5] reported that slow brain potentials were influenced by RF during a visual monitoring task. However, the possible functional consequences of these effects at the behavioral or cognitive levels remain unknown. In a recent study [6], exposure to 915 MHz RF speeded up choice reaction times but did not have an effect on performance in memory tasks. This effect was observed more strongly during analogical than digital RF exposure. The authors suggested that the effect might have been due to local cortical temperature rise which facilitated synaptic transmission in the left parietal region laying directly under the antenna. The present study aimed to examine the possible effects of the digital RF emitted by GSM telephones to behavioral responses in greater detail by employing a large battery of response time measures. The experimental tasks included both verbal and nonverbal stimuli, and allowed for separation of cognitive processing components from perceptual or motor ones.

MATERIALS AND METHODS

Forty-eight healthy volunteers (24 men, 24 women) took part in the study and gave their written informed consent. Their mean age was 26.0 years (range 18–49), all were right-handed and native Finnish speakers. Each subject participated in two testing sessions which were separated by 24 h. Twelve experimental tasks were conducted. Six of the tasks were selected from CogniSpeed reaction time software ([7], for previous studies see [8–11]). In the simple reaction time (SRT) task a '0' stimulus was presented (40 trials) until the subject pressed the '0' button. After the response, the next stimulus appeared with a random delay ranging from 1000 to 4000 ms. In the two-choice reaction

time (2-CRT) task the word KYLLÄ (yes) or EI (no) appeared and the subjects were asked to press the corresponding yes or no button (40 trials). In the ten-choice reaction time (10-CRT) task numbers ranging from 0 to 9 appeared in random order (40 trials). The task was to press the button with a corresponding number on it (on the standard 'num lock' number keys). The subtraction task was identical to the 10-CRT task with the exception that the subjects were asked to subtract the number appearing on the screen from nine and press the button for the remainder (9−x = ?). The sentence verification task included 40 statements of the form (0−9) is less than/equal to/greater than (0−9) (e.g. 6 is greater than 2). They were presented one number/word at a time for 1000 ms with a 700 ms interval. The subjects were asked to decide whether the statement was true or not. The vigilance task took 15 min to accomplish. Different letters were presented for 200 ms with a random 500–3000 ms interval between them. The subjects were asked to press the space bar as soon they saw the letter L, M, or Y. Fifteen percent of the letters were targets.

Six choice–reaction time tasks were conducted using CogniSpeed-2: Picture Experiment Generator [12]. The shape detection task included pictures of novel objects with a coherent shape and their scrambled versions (50 trials). The subjects were asked to decide whether the stimulus had a coherent shape or not. In the object detection task, pictures of familiar objects and their scrambled versions were presented (50 trials). The subjects were asked to decide whether the stimulus was a coherent object or not. The object familiarity detection task contained pictures of familiar and novel objects (50 trials). The subjects were asked to decide whether the stimulus was a real familiar object or not. In the semantic picture categorization task pictures of animals and inanimate artificial objects were presented (50 trials) and the subjects were asked to decide whether the stimulus depicted an animal or not. The semantic word categorization task was similar but the stimuli were words referring to animals or inanimate artificial objects. In the object name retrieval task, pictures of familiar objects whose name started with the letter K or with some other letter were presented (50 trials). The subjects were asked to decide whether the name of the object started with the letter K or not. The familiar object pictures in these tasks were derived from the set of Snodgrass and Vanderwart [13]. The novel objects were drawn to resemble the familiar objects as to their basic visual features. The scrambled objects were created from familiar and novel objects by randomly rotating small circular areas within them until the picture lost all coherent form and became unrecognizable (see also [14]). In the semantic categorization and name retrieval tasks the stimulus sets were matched for familiarity, visual complexity, name agreement and lemma frequency of the object's name in the Finnish language. In all the tasks, both speed and accuracy was stressed in the instructions and the subjects responded with their right hand. Practice trials preceded the experimental trials.

The subjects completed the experimental tasks twice: once with and once without the RF exposure. Half of the subjects received the RF exposure in the first session and half in the second one. Within the test sessions, half of the subjects completed the six tasks from CogniSpeed first and then the six tasks from CogniSpeed-2, and for the other half the order was reversed. The order of the tasks within CogniSpeed and CogniSpeed-2 was counterbalanced across subjects according to balanced latin-square with the exception that 10-CRT and subtraction and sentence verification and 2-CRT were always given in succession.

The RF exposure was given under single-blind conditions. A GSM telephone was mounted to the subject's head during both test sessions. It was orientated in normal position for use with the earphone positioned on the left ear and the microphone orienting towards the corner of the mouth. The antenna was located about 4 cm from the head, over the posterior areas of the left temporal lobe. The telephone was connected through a data cable to a laptop computer which was used to switch the RF on or off. The loudspeaker was removed so that acoustic cues could not indicate whether the RF was turned on or off. When the RF was switched on, the telephone emitted 902 MHz electromagnetic field pulsed at a frequency of 217 Hz and with a pulse width of 577 μs at 0.25 W mean net forward power. The RF exposure began at the beginning of the practice trials for the first task and continued to the end of the session, that is, for about 1 h.

RESULTS

Response times in each task were screened by eliminating trials 2 s.d. shorter or longer than each subject's mean. Only trials with correct responses were included in the reaction time analyses. The non-parametric Wilcoxon signed ranks test was used for statistical testing. Table 1 presents the mean RTs in the tasks and the p values. Subtraction time and verification time are estimates of pure cognitive RTs. Subtraction time was calculated by subtracting the RTs in the 10-CRT from the RTs in the subtraction task. Verification time was calculated by subtracting the RTs in the 2-CRT from the RTs in the sentence verification task.

The results showed that the RF exposure speeded up responses in SRT and vigilance tasks and the cognitive time needed in subtraction. In general, the error rate levels were low (on average 2.7%). Analysis of the errors between RF-off and RF-on conditions in the vigilance task showed fewer false alarms (that is, pressing the button to non-targets) when the RF was on (2.5% false alarms) than when it was off (3.6% false alarms; $z = -2.272$, $p = 0.022$). No other statistically significant effects of RF on accuracy were observed.

DISCUSSION AND CONCLUSION

Our results suggest that GSM cellular telephones may have an effect on cognitive processing. The exposure to digital 902 MHz RF speeded up responses in simple reaction time and vigilance tasks. In addition, the cognitive time needed to accomplish mental arithmetic in the subtraction task was speeded up during the RF exposure. Analysis of errors did not reveal any evidence that the facilitation of processing was due to a speed–accuracy trade-off. By contrast, in the vigilance task, both response times and accuracy were better with the RF exposure than without it. As a digital signal was used, our finding of no effect in the 2-CRT task is in line with the earlier study [6]

Table 1. Response times in the different tasks when the radiofrequency electromagnetic field (RF) was either off (RF-off) or on (RF-on).

Task	RF-off		RF-on			
	Mean	s.d.	Mean	s.d.	z	*p* value
SRT	282	39	273	29	−2.226	0.026
2-CRT	418	58	416	55	−0.001	<1.000
10-CRT	683	100	696	103	−1.805	0.072
Subtraction	927	184	912	178	−0.697	0.492
Subtraction time	245	148	216	124	−2.010	0.044
Sentence verification	703	229	681	204	−0.831	0.412
Verification time	285	184	266	163	−0.995	0.325
Vigilance	517	48	492	42	−4.944	<0.001
Shape detection	521	136	521	113	−0.318	0.757
Object detection	527	129	531	118	−0.544	0.593
Object familiarity detection	641	145	635	116	−0.031	0.980
Semantic picture categorization	552	102	546	105	−0.297	0.766
Semantic word categorization	600	98	592	82	−0.390	0.703
Object name retrieval	833	170	822	132	−0.533	0.600

which showed that only analog RF speeded up choice reactions in a similar task. The fact that none of the choice reaction tasks measuring the various stages of visual object (and word) recognition showed any effects for RF implies that the facilitation effect may not be located at motor or visual processing levels.

The results suggest that the RF emitted by GSM telephones has a facilitating effect on cognitive processing, especially in tasks that require attention or cognitive manipulation in working memory. According to the classification of anterior attentional functions by Stuss *et al*. [15], the tasks that were influenced in the present study require sustaining, concentrating and preparatory attention. The neural structures critical for these functions are believed to be located in the prefrontal cortex including the anterior cingulate, and in the parietal lobe [16]. Although the antenna was located over the posterior parts of the brain, changes in any part of the interconnected system supporting attention may affect the function of other components as well. Therefore it is conceivable that RF may affect performance on tasks that primarily depend on prefrontal cortical function but not on tasks that depend on occipito-temporal functions (visual perception and semantics). The mechanisms of the RF influences on brain function remain open but a slight temperature increase in brain tissue is one of the candidates [9]. However, one should note that the present study does not allow for conclusions about the possible effects of long-term cellular telephone use on cognition or health.

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