Effect of Modulated 450 MHz Microwave on Human EEG Rhythms and Cognitive Processes

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Introduction

Effects of microwave radiation on human brain bioelectrical activity have become of major interest with increasing applications of telecommunication devices.

The difficulties in independent replication of the experimental results cause doubts in these effects and mechanisms behind the effects are still unclear.

There are different reasons for difficulties in identification and doubts in microwave effects on EEG and cognitive processes.

In this talk I present main results of our studies on resting EEG and visual memory and information processing.

Introduction: reasons for doubts in MW effects on brain

- Microwave exposure as a weak physical stressor causes only small changes in the EEG and the effect is hidden in natural variability of the EEG signal.
- Effect of microwave exposure differs for individuals, some of the subjects under investigation may be significantly affected and the others not affected.
- Ability of the brain to adapt physiologicaly to an external stressor decreases or even compensates the effect.
- Variations in microwave power density inside the brain tissues can cause differences in the effects.
- Instability of the physiological state of the brain.

Aims of our studies

- To select and develop methods sensitive to reveal small hidden changes in the EEG signal.
- To evaluate the effect of a microwave modulated at certain fixed frequencies on human EEG.
- To take into account individual sensitivity and perform statistical analysis for individuals.
- To evaluate phenomena of brain physiological adaptation to microwave exposure.
- To investigate changes in the effect at different level of microwave power.
- To evaluate changes in human performance in visual memory tasks and processing of visual information.

Methods: subjects

- 1-st group, 23 persons (aged 21-24), 12 male and 11 female, modulation 7 Hz;
- 2-nd group, 13 persons (aged 21-30), 4 male and 9 female, modulation 7, 14 and 21Hz;
- 3-rd group, 15 persons (aged 21-24), 8 male and 7 female, modulation 40 and 70 Hz;
- 4-th group, 19 persons (aged 21-24), 8 male and 11 female, modulation 217 and 1000Hz;
- 5-th group, 7 persons (aged 19-21), 3 male 4 female, modulation 40 Hz, 10 W;
- Visual memory tasks 100 persons (aged 18-25), 63 male and 37 female, modulation 7 Hz;
- Method of face masking 10 persons (aged 19-32), 4 male and 6 female, modulation 7 Hz.

Methods: microwave exposure

- 450 MHz microwave radiation, 1 W output power (10 W for one recording protocol)
- 100% amplitude modulated at 7, 14, 21, 40, 70, 217 or 1000 Hz frequency (duty cycle 50%, stability of average energy)
- rod antenna located at a distance of 10 cm from left side of the head
- the spatial distribution of the power density was measured by the Fieldmeter C.A 43 Chauvin Arnoux (Paris, France) field strength meter
- field power density at the skin 0.16 mW/cm^2 (1.6 mW/cm^2 for one recording protocol)
- calculated average SAR 0.35 W/kg, 1 g peak SAR 1.17 W/kg.

Methods: EEG recordings

- resting eyes closed EEG
- Cadwell Easy II EEG
- international classification system of 10-20-electrode position
- 19 electrodes, EEG channels

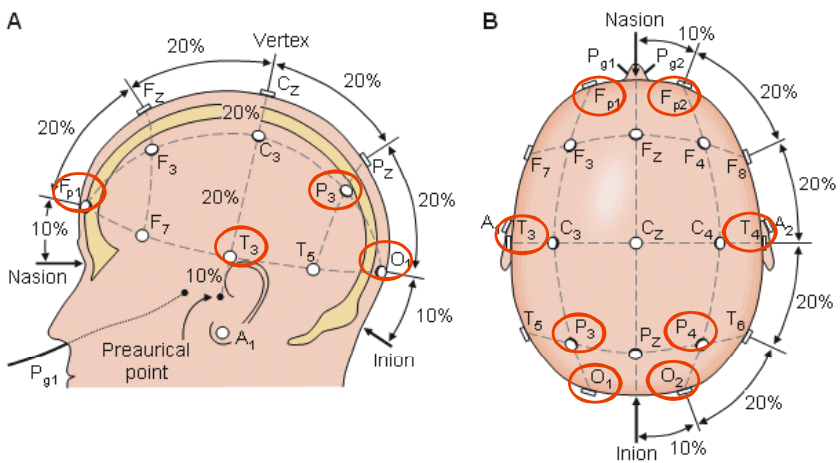
  frontal FP1, FP2,

  temporal T3, T4,

  parietal P3, P4,

  occipital O1, O2

  reference Cz

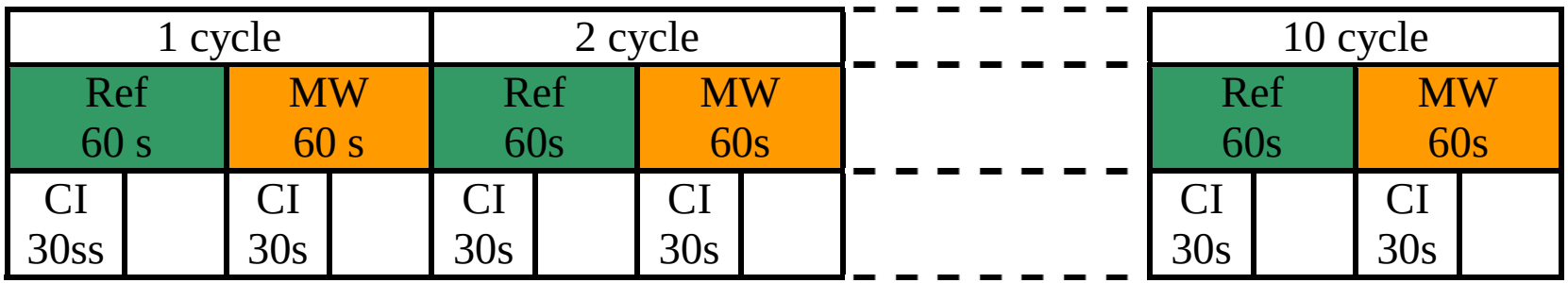


- sampling frequency 400 Hz.

Methods: EEG preprocessing

- The signals bands of four basic EEG rhythm for analysis were extracted from the total EEG signal (0.5 – 48 Hz) by filtering:
  theta (4 – 6.8 Hz),
  alpha (8 – 13 Hz),
  beta1 (15 – 20 Hz),
  beta2 (22 – 38 Hz).
- The instrumentation was validated before the experiments: recordings were conducted with an EEG cap placed on a passive phantom. Spectral components were detected at the modulation frequencies and their third harmonics (-30 dB) in some of the channels.
- Artifacts were removed from the EEG signals by off-line filtering during the pre-processing of the signals. The elliptic bandstop filters at 7, 14, 21 Hz with at least 50 dB attenuation in the stopband were used.
- Preprocessing was performed in the LabVIEW programming and signal-processing environment.

Methods: EEG recording protocol



10 cycles of modulated at fixed low frequency microwave were applied.

Methods: complexity of the EEG

Microwave exposure as a weak physical stressor causes only small changes in the EEG. and the effect is hidden in natural variability of the EEG signal.

Qualitative analysis of the changes in dynamics of the EEG is complicated due to the irregular nature of the EEG signal.

Our attempts on detection of the effect of microwave radiation on human EEG showed that some traditional methods of the EEG analysis such as quantitative EEG, bispectrum or fractal dimension, did not provide reliable distinction of microwave effect.

Methods: EEG analysis

Two original methods sensitive to reveal small hidden changes in the EEG signal were developed and proved most effective.

The method of **integration of differences (ID)** uses modulation with further integration of energy of the recorded signal of the EEG segments with and without stressor.

(Hinrikus et al. *Nonlinear Biomedical Physics* 2007, 1:9 28 July 2007)

Multifractal method of scaling analysis based on the **length distribution of low variability periods (LDLVP)** was developed and adopted for EEG analysis. The LDLVP method provides a simple route to detecting the multifractal characteristics of a time-series and yields better temporal resolution than the traditional multifractal analysis.

(Bachmann et al, *Medical & Biological Engineering & Computing*. 43, 142-149, 2005)

Analysis of the EEG based on the ID

The method of integration of differences consists of several steps.

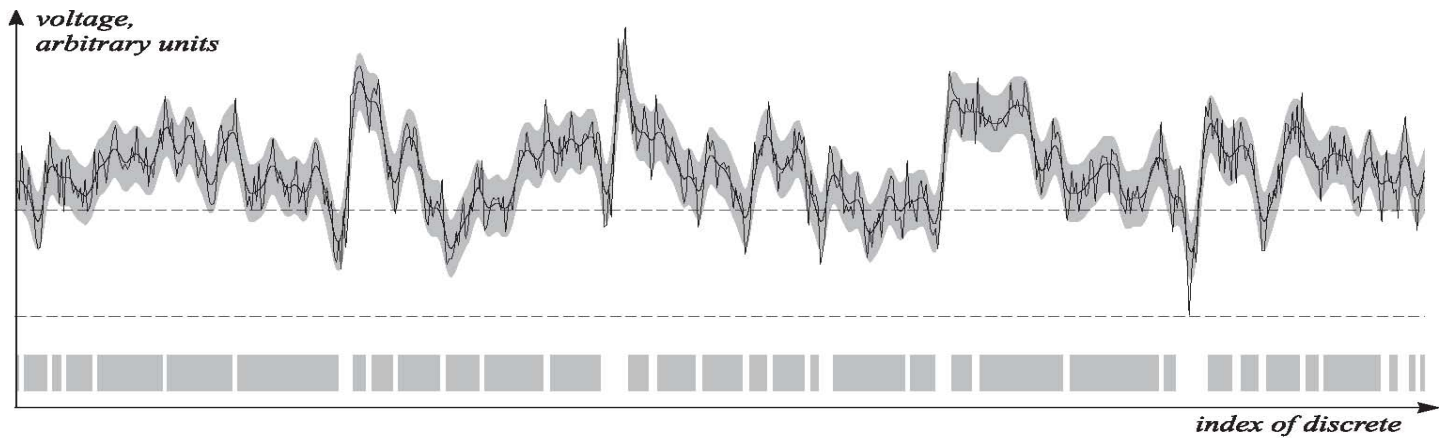
- Firstly, the average energy of the signal inside a selected comparison segment in a time-window T was calculated
- Secondly, relative differences in the average energies for every cycle was calculated as

$$S_f = \left(\frac{s_{2f} - s_{1f}}{s_{1f}} \right) \times 100\%$$

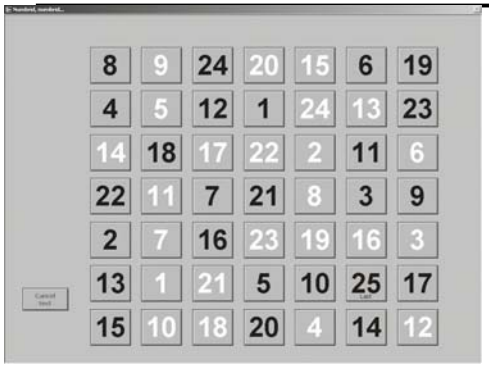
where s_{1f} and s_{2f} are the average energies in a comparison segment without and with exposure respectively

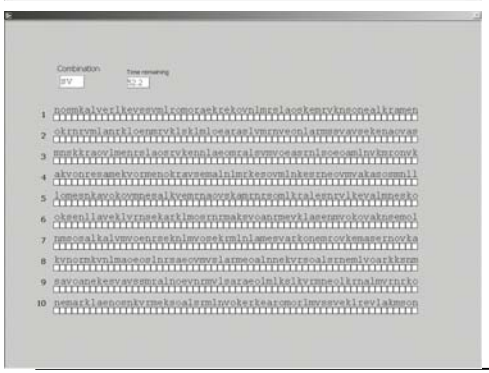
- Integration of the differences over ten cycles of exposure for a subject n is applied and characteristic parameter S_n was calculated

Analysis of the EEG based on the LDLVP method



- Firstly, we define the local average of the signal in time-window T
- Secondly, we define the local variability as the deviation of the current value of the signal from the local average $\delta V(t)$.
- Thirdly, the low-variability periods are defined as continuous intervals with $\delta V(t) < \delta_0$
- Finally, the number of low-variability periods N exceeding the length T_0 is plotted versus the length T_0
- The weighted area under the curve of the function $T_0 = T_0(N)$ was selected as the non-linear quantitative measure





Methods: visual memory task

Tests to measure attention and short-term memory:

Task 1 involved alternately selecting black digits from 1 to 25 in ascending and white digits from 24 to 1 in descending order. The time spent on the task and the number of errors were analysed.

Task 2 involved viewing a picture of 12 objects during 3 seconds, followed by a list of 24 words. The subjects were required to select words representing previously presented objects.

Task 3 presented an array of letters in 10 rows, the subject was required to identify all examples of a particular two-letter combination.

Methods: face masking

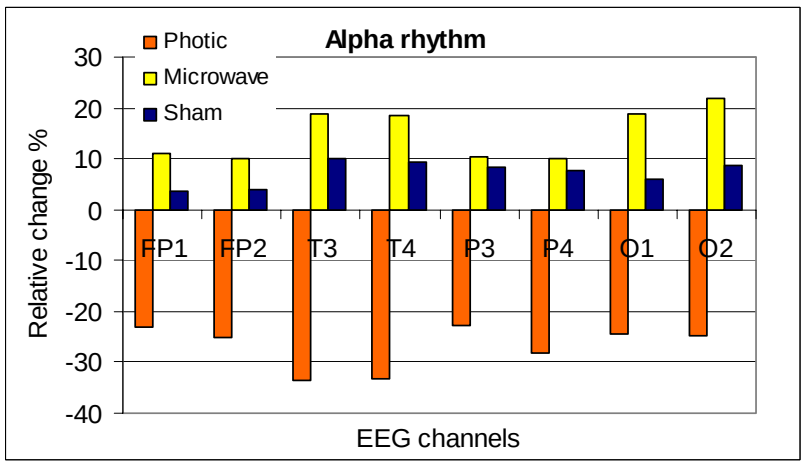
Subjects were presented two photos of a male face one after another (40 and 20 ms) at exactly the same place of the PC display.

Then they were asked to identify the pictures from a group of six photos.

Duration of a trial set (50 trials) 5 minutes; interval between the sets 15 minutes. Each subject made 800 trials in 8 sessions at microwave and sham exposure. Correct and incorrect answers were analysed.

Results: resting EEG, 7 Hz modulation

Comparison of short-term photic and ten cycles of the MW stimulation



Photic and microwave exposure did not cause statistically significant changes in the EEG activity level for the group.

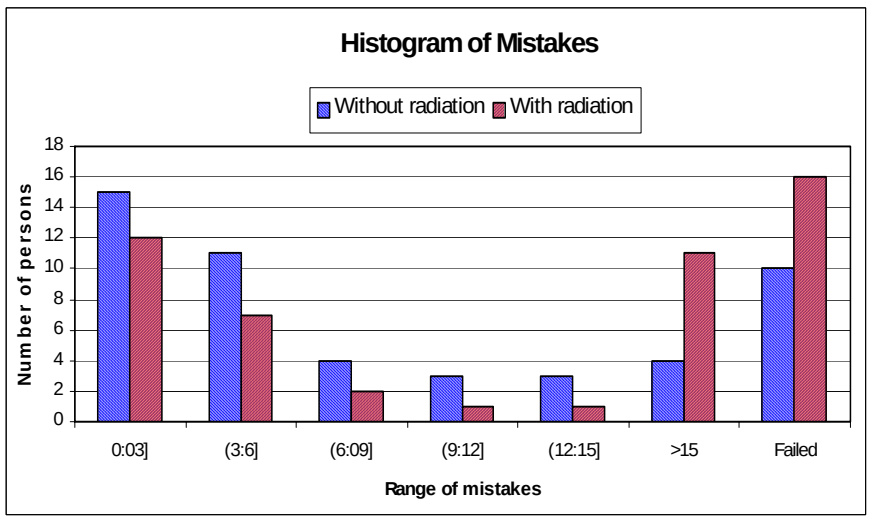
In our earlier studies we mentioned statistically significant difference not between average parameters calculated for exposed and sham exposed groups but between standard deviations of the parameters: exposure caused increase in standard deviation for the groups.

The increased by exposure variability between individuals showed that the effect should differ for individuals.

Hinrikus et al., *Bioelectromagnetics*, 2004, 25: 431-440.

Results: visual memory tasks and information processing, 7 Hz modulation

Visual memory task 1



No significant changes occurred in the means between the groups but the variances of errors differ significantly.

Lass et al., *Int. J. of Radiation Biology*, 2002, 78: 937-944

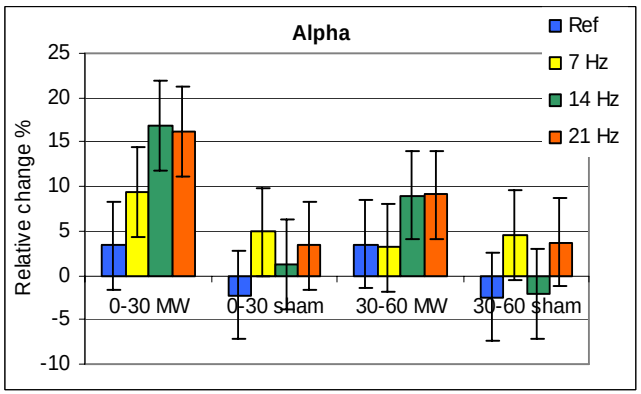
Face masking

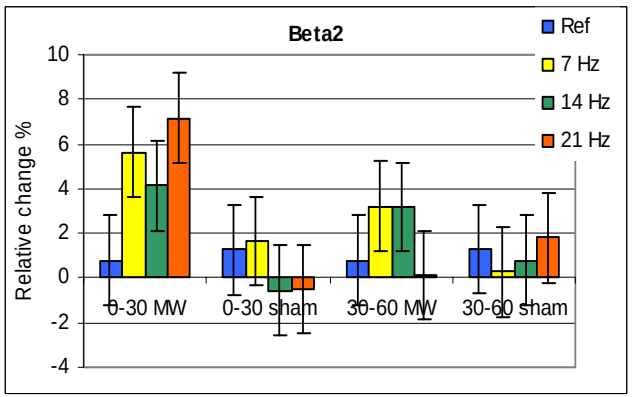
The responses were analysed regarding the correct identification of the faces and the order of their presentation.

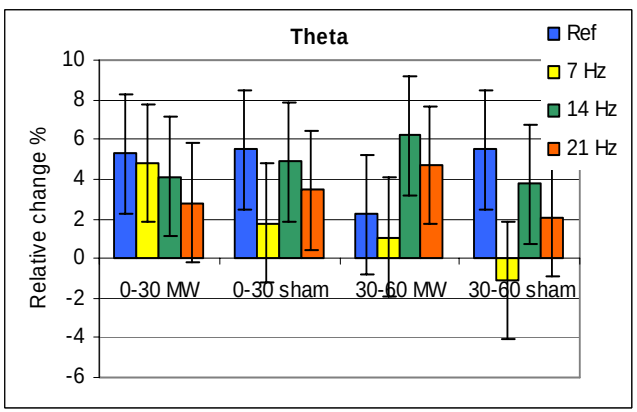
Recognition of both stimuli in a pair was better ($p<0.05$) under the sham exposure conditions but the actual difference was only 5%.

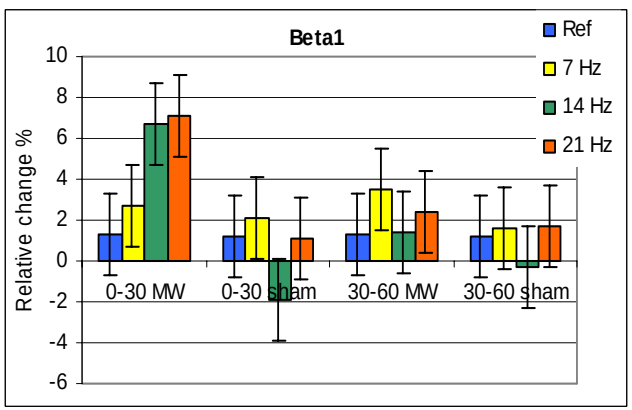
Rodina et al., *Bioelectromagnetics, 2005, 26: 571-577.*

Results: modulation 7, 14, 21 Hz, ID method









Average relative changes caused by modulated at 7, 14 and 21Hz MW in the EEG theta, alpha, beta1 and beta2 power.

Hinrikus et al. *Int. J. of Radiation Biology*, January 2008

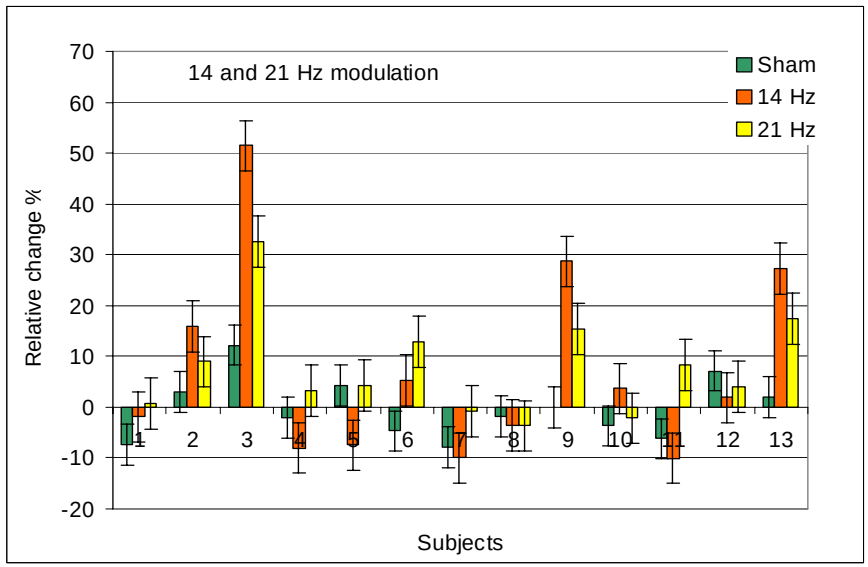
Results: ID method

- The microwave exposure caused significant **enhancement of the EEG power in the alpha and beta** frequencies. Changes in the alpha power were about twice higher than in the beta power.
- **The effect of the microwave modulated at fixed low frequency differs at different modulation frequencies.** Therefore the origin of the effect should be different from average heating.
- The changes were more obvious at the beginning of the exposure segments.

Results: individual sensitivity, ID method

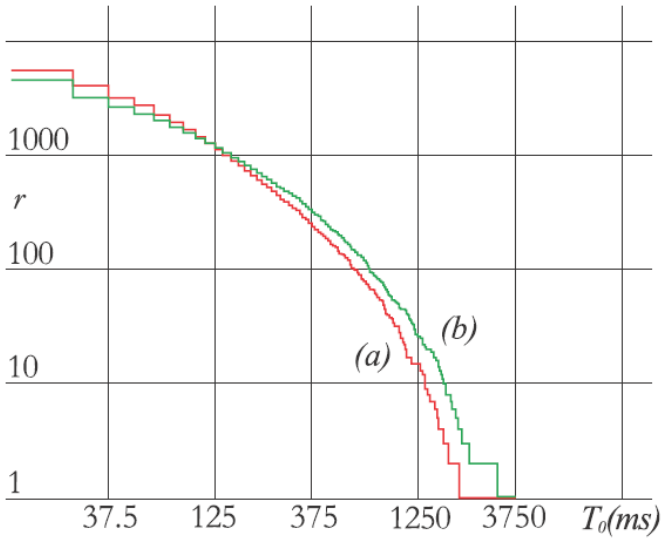
Number of subjects with statistically significant changes (p<0.05) in EEG:

Mod.Hz (total sub)	No of aff. subjects	Rate of aff. sub.
7 (23)	3	13%
14 (13)	4	31%
21 (13)	3	23%
40 (15)	3	20%
70 (15)	2	13%
217 (19)	3	16%
1000(19)	0	0%



Hinrikus et al. , *Int. J. Radiat. Biology*, 2008, Jan.
Bachmann et al., *The Environmentalist*, 2007, DOI: 10.1007/s10669-007-9069-9.

Results: individual sensitivity, LDLVP method



The number of low-variability periods N exceeding the length T_0 for a significant subject:
(a) – intervals with microwave;
(b) – intervals without microwave

Number of subjects with statistically significant changes (p<0.05) in EEG:

Mod.Hz (total sub)	No of aff. subjects	Rate of aff. sub.
7 (23)	6	26 %
40 (15)	4	27%
70 (15)	2	13%
217 (19)	5	26%
1000 (19)	0	0

Bachmann et al, *Medical & Biological Engineering & Computing*. 43, 142-149, 2005
Bachmann et al., *The Environmentalist*, 25, 165-171, 2005.
Hinrikus et al., *Nonlinear Biomedical Physics*, 1:9, July 2007

Discussion: individual sensitivity

Sensitivity of some subjects to exposure is most likely related not to hypersensitivity of these individuals but to variability of the physiological state of the brain.

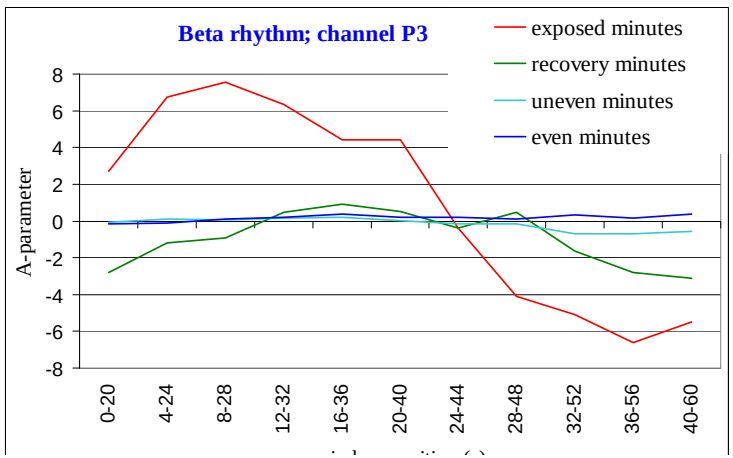
Human brain is highly complicated chaotic system and affected simultaneously by hundreds of physical, chemical, psychological etc. stressors. Microwave exposure is one of these stressors. Effect of microwave exposure as a weak stressor depends on combination of the other stressors and state of the brain.

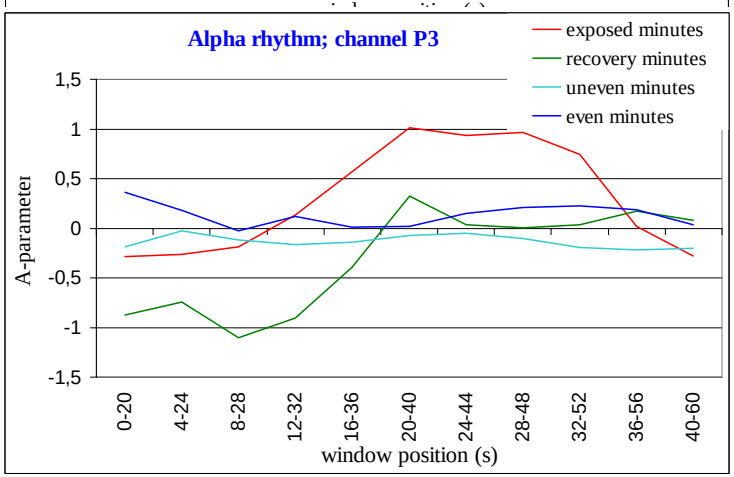
The effect of exposure varies in different days and conditions. Similar situation takes place in the case of the effects caused by alcohol.

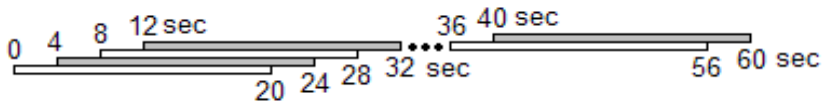
Replicability of the effect becomes complicated due to variability of many coexisting factors.

The rate of subjects affected during one experimental session depends on the physiological states of their brains at this time.

Results: adaptation, 40 Hz modulation







Sliding window 20 sec

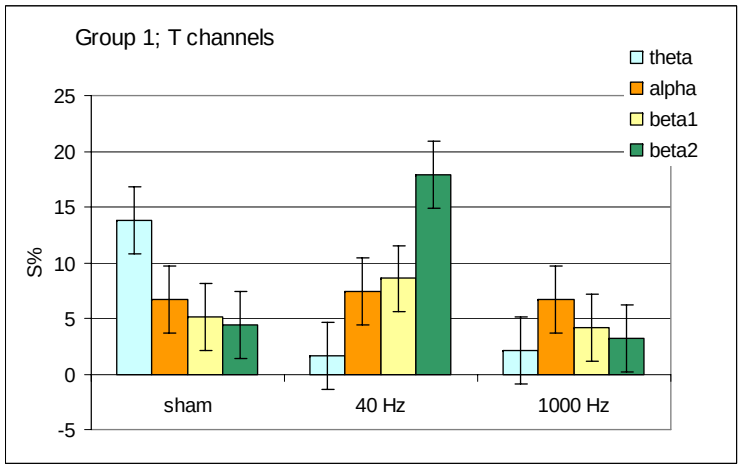
$$A_j = \frac{e_2 - e_1}{e_1} \times 100\%$$

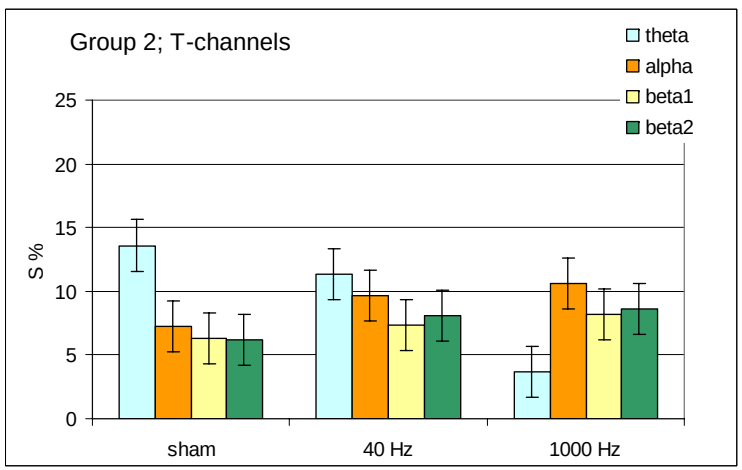
A_j – relative change in average power
e_1 – AP of reference segment (first 20 sec of recordings)
e_2 – AP of even or uneven segments

n=14 7m, 7f	Change MW	Change sham	*p*
alpha	0.71	0.27	0.0026
beta	4.48	0.38	0.0004

Rubljova et al., *Proceedings of the 29th Annual Conference IEEE EMBS*, Lyon, Aug. 23-26, 2007

Results: higher power





Number of subjects with significant changes

n=7 3m, 4f	sham	40 Hz	rate
1 W	0	2	28%
10 W	0	1	14%

The results suggest that the effect caused by modulated microwave does not have a linear dependence on the level of applied radiation power.

Tomson et al., *IFMBE Proceedings*, v.16, pp. 210-213, Medicon, Ljubljana, June 26-30, 2007.

Conclusions

- The results show that ID and LDLVP methods can detect small changes in the EEG signals caused by MW exposure.
- MW exposure causes most remarkable increase in the EEG alpha power (reported also in other studies) and less increase in the beta power (as characteristic for alcohol).
- The effect differs at different modulation frequencies and has nonthermal origin.
- Sensitivity to MW esposure differs for individuals, the rate of subjects significantly affected was 13-30%.
- The changes in human performance in visual memory tasks and visual information processing were small but statistically significant.
- The physiological adaptation of the brain compensates and even overcompensates the effect of MW exposure.
- Our preliminary results suggest, that MW effect is not linearly related to the applied MW power.

Our team

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R. Tomson, H. Hinrikus, M. Bachmann, J. Lass, and V. Tuulik. Effect of Modulated 450 MHz Microwave on HumanEEG at Different Field Power Densities, *IFMBE Proceedings*, v.16, pp. 210-213. 11th Mediterranean Conference on Medical and Biological Engineering and Computing, Ljubljana, 26-30, June, 2007.