Modulated low-level electromagnetic field effects on EEG visual event-related potentials

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Abstract. The aim of this study was experimental investigation of the effects of low-level modulated microwaves on the human central nervous system function using electroencephalographic (EEG) visual event-related potentials. Thirty healthy volunteers were exposed and sham-exposed to the electromagnetic field (EMF) (450 MHz, 0.16 mW/cm^2) modulated at 21 Hz frequency during visual oddball tasks. During the task the participants had to distinguish infrequent target stimuli from frequent standard stimuli. The task consisted of detecting visually presented random ball-shape stimuli of which 25% were target and 75% standard stimuli, in one task the subject was EMF-exposed and in another task sham-exposed. One task lasted 10 min, during the exposed task the EMF was switched on and off in one-minute intervals, so that the participants performed half of the task in exposed condition (EMF ON) and half of the task without the exposure (EMF OFF). The sham-exposed task was identical to the exposed task, except that the EMF generator was switched off all the time. Three-channel EEG was recorded during all the tasks using electrodes Fz, Pz and Cz. For analysis of the EEG event-related responses, the channel Pz was used. The EEG responses of a task were grouped into four different categories, taking into account the EMF exposure condition (ON, OFF) during the response and the response type (standard, target). The responses were averaged by categories; finally we had four types of average EEG event-related potentials for a task for every subject. The EMF ON and OFF potentials were compared pairwise. The hypothesis was that the EEG event-related potential component latencies, amplitudes and reaction times (RT) of the subjects to the target stimuli are not different in EMF ON and EMF OFF conditions during the same task. There were no statistically significant differences in responses in sham-exposed tasks, neither in standard nor in target-response components. In the exposed task the group mean N100 amplitude (measured from standard response) was -3.41 ± 4.54 µV in EMF ON category and -2.50 ± 4.71 µV in EMF OFF category; this difference was statistically highly significant ($p < 0.00009$). Differences in amplitudes, latencies and in RT between EMF ON and OFF conditions of other components were not significant. It is concluded that the modulated microwave effect has stronger impact on early (sensory) components of EEG visual event-related potentials compared with later stages of visual information processing during the oddball task.

Key words: RF exposure, visual perception, psychological effects, evoked potentials.

1. INTRODUCTION

Modulated microwave effects on electroencephalographic event-related potentials (ERP) and cognitive performance has been the subject of extensive discussion during the last decade. Most of the research in this field is carried out because of the massive spread of wireless communication devices and growing public concern about the probable health risk of the electromagnetic radiation, emitted from the devices and networks. For assessing the EMF effects in cognitive functions, different methods have been used [1–19]. The analysis of changes in persons' behavioural and performance characteristics is often carried out [1–6,9–11,17–19]. The changes in cognitive performance are typically accompanied by changes in the frequency and spatial coordination of the rhythmic activity in the neocortex. These changes can be detected by the analysis of EEG ERP responses. In most cases, visual or auditory stimuli are used for creating EEG ERP responses in EMF studies. There are studies that use classical phase-locked methods for time domain averaged EEG response analysis. In this case the amplitudes and latencies of characteristic peaks (N100, P100, etc) of averaged responses relative to stimulus onset are analysed [14–16]. Usually characteristic peaks are named by their polarity (N–negative, P–positive) followed by its approximate latency (100, 200 or 300 ms) [20]. There are also studies that use time-frequency methods for the analysis of EEG ERP responses. In this case the change in the signal power, occurring in a given band, relative to a reference interval is calculated and parameterized as event-related desynchronization (ERD) and event-related synchronization (ERS) [7–8,12,13]. By convention, ERD corresponds to the power decrease and ERS to the power increase [21].

In [1] it was found that during the EMF exposure the choice reaction time decreased in adult subjects; at the same time there were no changes in the word, number or picture recall, or in spatial memory [1]. Similar tendency was found in [2] in the EMF study of children, but the findings did not have statistical significance and were not confirmed in experiments with adults [2]. In [3,4] it was suggested that EMF has a facilitating effect on human attention. Since different measures of attention showed different results, it was also concluded that attention functions may be differentially enhanced after exposing to EMF and the effects may be dose-dependent. In [5] a measurable EMF effect on human cognitive performance was found, especially on attention and working memory. The EMF field, produced by the GSM phone, speeded up response times when the memory load was three items, but no effects of RF were observed with lower loads [5]. The improvement in the speed of processing of the information, held in working memory during the exposure to mobile phone EMF, was also found in a more recent study [6]. This study incorporated 120 volunteers and 8 different neuropsychological tasks. In [7] the effects of EMF, emitted by cellular phones on the ERD/ERS of the 4–6, 6–8, 8–10 and 10–12 Hz EEG frequency bands were studied in normal subjects performing an auditory memory task. The exposure to EMF increased EEG power significantly only in the 8–10 Hz frequency band.

The results suggested that the exposure to EMF does not alter the resting EEG *per se* but modifies the brain responses significantly during the memory task. In another study [8] the same team investigated the problem with the help of a visual sequential letter task (n-back task) with three different working memory load conditions: zero, one and two items. The conclusion was very similar to their first study – the exposure to EMF modulates the response of EEG oscillatory activity approximately by 8 Hz, specifically during cognitive processes [8]. In two replication studies by Haarala et al. [9,10] the authors could not reiterate their previous results. The improvements of both of the studies included multi-centre testing and a double-blind design. In the cognitive function study the number of tests was reduced. Neither had EMF an effect on the cognitive functions and on the reaction time nor on the accuracy of the subjects answers. The authors concluded that inability to replicate previous findings could be caused by the high sensitivity threshold of the test [9,10]. Similarly Haarala et al. [11] found no effects of 902 MHz mobile phones on children's cognitive functions. At the same time the results of Krause et al. [12] suggest that EMF, emitted by mobile phones, has an effect on brain oscillatory responses during cognitive processing in children. In this study 1–20 Hz event-related brain oscillatory EEG responses in children, performing an auditory memory task (encoding and recognition), was assessed while exposed to a digital 902 MHz mobile phone radiation. The results demonstrated that during memory encoding, the active mobile phone modulated the ERD/ERS responses in approximately 4–8 Hz EEG frequencies. During recognition, the active mobile phone transformed these brain oscillatory responses in approximately 4–8 and 15 Hz frequencies [12]. In [13] the authors investigated further possible effects of electromagnetic fields, emitted by mobile phones on the ERD/ERS during cognitive processing. In line with their previous studies, they observed that the exposure to EMF had modest effects on brain oscillatory responses in the alpha frequency range (approximately 8–12 Hz) and had no effects on the behavioural measures. The effects on the EEG were, however, varying, unsystematic and inconsistent with previous reports. The general conclusion was that the effect of EMF on brain oscillatory responses may be subtle, variable and difficult to replicate for unknown reasons [13].

In [14] the effects of electromagnetic fields, emitted by GSM mobile phones on human EEG event-related potentials and performance during an auditory task with 12 subjects were investigated. Participants of the study performed an auditory oddball task while they were exposed to the electromagnetic field of an active mobile phone during one session and sham-exposed during another. Each test lasted 1 h and the time between the two sessions was one week. For EEG ERP analysis phase-locked methods were used. The analysis showed that the N100 amplitude and latency to non-targets were reduced when exposure and sham exposure conditions were compared. P300 latency to targets was delayed in the exposure condition and also the reaction time increase was observed in expose condition. The results suggested that mobile phone exposure may affect neural activity; however, one should be cautious due to the small sample size.

In the next ERP study by Hamblin et al. [15] the authors increased the sample size to 120 subjects and decreased the EMF exposure time to 30 min. The results of this study showed no significant difference between exposure conditions for any auditory or visual ERP component or RT. As their previous positive findings were not replicated, it was concluded that there is currently no evidence that acute mobile phone exposure affects auditory N100 and P300, visual P100 and P300 amplitudes and latencies RT [15]. In the study [16] it was found that EMF, emitted by the mobile phone, affects the pre-attentive information processing reflected by the P50 auditory evoked potential.

In [17] the results of neurophysiological tasks, associated with attention and short-term memory, indicated that there is a significant increase in variances of errors in the EMF-exposed (450 MHz, modulation 7 Hz) and sham-exposed groups, and in more complicated tasks there was also a significant decrease in errors in the exposed group. In the visual perception study [18] with face masking task it was shown that recognition of stimuli was better under the sham-exposure conditions compared to exposed condition (450 MHz, modulation 7 Hz), but the actual difference was only 5%. It was concluded that early stages of the visual information processing are overwhelmingly robust so that the low-level 7 Hz modulated electromagnetic field effects are extremely weak [18]. In the visual perception study [19] the EMF (450 MHz, modulation 40 Hz) effects were examined with the attention blink phenomenon that can be described as impairment of the identification of the second of two targets if it is presented less than about 500 ms after the first. The results showed that 40 Hz modulated EMF had no immediate effect on attentional blink characteristics of human visual perception. Investigations [17–19] were different from mobile phone experiments described above since the electromagnetic field carrier had lower frequency (450 MHz) and the modulation was simplified compared to the GSM standard. In these studies simple on/off modulation was used with modulation frequencies inside the EEG frequency band (7 or 40 Hz).

The results of the described studies are quite different and contain contradictions when compared to each other. It is a clear indication to the fact that EMF effects on cognitive functions can not be easily detected and the interpretation of the results is extremely complicated. The reasons for that might be that the sensitivity to EMF is individual and it depends also very much on the physiological condition of the individual during the experiment. The aim of the current study was to experimentally investigate the effect of modulated microwave radiation in EEG ERP responses by the method introduced by Polich [20] and to combine it with an original design of the EMF exposure set-up. The idea of the exposure set-up is to keep the experimental conditions for a subject as uniform as possible in order to minimize the fluctuations of the physiological condition and ERP responses by unknown factors. This goal is achieved by recording the reference and exposed responses in a mixed way during the same task and making the exposed and sham-exposed tasks in the same day in short time.

2. EXPERIMENTS

2.1. Subjects

30 adult subjects participated in the current study. The group of volunteers consisted of 12 male and 18 female subjects, aged between 19 and 36 years with a mean age of 25 years. All participants were healthy, without any known medical or psychiatric disorders, and had normal or corrected to normal visual acuity. All subjects gave their informed consent before the start of the experiment.

EEG activity was recorded at the Fz, Cz, and Pz electrode sites, referred to linked earlobes, using forehead ground, with impedances at $5 \, k\Omega$ or less. Additional bipolar electrodes were placed at the outer canthus of both eyes, also above and below the left eye to measure the electro-oculographic (EOG) activity. The data were recorded using a sampling rate of 500 Hz, bandbass filtered (0.05–40 Hz). All data were recorded using Compumedics Neuroscan (7850 Paseo Del Norte El Paso, TX 79912, USA) electrode cap, Syn Amps amplifier and amplifier headbox.

2.2. Exposure conditions

Electromagnetic radiation of 450 MHz was generated by a signal generator (model SML02, Rhode & Swartz, Munich, Germany). The radio frequency signal was 100% pulse-modulated using a modulator (SML-B3, Rhode & Swartz, Munich, Germany) at the frequency of 21 Hz (duty cycle 50%). The signal from the generator was amplified by a power amplifier (model MSD-2597601, Dage Corporation, Stamford, CT, USA). The generator and the amplifier were carefully shielded. The output power of 1 W electromagnetic radiation was guided by a coaxial lead to the 13 cm quarter-wave antenna (NMT450 RA3206, Allgon Mobile Communication AB, Stockholm, Sweden), located 10 cm from the skin on the right side of the head. Spatial distribution of the power density of the electromagnetic radiation was measured by a field strength meter (Fieldmeter C.A 43, Chauvin Arnoux, Paris, France). The measurements were made by the Central Physical Laboratory of the Estonian Health Protection Inspection. The dependence of the field power density on the distance from the radiating antenna was obtained from the measurements, performed under real experimental conditions. During the experiments a Digi Field C field strength meter (IC Engineering, Thousand Oaks, CA, USA) was used to monitor the stability of the electromagnetic radiation level. The average field power density of the modulated microwave at the skin on the left side of the head was 0.16 mW/cm^2 as estimated from calibration curves. The specific absorption rate (SAR) was calculated using SEMCAD (Schmid & Partner Engineering AG, Zurich, Switzerland) software. The finite difference time domain (FDTD) computing method with specific anthropomorphic mannequin (SAM), specified in IEEE Standard 1528, was applied. The calculated spatial peak SAR averaged over 1 g

was 0.303 W/kg, which is below the thermal level. In the current study every subject performed two identical cognitive tasks, one of which was with exposure and the other one with sham exposure. One task lasted 10 min. During the exposed task the EMF was switched on and off in one-minute intervals, so that the participants performed half of the task with RF exposure (EMF ON) and half of the task as reference (EMF OFF) (Fig. 1). The sham-exposed task was identical to the EMF-exposed task, except that the EMF generator was switched off all the time.

2.3. Description of the visual task

All subjects performed a visual oddball task, where they had to distinguish infrequent target stimuli from frequent standard stimuli by pressing the mouse button. The task consisted of randomly appearing ball-shaped stimuli, of which 25% were targets and 75% were standards. The sequence of the stimuli was generated by the system Compumedics Neuroscan STIM^2 4.0. There were two different sequences of stimuli (one for the exposure task and another for the sham task) and the order of the sequences was counterbalanced.

The target stimulus was a blue circle of 2 cm diameter and the standard stimulus a blue circle of 4 cm diameter [20]. Stimuli were presented in the middle of the black computer screen. The duration of every stimulus was 100 ms. The inter-stimulus interval (ISI) was variable during the task in order to minimize habituation. ISI range was 1–2 sec, mean 1.5 sec (Fig. 1). Altogether 400 stimuli were presented on the computer screen during one 10-min task (Fig. 2), of which 100 were targets and 300 standards. The subjects were instructed to respond to the target as quickly as possible by pressing the left mouse button and to refrain from responding to standard stimuli.
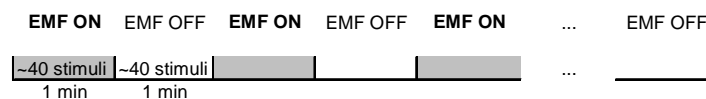

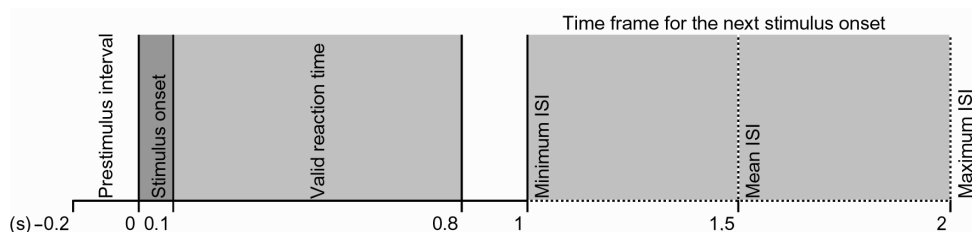**Fig. 1.** Timetable of the experimental task; total duration of the task is 10 min.

Fig. 2. Detailed diagram that explains the variables related to the stimuli presentation.

129

2.4. Experimental procedure

During the experiment, the room was dark and the participants were sitting in front of the 17" computer monitor with a viewing distance of approximately 80 cm. The monitor was calibrated at color temperature 6500 K and luminance 200 cd/m^2. The subjects were instructed to avoid movements during tasks and to keep the eyes focused at the middle of the screen. During the pauses between the tasks the lights were put on and the subject was asked how he/she was feeling and whether he/she felt tired.

The experimental session started with a preparatory task (3 min) and continued with two successive experimental tasks (10 min both), one of which was the exposure task and the other the sham task. There were 2 min resting time between the preparatory task and the first experimental task, and 10 min resting time between two experimental tasks. The whole session for a subject lasted 35 (3 + 2 + 10 + 10 + 10) min and was carried out on the same day, every subject had only one experimental session. EEG activity was recorded only during the experimental tasks. The order of experimental tasks (exposure versus sham) was counterbalanced as well as the order of stimuli sequences. The subjects were blind to the exposure time and duration, the antenna was located near the right side of the head during all experimental tasks.

2.5. Data processing

Eye moving artifacts were reduced using Compumedics Neuroscan Edit 4.3.3 software. The method employs regression analysis in combination with artifact averaging [22]. After that the signal was low-pass filtered at 30 Hz (48 dB octave/slope) and continuous EEG was offline epoched to 800 ms responses with a 200 ms prestimulus baseline. Every epoch was baseline-corrected using prestimulus interval –200 to 0 ms. Epochs, where the voltage in VEOG or HEOG channels exceeded ±100 μV (in the range –50 to 400 ms), were removed from the analysis. The epochs were grouped into four different categories taking into account the EMF condition (ON, OFF) and the response type (standard, target). The responses were averaged by categories. After the grouping and averaging process we had four different ERP responses for every experimental task for every subject (target EMF ON, standard EMF ON, target EMF OFF, standard EMF OFF). One averaged ERP standard signal contained approximately 150 epochs and the target signal approximately 50 epochs. The reaction times for target recognition were also recorded, valid mouse clicks had to be between 100–800 ms from the stimulus onset.

The components amplitudes were measured relative to the mean of the prestimulus baseline, with peak latency defined as the time point of the maximum positive (P) or negative (N) voltage within the latency window. Peak amplitudes and latencies were detected from the Pz channel. Sensory evoked potentials (P100, N100, P200, N200) were measured from the standard and P300

from the target stimuli. Peaks latency windows were defined as follows: P100(130–200 ms), N100(170–230 ms), P200(220–280 ms), N200(250–350 ms), P300(300–600 ms). After peak detection, waveforms were inspected manually to ensure that the peaks identified were genuine and proceeded each other in the correct order. Scalp distribution data from Fz and Cz channels were used for correct Pz peak detection. If the P300 wave had two peaks, the second peak was taken for the analysis. In addition to subject-averaged EEG ERP responses, averaged responses over all the subjects were calculated.

2.6. Statistical analysis

The null hypothesis was that the EEG event-related potential component latencies, amplitudes and reaction times of the subjects to the target stimuli are not different in EMF ON and EMF OFF conditions during the same task. The mean values of EMF ON and OFF response parameters were compared pairwise by two-tailed Students t-test ($p < 0.01$ considered to be significantly different). The exposed and sham tasks were analysed separately.

3. RESULTS

The only parameter found significantly different when comparing the mean values of the parameters in different EMF categories was N100 ($p < 0.00009$) amplitude in the exposed task. In the exposed task the group mean N100 amplitude (measured from standard response) was $-3.41 \pm 4.54\ \mu V$ in EMF ON category and $-2.50 \pm 4.71\ \mu V$ in EMF OFF category. In EMF ON category the N100 amplitude was 1.1 µV (36%) lower compared to EMF OFF during the same task. The P100 amplitude was lower in EMF ON category ($3.47 \pm 4.85\ \mu V$) compared to EMF OFF category ($4.01 \pm 4.55\ \mu V$) but the significance was on borderline ($p < 0.014$). No significant differences were found when sham task categories were compared. All the data is presented in Table 1.

This effect can also be observed on the grand mean response figure (Fig. 3); EMF ON grand mean has a different amplitude at N100 compared to other three grand mean ERP responses on the same figure. Moreover, standard EMF ON grand mean response has noticeably lower amplitude compared to other standard responses from 150 to 300 ms relative to the stimulus onset.

Figure 4 illustrates the grand mean potentials from ERP target responses. In EMF category, the signal amplitude is a little bit lower compared to sham signals. We can see that the same type of responses from different tasks are not as similar as the same type of responses from the same tasks. This is a general indication of slightly shifted experimental or psychological conditions within sham and exposed experimental tasks that were apart no more than 10 min.

Table 1. Measured parameters for all response categories during the exposure (EMF ON, EMF OFF) and sham (Sham 1, Sham 2) tasks. The types of responses from where the particular parameters were measured (standard, target) are also presented

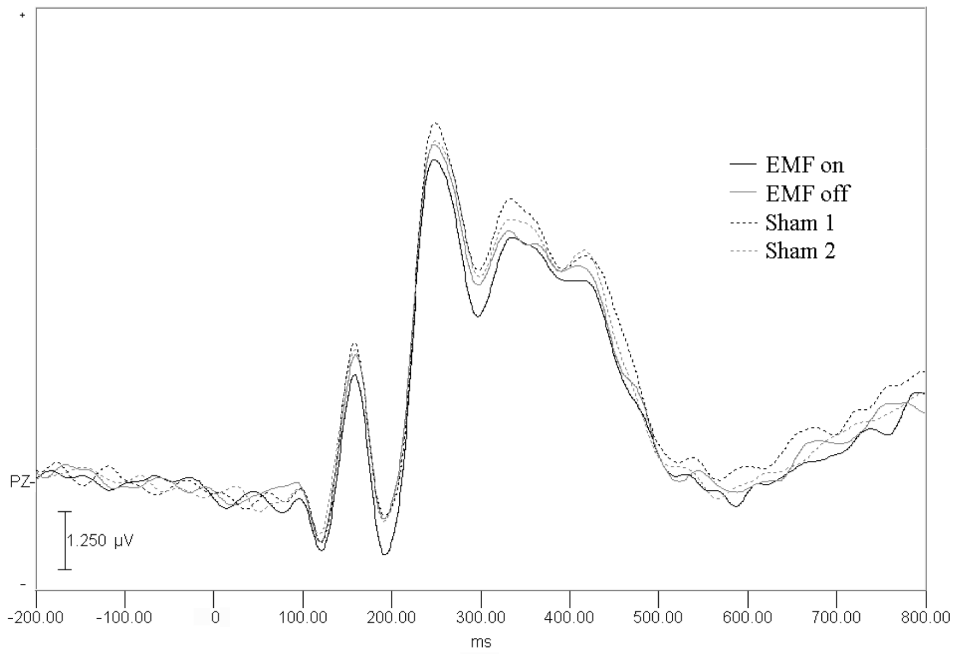| Parameter	EMF condition	Mean, ms	SD	p
RT	EMF ON	375.03	43.55	0.651
	EMF OFF	373.80	37.43	
	Sham 1	379.73	41.90	0.422
	Sham 2	377.77	41.35	
P100 lat.	EMF ON	157.33	13.25	0.914
(standard)	EMF OFF	157.47	13.08	
	Sham 1	159.47	12.09	0.585
	Sham 2	159.00	14.10	
P100 amp.	EMF ON	3.47	4.85	0.014
(standard)	EMF OFF	4.01	4.55	
	Sham 1	4.04	5.13	0.981
	Sham 2	4.05	5.03	
N100 lat.	EMF ON	194.73	15.37	0.472
(standard)	EMF OFF	196.00	15.49	
	Sham 1	195.27	13.92	0.936
	Sham 2	195.20	13.59	
N100 amp.	EMF ON	–3.41	4.54	**9.26E-05**
(standard)	EMF OFF	–2.50	4.71	
	Sham 1	–2.52	4.79	0.797
	Sham 2	–2.60	5.01	
P200 lat.	EMF ON	249.20	14.30	0.443
(standard)	EMF OFF	250.13	15.32	
	Sham 1	249.07	14.23	0.464
	Sham 2	249.67	16.31	
P200 amp.	EMF ON	8.70	4.90	0.424
(standard)	EMF OFF	8.88	4.72	
	Sham 1	9.38	4.91	0.400
	Sham 2	9.19	5.07	
N200 lat.	EMF ON	288.60	18.81	0.448
(standard)	EMF OFF	289.87	19.76	
	Sham 1	287.87	18.64	0.863
	Sham 2	287.67	19.22	
N200 amp.	EMF ON	2.57	3.56	0.094
(standard)	EMF OFF	3.01	3.27	
	Sham 1	3.61	3.74	0.652
	Sham 2	3.48	4.13	
P300 lat.	EMF ON	410.27	29.32	0.423
(target)	EMF OFF	412.33	29.47	
	Sham 1	415.47	25.79	0.401
	Sham 2	413.27	29.60	
P300 amp.	EMF ON	16.98	5.43	0.622
(target)	EMF OFF	16.67	4.86	
	Sham 1	17.67	4.84	0.786
	Sham 2	17.53	5.94	

Fig. 3. Grand averages for the standard stimuli event related potential ERP responses for the Pz channel.
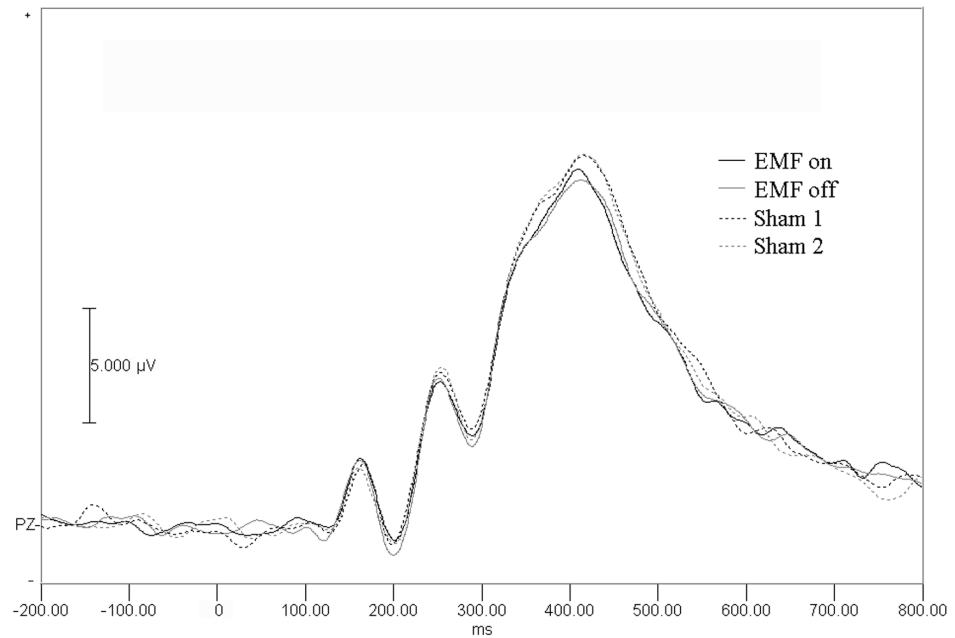

Fig. 4. Grand averages for the target stimuli event related potential ERP responses for the Pz channel.

In our experiment, mean RT in exposed tasks is somewhat shorter than in sham tasks: 375 ms (EMF ON) and 374 ms (EMF OFF) versus 380 ms (sham 1) and 378 ms (sham 2). However, within the same task the RT differences were not statistically significant.

4. DISCUSSION

Our current results are in good agreement with the study by Rodina et al. [18] on visual perception with a method of face masking. The method can be considered as a model of the initial level of visual perception. In the visual sense, practically all kinds of memory are used in face masking: the long-term memory for recognition, the short-term (working) memory for responding, and the sensory memory for immediate representation. In the masking experiment the most important role is probably carried out by the sensory memory, because only two stimulus alternatives of highly overlearned stimulus-type are used, which does not exceed the working memory capacity or pose serious problems for long-term memory processes [18]. In an auditory experiment very similar results were found in [16], where the main effect of EMF was revealed in pre-attentive information processing phase.

All this does not necessarily mean that EMF has no effect to the later stages of information processing but since the effect is very small, it could be that in later stages it may be even more difficult to reveal it in a meaningful way. As described in the Introduction, many studies have shown the effect also in working memory and attention but replication of these effects has been difficult in most cases [1–6,9–11,17–19]. It should also be noticed that our studies may not be directly compared to the studies that used GSM mobile phone radiation and this is mainly because of different modulation properties. It has been shown in [23,24] with resting EEG that different modulation frequencies have different impact, which leaves us a reason to believe that similar effects also exist for cognitive processes and EEG ERP responses. Another reason why we have got an effect where other similar studies have failed, might be the more sensitive protocol used in the current study. The key here is that the EMF ON and EMF OFF experiments were mixed into a single task (one minute exposure on and one minute exposure off) that rules out many artefactual as well as physiological factors that make the dispersion of the results higher when different tasks are carried out in different days. Our experimental procedure during the EMF ON and EMF OFF condition for a particular subject were as uniform as these theoretically can be. Our study also had another advantage, because there was no need to statistically compare exposed and sham-exposed tasks. Sham experiment in our case was made as a separate reference study and had to show that there were no significant changes of the parameters in the sham-sham comparison.

There are also weaknesses in this kind of set-up. For example, the continuous radiation time can not be very long (in our case it was one minute) and if the

effects would need longer time of EMF exposure to develop, we might have weakened it by our set-up. When comparing to other similar experiments, many studies use exposure times 30 min and more [14,15], whereas our total exposure time during one task was only 5 min. Because of the short exposure time and alternating EMF ON and EMF OFF conditions during the task, our set-up also reduces the chance of thermal effects. Another problem with our experiment might be related to the adaptation phenomena described in [25]. With short exposure and recovery times in our experiments we might have created the situation where the nervous system is in the constant adaptation phase. This on the one hand might enhance the effect, especially if the effect can only be observed during the adaptation phase, or, on the other hand, decrease the effect if adaptation during EMF ON phase is in the same direction as recovery during the EMF OFF phase. That, in turn, depends on time characteristics of the adaptation and recovery and is a subject for future analysis.

5. CONCLUSIONS

The results confirm that EMF effects on visual cognitive processes are extremely weak and the detection of these effects is difficult. It has been shown that modulated microwaves have rather strong impact on early (sensory) components of visual event related potentials (N100 amplitude) compared to later stages of visual information processing during the oddball task. No evidence was found that low-level 450 MHz EMF, modulated with 21 Hz, could alter EEG ERP response latencies or subject reaction times.

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Moduleeritud madalatasemelise mikrolaine kiirgusefektid visuaalsetele EEG erutuspotentsiaalidele

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Töö eesmärgiks oli eksperimentaalselt uurida madalatasemelise mikrolainekiirguse mõju inimese kesknärvisüsteemile, kasutades elektroentsefalogrammi (EEG) abil mõõdetud visuaalseid erutuspotentsiaale (ERP). Katsetel osalesid kolmkümmend vabatahtlikku, keda nn *oddball*-ülesande ajal kiiritati ja petukiiritati elektromagnetkiirgusega (EMF) (450 MHz, 0,16 mW/cm^2), mis oli moduleeritud 21 Hz sagedusega. Testi ajal tuli osalejal eristada harva esinevat eesmärkstiimulit sagedasest standardstiimulist. Test koosnes visuaalselt järjestikku esitatud värvilistest ringikujulistest stiimulitest, millest 25% olid eesmärkstiimulid ja 75% standardstiimulid. Üks test kestis kümme minutit ja kiirgusega testi ajal lülitati elektromagnetkiirgust sisse ning välja 1-minutiliste intervallidega. Lõpptulemusena tegi osaleja poole testist kiirguse mõju all ja poole ilma kiirguseta olukorras. Petukiirgusega testi puhul oli kiirgus kogu aeg välja lülitatud olekus, aga testi tegija seda ei teadnud. Testi ajal salvestati kolmekanaliline EEG, kasutades Fz-, Pz- ja Cz-lülitusi. Ühe ülesande EEG ERP-d grupeeriti nelja erinevasse kategooriasse, võttes arvesse EMF-i tingimust (SEES/VÄLJAS) ja ERP vaste tüüpi (eesmärkvaste, standardvaste). Vasted keskmistati igal katsealusel kategooriate kaupa ja selle tulemusena tekkis iga katsealuse kohta neli erinevat keskmistatud EEG ERP vastet. Tingimuste kiirgus sees ja kiirgus väljas ERP vasteid võrreldi paarikaupa. Statistiline nullhüpotees oli, et EEG ERP vastetest arvutatud parameetrid, nagu vastete komponentide latentsused ja amplituudid ning katsealuse reaktsiooniajad eesmärkstiimulitele, ei saa olla erinevad eri kiirguse tingimustes sama testi jooksul. Petukiirgusega katsetes parameetritel statistiliselt olulisi erinevusi ei leitud. Kiirgusega katsetes erines grupi keskmine N100 amplituud kiirguse ajal (−3,41±4,54 µV) oluliselt ilma kiirguseta olukorrast (−2,50±4,71 µV). See erinevus oli statistiliselt oluline ($p < 0{,}00009$). Erinevused teiste komponentide amplituudides, latentsustes ja katsealuste reaktsiooniaegades ei olnud statistiliselt olulised ka kiirgusega katses. Töö tulemusena on järeldatud, et moduleeritud madalatasemelisel mikrolainekiirgusel *oddball*-testis on suurem mõju varastele ehk sensoorsetele EEG erutuspotentsiaali komponentidele ning need ei mõjuta oluliselt hilisemaid komponente.