

Acute mobile phone effects on pre-attentive operation

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Received 7 October 2005; received in revised form 28 November 2005; accepted 1 December 2005

Abstract

There is a debate whether electromagnetic field (EMF) emitted by mobile phones (MP) have an effect on cognitive functions. Since the auditory P50 component of event-related potentials (ERPs) reflects pre-attentive processing and working memory (WM) operation, the present study was designed to investigate whether the exposure to MP-EMF affects the patterns of the P50 component of ERPs elicited during a WM test. The P50 elicited during a WM task and evoked by two warning stimuli low and high frequency (500 and 3000 Hz) has been assessed in 19 normal subjects (10 women and 9 men) both without and with exposure to a 900 MHz signal, emitted by a dipole antenna placed near the subjects. Results showed that the presence of MP-EMFs induced statistically significant increase in the amplitude of P50 evoked by the low frequency stimuli, at Fp1 and O1 electrode leads as compared to themselves without MP-EMF exposure. In contrast the exposure to MP-EMFs revealed statistically significant decrease of the amplitude of P50 evoked by the high frequency stimuli, at Fp1 electrode lead as compared to themselves without MP-EMF exposure. These findings provide evidence that the MP-EMF emitted by mobile phone affect pre-attentive information processing as it is reflected in P50 evoked potential. The basis of such an effect is unclear, although several possibilities exist and call for potential directions of future research.

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Keywords: Electromagnetic fields; Event-related potentials; Information processing; P50; Mobile phones; Working memory

Mobile phone (MP) use is increasing rapidly. The use of MP emits electromagnetic field (EMF). The close proximity of a mobile phone to the user's head leads to the absorption of part of the MP-EMF energy in the head and the brain [24]. This is especially important in view of the observation that the shape of the head is oval, with a short axis of 15–17 cm in length, which is half the wavelength of the 900 MHz transmission signals of the cellular phones. Consequently, the head may serve as a lossy resonator absorbing much of the energy emitted by cellular phones [28]. Therefore, it is imperative to study the possible effects of MP-EMF on brain and behavior [29].

Event-related potentials due to their high resolution properties can be of significant use in studying MP-EMF effects on brain activity [6]. There have been several studies of mobile phone emissions on the brain activity using the ERPs methodol-

ogy with various results [5,7,14,22]. However, there have been few specifically examining the effect on the auditory system, which is strongly exposed to the produced EMF during the use of MP.

The existing literature concerning the effects of MP-EMF on the auditory system is scarce and rather conflicting. Kellenyi et al. [10] showed that the latency of the fifth wave (V) of the auditory brainstem response (ABR) was significantly delayed after 15 min of exposure to MP-EMF. On the other hand Arai et al. [1], showed no effects both on ABR (i.e. I, II, V waves) and the middle latency evoked brain response before and after using a MP (the usual Japanese MP emitting 800 MHz) for 30 min in 15 normal hearing volunteers. It should be noted that the earlier components of the ERPs are thought to represent the activity of the sensory pathways that transmit the signal generated at peripheral receptors to central processing systems. These components are 'modality specific', that is they are influenced primarily by the stimulus parameters such as intensity and frequency [6]. Psychophysiological research suggested that the auditory P50

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component of ERPs (generally 30–80 ms post-stimulus) reflects the synchronized responses of the thalamocortical system that may underlie the pre-attentive operation [3,30]. Moreover, P50 has much in common with working memory (WM) operation, because on the one hand P50 is part of the gamma-band electroencephalogram (EEG) response [3] and on the other, the gamma-band EEG activity is thought of as a signature of synchronized cortical networks involved in the WM operation [17].

In view of the above considerations, we hypothesized that the electrophysiological brain activity, as reflected by P50, in association with WM operations, could be of value in identifying possible pathophysiological alterations evoked by MP-EMFs. Thus, the present study was designed to determine whether the presence of MP-EMF affects the patterns of P50 ERP component elicited during a WM test.

Nineteen healthy individuals (9 men and 10 women, mean age = 23.3 ± 2.23 years, mean education = 16.9 ± 1.82 years) participated in the experiment. The male and female subgroups were homogeneous with regards to age and educational level. All participants were right-handed and had no history of any hearing problem. Informed consent was obtained from all subjects.

The subjects were evaluated with the digit span Wechsler Auditory Test [22,27]. A warning stimulus of either high “(3000 Hz)” or low frequency “(500 Hz)” was presented through earphones to the subjects, who were asked to memorize the numbers that followed. The warning stimulus lasted 100 ms. 1 s interval followed the onset of the warning stimulus and then the numbers to be memorized were presented by a male voice. At the end of the number sequence presentation, the same signal tone was repeated. If the frequency of the signal tone was low the subjects had to recall the numbers in the same order as that presented, else, if the frequency was high, the subjects had to recall the numbers in the opposite order.

Before any ERPs’ recording, practice trials were administered until the subjects could clearly discriminate the warning stimuli (tones). After completion of the above-mentioned process, i.e. the practice trials, a rest period of five minutes followed, before the recording of the ERPs.

The experimental setup included a Faraday room, which screened any electromagnetic interference that could affect the measurements. The subjects sat in an anatomical chair and a certified dipole antenna was fixed near their right ear. The dipole’s model was ELECTRO-METRICS EM6924 and the antenna factor was 27.4 dB/m at 900 MHz. Care was taken so that the distance between telephone and ear (about 20 cm) was constant during the whole session. The antenna was driven by a signal generator, which could be switched on or off. In the on mode the antenna emitted a 900 MHz electromagnetic field with mean power at 64 mW [21]. The signal was not modulated. The field strength was 3 V/m at the point where the subjects’ head was standing.

ERPs were recorded during 1 s between the onset of the warning stimulus and the onset of the first administered number. The electrophysiological signals were recorded with Ag/AgCl electrodes. Electrode resistance was kept constantly below 5 k Ω . EEG activity was recorded from 15 scalp electrodes based on the International 10–20 system of electroencephalography [9],

referred to both earlobes. An electrode placed on the subject’s forehead served as ground. The bandwidth of the amplifiers was set at 0.05–35 Hz. During the administration of stimuli, the subjects had their eyes closed in order to minimize eye movements and blinks. Eye movements were recorded through electro-oculogram (EOG) and recordings with EEG higher than 75 mV were rejected. Warning stimuli, as well as learning material, i.e. the numbers to recall, were presented binaurally via earphones at an intensity of 65 dB sound pressure level. The earphones did not have metal components in order to avoid EMF concentration. The evoked biopotential signal was submitted to an analog-to-digital conversion, at a sampling rate of 1 KHz, and was averaged by a computerized system. Each recording session consisted of 52 repetitions of the trial.

The subjects performed the task twice, with (on mode) and without (off mode) radiation, with an interval of 2 weeks between the measurements. The order in which the subject was exposed at the EMF (exposure at the first or second visit) was random.

Because the P50 component is included in the array of early-endogenous ERPs components, which normally are modality specific, the ERPs induced by the two modal stimuli were averaged separately [6]. In particular, two varieties of P50 waveforms were obtained, one (low P50) evoked by the low frequency modality (26 trials) for each lead in all subjects and another (high P50) evoked by the high frequency modality (26 trials) for each lead in all subjects.

The following parameters were calculated:

- (a) ERPs were recorded for each subject at EEG leads Fp1, Fp2, F3, F4, C3, C4, C5, C6, P3, P4, O1, O2, Pz, Cz, and Fz. Recordings with acceptable EEG level were averaged for each lead by a computerized system. An algorithm was used, which identified the P50 as the most positive peak in each averaged lead curve, between 30 and 80 ms, after the warning stimulus. Peak amplitudes were measured relative to the mean amplitude of the 100-ms prestimulus baseline period and latency measurements were computed relative to stimulus onset Fig. 1.
- (b) The behavioral performance refers to the number of recalled digits. The total digits presented per each session were 298 digits, 149 digits for the part of the session which engaged the low frequency stimuli and likewise 149 for the part which engaged the high frequency stimuli.

The values of the P50 amplitudes at the fifteen leads were subjected to multivariate analysis of variance with the two frequency tones and the two radiation conditions as the between subjects factors [19]. The appropriate adjustments were made for multiple comparisons. The frequency X radiation interaction was also taken into consideration. Post hoc pairwise comparisons were carried out between the two frequencies in the absence and presence of radiation, as well as between the two radiation conditions at the low and high frequencies. Separately, for the two radiation conditions stepwise logistic regression models were employed, with the frequency modality as the binomial dependent variable and the P50 amplitudes at the fifteen leads as the independent

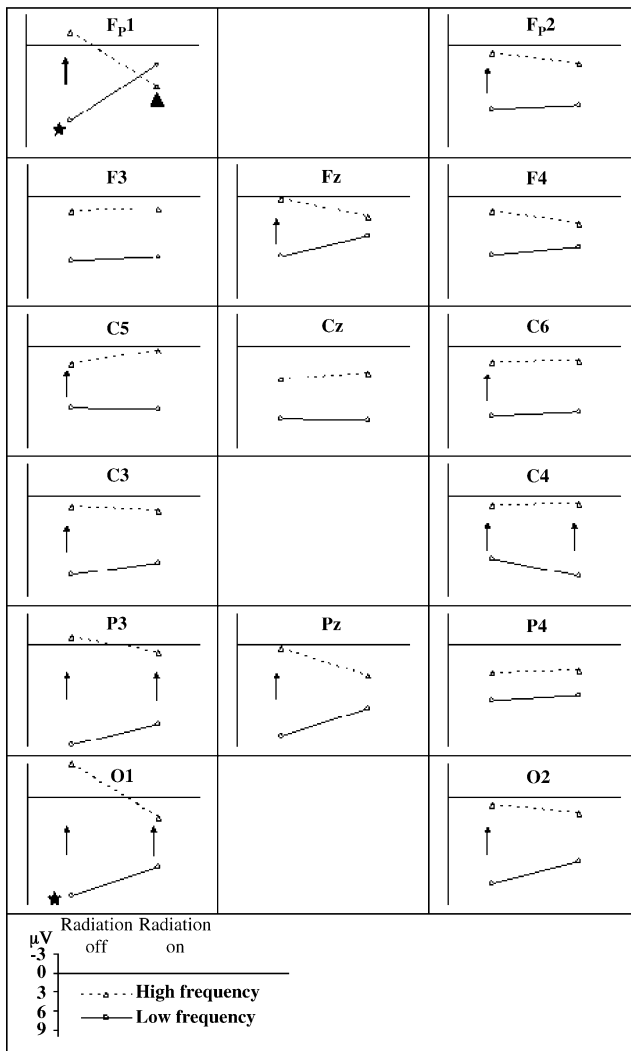


Fig. 1. Comparisons of the P50 amplitudes between the low and high frequencies in the absence and presence of radiation and between the two radiation conditions (off-on) at the low and high frequency tones. Arrows denote significant differences between the two frequency modalities—(○) significantly elevated (more positive) P50 amplitudes at the high frequency modality (found at 11 leads in the absence of radiation and at only three leads in the presence of radiation. Star denotes significant differences between the two radiation conditions; (*) significantly higher (more positive) P50 amplitudes in the absence of radiation (found at two leads, Fp1 and O1, at the low frequency modality); (▲) significantly higher (more positive) P50 amplitudes in the presence of radiation (found at lead Fp1 in the high frequency modality).

variables. The purpose of this analysis was to examine whether the causal tonality can be deduced by its resultant P50 amplitudes. Correlations of memory performance, P50 amplitudes and latencies were examined with the Pearson's correlation coefficients.

Statistical significance was set at the 0.05 level.

The multivariate analysis of the P50 amplitudes revealed their strong dependence on the frequency modality (p -value of Pillai's trace = 0.003). There was, however, a significant frequency X radiation interaction effect (p -value of Pillai's trace = 0.008).

The segregation of the amplitude values caused by the frequency modulation is more profound under normal conditions,

i.e. in the absence of radiation. As Table 1 and Fig. 1 show, the high frequency tone induces higher positive peak amplitude values of the P50 component than the low frequency one at all the fifteen leads under consideration. This difference achieves statistical significance at eleven electrodes.

The introduction of radiation seems to alleviate these differences, since in this case statistically significant differences of the P50 amplitudes for the two frequency tones are observed only at three leads. In most cases this is accomplished by a slight decrease of the P50 amplitudes at the high frequencies together with a slight increase of the P50 amplitudes at the low frequencies. At two leads (Fp1 and O1) this increase achieves statistical significance. At lead Fp1 statistically significant is also the decrease of the P50 amplitudes at the high frequencies. The crossover effect of these changes results in the fact that Fp1 stands as the only lead, at which in the presence of radiation the P50 amplitudes are higher at the low frequency than at the high frequency tone. This is the main reason for the appearance of a significant overall frequency X radiation interaction effect.

The stepwise logistic regression model for the radiation off condition revealed that from the amplitudes at leads P3, Pz and Cz we are able to infer correctly the frequency tonality in 92.1% of the cases. For the radiation on condition this percentage is 71.1% and includes the amplitudes at leads C4 and Fp1.

Memory performance did not differ between the two frequency modalities (58.4 ± 26.5 for the low frequency tone, and 54.9 ± 24.6 for the high frequency tone, t -test, $p = 0.552$). It also did not seem to depend on radiation, and sex. Finally, memory performance did not correlate either with the latencies or the amplitudes, both at low and high frequency stimulation.

The present study demonstrated that MP-EMF may alter the patterns of P50 elicited in a working memory task. More precisely, results showed that the presence of MP-EMFs induced statistically significant increase in the amplitude of P50 evoked by the low frequency stimuli, at Fp1 and O1 electrode sites as compared to themselves without MP-EMF exposure. In contrast, the exposure to MP-EMFs revealed statistically significant decrease of the amplitude of P50 evoked by the high frequency stimuli, at Fp1 electrode site as compared to themselves without MP-EMF exposure. Also the amplitude of P50 without radiation appeared significantly smaller in the high frequency warning stimulation as compared with those of low frequency stimulation.

The observed differences of the amplitude of P50 without radiation may be explained considering the fact that (as mentioned above) the P50 component belongs to the earlier components of ERPs which are 'modality specific' [6]. In addition, it is noteworthy that the auditory pathways from the cochlear nucleus to the auditory cortex exhibit tonotopic organization [23].

A dissociation between P50 potential with reference to the modality of the warning stimuli just mentioned, suggest that an alternative explanation must be considered in connection with the effects of MP-EMF upon the P50 evoked by low frequency and the P50 potential evoked by high frequency stimulus.

The findings of P50 amplitudes in relation to the MP-EMF radiation cannot be compared with those of other studies, because to our knowledge there are no previous reports assessing

Table 1
Amplitudes (μV) of the P50 component (mean $\pm$ standard deviation) at the low and high frequency warning stimuli in the radiation on and radiation off condition

Lead	P50 amplitudes (μV) (mean $\pm$ S.D.)				Pairwise comparisons (p -values)			
	R off		R on		Between F		Between R	
	Low F	High F	Low F	High F	R off	R on	Low F	High F
Fp1	-1.2 ± 6.1	7.4 ± 7.8	4.1 ± 7.2	1.9 ± 7.5	0.001	0.362	0.018	0.034
F3	1.5 ± 8.6	6.3 ± 8.2	1.3 ± 7.5	6.0 ± 9.3	0.086	0.099	0.937	0.897
C5	1.8 ± 5.2	6.1 ± 7.5	0.5 ± 9.5	6.2 ± 9.0	0.049	0.067	0.616	0.960
C3	1.2 ± 6.3	7.7 ± 6.8	1.5 ± 8.7	6.6 ± 9.2	0.004	0.086	0.927	0.674
Fp2	0.8 ± 7.5	6.2 ± 7.3	1.8 ± 7.6	5.8 ± 7.9	0.030	0.120	0.703	0.851
F4	1.6 ± 6.2	5.7 ± 7.5	2.7 ± 8.3	4.9 ± 9.4	0.072	0.461	0.633	0.760
C6	1.7 ± 6.0	6.8 ± 7.2	1.6 ± 8.7	6.5 ± 7.9	0.023	0.078	0.960	0.897
C4	1.1 ± 6.8	6.2 ± 7.5	0.9 ± 6.8	7.9 ± 8.7	0.036	0.009	0.906	0.524
O1	-3.0 ± 8.0	9.1 ± 9.3	1.9 ± 6.0	6.5 ± 7.7	0.001	0.044	0.043	0.354
O2	0.8 ± 7.2	8.0 ± 7.8	1.6 ± 7.3	6.0 ± 7.0	0.006	0.068	0.739	0.408
P4	2.8 ± 8.4	5.4 ± 9.8	2.6 ± 7.7	4.9 ± 7.5	0.369	0.374	0.962	0.835
P3	-0.7 ± 6.9	9.7 ± 7.2	0.8 ± 8.8	7.7 ± 7.6	0.001	0.014	0.562	0.417
Pz	0.4 ± 7.0	8.9 ± 8.4	3.0 ± 8.3	6.2 ± 6.7	0.002	0.188	0.316	0.284
Cz	3.3 ± 8.0	7.1 ± 8.7	2.7 ± 7.6	7.2 ± 7.7	0.168	0.080	0.827	0.963
Fz	0.3 ± 6.3	5.8 ± 8.3	2.0 ± 8.6	4.0 ± 8.5	0.028	0.466	0.500	0.527

The p -values in bold denote statistically significant differences. F: frequency, R: radiation.

this ERP component in relation to MP-EMF radiation. An exception appears to be the study by Arai et al. [1], which reported no effects on mid latency evoked brain potentials in 15 healthy controls using the Japanese mobile phone emitting 800 MHz. But there are important differences in methodology that make a direct comparison difficult, for instance, in the present study the obtained findings would likely have occurred immediately upon presentation of the MP-EMF and lasted throughout its presence, whereas, in the study by Arai et al. [1] the reported effects referred to evoked brain response before and after using a mobile phone for 30 min. The main difference is that in the present study the evoked potentials were recorded during the presence of the radiation and without the presence of the radiation, while in the study of Arai the ERPs were studied before and after the expose to the MP-EMF. However, it may be easier to understand the importance of the patterns in P50 amplitude during MP-EMF radiation reported here in the light of psychophysiological indices concerning the meaning of the P50 potential on the one hand, and on the other considering the proposed influence of MP-EMF on brain function. The P50 potential is a subcomponent of the γ EEG activity reflecting the transient synchronization of thalamocortical activity in response to sensory stimulation [3,30]. In keeping with this suggestion, concerning the low frequency amplitude of P50 waveforms, the present findings, seem to be compatible with a recent study by Croft et al. [4] focusing on the effects of mobile phone on EEG as a function of time, which show ‘an increase in the γ response at midline frontal and lateral posterior sites’. Further, since the MP-EMF is observed to enhance the enzymatic activity of the cholinergic system [2,15,16], and on the other hand the augmentation in P50 amplitude is thought to reflect increased cholinergic activation during arousal [8,26], thus it is reasonable to suppose that this mechanism could account for the observed increase in the amplitude of P50 evoked by the low frequency stimuli, in association with MP-EMF radiation.

Moreover, as regards the P50 potential evoked by high frequency stimuli, it cannot be ruled out that the observed changes might be due to the thermal effects of the MP-EMF radiation, since there are findings indicating a decrease of mid latency evoked potentials due to heating [18]. It is in the same fashion that Pakhomov et al. [20] found that nerve velocities did not change, but brain activity potential amplitudes decreased using 915 MHz pulsed waves.

Taken together, the obtained results provide evidence that the MP-EMF emitted by mobile phone affect pre-attentive information processing; however, the underlying mechanisms of such influence are still unclear, although several possibilities exist, calling for potential directions of future research. These highly complex physical and biological phenomena necessitate the development of new experimental, measuring and observation procedures.

As far as the memory performance concerned, the present study showed no statistically significant differences between the radiation-on condition compared to that of radiation-off one. This finding is in agreement with results of recent studies reporting no effect of MP-EMF on reaction time and performance of visual working memory [13], but it is in contrast with others (as mentioned earlier) reporting that exposure to MP-EMF may have an effect upon cognition [11,12]. Further studies with more rigorous and standardized methodologies may elucidate these discrepancies.

In conclusion, using available non-invasive electrophysiological methods it has been shown that exposure to MP-EMF emitted by a mobile phone results to changes in pre-attentive information processing in the central nervous system (CNS). The physiological mechanisms underlying such influences are as yet poorly understood, although several prospects can be considered a promising future research effort. In this respect the nature of this effect needs to be clarified through the employment of a larger sample size and the analysis of a greater range of tasks.

Acknowledgements

The authors would like to thank M. Kyprianou, Scientific Investigator, Athens, Greece, for his support on the statistical analysis of the experimental results. This study was supported by the Astra Zeneca Hellas.

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