SENSITIVITY OF HUMAN EEG TO MODULATION FREQUENCY OF MICROWAVE RADIATION

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Abstract: The aim of this study was to investigate the effect of microwave radiation on EEG at modulation frequencies much higher than EEG rhythms (217 - 1000 Hz) and compare these results with the effect reported at the modulation frequencies within EEG spectrum (7-14-21 Hz). During the experiment, 19 healthy volunteers were exposed to microwave stimulation (450 MHz) with on – off modulation frequency of 217 and 1000 Hz. Field power density at the scalp was 0.16 mW/cm^2. The protocol consisted of two series of ten cycles of repetitive microwave exposure (1 minute on, 1 minute off) at fixed modulation frequencies. All the subjects also passed the experiment with sham exposure. Signals from the frontal, temporal, parietal and occipital regions were analysed. Relative changes in EEG theta, alpha and beta rhythms energy were calculated and analysed for a group. The strongest effect was produced by different modulation frequencies in temporal region. The findings suggest that the effect of microwave radiation is most evident in temporal region (channels T3, T4) and in higher EEG rhythms (beta1 and beta2).

Introduction

The problem of the influence of microwave radiation on human nervous system and brain has been a subject of interest during decades. With portable telecommunication solutions, artificial electromagnetic fields present stronger radiation than the fields created by natural sources.

Extensive research in the field of microwave effects on the nervous system has been carried out during recent decades [1 - 17]. Despite intensive study, the reports of possible effects are often contradictory and the mechanisms behind the effects are still unclear. The difficulties in independent repeating of the experimental results cause doubt in these effects.

Several investigators have reported that microwave exposure produces different alterations in the EEG signal. Chizhenkova mentioned an increase in the number of slow rhythms in the EEG of rabbits [5]. Bawin et al. reported that modulated at brain rhythm frequencies EMF affect EEG patterns in the cat [3]. Vorobyov et al. demonstrated a significant elevation of the EEG hemispheric asymmetry during the first 20 seconds of the stimulation period [7].

Several authors have reported EMF effects on the human sleep EEG. Reiser et al. recorded the outlasting effect and an increase in the alpha and beta power in the EEG [8]. A hypnotic effect with shortening of sleep onset latency and a rapid eye movement sleep (REM) have been described by Mann and Roschke [9]. An increase in the spectral power of the EEG during non-REM sleep has been reported by Borbely et al. [11] and Huber et al. [12]. However, some of authors were unable to confirm their previous findings in their later studies [10].

The conclusion reported by other researchers is that the exposure to microwave does not alter the resting EEG [15, 16, 17].

Our previous studies demonstrated influence of low-level microwaves to human EEG and mental behaviour [18, 19, 20]. We found in our recent study that significant changes in EEG energy can be caused by modulation frequencies higher or comparable with EEG rhythms frequencies [21].

This study is aimed to

- investigate the effect of microwave radiation on EEG at modulation frequencies much higher than EEG rhythms (217 Hz and 1000 Hz, taking into account frequency band of technical systems)
- compare these results with the effect reported at the modulation frequencies within EEG spectrum (7-14-21 Hz).

Materials and methods

The experimental study was carried out on a group of volunteers. The group consisted of 19 young (age 21-24) persons. A questionnaire and a clinical interview were used to evaluate their physical and mental condition (tiredness, sleepiness) before the experiment. All the subjects selected were healthy and without any medical or psychiatric disorders. Tired or sleepy persons were excluded. After the recordings the subjects reported no alertness or experienced strain during the experiment.

The experimenter and the subjects were in the same laboratory room during the experiment. The room was dark but no other special conditions were provided. During the experiments the subjects were lying in a relaxed position, eyes closed and ears blocked.

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All subjects were exposed and sham exposed. Only one experimental EEG recording was performed for a subject during a day. In each test session, the exposed and sham – exposed subjects were randomly assigned. The subjects were not informed of their exposure, however they were aware of the possibility of being exposed. The experiments were conducted with the understanding and the written consent of each subject.

Modulated microwave radiation at non – thermal level of field power density, identical for this in our previous studies [18 - 21], was used. Microwave exposure conditions were same for all subjects.

The 450 MHz microwave radiation was generated by the Rhode & Swartz (Germany) signal generator model SML02. The RF signal was 100% amplitude modulated by the pulse modulator SML-B3 at 217 or 1000 Hz frequency (duty cycle 50%). The generator signal was amplified with the Dage Corporation (USA) power amplifier model MSD-2597601. The generator and amplifier were carefully shielded and located in the laboratory room. The 1W EMF output power was guided by a coaxial to the 13 cm quarter-rhythm antenna NMT450 RA 3206 by Allgon Mobile Communication AB, Sweden, located at 10 cm from skin from the left side of the head.

The calculation of the specific absorption rate (SAR) inside the brain was based on the known field power density at skin. The Central Physical Laboratory of the Estonian Health Protection Inspection measured the spatial distribution of the microwave power density by the Fieldmeter C.A 43 Chauvin Arnoux (France) field strength meter. The calibration curves of the field power density dependence on the distance from the radiating antenna were obtained from these measurements performed in the real condition of the experiment. During the experiments the stability of the microwave level was monitored by the IC Engineering (USA) Digi Field C field strength meter. Estimated by the measured calibration curves, the field power density at the skin was 0.16 mW/cm^2. The SAR calculated by the formula: SAR=$\sigma E^2/2\rho$ for brain conductivity at 450MHz σ=1.18 S/m and density ρ=1000 kg/m3 was 0.35 W/kg. The level of power density as well as the calculated SAR was so low that thermal effects are extremely unlikely.

The study consisted of two experimental protocols identical for all subjects. . The first protocol consisted of two series of ten cycles of repetitive microwave exposure at fixed modulation frequencies and was recorded as follows:

Initially, the reference EEG was recorded for 60 seconds.

Next, the microwave radiation, modulated at the first modulation frequency, was applied. The duration of the exposure was 60 seconds and the compensatory pause after the exposure was also 60 seconds. Continuous recordings of the EEG were performed during as well as 60 seconds after the exposure. The procedure of the cycle was repeated ten times. The microwave exposure was switched on for every first 60 seconds of the cycle. During ten cycles of the microwave stimulation, the modulation frequency was always the same.

Secondly, the microwave radiation, modulated at second modulation frequency, was applied. The procedure of this step was identical to the previous one, except the modulation frequency was different.

The selection of the 217 Hz and 1000 Hz as first or second modulation frequency was randomly assigned.

The recording protocol for one subject lasted for 41 minutes, during which the EEG was continuously recorded.

The second protocol for the sham exposure included the same steps, except the microwave generator was switched of.

The Cadwell Easy II EEG measurement equipment was used for the EEG recordings. The EEG was recorded using 19 electrodes, which were placed on the subject's head according to the international 10-20-electorde position classification system. The channels for analysis were chosen to cover the entire head: frontal - FP1, FP2; temporal - T3, T4; parietal - P3, P4; occipital - O1, O2. The EEG recordings were stored on a computer with a 400Hz sampling frequency. The recorded EEG signals were observed by an experienced neurologist. Artefacts in EEG signal in all channels were detected by visual inspection. The recordings containing multiple artefacts were removed, and the recording was repeated.

The dynamics of the EEG energies of the theta, alpha and beta rhythms were analysed. At first, the energies of four basic EEG rhythm frequencies, theta (4-7 Hz), alpha (8-13 Hz), beta1 (15-20Hz) and beta2 (22-40 Hz), were extracted from the total EEG signal (0.5 - 48 Hz) by filtering.

A further analysis follows the method, applied in our previous study [18], except for different comparison intervals. Energies of the different EEG rhythms were analysed separately. Average energies for segments with and without stimulation were compared. The 60 s recording segments with and without stimulation were selected as intervals for comparison. The average energy of an arbitrary comparison interval was calculated for the recording segment as follows:

$$s_i = \frac{1}{N}\sum_{r=1}^{N}[x(r)]^2 \qquad (1)$$

where x is the amplitude of the recorded signal and N is the number of samples, during 60 seconds N=24000. The relative change in the energy of the recording segments with and without stimulation was selected for the further analysis. Finally, parameter S was calculated as follows:

$$S = (\frac{s_2}{s_1} - 1)100\% \qquad (2)$$

where s_1 and s_2 were the average energies inside the comparison intervals without and with stimulation respectively. For sham recordings the same parameter was calculated for comparison intervals as even and odd minutes of the recordings. The parameters S were calculated separately for the EEG energies of the theta (4-7 Hz), alpha (8-13 Hz), beta1 (15-20Hz) and beta2 (22-40 Hz) rhythms.

Signal processing and calculation of parameters were performed in the LabVIEW programming and signal processing environment.

After that, the average values of the parameter *S* for 10 cycles of recordings for the whole group were calculated.

For statistical comparison of sham and exposed recordings the repeated measures of variance (3-D ANOVA) was performed for the group of subjects for each EEG frequency band (theta, alpha, beta1 and beta2). Ten cycles of relative energy calculations were considered as repeated dependent variable. Different EEG channels (8) and microwave exposure conditions (3) were considered as categorical factors. Post-hoc mean comparisons were tested by Bonferroni approach with a 0.05 confidence level. Software package Statistica 6.0 (StatSoft. Inc., Tulsa, USA) was used for the analysis.

Results

Statistical analysis by ANOVA of recordings was performed for each EEG frequency band (theta, alpha, beta1 and beta2). The analysis revealed significant differences between microwave exposure conditions but not between EEG channels. Calculated *p* – values for microwave exposure conditions in different EEG channels are presented in Table 1. Statistically significant results were obtained in channels T3, T4 for alpha rhythm (8 – 13 Hz), FP1, FP2, T3, T4, P3, P4, O1, O2 for beta1 rhythm (15 – 20Hz), T3, T4, O1, O2 for beta2 rhythm (22 – 39Hz). There where no differences between exposure effects at different modulation frequencies in theta rhythm (4 – 8Hz).

Post – hoc analysis by Bonferroni test for microwave exposure conditions was performed for each EEG rhythm. Calculated *p* – values for EEG channels and exposure conditions are presented in Table 2. At modulation frequencies 217 and 1000 Hz statistically significant results were obtained after Bonferroni correction at 217Hz modulation frequency in channels FP1, FP2, T3, T4, P3, P4, O1, O2 for beta2 rhythm, in channels T3, T4 for beta1 rhythm and for 1000Hz modulation frequency in channels O1, O2 for theta rhythm. At modulation frequencies 7, 14, 21Hz statistically significant results were obtained after Bonferroni correction at 14Hz modulation frequency in channels FP1, FP2, T3, T4, P3, P4 for beta1 rhythm.

Modulated microwave radiation caused average increase in total EEG energy for a group in all EEG channels. The strongest effect was produced by different modulation frequencies in temporal region. Therefore the comparison of the effects caused by lower and higher modulation frequencies is provided for T3-T4 channels (see Fig.1).

Table 1: Calculated *p* – values for different EEG rhythms and channels, as a result of analysis by 3 – D ANOVA test for different microwave exposure conditions

EEG rhythm	*p* - values			
	FP1,FP2	T3, T4	P3, P4	O1, O2
Theta	0.096	0.067	0.516	0.273
Alpha	0.653	**0.010**	0.484	0.165
Beta1	**0.011**	**0.009**	**0.030**	**0.004**
Beta2	0.063	**0.044**	0.221	**0.025**

Table 2: Results of post-hoc Bonferroni test analysis for different modulation frequencies and EEG rhythms

EEG rhythm		*p* - values			
		FP1,FP2	T3, T4	P3, P4	O1, O2
Theta	7Hz	0.467	1.000	1.000	1.000
	14Hz	0.979	0.537	0.415	1.000
	21Hz	1.000	0.709	0.800	1.000
	217Hz	1.000	1.000	1.000	1.000
	1000Hz	0.230	0.062	0.308	**0.023**
Alpha	7Hz	1.000	1.000	1.000	1.000
	14Hz	1.000	0.384	1.000	1.000
	21Hz	1.000	0.520	1.000	1.000
	217Hz	0.146	0.068	0.849	0.353
	1000Hz	1.000	1.000	1.000	1.000
Beta1	7Hz	1.000	1.000	1.000	1.000
	14Hz	**0.018**	**0.003**	**0.003**	0.538
	21Hz	1.000	1.000	1.000	1.000
	217Hz	1.000	**0.010**	0.789	0.353
	1000Hz	1.000	1.000	1.000	1.000
Beta2	7Hz	1.000	1.000	1.000	1.000
	14Hz	1.000	1.000	1.000	1.000
	21Hz	1.000	0.078	1.000	1.000
	217Hz	**0.010**	**0.007**	**0.044**	**0.003**
	1000Hz	1.000	0.787	1.000	0.512

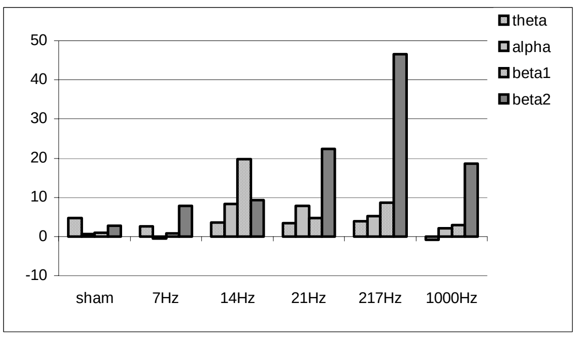

Figure. 1: The average value of the relative changes in the EEG rhythms total energy in T3-T4 channels of the recording segments with and without microwave exposure at different modulation frequencies for the whole group.

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Discussion

The experimental data achieved in this study confirm the hypothesis raised in our previous study, that changes in the EEG rhythms energy, caused by modulated low-level microwave stimulation, are different at different modulation frequencies.

The results demonstrated clear tendency of changes of the EEG rhythms energy between the segments with and without microwave stimulation: these changes became evident at the EEG rhythm frequencies lower than the modulation frequencies and the effect is statistically significant (Fig.1).

This trend was already mentioned in our previous study with 7 Hz, 14 Hz and 21 Hz modulation frequencies, where the highest EEG rhythm affected by microwave was beta1 [21]. The effect was not noticeable at the EEG rhythm frequencies higher than 21 Hz. The current study confirms the hypothesis, that the modulation frequency higher than 21 Hz can affect also beta2 rhythm.

Microwave exposure with modulation frequency 7 Hz does not produce any detectable change in the EEG rhythms energy. In our earlier study we also did not find statistically significant effect but only trend of the changes in EEG where 7 Hz modulation frequency was applied [18]. In this case modulation frequency is too low to cause detectable changes in the EEG alpha rhythms. The EEG theta rhythms are quite constant and less affected by the external stimulation.

The results of both studies show an increase of the EEG energy level related to the microwave stimulation in all EEG rhythms frequencies (except the alpha rhythm level at 7 Hz frequency modulation). The change caused by the stimulation is higher than natural fluctuations in the reference EEG energy level and sham recordings and increases with modulation frequency.

The mechanisms of this effect are not clear. Processes in synapse, operating as a low-pass filter, reported by Galarreta and Hestrin, can cause the phenomenon of stronger influence at lower EEG frequencies [22]. Similar phenomenon can also be caused by parametric excitation of the cortical oscillators: in the case of weak parametric factor the excitation effect is optimal if the excitation frequency is twice higher than the oscillation frequency. In this case the effect is maximal at the EEG frequency twice less than the modulation frequency. Experimental effects, that depend on low frequency modulation of microwave radiation, can also be related to more complicated nonlinear responses in biological tissue and living cells [23].

The ANOVA test revealed a significant effect of the microwave exposure conditions – recordings at different modulation frequencies – in the case of beta1 and beta2 rhythms. There where no differences between exposure effects at different modulation frequencies in theta rhythm. This is in good agreement with our previous studies, where changes in the EEG theta rhythm were less regular than alpha rhythm [18].

The results of post – hoc analysis by Bonferroni test for microwave exposure conditions demonstrate significance between recording data at different modulation frequencies. The findings suggest that the effect of microwave radiation is most evident in temporal region (channels T3, T4) and higher EEG rhythms (beta1 and beta2).

By comparison of the calculated relative changes of the different EEG rhythms energies in channels T3, T4 for exposed and sham recordings (Fig.1) one can conclude that microwave exposure with higher modulation frequencies causes remarkable increase of the EEG beta1 and beta2 rhythms average energy. The exposure with any modulation frequency affects much less alpha and theta rhythms. Theta rhythm is very little affected by the microwave exposure.

Results presented show that in most of the cases microwave exposure causes significant effect when the modulation frequency is higher or comparable to the EEG rhythm.

Results support the idea about frequency dependence of the low-level microwave exposure effect on human brain bioelectrical activity.

Conclusions

Modulated low-level electromagnetic radiation causes statistically significant changes in the EEG rhythms energy at the EEG frequencies lower than the modulation frequency or close to this. The findings allowed us to determine the following tendencies:

- microwave stimulation causes increase of the EEG energy level;
- the effect is most intense at higher modulation frequencies.

The experimental results suggest that the effect of microwave radiation is most evident in

- temporal region (channels T3, T4)
- higher EEG rhythms (beta1 and beta2).

The mechanism of the findings is not clear and the effect needs further investigation.

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