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NO EFFECTS OF ACUTE EXPOSURE TO THE ELECTROMAGNETIC FIELD EMITTED BY MOBILE PHONES ON BRAINSTEM AUDITORY POTENTIALS IN YOUNG VOLUNTEERS

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Abstract
Objectives: A widespread use of mobile phones evokes a growing concern for their possible adverse effects on the human central nervous system. This study was aimed at evaluating the effects of EMF generated by mobile phones, at all standard wavelengths: 450, 935 and 1800 MHz used in Poland, on the auditory brainstem-evoked responses (ABR) during and after the exposure. **Materials and Methods:** The effects of acute exposure to electromagnetic fields (EMF) on ABR were evaluated in 45 young, healthy volunteers of both genders. The electromagnetic impulses were generated with the antenna of mobile phone. The exposure was induced by repeated phone activation for 20 min. The ABR evaluation was performed before, during and immediately after the exposure, and the latencies of waves I, III and V, and inter-waves I-V were analyzed. **Results:** Prior test calibration on a phantom did not show the influence of the external EMF generated by the mobile phone on the ABR equipment. For neither EMF frequency, differences were observed in wave and inter-wave latencies during and after exposure to EMF compared to the initial ABR pattern, in both men and woman. **Conclusions:** This implies that commonly used mobile phones do not affect propagation of electrical stimuli along the auditory nerve to auditory brainstem centers.

Key words:
Auditory brainstem-evoked responses, Cellular phones

INTRODUCTION

Wireless telecommunication systems, including cellular phone networking, generate radiofrequency electromagnetic fields (EMF) that are substantially different from natural environmental spectrum. Moreover, a rapid development of microprocessor systems of information coding and delivery is associated with a novel mode of impulse coding.

Regarding the absorption properties of human body, the radiofrequency EMF may be divided into four distinct regions [1]:

- subresonance region with frequencies below 30 MHz; at those frequencies the superficial absorption of human trunk is predominant,
- resonance region for entire body with frequencies between 30 MHz and approximately 300 MHz,
- "hot spots" region with the frequencies from 400 MHz up to about 3 GHz; at those frequencies remarkable doses of energy may be absorbed, particularly by the head,
- superficial absorption region with frequencies above 3 GHz; at those frequencies the increase in the body temperature is limited to the superficial body tissues.

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The electromagnetic fields emitted by cellular phones include the bands of 450 MHz, 935 MHz and 1800 MHz; thus they may belong to the third region listed above. Based on the theoretical grounds, they may influence human body via so called thermal effect. The thermal effect is usually a basis for establishing threshold limits. The studies on the phantom head provided with implanted sensors of electric field indicated that the specific absorption rate (SAR) does not exceed the threshold limits recommended by the National Council for Radiation Protection and Measurement (NCRP) [2].

Theoretical studies of SAR distribution in the human head have been conducted along with experimental research**.** These studies prove substantial differences in SAR distribution for EMF frequencies within the range of 900–1800 MHz, related to the place and origin of the stimulation**.** For instance, a mobile phone located in front of the eye bulb significantly increases the SAR parameters calculated for other places of the stimulation (i.e., ear). However, even in that case, like in experimental studies, the maximum intensity of SAR did not exceed the recommended threshold values [3].

Although the recommended SAR values were not challenged, a new hazard to the human health from the wireless phone networking has attracted much attention of researchers who have started to investigate the effects of EMF on the function of the central nervous system (CNS) using electroencephalography in animal and human studies. However, the experiments yielded either contradictory or irrelevant results when extrapolated to human body. Although the EEG method has constantly been developed, the interpretation of the results is still based on the EEG morphology assessment. The results of recent experimental studies differ widely – from no changes to a significant decrease in functional potentials after exposure to PEM [4–9].

The EEG study by Ayoub et al. [4] on healthy volunteers indicated that one hour exposure to EMF of mobile phones, running with the frequency of 935 MHz, was associated with the increase in alpha 1 wave power density (from 32 to 54%) when compared with non-exposed controls. On the other hand, Röschke and Mann [5] obtained different data with shorter time of exposure, much more relevant to a standard phone conversation (3.5 min). The study by Vorobyov et al. [6] on a rat model neither demonstrated significant EEG effects of weak electromagnetic fields at the frequency modulated wavelength of 945 MHz.

A lack of clear evidence to prove the effect of electromagnetic field on the 'rest' EEG has led to the development of task experiments. Freude et al. [7] studied brain slow potentials in subjects exposed to EMF at 916.2 MHz who were performing visual tasks (visual monitor task). The source of EMF was located typically on the left side of the volunteer's head. The exposure was related to the decrease in slow potential voltage at temporal, occipital and parietal regions. These experiments were further developed in the study of Krause et al. [8] who investigated the effects of EMF emitted by mobile phones on the EEG pattern during memory tasks. The EMF exposure resulted in the increase in the amplitude of 8–10 Hz EEG waveforms. The authors have concluded that the exposure to EMF generated by mobile phones does not itself affect EEG patterns but it does influence brain response at the time of memory tasks. Similar conclusion was also reported by Eulitz et al. [9] in a group of volunteers involved in auditory discrimination task at the time of the exposure.

The auditory brainstem-evoked responses (ABR) may allow to quantify the activity and functions of auditory organ, including the auditory nerve and subcortical centers. Up till now, a few reports on the effects of EMF generated by mobile phones on the ABR have been published in an abstract form. The majority of researchers studied ABR before and after exposure to EMF generated by GSM mobile phones identifying no EMF effects on ABR patterns, and analyzed only one frequency of 935 MHz and did not evaluate ABR at the time of exposure. Therefore, this study was aimed at evaluating the effects of EMF generated by mobile phones, at all standard wavelengths: 450, 935 and 1800 MHz used in Poland, on the ABR during and after the exposure.

MATERIALS AND METHODS

Study population

The exposure was performed on 45 healthy volunteers (21 males, mean age, 25 ± 3 years and 24 females, mean age, 24 ± 3 years). During the enrollment visit, all subjects were interviewed and routine neurological and otolarygological examinations were performed along with the registration of prior-exposure (normal) ABR. Each subject, in addition to passing routine neurological and laryngological examinations, responded to a questionnaire containing inquiries about a patient's subjective assessment of his/her health condition and the routine of using cellular phone in every day life. The study population was divided into three groups exposed to different wavelength of EMF (450 MHz, 935 MHz or 1800 MHz). Each group comprised only a few regular users of cellular phones (4 subjects in the group exposed to 450 MHz, 2 – in the group exposed to 935 MHz; and 4 – in the group exposed to 1800 MHz wavelength of EMF). The presence of general symptoms, such as sleep disorders or headaches were sporadic both in subjects who used and in those who did not use cellular phones.

Local Ethics Committee at the Institute of Occupational Medicine approved the study design, and written informed consent was obtained from each participant.

Exposure to electromagnetic radiation

Electromagnetic fields were generated by cellular phones with working frequencies of 450 MHz, 935 MHz and 1800 MHz. The EMF source was the external antenna of the phone, attached directly to skin at the tempo-occipital region of the head, just above the examined ear.

The exposure involved repeated activation of the phone over the time of 20 min, 4 times/min at 1 s intervals between exposures. The stimulation was first performed on the right ear, and after completing the ABR measurement procedure (around 20 min) the left ear was stimulated. Thus, the total testing time of exposure for each subject was around 40 min.

To evaluate the differences in the exposure to EMF between three generators (operated at three different frequencies), the power density was measured with broad band intensity meter MEH-1a with AS-2 probe (Wrocław Technical University, Wrocław, Poland). These devices allow measurements of power density radiation at the frequency range of 0.4–14 GHz with a 15% accuracy. The measurements were performed at the distance of 15 cm away from the site of radiation source.

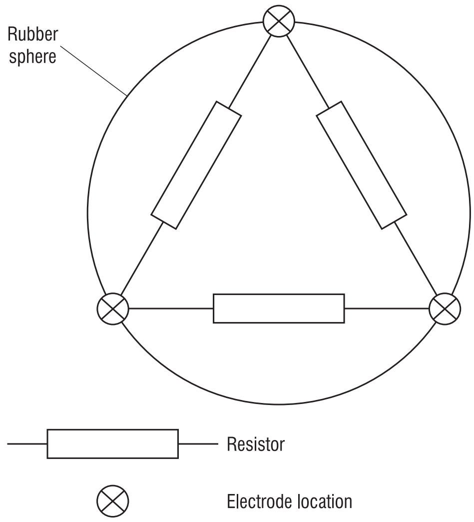

Fig. 1. Scheme of human head phantom.

Further, to exclude the effect of EMF generated by mobile phones on the measurement equipment, it was calibrated prior to the experiments on a human head phantom with the surface resistance properties similar to that of human skin. The phantom was made in the form of rubber sphere with 1.5 kΩ resistors arranged in a regular triangle (with electrodes at its angles) attached thereto. ABR headphones were placed on both sides of the sphere. The calibration involved EMF determination on the phantom with a generator on an off, and subsequent comparison of detected amplitudes with real ABR amplitudes found in human subjects (Fig. 1).

Auditory brainstem-evoked responses

The examination was performed with Centor-O equipment, provided by Racia-Alvar Company, France, and Beyerdynamic DT 48 headphones. The acoustic stimulus was wide band click of 12.5 ms duration and 85 dB nHL intensity, alternating polarization, delivered with the frequency of 20/s. The response was averaged for 1600 of the delivered stimuli. The examination was performed in darkened, audiometric sound-proof room and the volunteers were lying comfortably during the test.

The research procedure involved three series of the ABR in each subject for each ear. The first set of measurements was performed before exposure to EMF, the second at the time of exposure, and the third one directly after completing the exposure. Each set of measurements consisted of ten ABR patterns (curves). The time of experiment was 10 min per one ear. The latencies of waves I, III and V, and inter-waves I–V were measured.

Statistical analysis

All data were classified into different groups respectively by three factors: gender, time measurement before, during and after exposure to EMF and EMF frequency. The statistical analysis was performed for each gender separately.

The mean values of the latencies obtained for different EMF frequencies (between-groups factor) and for different time measurement in relation to exposure (repeated measures factor) were tested with multivariate analysis of variance (one-way MANOVA with three dependent variables). The effect of combined factors to mean latencies (inter latencies) was tested witch multivariate tests. Additionally, the effect of each factor was tested by between-groups comparison. In the case of EMF frequency (between-groups factor), latencies measured before, during and after exposure were analyzed with univariate analysis of variance (ANOVA). For each EMF frequency, the effect of exposure condition factor was tested with MANOVA.

RESULTS

Exposure to EMF

The comparison of power density between three phone systems generating different EMF frequency indicated the maximum value of 0.15 W/m^2 in case of 450 MHz; medium-high value of 0.11 W/m^2 for 1800 MHz; and the lowest value of 0.052 W/m^2 for 935 MHz.

Evaluation of the effect of external EMF on the measurement equipment

By comparing the amplitude of ABR simulated on the phantom at EMF generators on and off with the potentials from healthy volunteers, it was demonstrated that:

- the external generator of EMF did not interfere with the ABR equipment,
- the amplitudes of physiological activity of auditory nerve and auditory brainstem were approximately 10 times higher than the amplitude of the equipment-related background noise.

Auditory brainstem evoked responses

Mean latencies of waves I, III and V, and inter-waves I-V obtained for different EMF frequencies, before, during and after exposure, separately for men and women are presented in Figs. 2–5. Although, there were some between-group differences in wave latencies. For example, the mean latencies of wave I in the group of women exposed to EMF of 935 MHz were generally longer as compared to other groups (Fig. 2); and the mean latencies of wave III in the group of women exposed to EMF of 1800 MHz were shorter than for other groups (Fig. 3). No changes related to exposure to EMF were observed, neither in males nor in females (the mean latencies before, during and after exposure did not differ significantly within each experiment).

The analysis of the effect of combined factors (EMF frequency and time measurement in relation to exposure) on the ABR wave and inter-wave latencies neither shows significance for any of the parameters except for the latency of wave I in women (Table 1). This effect was explored further by the MANOVA analysis with dependent variables. However, no effect of time measurement in relation to exposure (before, during an after exposure) on the wave I latency was proved for any EMF frequency, in any of the gender groups (Table 2). The same was true for other ABR wave and inter-wave latencies.

DISCUSSION

The ABR assessment determines the time of nerve impulse conduction throughout the respective anatomical structures, and thus makes it possible to distinguish between cochlear hearing loss and the retrocochlear type of hearing loss. The ABR pattern includes five typical waveforms: wave I originates at auditory nerve, wave II – at

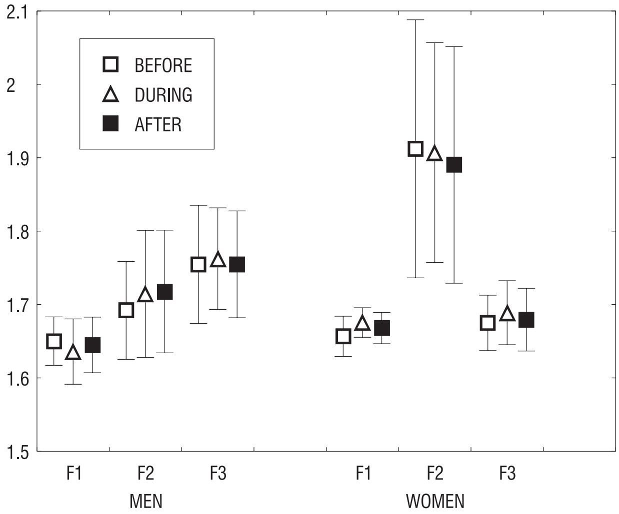

Fig. 2. The mean values and 95% confidence intervals of the wave I latency before, during and after exposure to EMF at different frequencies (F1-450 MHz, F2-935 MHz, F3-1800 MHz) in men and women.

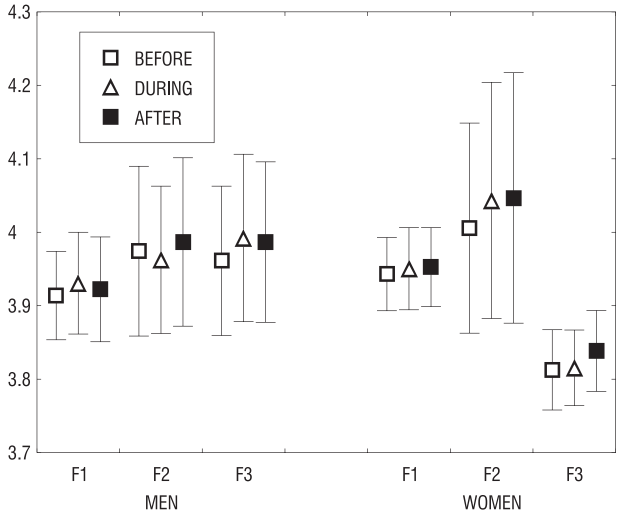

Fig. 3. The mean values and 95% confidence intervals of the wave III latency before, during and after exposure to EMF at different frequencies (F1-450 MHz, F2-935 MHz, F3-1800 MHz) in men and women.

cochlear nucleus, wave III – at the complex of upper olive and trapezoid body, whereas waves IV and V often interfere and form one double peak wave that originates at the neural fibers and auditory nuclei of lateral strip (IV), and inferior prominence of the midbrain (V). Therefore, it could be expected that ABR potentials would allow for detecting minor abnormalities of neural conduction at the cochlea or auditory nerve level, possibly caused by the EMF exposure. The choice of this method was also related to the close vicinity of the EMF generator and the inner ear structure.

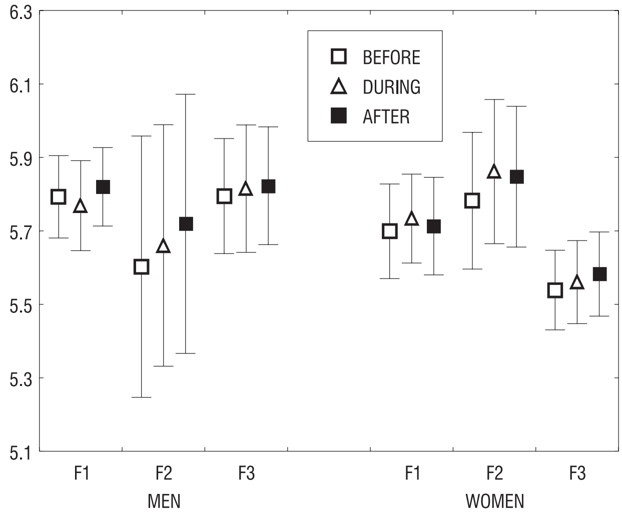

Fig. 4. The mean values and 95% confidence intervals of the wave V latency before, during and after exposure to EMF at different frequencies (F1-450 MHz, F2-935 MHz, F3-1800 MHz) in men and women.

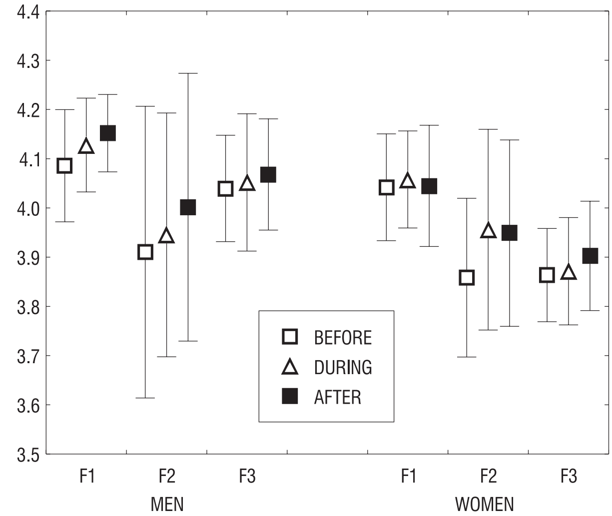

Fig. 5. The mean values and 95% confidence intervals of the inter-wave I-V latency before, during and after exposure to ENF at different frequencies (F1-450 MHz, F2-935 MHz, F3-1800 MHz) in men and women.

The exposure involved continuous stimulation with EMF generated by switching mobile phones on and off, without additional burden of telephone conversation. At the time of turning the cellular phone on and off, the exposure reaches the highest levels. The study evaluated the effects of 450 MHz, 935 MHz and 1800 MHz frequencies that are regarded as those located within 'hot points' of the head.

The results of our investigation did not reveal significant effects of EMF on the ABR. They seem to confirm earlier studies performed by Thimonier et al. [10], who compared the ABR pattern before and after exposure to EMF. Insig-

Table 1. Effect of combined factors (EMF frequency and time measurement in relation to exposure) on mean latency of waves I, III and V and intervals I–V

Latency	Men			Women		
	Test parameters	Value	P	Test parameters	Value	P
I	Degrees of freedom	6.34		Degrees of freedom	6.4	
	Wilks' Lambda	0.5855		Wilks' Lambda	0.4568	
	Rao's	1.6365	0.1693	Rao's	3.0369	0.0159
III	Degrees of freedom	6.3		Degrees of freedom	6.36	
	Wilks' Lambda	0.4862		Wilks' Lambda	0.5074	
	Rao's	2.0258	0.0955	Rao's	2.2886	0.0581
V	Degrees of freedom	6.3		Degrees of freedom	6.38	
	Wilks' Lambda	0.6458		Wilks' Lambda	0.5327	
	Rao's	1.1401	0.3654	Rao's	2.2203	0.0633
I–V	Degrees of freedom	6.34		Degrees of freedom	6.4	
	Wilks' Lambda	0.7906		Wilks' Lambda	0.5678	
	Rao's	0.6647	0.6785	Rao's	2.0719	0.0796

Table 2. Effect of time measurement in relation to exposure to EMF (before during and after exposure) on the wave I latency by EMF frequency

Frequency	Men			Women		
	Test parameters	Value	P	Test parameters	Value	P
450 MHz	Degrees of freedom	2.17		Degrees of freedom	2.20	
	Wilks' Lambda	0.9603		Wilks' Lambda	0.9775	
	Rao's	0.3516	0.7086	Rao's	0.2304	0.7963
935 MHz	Degrees of freedom	2.17		Degrees of freedom	2.2	
	Wilks' Lambda	0.8932		Wilks' Lambda	0.9255	
	Rao's	1.0161	0.3830	Rao's	0.8054	0.4609
1800 MHz	Degrees of freedom	2.17		Degrees of freedom	2.2	
	Wilks' Lambda	0.9795		Wilks' Lambda	0.9838	
	Rao's	0.1782	0.8383	Rao's	0.1649	0.8491

nificant abnormalities in ABR potentials, also at the time of exposure, may be quoted as a novel finding of our study.

Urban et al. [11] reported similar findings of the study on visual evoked potentials in 20 healthy subjects. In their study the parameters before and after the exposure were compared and no significant differences were observed.

The static magnetic field at high induction (the range of 1.5 T), neither seems to affect the ABR. Muller and Hotz [12] analyzed the ABR patterns in the group of 11 healthy volunteers during the routine examination with magnetic resonance imaging (MRI) at three different levels of magnetic induction within the range of 0–2 T. The MRI–related EMF exposure did not affect the latency of respective ABR wave forms.

It is quite likely that the ABR method is not most appropriate for assessing the effects of EMF generated by mobile phones. Although this method makes it possible to discriminate between cochlear and retrocochlear changes in the auditory pathway, the conventional level of click stimulation applied in the present study (85 dBnHL) is not optimal for the evaluation of subtle changes in the cochlea. Lower (close to the threshold) stimulus intensities are more useful in detecting the decrease in the inter-wave I–V latency, the most typical for the cochlear abnormalities. The abnormalities in cortical activities may be expected to provide more significant results, especially if the recent findings of psychological studies are taken into consideration.

It is noteworthy that ABR reflect the function of only a minor part of the auditory pathway, that is auditory nerve and brainstem auditory centers. Thus, ABR do not provide information on the cortical auditory centers. The assessment of auditory cortex function during EMF stimulation is highly advisable in view of the recent findings of psychological studies.

Koivisto et al. [13] studied the effects of EMF generated by mobile phones (GSM) on reaction time in 48 volunteers both before and after the exposure. The authors report that EMF accelerates response time, resulting in the decrease in the time period required to solve intellectual and perceptional tasks. Similar conclusions were drawn from the study carried out by Lee et al. [14]. That study covered 72 teenagers exposed to EMF generated by GSM mobile phones and involved in the rapidity of resolving the problems that required intense concentration. The results demonstrated that the owners of mobile phones solved the study tasks faster, which may further imply the enhancement of cognitive functions by EMF stimulation.

Electromagnetic interference may exist between cellular phones and bone-anchored hearing aids (BAHA). Majority of BAHA users reported hearing annoying noises while examining a digital mobile phone [15]. On the other hand, to date there is no evidence that such interference may be harmful or dangerous to the users of conventional hearing aids or BAHA. Moreover, the new generation of BAHA seems to be less susceptible to mobile phone EMF interference than the older one [16].

Another problem may arise from the possibility of tissue heating due to auditory brainstem implant or a modified cochlear implant during MRI. Although experimental phantom data showed no observable heating associated with the implants during worst-case MRI of the head, this examination in implant users should be performed only in case of a strong medical indication [17,18].

Our study included the group of adult subjects. Apparently, children and young people may be the most sensitive subjects to the EMF effects. This could be the consequence of the difference in the size and dimension of children' skull, hence a possible difference in the SAR distribution throughout the head. The assessment of the effects of EMF on the ABR in teenagers may therefore bring more conclusive data.

The sum up, the results of our study show that there are no significant effects of common mobile phones on the neural conduction along the auditory nerve to the auditory brainstem.

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