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EFFECTS OF GSM SIGNALS DURING EXPOSURE TO EVENT RELATED POTENTIALS (ERPs)

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Abstract
Objectives: The primary aim of this work was to assess the effect of electromagnetic field (EMF) from the GSM mobile phone system on human brain function. The assessment was based on the assay of event related potentials (ERPs). **Material and Methods:** The study group consisted of 15 volunteers, including 7 men and 8 women. The test protocol comprised determination of P300 wave in each volunteer during exposure to the EMF. To eliminate possible effects of the applied test procedure on the final result, the test was repeated without EMF exposure. P300 latency, amplitude, and latency of the N1, N2, P2 waves were analysed. **Results:** The statistical analysis revealed an effect of EMF on P300 amplitude. In the experiment with EMF exposure, lower P300 amplitudes were observed only at the time in which the volunteers were exposed to EMF; when the exposure was discontinued, the values of the amplitude were the same as those observed before EMF application. No such change was observed when the experiment was repeated with sham exposure, which may be considered as an indirect proof that lower P300 amplitude values were due to EMF exposure. No statistically significant changes were noted in the latencies of the N1, N2, P2 waves that precede the P300 wave, nor in the latency of the P300 itself. **Conclusions:** The results suggest that exposure to GSM EMF exerts some effects on CNS, including effects on long latency ERPs.

Key words:
Cellular phones, P300, Electromagnetic fields

INTRODUCTION

The development of wireless communication systems, and of mobile phone systems in particular, causes that human living environment is polluted by a growing number of new electromagnetic field (EMF) frequencies that have never been present there [1]. The growing man-made EMF emissions, often referred to as electromagnetic smog, result in growing EMF exposure of the general population. The gravity of the problem has been recognised by the European Community, which has resulted in support for a number of research projects, including the project intended to study the possible effects of EMFs from UMTS mobile phone systems on the CNS cognitive function.

Research on biological effects of EMF has been devoted primarily to two areas — assessment of thermal

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and non-thermal EMF effects. While the thermal effect of EMF in the tissues, including the brain, has been confirmed [2,3], EMF non-thermal effects continue to be disputable. The latter refers also to function changes in EMF-exposed brain. Some authors confirm [4–6], while other authors deny [7–9] such changes. Up to now, no hypothesis capable of reliably accounting for the discrepancies in the results by various authors has been formulated.

Recording of auditory event related potentials, such as wave P300, is one of the method for CNS function testing. The test involves applying auditory stimuli according to the beep-boop paradigm; during the process of their discrimination in the CNS, those stimuli produce changes in neuronal functional potentials. Assessment of test result involves determination of wave peaks in terms of their amplitudes and latencies. In the few works accessible in the literature that took into consideration acoustic stimulus-evoked P300 wave, long latency response characteristics were analysed before and during the EMF exposure without analysing post-exposure data, and thus without verifying the effect of the procedure itself on the results.

The aim of our study was to assess the effect of exposure to EMF generated by GSM mobile phone system on long latency response recordings, including P300 wave, both during and after the exposure.

MATERIAL AND METHODS

Subjects

The study group consisted of 15 volunteers, including 7 men and 8 women, with normal hearing. Education level of all volunteers was similar. Each volunteer had been informed about the aim of the experiment. The Bioethical Commission of the Nofer Institute of Occupational Medicine granted its consent to perform the experiments.

The inclusion criteria were as follows:

- good general condition of health,
- no alcohol or drug addiction,
- no exposure to noise during the 24 hours preceding the experiment,
- normal tympanic membrane image,
- normal tympanogram with ipsilateral reactions from stapedial muscles at 500, 1000, 2000 and 4000 Hz frequency bands (assessed on a Madsen model Zodiac 901 Impedance Audio Meter, Taastrup, Denmark),
- normal hearing as assessed by pure tone audiometry: hearing threshold within 20 dB HL for each frequency within the 250–8000 Hz range (assessed on an Interacoustic AC40 Pure Tone Audiometer, Assens, Denmark),
- normal transient evoked otoacoustic emission (TEOAE) with signal to noise ratio not worse than 6 dB at two or more 1000, 2000, 3000, 4000 and 5000 Hz octave bands (assessed on an Otodynamics ILO-96, London, United Kingdom unit for TEOAE testing).

P300 wave

P300 wave testing involved discrimination and counting of one of the two semi-random acoustic stimuli. The signal to be counted was 1500 Hz pure tone, while the spurious signal was 1000 Hz pure tone. The intensity (volume) of the stimuli was 70 dB nHL, and the distribution was 70% of spurious stimuli and 30% of the counted stimuli. The repetition frequency was 0.9 Hz, duration 20 cycles, rise and decay time 5 cycles. Wave P300 was tested bilaterally. The response from the auditory cortex was recorded by means of 4 electrodes (silver cups) placed as follows: Cz on top of head, A1 on mastoid bone of left ear, A2 on mastoid bone of right ear, Fpz on the forehead (at the hair/bare skin borderline). The examination was performed in a darkened soundproof test chamber; to eliminate artefacts produced by eyeball movements and those produced during dazzles, the volunteer had been asked to fix his/her stare at a point located somewhere in front while remaining in horizontal position. The examination was started only when the electrode/skin resistance could be kept below 5 kΩ. The resultant potential record was analysed and stored by the Nicolet Spirit 2000 system.

There were two measurement sessions for each proband, one with true, the other with sham EMF exposure. During each measurement session, P300 wave was determined three times (series I, II, III). The proband was informed that during one run he/she would be exposed to cellular phone EMF, but he/she did not know during which. The whole procedure was repeated without EMF exposure to eliminate possible effects of the procedure on the results.

During the test the proband was motionless and relaxed while counting suitable sounds and memorising the result. The result was checked by comparing the number of the 1500 Hz sounds received and counted by the proband with the respective data generated by the computer. A counting error above 1% of the generated 1500 Hz stimuli caused that the result was rejected, as it was assumed that the result was a function of patient's vigilance.

Exposure to EMF

The most popular GSM 935 MHz telephones were used in all tests. In terms of technology, the GSM system is based on time division multiple access (TDMA) principle, which means that multiple users can use the same frequency at the same time, because each user has been assigned a time interval known as time gap. The GSM system enables 8 calls to be received using one frequency, whereby its capacity ("throughput") is much higher than that of the analogue systems. Thus, an acoustical input, after it has been converted into a digital signal, is modulated on 900 MHz carrier frequency and encoded in the form of chain of 217 Hz pulses, thus meeting the requirements of pulse modulation definition. A factory-made telephone with its original antenna was placed in a location typical for receiving telephone calls. The mobile phone was fixed in a plastic holder so as to enable its displacement. Cellular phone connected to an external microprocessor so as to enable phone operation without touching its keyboard was used to produce EMF. The EMF exposure was achieved by connecting the phone with the base station during the test. The tests were conducted at the same hours (15–18) only during week days. The call was simulated by directly wiring the phone to a tape recorder playing a pre-recorded voice message, thus generating an acoustic wave which, after it had been converted to a digital form, was radiated as electromagnetic wave. The phone was completely mute and did not generate any external sound. The connection and the call (the exposure) was monitored by receiving the call in another phone. The connection time was about 20 minutes per series. The level of exposure to electromagnetic fields in any of the experiments did not exceed the maximum admissible values specified by relevant EU regulations. According to manufacturer's specifications, SAR for the phone used in our experiment was 0.81 W/kg. Determination of SAR was performed according to the requirements of the standards BS EN 50360-2001 [10] and BS EN 50361:2001 [11]. Cellular phone position during experiment was in line with the specifications of the standard.

To control the conditions of mobile phone EMF exposure, power flux density was measured by a MEH-25 Universal EMF Meter provided with an AS-1 Probe developed at the Technical University of Wrocław. This measuring set enables measurements of microwave power densities ranging from 0.01 W/m^2 to 100 W/m^2 within the 0.3 GHz to 3 GHz frequency range. Mean power density value was within 0.052 W/m^2 during the experiment and was comparable for all exposed people.

Data Analysis

The following data obtained during recording of event-related auditory potentials were analysed: latency and amplitude of P300 wave and the latencies of N1, N2, P2 waves. Due to small size of the test group, the data were not analysed separately for men and women.

Results of the measurements performed during measurement session 1 and 2 were subjected to the following tests and analyses:

— differences between measurements were assessed in various exposure conditions (before, during and afterwards) by Friedman's non-parametric analysis of variance with calculation of Kendall's coefficient of concordance (separately for each of measurement sessions 1 and 2),
— in each measurement session 1 and 2, measurement results obtained in different exposure conditions (before, during and after) were compared by Wilcoxon Matched-Pairs Ranks test for dependent samples,

— measurement results obtained in different exposure conditions (before, during and after) in each measurement session 1 and 2 were compared by Kruskal-Wallis one way analysis of variance by ranks for independent samples and by the median test.

The analysis was performed by StatSoft Inc. (2004) STATISTICA 6.1 software.

RESULTS

Testing of long-latency auditory potentials did not reveal statistically significant changes in the latency of N1, N2, P2 waves that precede the P300 wave, nor in the latency of the P300 wave itself during and after the exposure to 935 MHz EMF in relation to respective pre-exposure values. Also in the sham EMF exposure measurement series, mean values of those waves did not differ from the original values, Fig. 1–4).

On the other hand, our statistical analysis showed a statistically significant EMF effect on P300 amplitude.

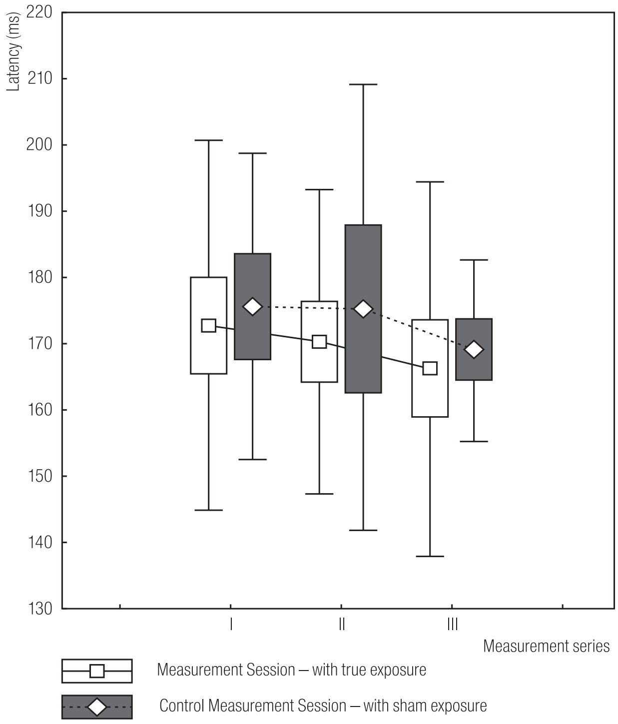

Fig. 2. Mean values of P1 wave latency (plus standard error and standard deviation) before (I) during (II) and after (III) 935 MHz EMF exposure in measurement session with true and sham exposure.

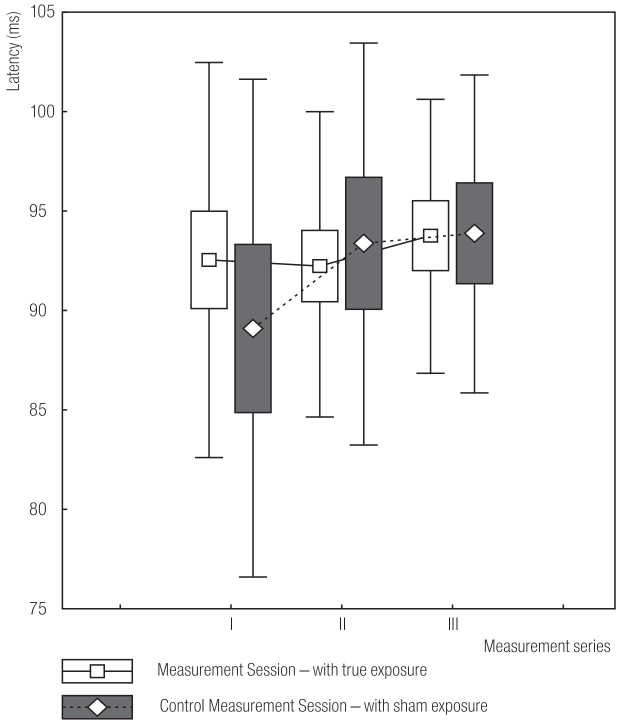

Fig. 1. Mean values of N1 wave latency (plus standard error and standard deviation) before (I) during (II) and after (III) 935 MHz EMF exposure in measurement session with true and sham exposure.

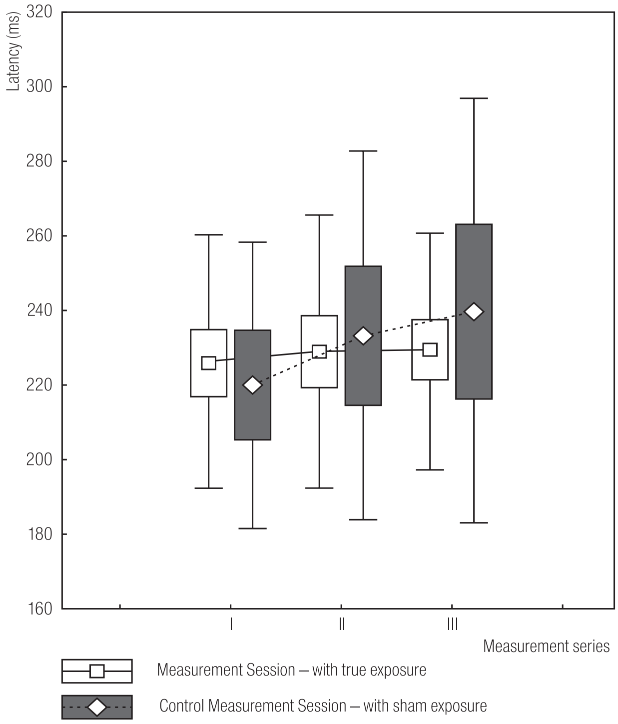

Fig. 3. Mean values of N2 wave latency (plus standard error and standard deviation) before (I) during (II) and after (III) 935 MHz EMF exposure in measurement session with true and sham exposure.

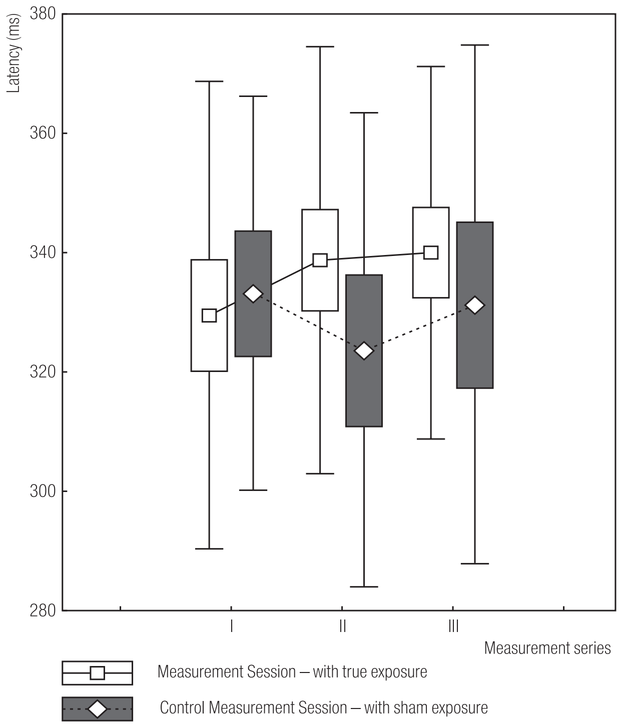

Fig. 4. Mean values of P300 wave latency (plus standard error and standard deviation) before (I) during (II) and after (III) 935 MHz EMF exposure in measurement session with true and sham exposure.

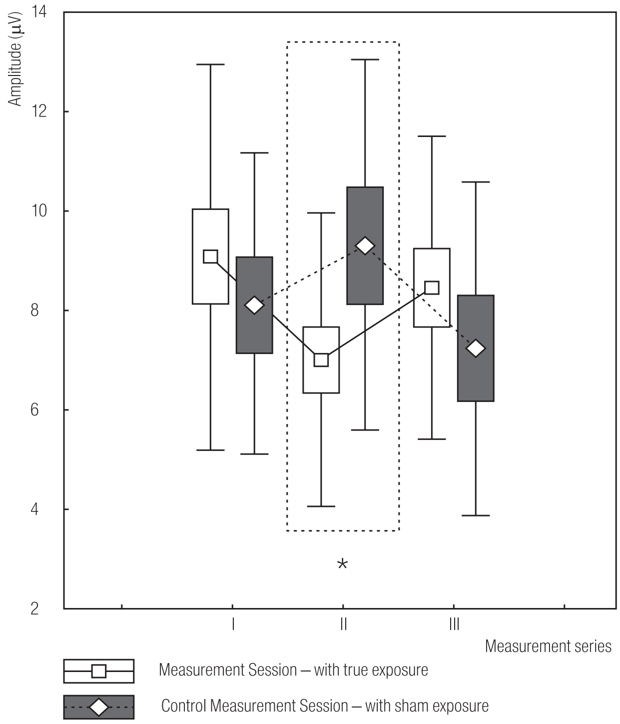

Fig. 5. Mean values of P300 wave amplitude (plus standard error and standard deviation) before (I) during (II) and after (III) 935 MHz EMF exposure in measurement session with true and sham exposure. The asterisk denotes statistically significant difference.

In the test series with true EMF exposure, P300 amplitude was lower during the exposure. Afterwards, the amplitude returned to the pre-exposure value (Fig. 5). No such effect was noted after the test procedure had been repeated with sham exposure, which indirectly suggests that the reduction in P300 wave amplitude was due to EMF exposure.

DISCUSSION

The original assessments of EMF effect on cerebral cortex were performed using EEG. The results were ambiguous. Some of the studies indicated that EMF caused a reduction in the voltage of slow potentials. However, a more detailed analysis of the results and their verification in further experiments did not confirm the earlier observations [12–14]. Considering the limitations of the EEG method, in our current work we decided to use determinations of P300 wave to assess EMF effect on auditory cortex ERPs. Results of our experiments did not reveal any statistically significant changes in the latencies of the N1, N2, P2 waves that precede the P300 wave, or in the latency of the P300 wave itself during and after EMF exposure compared to respective pre-exposure values. Also in the measurement session with sham EMF exposure, mean values of those waves during and after the experiment did not differ from the original values. On the other hand, our analysis revealed a statistically significant EMF effect on the values of P300 wave amplitude. In the true EMF exposure test series, lower P300 amplitude values were noted throughout the exposure. After the exposure had ceased, the amplitude returned to its pre-exposure values. No such effect was noted when the experiment was repeated with sham exposure, which suggests indirectly that the reduction in P300 amplitude was due to the EMF exposure. Thus, the results of our experiments indirectly confirm the results by other authors reporting a drop in voltage of the cortical responses due to cellular phone EMF exposure.

Results of works published heretofore on the effect of EMF on P300 wave records are not unequivocal. The study by Hamblin et al. [15] involved assessment of the effects of EMF on CNS by analysing the characteristics of ERPs and reaction time during and after the exposure.

The authors have found that EMF exposure of 12 healthy volunteers resulted in a drop of N100 wave amplitude and latency, and an increase in P300 wave amplitude. Similar conclusions have been reported by Maby et al. [16], who have demonstrated that EMF exposure results in lower amplitude and shorter latency of N100 wave. Both authors re-examined the question to verify their earlier results. Hamblin et al. [17] reassessed the effects of EMF on ERPs and response time in a large group of 120 volunteers, mean age 31±13 years. Both auditory and ocular ERPs appeared to be not affected by EMF, although there was a statistically insignificant tendency to longer response times during the exposure. The authors explain the evident differences in the results by small number of study subjects and no blind control in the earlier study. They conclude that ERPs ought not be connected with the effects of EMF on CNS, while they may only serve to explain the association. EMF exposure modifies brain response in terms of the expected stimuli, without changing P300 wave latency. Our results confirm that conclusion because our experiments do not reveal EMF effect on the latencies of the individual waves.

Charalabos et al. [18] tested unilateral cephalic exposure to GSM EMF in 19 volunteers who discriminated between the 500 Hz and 3000 Hz acoustic stimuli and memorised the number of the 3000 Hz stimuli during EMF exposure. The experiment was performed twice (with and without EMF exposure) at a two-week interval. The P50 ERP component was analysed. It was demonstrated that EMF exposure resulted in an increase of the P50 component evoked by the low-frequency (500 Hz) stimulus, while lowering amplitude of that component was evoked by the high-frequency (3000 Hz) stimulus. Somewhat different experiment intended to verify EMF effect on specified brain regions were performed by Eliyahu et al. [19]. They subjected 36 volunteers to a procedure comprising one unilateral (right-side) and one unilateral (left-side) head exposure to EMF, and one run without EMF exposure. During each of those three runs, the volunteers performed four tests that enabled examination of the regions being currently exposed. The experiment consisted of two 1h sessions with 5-min. interval between the sessions. Response time and precision of the responses were analysed. It has been demonstrated that, for cases of left-side head EMF exposure, the time of response signalled by the volunteers with their left hand was considerably longer. Tsiafakis et al. [20] demonstrated statistically significant differences in P300 wave during EMF exposure in the subgroups of women and men. They exposed a group of 19 volunteers (10 women and 9 men) to GSM EMF while the volunteers were twice subjected to the auditory Wechsler test (with true and sham EMF exposure) at two-week interval. During that test, the volunteer was presented two acoustic stimuli with equal intensity and different (500 and 3000 Hz) frequency. The experiments quoted above were performed at different exposures using different apparatus and test procedures. Kuster et al. [21] have attempted to specify standard conditions to be met by experiment intended to assess EMF effect on human organism. Unfortunately, their conclusions, although correct, are purely theoretical. The majority of the research works quoted above fail to meet any of the requirements postulated by Kuster.

Small number of subjects is another source of criticism in the works confirming EMF effect on CNS activity. Russo et al. [22] experimented with 168 volunteers exposed to GSM EMF and 888-Hz continuous wave using double blind test. Four test types applied earlier by Koivisto [23] were used to test EMF effect on CNS activity. The study showed no effect of EMF on cognitive functions.

The idea of EMF modifying brain responses during performing tasks intended to determine ERPs has been further developed during further research. Preece [24] exposed 36 volunteers (whose age differed considerably, from 20 to 60 years) to GSM and 915 MHz analogue EMF, with EMF source located at the left side of the head. The test group comprised both right- and left-handed subjects. Exposure duration was 25–30 minutes and the subjects were subjected during that time to a series of test associated with ERPs. The only statistically significant difference was the shorter reaction time observed only for the analogue exposure.

Please note that (like in ABR testing) in our own experiments, unlike in works by other authors presented above, P300 wave was assessed at all stages of the experiment, whereby our assessment of EMF was more comprehensive. In all other works, the authors failed not only to record P300 wave at all stages of the experiment, i.e. before, during and after the exposure, but also to verify EMF effect on the measuring system or the effect of the test procedure itself on the results.

P300 wave variability due to numerous factors causes that it is difficult to assess. Studies comparing P300 response characteristics in subjects of varying age show that its amplitude tends to be lower and its latency longer with age [25]. The optimum solution would be to provide test groups with identical age range (SD = 0) which, although technically feasible, would be not practical due to other specific characteristics required from the probands. In the discussed work, mean age in the group of men was 37±10 years, and in the group of women it was 34±5 years, which is not different than mean age of groups studied by other authors. Conducting research with test group split into gender subgroup constitutes a problem, which is raised in P300 wave analysis. It is generally recognised that women are more sensitive in detecting the stimulus than men, which results in greater amplitude and shorter P300 latency in the records from female relative to male volunteers. Some authors suggest that this is associated with different skull characteristics. Head size and thickness of skull bones and the adjacent tissues differ depending on gender, and those differences may affect test results. Gender-related differences in brain functioning are quoted as another possible cause of the differences. It has been established that cognitive processes differ between genders. Women are characterised by better speech recognition and fluency, coordination of movements. Men are superior to women in performing tasks associated with spatial orientation, manual precision or mathematical analysis. Other authors point to the possible effects of hormones on the shape of P300 wave depending on female menstrual cycle [26]. According to this data, ERP results obtained in the subgroup of women may be considered as a confounder. Thus, it is vital that results for the male and female subgroups are analysed separately. The participants of the experiment were 15 volunteers, including 7 men and 8 women. Attempts to ensure that all women were at the same stage of the menstrual cycle made study design extremely complex and, therefore, that factor was ignored. Level of education may be another factor capable of affecting P300 wave record. It should be identical (ideal condition) or at least similar in all patients. Our experiment meets the latter condition.

Some authors maintain that the characteristics of the resultant P300 wave depend on proband motivation. The level of P300 wave amplitude depends on the emotional condition of the participants [27], which is directly reflected in the magnitude of that value. In our experiment, each participant had been informed about the aim of the study and the payment to be received for the participation; thus, all participants were motivated in the same way. Literature data are also accessible suggesting that P300 wave amplitude is inversely proportional to the amount of incident daylight, i.e. to the season of the year [28]. In our study this factor was negligible, considering that the day/night hours ratio at our latitude is relatively small.

Latency of P300 wave is a function of the difficulty in discriminating between the rarely appearing stimulus and the background stimulus. The more difficult the process of discrimination, the longer P300 wave latency. This factor was also of no consequence in our study, because the same stimulus was used in all trials.

Extremely essential is also the interval between consecutive P300 wave determinations. Experiments intended to determine the effects of repeated P300 wave recording (wave's parameters, and its amplitude in particular) at 7–10 days (or its multiple) interval [29,30] showed a decrease in P300 amplitude already after the second attempt to repeat the recording within 2–4 weeks. The maximum drop was observed during the fourth week of the experiment, and the amplitude returned to its original value during ca. 5th week of the experiment. Karniski and Blair [31] proved stability of P300 wave records both in trials repeated at short (15-min) intervals and after 1–2 months. Considering the reports quoted above and the results of the verification of the effects of the applied procedure with sham EMF exposure, the subsequent studies were scheduled at two time intervals, either maximum 2-week, or after the period of amplitude drop. This was intended to reduce the chances of receiving two false positive results that were not associated with the objectives of our research.

As there are no generally accepted standards for the characteristics of the P300 wave or other endogenous waves, the individual laboratories must develop the standards on their own, and this was the case in our instance. Bearing in mind the conclusions by Krause et al. who, after they had compared results of two separate but similar experiments, suggested that the resultant differences were due to a remarkable variability in EEG record of each proband of the test group, in our current work each proband was a control for himself/herself, both in the measuring session with true and sham exposure.

Recent studies did not solve this problem either. They failed to show mobile phone EMF effect on any aspect of ERP recording. It should be noted, however, that the authors of the relevant reports stress that the sensitivity of their tests is too low in relation to the minute changes resulting from mobile phone EMF exposures [32,33].

CONCLUSIONS

From our experiments we may conclude that exposure to EMF generated by GSM mobile phones affects CNS, including its auditory event related potentials (ERPs). This conclusion is confirmed by results of other authors. Further research is required to explain the physiological significance of the observed effects; this may be difficult, because the studied potential is generated by several (possibly more than ten) brain structures, while the function of those structures represents a result of neuronal interaction that modifies their electric input rather than the process of pure neuronal conduction.

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