Integration of differences in EEG Analysis Reveals Changes in Human EEG Caused by Microwave

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Abstract: **Three different methods in combination with integration of differences in signals were applied for EEG analysis to distinguish changes in EEG caused by microwave: S-parameter, power spectral density and length distribution of low variability periods. The experiments on the effect of modulated low-level microwaves on human EEG were carried out on four different groups of healthy volunteers exposed to 450 MHz microwave radiation modulated with 7 Hz, 14 Hz, 21 Hz, 40 Hz, 70 Hz, 217 or 1000 Hz frequencies. The field power density at the scalp was 0.16 mW/cm^2. The EEG analysis performed for individuals with three different methods showed that statistically significant changes occur in the EEG rhythms energy and dynamics between 12% and 30% of subjects.**

Keywords: **EMF effects, low-level radiation, EEG rhythm, nonlinear analysis, modulation .**

I. INTRODUCTION

The increasing applications of IT and telecommunication devices in everyday life have aroused a problem of possible interaction effects of the microwave radiation on human brain physiology. Biological effects of electromagnetic field on nervous system have been the subject of intensive investigation for many years [1-4]. Despite extensive research in this field during recent decades the reports of possible effects are often contradictory and the mechanisms behind the effects are still unclear. The difficulties in interpretation of the experimental results cause doubt in these effects.

Most sensitive to external exposure is human nervous system [2]. Therefore, studies on influence of the microwave exposure on human brain bioelectrical activity and behavior are important [3, 4]. As a quantitative measure changes in electroencephalogram (EEG) caused by microwave exposure can be used. Qualitative analysis of the changes in dynamics of the EEG is complicated due to the irregular nature of the EEG signal. It is difficult to detect small variations in the EEG signals on the background of their high natural variability.

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Our previous studies on detection of the effect of microwave radiation on human EEG showed that some traditional methods for EEG analysis such as weighted spectral intensity, bispectrum or fractal dimension, usually successfully applied, did not provide distinction of small changes caused by microwave in EEG [5, 6]. In the case of detection of small changes in stochastic signals the method of modulation with further integration of differences between the segments of signal with and without expected change would be useful. Such approach has been shown to be able to detect significant changes in EEG caused by 7 Hz modulated microwave [7, 8].

This study is focused on detection of the effect of microwave radiation modulated with 7, 14, 21, 40, 70, 217 and 1000 Hz frequencies on human EEG rhythms. The on-off switching of the modulated exposure with further integration of differences between the EEG segments with and without exposure was applied. In this paper we present the results of analysis and conclusions about individual sensitivity to microwave based on EEG analysis. The experimental studies with different modulation frequencies were performed on four groups of subjects.

II. METHODOLOGY

A. Subjects

The experiments with different modulation frequencies were carried out on four different groups of healthy volunteers:
1) 7 Hz modulation frequency, 23 persons (aged 21-24, 12 male and 11 female) [8];
2) 7 Hz, 14 Hz and 21 Hz modulation frequencies, 13 persons (aged 21-30, 4 male and 9 female);
3) 40 Hz and 70 Hz modulation frequencies, 15 persons (aged 21-24, 8 male and 7 female);
4) 217 Hz and 1000 Hz modulation frequencies, 19 persons (aged 21-30): 4 male and 9 female.

All the subjects selected were without any medical or psychiatric disorders and tired or sleepy persons were excluded.

All subjects passed the first experimental protocol (with exposure) and second (sham) once. During each test session, the exposed and sham-exposed subjects were randomly assigned. The computer also randomly assigned the succession of modulation frequencies. The subjects were not informed of their exposure, however, they were aware of the possibility of being exposed. Subjective factors were also excluded from the computer-performed data analysis.

The experiments were conducted with understanding and written consent of each participant. The study was conducted in accordance with the Declaration of Helsinki and has formally approved by the local Medical Research Ethics Committee.

B. Recording Protocol and Equipment

The study included two experimental protocols similar during all experiments. The first protocol was recorded as follows.

First, the reference EEG was recorded during 10 minutes.

Second, microwave radiation, modulated at first modulation frequency, was applied. The duration of the stimulation was 1 minute, and the compensatory pause after the stimulation was also 1 minute. Continuous EEG recordings were performed during as well as 1 minute after the stimulation. The procedure of the cycle was repeated ten times. During ten cycles of the microwave stimulation, the modulation frequency was always the same. This second step was repeated in the same way for other 1 or 2 modulation frequencies according to the considered group of subjects.

The selection of the 7 Hz, 14 Hz or 21 Hz; 40 Hz or 70 Hz; 217 Hz or 1000 Hz as first, second or third modulation frequency was randomly assigned.

The second protocol (sham) included the same steps, except that the microwave generator was switched off.

The Cadwell Easy II EEG measurement equipment was used for the EEG recordings. The EEG was recorded using 9 electrodes, which were placed on the subject's head according to the international 10-20-electrode position classification system. The channels for analysis were chosen to cover the entire head: frontal FP1, FP2; temporal T3, T4; parietal P5, P4; occipital O1, O2; and the reference electrode Cz. The EEG recordings were stored on a computer with a 400 Hz sampling frequency.

C. Data analyses

Initially, all the EEG recordings were divided into two sub-signals:
- the first sub-signal contained all 1-minute periods without microwave exposure,
- the second sub-signal contained all minutes with microwave exposure.

EEG signals for segments with and without stimulation were compared using three different methods. According to S-parameter method the relative changes of the EEG rhythms energy were compared and the parameter S was calculated as

$$S=(s_1/s_2-1)\, x100\,\%,$$

where s_1 and s_2 were the average energies inside the comparison intervals with and without exposure respectively [7]. In the case of power of spectral density (PSD) analysis the difference of two sub-signals with and without exposure was also selected as the PSD measure for further analysis

[8]. A new method for EEG analysis - scaling analysis of length distribution of low variability periods (LDLVP) has common roots with the multifractal analysis of time-series and yields somewhat better temporal resolution than the traditional multifractal analysis. The local variability was defined as the deviation of the current value of the signal from the local average. Low-variability periods were defined as continuous intervals with variability within the predicted deviation limits. The number of low-variability periods N exceeding length T_o was plotted against T_o [9].

The dynamics of the EEG energies of the theta, alpha and beta rhythms were analyzed using S-parameter and PSD methods. 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. Total EEG signal was analysed by the LDLVP method. As one of the modulating frequencies belonged to the region under investigation (7 Hz), it was removed by a special narrow band (0.2 Hz) filter.

For statistical comparison the repeated measures of variance (3-D ANOVA) was performed for subjects with post-hoc Bonferroni test by approach with a 0.05 confidence level.

D. Microwave exposure

Microwave exposure conditions were the same for all subjects in all groups, except modulation frequencies. The 450 MHz microwave radiation was 100% amplitude modulated by the pulse modulator at 7, 14, 21, 40, 70, 217 or 1000 Hz frequency (duty cycle 50%). The 1 W output power was guided by a coaxial cable to the 13 cm quarter wave antenna, located 10 cm from the left side of the head. The field power density at the skin, estimated by the measured calibration curves, was 0.16 mW/cm^2, SAR was about 0.35 W/kg [5].
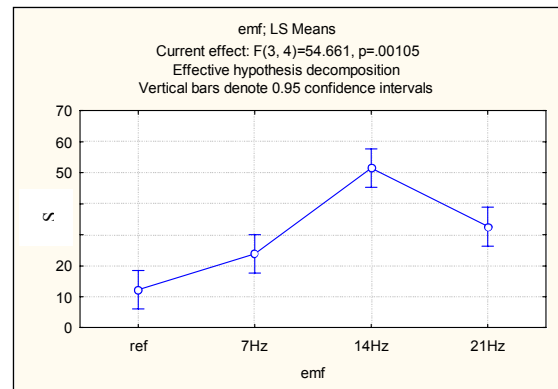

Fig.1. Relative changes (S parameter) in beta1 rhythm in P-channels for a subject; p= 0.127 for 7 Hz, p=0.001 for 14 Hz, p=0.015 for 21 Hz.

III. Results

Calculated by S-parameter method relative significant change in EEG beta1 rhythm energy in parietal channels for a subject at three different modulation frequencies is presented in Fig.1. The effect is most intense at higher modulation frequencies 14 Hz and 21 Hz, close or higher than beta1 band 15-20 Hz. In these recordings the EEG beta2 rhythm was affected in majority only by 21 Hz modulation frequency. Modulation frequency 7 Hz is lower than beta1 band and does not affect the EEG inside this band.
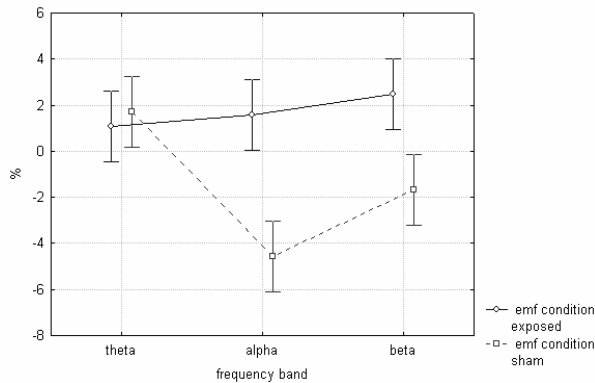

Fig. 2. Relative changes of intensity in T-channels (modulation frequency 217 Hz) between exposed and non-exposed segments of the EEG signals on main EEG rhythms for a subject. Vertical bars denote 0.95 confidence intervals.
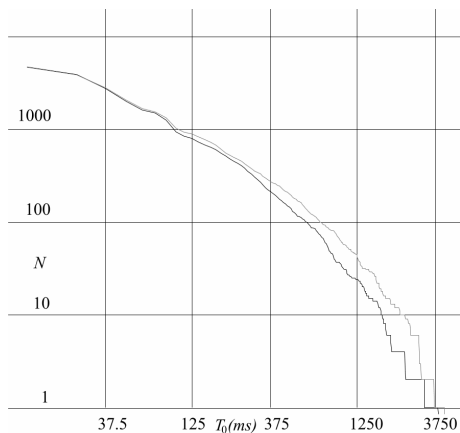

Fig. 3. The number of low-variability periods N exceeding the length T_0 for a significant subject: black line - intervals with microwave; gray line - intervals without microwave exposure in T-channels, 217 Hz modulation frequency.

The EEG characteristics calculated by PSD and LDLVP methods for a subject with significant changes in EEG caused by 217 Hz modulated microwave field are presented in Fig. 2 and Fig. 3. These graphs demonstrate general tendencies in majority of performed experiments: microwave stimulation causes an increase in the EEG energy level and its temporal variability.

As an example, the results of statistical analysis of the LDLVP quantitative measures for sham and microwave-exposed at modulation frequency 40 and 70 Hz recordings, calculated for each subject, are presented in Table 1. The ratio of the computed power difference to the standard deviation of differences $\sqrt{x}$ of more than three, and p values not larger than 0.001 were considered as significant deviations from the zero hypothesis and are marked bold. Changes that were statistically significant after Bonferroni correction were marked with *.

TABLE 1.
THE RESULTS OF STATISTICAL ANALYSIS OF THE LDLVP MEASURE FOR 40 Hz AND 70 Hz MODULATION FREQUENCIES: RATIO OF THE COMPUTED POWER DIFFERENCE TO THE STANDARD DEVIATION OF DIFFERENCES SQRT(X) IN T CHANNELS

Frequency band	sqrt(x)		
	0.5 - 39 Hz		
Subject nr.	Sham	40Hz	70Hz
1	-0.39	-2.00	-0.39
2	-0.69	-0.47	-2.12
3	-0.69	1.49	-1.25
4	1.11	0.13	0.90
5	0.31	-2.57	0.94
6	0.82	**3.57***	-0.96
7	0.84	0.25	0.89
8	0.84	-0.87	0.00
9	-0.31	**3.19**	-0.88
10	2.85	-0.72	0.63
11	-0.11	-0.03	0.34
12	-0.70	-0.57	**-3.01**
13	0.44	-2.37	0.30
14	1.10	**-6.24***	0.13
15	0.61	0.90	**-3.68***

Statistically significant changes in the EEG energy level and dynamics were revealed in all experiments at different modulation frequencies and groups of subjects. The changes occurred in different EEG channels and rhythms. The summary of experimental results is presented in Table 2. The channels and rhythms with maximal numbers of the affected subjects are shown.

The changes in different EEG rhythms were different. Theta rhythm was least affected – there were no unidirectional significant changes. Major increase in EEG rhythm energy was observed in alpha rhythm. Most sensitive to the exposure was the EEG beta rhythm – the number of subjects with significant changes was the highest.

Table 2.
Number of subjects with significant changes in the EEG energy or variations

Modul Ation frequen Cy Hz	Number of subjects	EEG channel and rhythm	Method of EEG analysis	Subjects affected
7	20	F, beta	S-parameter	3 - 15%
7	23	F	LDLVP	6 - 26%
14, 21	13	P, beta	S-parameter	4 - 30%
40	15	T, beta	S-parameter	3 - 20%
		T, beta	PSD	3 - 20%
		P	LDLVP	4 – 26%
70	15	T, beta	S-parameter	2 - 12,5%
		T, beta	PSD	1 – 7%
		T	LDLVP	1 – 7%
217	19	T, beta	S-parameter	3 – 16%
		T, beta	PSD	3 – 16%
		T	LDLVP	5 - 26%
1000	19	T, beta	S-parameter	4´- 21%
		T, beta	PSD	3 – 16%
		T	LDLVP	0

Major changes were revealed in tempora-parietal brain region. Little effect was noticed in frontal channels at lower modulation frequencies, while no effect was detected in occipital region.

Statistically significant changes in the EEG rhythms took place at the modulation frequencies higher or close to the EEG rhythm frequency.

V. Discussion

The principle of integration of differences provides distinction of small differences in the EEG signal not related to any known change in the shape of the signal in the case of all three applied measures, S-parameter, PSD and LDLVP.

All three methods applied for EEG analysis showed clearly that the EEG of a part of subjects is affected by modulated 450 MHz microwave exposure. The rate of sensitivity to microwave depends on modulation frequency and is higher at frequencies higher or close to the brain physiological frequencies.

The rate of multiple chemical sensitivity (exposures to multiple chemically unrelated compounds at doses far below those established to cause harmful effects occurrence) is estimated to be between 2 and 10 % in the general population [10]. This is even lower than sensitivity to microwave between 12 and 30%.

Main trend of changes for all modulation frequencies was increase of the EEG energy in beta rhythm. Increased beta absolute power was also observed in alcohol-dependent subjects [11].

V. Conclusion

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 and higher EEG rhythms (beta1 and beta2).

Statistically significant changes were revealed in the EEG rhythms energy and dynamics for 12-30% of subjects investigated.

Our results suggest that the microwave exposure causes significant changes in human EEG, affects more part of population than chemically unrelated compounds and can have an impact on health. The mechanism of the findings is not clear and the effects need further investigation.

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