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Effect of modulated microwave radiation on human resting electroencephalographic signal

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree.

Maie Bachmann

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MAIE BACHMANN

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INTRODUCTION

Effects of microwave radiation on human brain bioelectrical activity have become of major interest along with increasing uses of telecommunication devices. The effects caused by microwave radiation are investigated either in vitro, in vivo or epidemiologically. While in vitro studies provide information and knowledge about the mechanisms of action, the results are difficult to be interpreted on the living organism as experimental conditions have fewer variables than inside the living organism. On the other hand, epidemiological studies intended for the population are very fragile because of different cofactors acting, which have not been thoroughly considered. In vivo studies are in-between, providing results on the effects in a living organism.

Today's microwave source closest to human organism is a mobile phone, which is usually positioned close to the ear during active transmission. In addition, human nervous system is also the most sensitive to electromagnetic field (EMF) exposure (Baranski and Edelwejn, 1975). Therefore, it is the human brain that has attracted prime attention in different research programs that focus on the effects of microwave radiation (Hamblin and Wood 2002; D'Andrea *et al.*, 2003; Cook *et al.*, 2006; Valentini *et al.*, 2007).

The well-known thermal effect of a high-frequency EMF — heating caused by absorption of the EMF in human tissues — was discovered by d'Arsonval in 1892. Absorbed in tissues, microwave energy produces heat and the temperature rises if the thermoregulatory mechanisms are unable to overwhelm heating. ANSI/IEEE regulation and health protection guidelines are based on heat generation by the radio-frequency power and the specific absorption rate (SAR) of the power in tissues is selected as a main criterion for health hazard. The potential health hazard occurs at high radiation power levels when SAR > 4 W/kg (IEEE C95.1, 2005).

Microwave heating (temperature rise about 1K) is known to affect memory and learning ability (Saunders *et al.*, 1991; Adair *et al.*, 1999; Adair *et al.*, 2001). An increase of 1 K in colonic temperature, produced by radio frequency exposure, causes changes in performance and would almost certainly disrupt ongoing learned behaviour (Mitchell *et al.*, 1977; De Lorge and Ezell, 1980). As the frequency of microwave radiation is much higher than physiological frequencies, the thermal effect, as the only possible, has been accepted at microwaves. No other adequate possible interaction mechanisms with the nervous system have been proposed.

During recent decades, discussions have focused on the effects of low-level (SAR<4 W/kg) microwave radiation on the human brain. Several investigators have reported that exposure to a low-level microwave produces alterations in the resting or sleep EEG signal and/or brain behaviour (Mann and Roschke, 1996; Borbely *et al.*, 1999; Huber *et al.*, 2000; Krause *et al.*, 2000a; Lass *et al.*, 2002; Curcio *et al.*, 2005; Huber *et al.*, 2002; Hinrikus *et al.*, 2005). Pulse-modulated microwave exposure enhances the EEG power in the alpha frequency range (Curcio *et al.*, 2005; Huber *et al.*, 2002). Exposure to a microwave without pulse modulation has been found not to enhance power in the waking or sleep EEG

(Huber *et al.*, 2002). The exposure to a microwave modulates the responses of the EEG oscillatory activity in the 6-8 and 8-10 Hz frequency bands, specifically during cognitive processes (Krause *et al.*, 2000b). However, some authors were unable to confirm their previous findings in their later studies (Krause *et al.*, 2004; Wagner *et al.*, 1998). The conclusion reported by other researchers is that the exposure to microwave does not alter the resting EEG (Hietanen *et al.*, 2000; Krause *et al.*, 2000). One recent study suggests that microwaves emitted by a mobile phone have an effect on brain oscillatory responses during cognitive processing in children (Krause *et al.*, 2006). Authors of other studies have demonstrated that exposure to a pulse-modulated microwave alters not only the EEG but also the regional cerebral blood flow (Huber *et al.*, 2002, Huber *et al.*, 2005). The studies of the microwave effects on the permeability of the blood-brain barrier (BBB) have shown that a microwave can open up the BBB for albumin passage (Salford *et al.,* 1994). The results of this group were obtained at the field power densities much lower than the thermal limit. On the other hand, several authors have declared no microwave effects on the BBB (Cosquer *et al.*, 2005; Kuribayashi *et al.,* 2005; Finnie *et al.* 2006a, 2006b).

Difficulties experienced in independent repetition of experimental findings have caused doubts concerning these effects; moreover, mechanisms behind the effects are still unclear.

The aim of this work was to detect characteristic changes caused by modulated low-level microwave radiation (450 MHz) in the human resting EEG. The changes in the EEG were evaluated at different modulation frequencies. The effect on groups and individual subjects was evaluated. In addition, the possible brain physiological adaptation to microwave exposure was investigated.

This thesis is a summary of the author's work at the Department of Biomedical Engineering of the Technomedicum of Tallinn University of Technology. The thesis consists of publications and an overview. The thesis presents the results of the study of the effects of low-level modulated microwave radiation on human brain bioelectrical activity based on the EEG signal analysis. The overview consists of a review of the current status of the research problem and the main results presented in the author's publications.

The present thesis is based on the following papers that are referred to in the text by their Roman numerals I-VII.

I Hinrikus, H., **Parts (Bachmann), M.,** Lass, J., Tuulik, V. (2004). Changes in human EEG caused by low level modulated microwave stimulation. *Bioelectromagnetics*, 25(6):431-40.

II **Bachmann, M.,** Kalda, J., Lass, J., Tuulik, V., Säkki, M., Hinrikus, H. (2005). Non-linear analysis of the electroencephalogram for detecting effects of low-level electromagnetic fields. *Med Biol Eng Comput*, 43(1):142-9.

III Hinrikus, H., **Bachmann, M.,** Lass, J., Tomson, R., Tuulik, V. (2008). Effect of 7, 14 and 21 Hz modulated 450 MHz microwave radiation on human electroencephalographic rhythms. *Int J Radiat Biol*, 84(1):69-79.

IV Hinrikus, H., **Bachmann, M.,** Kalda, J., Säkki, M., Lass, J., Tomson, R. (2007). Methods of electroencephalographic signal analysis for detection of small hidden changes. *Nonlinear Biomedical Physics,* 1:9

V **Bachmann, M.**, Säkki, M., Kalda, J., Lass, J., Tuulik, V., Hinrikus, H. (2005). Effect of 450 MHz Microwave Modulated with 217 Hz on Human EEG in Rest. *The Environmentalist*, 25:165–171.

VI **Bachmann, M.,** Lass, J., Kalda, J., Säkki, M., Tomson, R., Tuulik, V., Hinrikus, H. (2006). Integration of differences in EEG analysis reveals changes in human EEG caused by microwave, Proceedings of the 28th IEEE EMBS Annual International Conference: IEEE, pp. 1597-1600, New York City, USA, 30 August – 3 September 2006.

VII **Bachmann, M.,** Rubljova, J., Lass, J., Tomson, R., Tuulik, V., Hinrikus, H. (2007). Adaptation of human brain bioelectrical activity to low-level microwave, Conf Proc IEEE Eng Med Biol Soc, pp. 4747-4750, Lyon, France, 23-26 August 2007.

Approbation

4th BSI International Workshop, IEEE EMBS Biosignals Interpretation International Workshop, Como, Italy, June 24-26, 2002.
2nd International Workshop on Biological Effects of Electromagnetic Fields, Rhodes, Greece, October 7-11, 2002
25th Annual International Conference of the IEEE, Cancun, Mexico, September 17-21, 2003
3rd International Workshop Biological Effects of EMFs, Kos, Greece, October 4-8, 2004
COST Action B27, Electrical Neuronal Oscillations and Cognition – ENOC, Swansea Meeting, September 16-18, 2006
COST Action B27, Electrical Neuronal Oscillations and Cognition – ENOC, Florence Meeting, March 26-28, 2007

Author's own contribution

In all the publications the author participated in the EEG recordings, performed a substantial portion of the processing and the EEG signal analysis, except the measurement and calculation of the electromagnetic field parameters and the EEG signal analysis using the LDLVP method.

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1. EFFECTS OF LOW-LEVEL MICROWAVE RADIATION ON HUMAN BRAIN: STATE OF THE ART

1.1 Resting EEG studies

Changes in the EEG caused by microwave exposure can be used as a quantitative measure for the estimation of the microwave effect. However, qualitative analysis of the changes in the 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. Therefore, the question of whether a feasible effect of low-level radiation on the brain's bio-electric activity exists, is still open.

Röschke and Mann (1997) investigated the influence of digital mobile radio telephone on the awake closed eyes EEG. 34 male subjects were exposed to 900 MHz microwave (modulation frequency 217 Hz, pulse width of 0.580 ms, average power density 0.05 mW/cm^2) for about 3.5 minutes or sham exposed. It was found that the exposure to an active digital mobile radio telephone does not cause any significant differences in the spectral power density measures, as compared to an inactive condition. As the active and inactive conditions were recorded as two consecutive EEG recordings, separated by a 30-minute break, for half of the sham recordings there might arise a concern of contamination by a preceding exposure that would diminish the size of the effect. The other issue in favor of insignificant differences could be related to relatively short exposure times.

Huber *et al.* (2002) investigated the effects of a microwave on waking and sleep EEG. The GSM "handset-like" signal was used with the carrier frequency 900 MHz modulated at frequencies 2, 8, 217, 1736 Hz, plus corresponding harmonics (pulse width 0.576 ms, SAR averaged over 10g was 1W/kg). In this study, the spectral power of these modulation components was higher than in the case of "base-station-like" signal used in their previous study (Huber *et al.,* 2000). The waking and night time sleep (n = 16) was analyzed after the subsequent left exposure for 30 minutes to either "handset-like" signal, continuous wave signal (only carrier frequency), or sham exposure as a control. The results showed that "handset-like" microwave exposure significantly enhanced the alpha power prior to sleep and in the spindle frequency range during stage 2 sleep. The enhancement of alpha power was not discovered in the case of continuous microwave exposure. Thus, the authors demonstrate that pulse modulation is necessary to produce microwave-induced changes. They also contemplate that the observed effects might be due to the mixture of modulation frequency components or a single component. Current experiments have also indicated an extended duration of pulse modulated microwave induced changes in the sleep EEG compared to a previous study (Huber *et al.* 2000), which might be due to differences in the pulse structure.

D'Costa *et al.* (2003) investigated the effect of mobile phone microwave exposure on human EEG. 10 subjects awake, eyes closed were exposed to a microwave over the midline occipital region during two experimental trials: a GSM mobile phone with a disabled speaker configured to transmit full power (900 MHz, modulated at 217 Hz, 2W peak output, average power 250 mW) and a GSM phone (non-modified) in active standby mode (900 MHz, modulated at lower frequencies used in GSM). One experimental trial consisted of ten 5-minute EEG recordings of which half were under the exposure conditions and another half were sham recordings (in randomized order). In addition, there were breaks of 10-15 minutes between them. The results indicate that exposure in the full power mode decreases the average EEG alpha and beta power compared to the corresponding average sham values. However, the results, particularly for the EEG beta band, are very close to the limit of significance (0.05). The authors also report significant differences for 7 out of 32 frequency components for different recording sites. However, as there are no corrections for multiple comparisons, the results seem doubtful. In addition, as there exists at least one significant p-value for one frequency component in the standby mode, it would be interesting to see a sham-sham comparison, to observe whether normal bioelectrical activity can produce also "significant values". In addition, the phone's antenna top seemed to be oriented towards the subjects. This gives rise to the assumption that the results might show the normal variability of the brain bioelectrical activity.

Croft *et al.* (2002) tested whether exposure to an active mobile phone affects resting EEG as a function of time. The results showed that the midline exposure (900 MHz, pulsed at 217 Hz, 0.577 ms pulse width; average power 3-4 mW) increases the alpha activity as a function of exposure duration (midline posterior sites) and decreases the delta activity. However, it remains unclear whether the exposure has any additional low frequency modulation components which might be the origin of the results. There are also some additional problems while using mobile phones, for example, some audible noises due to the battery (Haarala *et al.*, 2003) or some other additional frequencies caused by the battery (Croft *et al.*, 2008). In this case the results might be entirely or partly due to battery properties. In addition, one has to keep in mind that the results gained by Croft *et al.* (2008) were derived from the eyes opened condition.

Curcio *et al.* (2005) investigated the effect of a microwave on the EEG waking activity and its temporal development after a 45-minute microwave exposure for 7 minutes (group one – 10 subjects) and during the last 7 minutes of the 45-minute exposure (group two – 10 subjects). The recordings on both groups were performed under three different conditions: baseline, real exposure (902.40 MHz, pulsed at 217 Hz, average power 0.25 W) and sham exposure. The results indicate that microwave exposure increases the power in the 9-10 Hz region on the central derivation compared to baseline and sham exposure. A similar effect was also found at parietal lead at 11 Hz. In addition, the subjects exposed during the EEG recording showed higher EEG power than the subjects exposed before the recording. However, because of the small sample and effect size the authors suggest that the results should be looked at with caution.

The study of Curcio *et al.* (2005) was repeated by Croft *et al.* (2008) with a larger sample size (120 subjects). For microwave exposure a GSM mobile phone transmitted an 895 MHz digital signal modulated at 217 Hz (peak power of 2 W). The assessment of phone emissions spectrum revealed frequencies 16 and 217 Hz with no 8Hz component present. This study used a double blind, counterbalanced (left (60 subjects) vs. right (60 subjects) hemisphere exposure; between subjects) crossover (sham vs. active) design in two sessions separated by a week. While Curcio *et al.* (2005) exposed subjects to a microwave for 45 minutes and analyzed the last 7 minutes of exposure and 7 minutes after the exposure, the total exposure in the study of Croft *et al.* (2008) was 30 minutes: the first 10 minutes to discover microwave effects and 10 post-exposure minutes to evaluate microwave cessation effects.

The results indicate that exposure to a microwave increases the EEG alpha power. The increased alpha was more pronounced on the side of the exposure, particularly at posterior sites. Evaluation of the cessation effects showed no overall change in the alpha power. The authors also speculate whether there are two different effects of microwave – a direct effect close to the exposure site that lasts as long as the exposure and secondary neural processes that manifest themselves in a longer lasting alpha increase more frontally. In addition, the authors point out that the effects were very small and could be very easily overlooked while repeated-measures analysis technique is not in use. It is also very important that for the main effect of exposure only 60 % showed an increase in alpha, which is suggested to be related to individual differences between the subjects and makes it even more difficult to gain constant results with small sample sizes. No increase in alpha as a function of exposure duration reported by Croft *et al.* (2002) was found.

Regel *et al.* (2007a) investigated the microwave effects on waking EEG and cognitive tasks. 24 subjects were exposed to pulse modulated microwave (900 MHz, modulated at 2, 8, 217, 1733 Hz plus higher harmonics, peak specific absorption rate 1W/kg) for 30 minutes, continuous-wave microwave (not modulated) or were sham exposed. The study used a double blind, randomized and counterbalanced crossover design in three sessions separated by a week. During the exposure subjects were performing cognitive tasks in a fixed order. The waking EEG was recorded during baseline, immediately after, 30 and 60 minutes after exposure for 6 minutes, during 3 minutes of which eyes were closed and another 3 minutes eyes open. The results indicated that exposure to a pulse modulated microwave reduced reaction speed and increased accuracy in working-memory task. The waking EEG power was increased in the 10.5- 11 Hz range 30 minutes after exposure compared to sham while eyes were closed. No effects were reported for eyes opened condition.

1.2 Event related synchronization and desynchronization

The effect of microwave exposure on human brain bioelectric activity during cognitive processing can be evaluated using evoked potentials. Several events can induce time-locked changes in the activity of neuronal populations. The evoked potentials (EP) can be defined as time-locked electrical or magnetic responses to certain stimuli. There exist also changes that are time-locked to the event but not phase-locked – stimulus-induced changes in the ongoing brain dynamics. Those frequency specific changes may consist decreases or increases in synchrony of the underlying neuronal populations and are called event related desynchronization (ERD) or event related synchronization (ERS), respectively (Pfurtscheller and Lopes da Silva, 1999).

Krause *et al.* (2000a) investigated the effects of a microwave on the ERD and ERS of different EEG frequency bands during auditory memory tasks. 16 subjects were sham exposed and exposed to 902 MHz electromagnetic field using a cellular telephone during a single trial in the counterbalanced order. The overall microwave exposure time was about 30 min. The results indicate that the microwave increases significantly the EEG power in the 8-10 Hz frequency band and the oscillatory activity in the EEG was altered in all studied frequency bands as a function of time and memory task. However, the findings were inconsistent as those could not be replicated by Krause *et al.* (2004). The replication study was double blind and the exposure site was on the left instead of right. As a result, the replication study found a significant increase of errors by a microwave, which was not the case in the earlier study. The only consistent finding was that microwave decreases the magnitude or the ERS responses in the 4-6 Hz frequency band. Could the variations in the results be due to different exposure sites or does the double blind exposure design play a role? Is there a possibility that a single trial design makes it even more difficult to get consistent and clear results? There is also a possibility that the results are not easily replicative as the emergence of the microwave influence might depend on the subjects' behavioural condition etc.

The study of Krause *et al.* (2000b) analyzed the effects of a microwave on the ERD/ERS of the different EEG frequency bands during visual working memory tasks. 24 subjects were sham exposed and exposed to 902 MHz electromagnetic field using a cellular telephone during a single trial in the counterbalanced order. The overall microwave exposure time was about 30 min. They conclude that the exposure to a microwave modulates the responses of the EEG oscillatory activity near 8Hz specifically during cognitive processes. However, again no information is provided by the authors about the activation of the discontinuous transmission mode. As a result, there exists a possibility that the results are imprecise because of the low frequency modulation component.

A partial replication study for studies by Krause *et al.* (2000a,b and 2004) was performed in 2007 (Krause *et al.,* 2007). They investigated the effects of a microwave on ERD/ERS EEG responses on two groups performing either auditory or visual working memory tasks. The experiments were conducted in three sessions according to the microwave exposure condition: sham, CW microwave and PM microwave. The sessions were separated by a week. Also, the exposure location, left vs right, was under investigation. The tests were double blind. In those studies the ordinary mobile phone was replaced with a signal generator and an amplifier connected to the dummy phone antenna – in this case the generator created a 902 MHz microwave that was either continuous or modulated at 217 Hz frequency.

The results reported are a modest microwave effect on brain oscillatory responses in the 8-12 Hz frequency range and no effects on behavioral measures. Still the authors conclude that the results are varying, unsystematic and inconsistent with previous reports. However, brain responses are very variable and depend on many factors, as a result, the partial replication of previous studies (double blind vs single blind, left vs. right exposure site, single trial vs trials separated by a week, different exposure equipment) makes it even more complicated to achieve consistent results.

1.3 Cerebral blood flow

The effect of modulation frequencies has also been examined by Huber *et al.* In 2002 Huber *et al.* were the first to investigate the effects of a microwave on waking regional cerebral blood flow (rCBF) of human brain *in vivo*. They used a "handset-like" signal with the carrier frequency 900 MHz and modulation frequencies 2, 8, 217, 1736 Hz, however, the spectral power of these modulation components was higher than in the "base-station-like" signal used in the sleep EEG study (Huber *et al.,* 2000). For rCBF experiments 16 male subjects were exposed unilaterally for 30 minutes prior to the positron emission tomography (PET) scans. The sham exposure was used as a control. The results showed that "handset-like" microwave exposure increased relative rCBF in the dorsolateral prefrontal cortex on the same side to exposure.

As previously, the effects of a microwave on waking rCBF were investigated only after the exposure to a "handset-like" signal and sham exposure, the next study of Huber *et al.* (2005) covers additionally the exposure to a "base-station-like" signal. The increase in the relative rCBF in the dorsolateral prefrontal cortex on the side of exposure (left) was revealed. As expected, the effect was found to depend on the spectral power in the amplitude modulation of the microwave exposure: the rCBF was affected by a "handset-like" microwave exposure but not by a "base-station-like" exposure. The authors remain open whether the effect is due to differences in the strength of certain low-frequency components or the difference in the crest factor. Huber *et al.* (2005) also pointed out that Haarala *et al.* (2003) did not observe changes in the rCBF due to microwave exposure. They presume that as microwave exposure may induce long-lasting effects, the active microwave exposure might have contaminated half of the sham recordings and obscured rCBF alterations, as the active and sham condition were recorded consecutively in a randomized, cross-over design by Haarala *et al.* (2003). However, there are many other dissimilarities in those studies, which could prevent obtaining the same results. First of all, Haarala *et al.* (2003) state that a standard phone battery was used as a power source. Even though the loudspeaker of the phone was removed, the measurements revealed an acoustic signal which was higher in the microwave on condition compared to off condition, therefore caused by the battery. The pilot experiments indicated that subjects were unable to detect the acoustic signal. However, the authors speculate whether the reported main effect - relative bilateral decrease of rCBF - caused by the active mobile phone in the auditory cortices might be due to the more susceptible areas further away from the source of exposure or the consciously not perceived auditory signal lead to deactivation in the auditory cortices. Their follow-up study that used a silent power source rather confirms the latter.

The other difference emerges in the applied microwave exposure. Haarala *et al.* (2003) were using a mobile phone which emitted 902 MHz microwave, pulsed at a frequency of 217 Hz, whereas the discontinuous transmission mode was not activated.

One of the biggest differences in those studies is that Huber *et al.* (2003) investigated the after-effect of the microwave, whereas Haarala *et al.* (2003) observed changes in the rCBF during exposure while the subjects were performing a visual working memory task.

Aalto *et al.* (2006) eliminated the acoustic effect described by Haarala *et al.* (2003). In addition, to examine the effect of a microwave on the rCBF, only one working memory task was used. Thus, 12 subjects were performing a simple working memory task (1-back task). Their PET scans were acquired using a double-blind, counterbalanced study design. The results showed that the exposure (902 MHz, at modulation frequency 217 Hz, pulse width 0.577 ms, mean power of 0.25 W) induced a local decrease in the rCBF in the inferior temporal cortex and an increase in the prefrontal cortex.

The studies by two different research groups are still not comparable. However, both research groups found changes in the rCBF due to the microwave radiation.

1.4 Electromagnetic sensibility and hypersensitivity

According to Leitgeb and Schröttner (2003), electromagnetic sensibility addresses the ability to perceive electric or electromagnetic exposures without necessarily developing health symptoms, while electromagnetic hypersensitivity refers to the development of health symptoms caused by environmental electromagnetic field exposures. There have been some assumptions that those people might be more easily affected by a microwave, however, the results of studies indicate that subjective feelings perceived are not due to a microwave nor are the self-reported electromagnetically sensitive persons perceiving the microwave better than by chance.

For example, Koivisto *et al.* (2001) report no differences in subjective symptoms or sensations between exposure and nonexposure conditions. They used a GSM mobile phone (902 MHz, at modulation frequency 217 Hz) for the RF exposure for the duration of 60 (experiment 1) or 30 minutes (experiment 2). The subjective symptoms or sensations were rated at the beginning of the session and at the end of exposure and nonexposure conditions. Although the single-blind designs were used for both experiments, the authors conclude that a 30-60-minute exposure to the used RF does not produce subjective symptoms.

Hietanen *et al.* (2002) investigated whether there exist RF hypersensitive persons and if the subjects reporting themselves as sensitive to cellular phones are able to determine whether the RF field is on or off. 20 subjects were exposed to an analogue NMT phone (900 MHz, output power 1 W), digital GSM phones (900 MHz and 1800 MHz, modulated at 217 Hz, average output power 0.25 and 0.125 W, respectively) and sham exposed. The duration of each exposure was 30 minutes, separated by a break at least 60 minutes. The subjects had to report any symptoms or sensations associated to abnormal feelings. In addition, the blood pressure, heart rate and breathing frequency was monitored. The authors report that the number of reported symptoms was higher during sham exposure compared to microwave exposure, and the subjects could not distinguish RF exposure from sham exposure.

Similar conclusions are drawn by Kwon *et al.* (2008). They used a large sample of subjects (n= 84) to perceive the GSM mobile phone microwave exposure (902 MHz, modulated at 217 Hz, mean power 0.25 W). The performance was as good as by chance. However, there were two subjects who gave correct responses for 97 % and 94 % of cases ("Was the field on?", n= 100 trials). Nonetheless, a month later, they were not able to replicate the results.

Due to the negative results gained there is a reason to doubt if there exists a subgroup of those electromagnetically sensitive to mobile phone microwave exposure and therefore there are no criteria of how to select the most influenced subjects to the microwave exposure studies.

1.5 Reasons for doubts and difficulties in the identification of microwave effects on the brain

It is difficult to draw conclusions from the review articles as different studies use different exposure set-ups and recording protocols. Even the replication studies have always some improvements which probably influence also the outcome. Still there seems to exist a trend that a microwave increases the EEG alpha power. This effect has been observed during the exposure and as an aftereffect. However, even while having exactly the same methodology, there are different reasons for difficulties in identification and doubts in microwave effects on the EEG, some of the most obvious ones are listed below:

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

2) The mechanism of the microwave effect is still unclear and therefore interpretation of the effects is complicated.

3) Effects of microwave exposure differ for individuals, some of the subjects under investigation may be significantly affected and others appear unaffected. Therefore it is complicated to obtain a statistically significant result for the group.

4) Variability of the physiological states of the brain may cause significant differences in sensitivity to an external stressor.

5) The brain is able to physiologically adapt to an external stressor. This behaviour may decrease the microwave effect.
6) Variations in microwave power density inside the brain tissues can cause differences in the effects.

With regard to all of those factors, it is relatively complicated to gain statistically reliable results that would indicate to microwave effects on the human nervous system.

In this study the method and experimental protocols were selected to minimize the influence of natural variability of the EEG. Three different methods were applied for the EEG analyses to reveal hidden changes in the EEG signal caused by microwave radiation: integration of differences (ID) in the energy of the EEG segments with and without the exposure - Publication III; power spectral density (PSD) to analyze the difference of the subsignals with and without the exposure – Publication II, Publication V; multifractal method of scaling analysis of the EEG signal based on the length distribution of low variability periods (LDLVP) to analyze the difference of the subsignals with and without the exposure – Publication II. Experiments were performed at single fixed modulation frequencies. To reveal the changes caused by microwave exposure more effectively, the individual sensitivity will be taken into account by applying statistical analysis not only for groups but also for individuals. Finding the possible explanation to contradictive results the phenomena of brain physiological adaptation to microwave exposure will be evaluated.

2. EXPERIMENTAL STUDIES: DESIGN OF THE METHOD, RESULTS AND DISCUSSION

2.1. Selection and analysis of methods

At the start, there was a need to exclude at least some of the misleading factors. First of all, the used microwave radiation 450 MHz was on-off modulated at a fixed frequency. As various studies have shown, the microwave effects emerge only under the influence of modulated microwave radiation. For example, Regel *et al.* (2007a) found that pulse-modulated radio frequency electromagnetic field increases spectral power in the waking electroencephalogram in the 10.5-11 Hz range 30 min after exposure. On the other hand, no effects were observed for continuous-wave radio frequency electromagnetic fields.

Similar conclusions were drawn by Huber *et al.* (2002 and 2005). The pulse modulated microwave exposure (similar to the GSM mobile phone “handset”), enhances the EEG power in the alpha frequency range prior to sleep onset and in the spindle frequency range during stage 2 sleep. Meanwhile, the exposure to microwave without pulse modulation did not enhance power in the waking or sleep EEG.

Also, while investigating the effects of “handset like” and “base station like” exposure (Huber *et al.,* 2005), an increase in rCBF in the dorsolateral prefrontal cortex on the side of exposure was observed. The effect was found to depend on the spectral power in the amplitude modulation of the RF carrier.

The abovementioned findings confirm that pulse modulation is crucial for microwave-induced alterations in brain physiology.

The studies referred to above were conducted with microwave exposure that corresponds to the radiation of cellular phones. As a result, distinctions of microwave effects at different modulation frequencies were not differentiated.

Within this work, the effect of microwave radiation modulated at different frequencies was evaluated, exploiting several modulation frequencies one by one.

The used carrier frequency (450 MHz) is also much lower than the 900 or 1800 MHz used in modern cellular phones. 450 MHz penetrates deeper into the brain and the microwave effect is considered to be more easily detected.

To create the recording protocols, a two-session design is needed: one session for evaluating the effect of microwaves and the other for sham condition. Otherwise, during lengthy recordings the reported results might be due to decreased arousal level. It is particularly true while reporting the decrease of fast EEG frequencies during microwave exposure. The results of Maltez *et al.* (2004) support this idea by demonstrating that during resting conditions towards the end of the recording, there is a decrease in the alpha and beta power and an increase in the delta and theta power. As a result, there is a need for sham sessions performed on different day than microwave exposure sessions. In this way, sham and exposed sessions can be considered as having similar arousal levels.

It is also necessary to consider the fact that microwave radiation might have long-lasting effects on human brain bioelectrical activity. For example, Cook *et al.* (2005) demonstrated that exposure to a pulsed extremely low frequency magnetic field affects the human EEG and the changes in the EEG are related to the order of exposure (magnetic field – sham vs. sham – magnetic field). In addition, Huber *et al.* (2005) show that microwave exposure has long-lasting effects and therefore using consecutive recordings of sham and active condition may contaminate sham recordings. They speculate whether the results of Haarala *et al.* (2003), indicating no changes in the rCBF caused by microwave exposure, might be due to the field-induced contamination of the sham period. Therefore, also the possibility of long-lasting effects of microwave exposure demand that the sham sessions be performed on a day different from microwave exposure sessions. This was taken into account in the current work, i.e. the sham session was always recorded on a day different from that of the exposed one.

During our preliminary recordings, at fixed modulation frequency only one-minute long exposure periods were used. Since three different modulation frequencies were under investigation, the total exposure time was 3 minutes – all separated by 1-minute recovery periods. However, this kind of protocol did not provide statistically reliable results (Parts (Bachmann) *et al.,* 2002).

Our suggestions were that most likely there is a need for repeated microwave exposure. The effect might not emerge or is too small during the first exposure period. However, repetition could initiate or enhance the effect. Therefore, our successive protocols consisted of one modulation frequency and a 1-minute exposure period was repeated for 10 times – each exposure minute followed by a recovery minute without exposure. However, all 10 exposure periods were still analyzed individually with a target to discover the exposure cycle when the effect appears. The results reported in (Parts (Bachmann) *et al.*, 2002) provide no statistically reliable results for a group. Only trends of changes in the EEG were found for a group. However, some particular subjects sensitive to a microwave were also present. In addition, it was also assumed that the start of the first exposure period might not trigger the effect of the microwave. It is concluded that a repetitive exposure causes more remarkable changes in the EEG rhythms level than a short term exposure.

Hence, it was understood that the influence of a microwave is not always present and in case it emerges it is probably weak and therefore difficult to detect. It is also clear that even if there is a correct exposure cycle from which the influence emerges for one person, it is probably not the same for others. As a result, all the following analyses were performed by integrating the influence of all 10 exposure cycles. It was considered that small differences between microwave exposed and recovery periods will accumulate, allowing statistically significant results to be obtained.

However, while using a new method - different parameters from bispectrum - the integration over all exposure cycles and all subjects did not help discover the effect of microwave modulated at 7 Hz (Parts (Bachmann) *et al.,* 2003). In this study the photic stimulation at 16 Hz was used as a known stressor for comparison and the effect was clear even though the parameters for photic stimulation were not integrated over cycles, as it was applied only once for a subject.

It should be emphasized that difficulties related to discovering the effects are not an indication that there is no influence. As the parameters calculated were found by the help of visual inspection and modification of the SynchFastSlow parameter – a component from the Bispectral Index used for monitoring the depth of anaesthesia (Rampil *et al.,*1998), it is assumed that the parameters were not most appropriate to discover the effect.

In fact, there are also some opinions that bispectral analysis probably does not add any information in the analysis of the depth of anaesthesia. Miller *et al.* (2004) could not show that bispectral analysis gives more information than power spectral-based analysis. Roustan *et al.* (2005) found that bispectral analysis of the EEG provides a slight improvement over simple spectral analysis. Our results based on bispectral analysis and studies from Miller *et al.* and Roustan *et al.* raised some uncertainty about the reasonability to proceed with bispectrum. Most probably the use of bispectral analysis does not provide a solution to the difficulties encountered in the detection of microwave effects, as there are so many other issues related (different modulation frequencies, possible adaptation, inter and intra individual differences between subjects etc.).

In the subsequent studies only the power spectral analysis was continued. The next modification was the individual evaluation of changes caused by microwave radiation. As discovered in **Publication I**, some subjects were found more sensitive to a microwave. It was even proposed that intra-individual changes could play a part, as the individual sensitivity might depend on the variability of the functional state of the brain. Therefore, different responses to microwave exposure on diverse time points result from one day versus the other for the same individual. Nevertheless, for an individual evaluation, it was assumed that calculated parameters are within normal fluctuations during sham recordings, and large differences in parameters between microwave exposed and sham recordings for individual subjects indicate the microwave effect.

The other studies on the microwave effects show a rise in *the EEG* alpha power (Huber *et al.,* 2002; Croft *et al.,* 2002, 2008; Curcio *et al.,* 2005; Regel *et al.,* 2007a).

Those are in agreement with the results in **Publication I**, indicating a rise in the alpha power – although insignificant for the whole group. In this article the theta band was also investigated, the results showed a decreasing trend of the theta power. This explains the reasons why the investigation of the microwave effect individually for the total EEG power provided statistically reliable results only for one subject (**Publication II**). As the response to microwave in the alpha and theta band seems to be opposite, changes in the total EEG power were diminished. Hence, it was concluded that all the EEG bands need to be looked at separately and the beta band less explored was focused on.

2.2 Dependence on the modulation frequency

Recent achievements in the electric and transcranial magnetic stimulation (TMS) in brain research and neurotherapy have initiated interest in the possible effects of the magnetic field at different frequencies (Lemon 2002, Rohan *et al.,* 2004). Changes in the behavioural state of the brain are typically accompanied by changes in the frequency and spatial coordination of rhythmic bioelectrical activity in the neocortex. Cortical excitability by the magnetic field has been shown to vary at different frequencies: low-frequency TMS causes inhibition whereas stimulation at higher frequencies produces activation (Lemon, 2002). Therefore, we can assume that any effects caused by the electromagnetic radiation on the bioelectrical activity of the human brain may also depend on the stimulation frequency. Whereas microwaves cannot cause any regular changes in the movement of ions due to their small cross-section of absorption (wavelength is much larger than cell dimension) as well as inertial properties and viscosity of the liquid medium (Adair, 2002), the effect may depend on the modulation frequency rather on the radio frequency. The same conclusions were reported for the ELF modulated microwave effects (Huber *et al.,* 2002, 2005; Regel *et al.,* 2007a).

As can be seen, different investigators use different modulation frequencies or a sum of those (Huber *et al.,* 2000, 2002, 2005, Regel *et al.,* 2007a, Croft *et al.,* 2008). In addition, it is not always understandable whether the spectrum of emissions was assessed to discover all the appearing modulation frequencies. For instance, Croft *et al.* (2008) discovered the modulation frequency 16 Hz in addition to 217 Hz – the former probably occurring due to battery operations. Additionally, while using public phones, there is a necessity to check for the lower modulation components accompanying the traditional GSM, as even while the discontinuous transmission mode is not used, the lower level component of 8 Hz and its harmonics are present (Pedersen 1997). The modulation character is even more complicated when the discontinuous transmission mode is active. Therefore, while investigating the microwave effects using unmodified commercial telephones, it is impossible to differentiate various modulation frequencies. As a result, findings of the analysis based on the EEG are doubtful, in addition one can never understand which modulation frequency causes the effect.

According to **Publication I**, there exist individual differences between subjects. To go further, there might exist a large variability in individual subject sensitivity with respect to the microwave exposure. As a result, while using several modulation frequencies, the outcome is rather unexpected. According to **Publication III**, significant differences appear between the reference and the exposed series at the modulation frequency of 14 Hz for the EEG alpha and beta1 rhythms, while modulation frequency 21 Hz influences also the EEG beta2 rhythms. With regard to the modulation frequency 40 Hz, an increase in the EEG beta rhythm was found (**Publication IV**). Comparing the results at modulation frequency 40 Hz, the beta increase was observed on the same group to a smaller extent at modulation frequency 70 Hz (**Publication VI**). In the study of the modulation frequency that coincided with cellular phones (217 Hz), statistically significant changes were found to appear again in the EEG beta intensity (**Publication V**). Similar results appeared on the same group at modulation frequency 1000 Hz (**Publication VI**). However, there were no significant differences between the reference and the exposed series at the lower modulation frequency of 7 Hz (**Publication III**), which belongs to the EEG theta frequency range. The significant results in the beta energy reported at 7 Hz frequency for the first group in **Publication VI** are not Bonferrroni corrected and therefore were not taken into account.

Therefore, it can be concluded that the effect of the external stimulus on brain oscillations is stronger if the frequency of the stimulus is higher or close to the physiological frequency of brain rhythms. The 7 Hz modulated radiation could affect only the EEG theta power, but the theta band appears to be insensitive to the exposure. In addition, with the increase of modulation frequency (at 40 Hz to 1000 Hz) the effects of microwave radiation seem to significantly influence only higher EEG rhythms (beta).

It can be concluded that the effect is modulation frequency dependent as there exists a modulation frequency (7 Hz), which does not have a significant effect. In addition, the used modulation frequencies 40 and 70 Hz caused effects that were rather different in terms of their extent on the same group. Therefore, the effect is probably not linear. Based on the results at different modulation frequencies, it is impossible to presume what takes place between those investigated modulation frequencies.

The results support the idea that the influence of the microwave exposure on the cortical activation depends on the modulation frequency.

2.3 Increase in the EEG alpha and beta power

The EEG alpha power increase was observed at 7 Hz modulation frequency in **Publication I** - although insignificant for the whole group.

In the following experiments a significant increase appeared not only in the EEG alpha but also in the beta rhythm power. According to **Publication III**, the EEG power increased in alpha and beta1 rhythms at the modulation frequency of 14 Hz, and in the EEG alpha, beta1 and beta2 rhythms at the modulation frequency of 21 Hz. No significant changes occurred in the EEG theta rhythm at any modulation frequency. In addition, no significant differences between the reference and the exposed series were detected at the lower modulation frequency of 7 Hz.

450 MHz microwave exposure modulated at 40 Hz caused statistically significant changes in the EEG energy variations – 20 % of subjects in T channels (**Publication VI**; Tomson *et al.,* 2007) and 13.3% of subjects in P channels (**Publication IV,** Bachmann *et al.*, 2007). Main trend in the changes caused by microwave exposure was the increase of the EEG energy in the beta rhythm.

450 MHz modulated at 70 Hz caused significant changes in T channels in the EEG beta rhythms energy variations for 13% of subjects (**Publication VI**).

Exposure at the modulation frequency 217 Hz caused an average increase in the EEG alpha and beta activity (**Publication V**). Statistically significant changes emerged in the EEG beta intensity for about 10-20% of healthy subjects in temporal and parietal regions of the human brain.

The maximum percentage of subjects significantly affected by 450 MHz modulated at 1000 Hz emerged in T channels, causing statistically significant energy variations in the EEG beta rhythms for 21% of subjects (**Publication VI**).

The main trend of changes for most of the modulation frequencies was the increase of the EEG energy in the alpha and beta rhythm.

Maltez *et al.* (2004) demonstrated that during resting conditions towards the end of the recording there is a decrease in the alpha and beta power and an increase in the delta and theta power. In accordance with Maltez *et al.* (2004), in **Publication V**, it was also found that during sham recordings the alpha and beta power were reduced while the theta power was increasing.

However, the results discovered under microwave exposure were rather opposite and therefore can not be referred to as the lowering of arousal level. On the contrary, it seems that microwave exposure helps to maintain the arousal level.

The effect resembles also to the findings of Rangaswamy *et al.* (2002) who found that beta power in resting EEG is elevated in alcoholics. Similar findings from Coutin-Churchman *et al.* (2006) show decreased power in slow bands in alcoholic patients which may be an indicator of brain atrophy or chronic brain damage, while the discovered increase in the beta band is related to medication use, family history of alcoholism, hallucinations and seizures, suggesting a state of cortical hyperexcitability.

2.4 Individual sensitivity

In previous studies an increase in the EEG energy and variability was discovered (Hinrikus *et al.*, 2006). The increase in the EEG variability refers to individual differences between subjects. To go further, there might exist a large variability in individual subject sensitivity with respect to the microwave exposure, since variability of the physiological states of the brain can cause significant differences in sensitivity to an external stressor.

The main experiments on resting EEG were carried out on four different groups of healthy volunteers. Group 1 exposed at 7 Hz modulation consisted of 23 young persons (aged 21-24), 12 male and 11 female; group 2 exposed at 7, 14 and 21 Hz modulation consisted of 13 young persons (aged 21-30), 4 male and 9 female; group 3 exposed at 40 and 70 Hz modulation consisted of 15 young persons (aged 21-24), 8 male and 7 female; and group 4 exposed at 217 and 1000 Hz consisted of 19 young persons (aged 21-24), 8 male and 11 female.

While investigating frequency bands separately, the rate of subjects sensitive to modulated microwave exposure in different groups was in the range of 13-30 %

(**Publication VI**). This is even higher than the rate of multiple chemical sensitivity estimated to be between 2 and 10 % in the general population (Cullen, 1987).

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

The effect of the exposure on a subject can vary on different days and conditions. The rate of subjects affected during an experimental session depends on the physiological state of their brain at that time. Replicability of the effect becomes complicated due to variability of many coexisting factors.

2.5 Possible physiological adaptation

It is well-known that the brain has an ability to adapt its physiological behaviour to an external stressor. If it is the case also with microwave exposure, the explanation to the reviewd contradictive results could be the adaptation of the brain to microwave exposure as an external stressor (Kwee, 2006).

The answer to the question whether an adaptation during microwave exposure exists and if so, then how it is revealed is unknown. With regard to auditory stimulation, Haenschel *et al.* (2000) investigated the gamma and beta frequency oscillations in response to novel auditory stimuli. Among other findings, they reported that both gamma and beta oscillations habituate markedly after the initial novel stimulus presentation.

Taking the previous into account, it is reasonable to presume that the adaptation might exist also while microwaves are concerned. As a result, focus on a preliminary study was on the adaptation effect (**Publication VII**). The most evident microwave effect was the initial increase of the beta power at the beginning of microwave exposure. The alpha band expressed also a power increase, but with a longer latency from microwave exposure onset than the beta power. In both frequency bands the power increase was followed by a decrease to the reference level. The results of the preliminary study suggest that the adaptation effect of human brain to low-level microwave exposure is evident in the EEG alpha and beta rhythms. Furthermore, after longer exposure time, the brain seems to react also to the sudden end of the exposure. However, to draw final conclusions, there is a need for more data analysis using a larger database.

Although the mechanisms how the brain reacts to auditory stimulation and microwave stimulation are evidently different, our current adaptation study has some common features with the results of Haenschel *et al.* (2002). They observed that after a stimulus, evoked gamma and beta oscillatory activity peaked earlier than alpha activity. In our study also the beta power reacted to microwave exposure quicker than the alpha power. The results by Haenschel *et al.* (2002) demonstrated that habituation occurs after the initial novel stimulus presentation. In our study the on-off microwave exposure was applied for a minute and the adaptation phenomena emerged during that time, in other words, the last part of exposure did not cause any increase in power – the brain was already adapted. The 60 second recovery period after the exposure allows us to treat the start of the next exposure as a novel one.

The same conclusions can be drawn on the basis of **Publication III**. It was discovered that the microwave effect was significant only while comparing the first half of the microwave exposed and recovery minutes.

CONCLUSIONS

The results of the study add knowledge to understanding of the modulated microwave radiation effects on the EEG.

1. The results show that microwave exposure causes most remarkable increases in the EEG alpha power (reported also by other authors) and lower increases in the beta power, detected by a more sensitive method of the EEG analysis applied in this study.
2. The effect of microwave radiation on the EEG rhythms differs at different modulation frequencies and is most remarkable at modulation frequencies higher or close to the EEG rhythm frequency.
3. Sensitivity to microwave exposure varies with individuals; the rate of the subjects significantly affected was 13-30 % for different groups.
4. All three methods selected for the EEG analysis (ID, PSD, LDLVP) led to statistically significant results, demonstrating microwave effects.
5. The preliminary results suggest that physiological adaptation of the brain compensates and even overcompensates the effect of microwave exposure.

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IV Hinrikus, H., **Bachmann, M.,** Kalda, J., Säkki, M., Lass, J., Tomson, R. (2007). Methods of electroencephalographic signal analysis for detection of small hidden changes. *Nonlinear Biomedical Physics,* 1:9

V **Bachmann, M.**, Säkki, M., Kalda, J., Lass, J., Tuulik, V., Hinrikus, H. (2005). Effect of 450 MHz Microwave Modulated with 217 Hz on Human EEG in Rest. *The Environmentalist*, 25:165–171.

VI **Bachmann, M.,** Lass, J., Kalda, J., Säkki, M., Tomson, R., Tuulik, V., Hinrikus, H. (2006). Integration of differences in EEG analysis reveals changes in human EEG caused by microwave, Proceedings of the 28th IEEE EMBS Annual International Conference: IEEE, pp. 1597-1600, New York City, USA, 30 August – 3 September 2006.

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KOKKUVÕTE

Moduleeritud mikrolainekiirguse mõju inimese puhkeoleku elektroentsefalograafilisele signaalile

Käesolev töö uurib moduleeritud mikrolainekiirguse mõju inimese aju bioelektilisele aktiivsusele, kasutades selleks elektroentsefalograafiliste (EEG) signaalide analüüsi. Töö autor annab ülevaate antud teema olulisematest uurimistulemustest ning esitab kokkuvõtte oma töö tulemustest.

Esimeses osas esitatakse ülevaade madalatasemelise moduleeritud mikrolainekiirguse mõjust inimajule. Vaadeldakse mõju puhkeoleku EEG-le, esile kutsutud sünkronisatsioonile ja desünkronisatsioonile EEG signaalis ning ajuvereringele. Lisaks antakse lühem ülevaade elektromagnetilise (hüper)tundlikkuse olemusest. Analüüsi tulemusena tuuakse välja olulisimad probleemid mikrolainekiirguse mõju tuvastamisel inimajule.

Teises osas annab autor ülevaate oma eksperimentaalsestest uurimustulemustest. Moduleeritud mikrolainekiirguse mõju EEG-le uuriti kokku neljal erineval vabatahtlike grupil. Selleks kasutati mikrolainekiirgust kandesagedusega 450 MHz, mida moduleeriti erinevatel modulatsioonisagedustel: 7, 14, 21, 40, 70, 217 ning 1000 Hz. Välja võimsustihedus, mõõdetuna pea vahetus läheduses, oli 0.16 mW/cm^2. Mikrolainekiirguse mõju hinnati analüüsides suhtelisi muutusi EEG võimsuses mikrolainekiirguse ajal ning ilma kiirguseta olukorras.

Töö tulemusena leiti:

1. Mikrolainekiirgus põhjustab kõige märgatavamana EEG alfa võimsuse tõusu (sama on leidnud ka teised uurimisgrupid) ning vähemal määral beeta võimsuse tõusu, mille tuvastamise võimaldasid antud töös kasutatud tundlikumad EEG analüüsi meetodid.
2. Mikrolainekiirguse mõju EEG rütmidele erineb erinevatel modulatsioonisagedustel ning mõju on kõige suurem modulatsioonisagedustel, mis on lähedased või kõrgemad kui EEG rütmide sagedused.
3. Tundlikkus mikrolainekiirgusele on individuaalne – erinevates gruppides oli oluliselt mõjutatud katsealuste hulk 13 - 30 protsenti.
4. Kõik kolm töös kasutatud analüüsi meetodit (ID, PSD, LDLVP) viisid statistiliselt oluliste tulemusteni, näidates mikrolainekiirguse mõju.
5. Esialgsed katsetulemused viitavad, et mikrolainekiirguse toimel aju adapteerub – kompenseerib mikrolainekiirguse mõju ning kohati kompenseerib suuremal määral kui vajalik.

Võtmesõnad: mikrolainekiirguse mõju, EM-välja mõju, EEG analüüs, individuaalne tundlikkus, adaptatsioon.

ABSTRACT

Effect of modulated microwave radiation on human resting electroencephalographic signal

The thesis focuses on the effects of low-level modulated microwave radiation on human brain bioelectrical activity based on the electroencephalographic (EEG) signal analysis. The author gives an overview of the main results in the study of microwave radiation effects, and summarizes her own original results.

Section 1 summarizes the effects of low-level modulated microwave radiation on human brain. The effects on resting EEG, event related synchronization and desynchronization and cerebral blood flow are covered. In addition, a few studies on the existence of electromagnetic sensibility and hypersensitivity are reviewed. Finally, difficulties in the identification of microwave effects on the brain and major obstacles in the detection of microwave effects on human brain are indicated.

Section 2 presents an overview of the results of author's experimental studies. The experiments on the effect of modulated microwaves on human EEG were carried out on four different groups of healthy volunteers exposed to 450 MHz radiation modulated at 7, 14, 21, 40, 70, 217 and 1000 Hz frequencies. The field power densities at the scalp were 0.16 mW/cm^2. A relative change in the EEG power with and without exposure was used as a quantitative measure.

The results of the study add knowledge to understanding of the modulated microwave radiation effects on the EEG.

1. The results show that microwave exposure causes most remarkable increases in the EEG alpha power (reported also by other authors) and lower increases in the beta power, detected by a more sensitive method of the EEG analysis applied in this study.
2. The effect of microwave radiation on the EEG rhythms differs at different modulation frequencies and is most remarkable at modulation frequencies higher or close to the EEG rhythm frequency.
3. Sensitivity to microwave exposure varies with individuals; the rate of the subjects significantly affected was 13-30 % for different groups.
4. All three methods selected for the EEG analysis (integration of differences, power spectral density, length distribution of low variability periods) led to statistically significant results demonstrating microwave effects.
5. The preliminary results suggest that physiological adaptation of the brain compensates and even overcompensates the effect of microwave exposure.

Keywords: microwave effect, EMF effect, EEG analysis, individual sensitivity, adaptation.

APPENDIX 1

PUBLICATIONS

Publication I

Hinrikus, H., **Parts (Bachmann), M.**, Lass, J., Tuulik, V. (2004). Changes in human EEG caused by low level modulated microwave stimulation. *Bioelectromagnetics*, 25(6):431-40.

PUBLICATIONS

Publication II

Bachmann, M., Kalda, J., Lass, J., Tuulik, V., Säkki, M., Hinrikus, H. (2005). Non-linear analysis of the electroencephalogram for detecting effects of low-level electromagnetic fields. *Med Biol Eng Comput*, 43(1):142-9.

APPENDIX 1 Continued

PUBLICATIONS

Publication III

Hinrikus, H., **Bachmann, M.**, Lass, J., Tomson, R., Tuulik, V. (2008). Effect of 7, 14 and 21 Hz modulated 450 MHz microwave radiation on human electroencephalographic rhythms. *Int J Radiat Biol*, 84(1):69-79.

PUBLICATIONS

Publication IV

Hinrikus, H., **Bachmann, M.,** Kalda, J., Säkki, M., Lass, J., Tomson, R. (2007). Methods of electroencephalographic signal analysis for detection of small hidden changes. *Nonlinear Biomedical Physics,* 1:9

PUBLICATIONS

Publication V

Bachmann, M., Säkki, M., Kalda, J., Lass, J., Tuulik, V., Hinrikus, H. (2005). Effect of 450 MHz Microwave Modulated with 217 Hz on Human EEG in Rest. *The Environmentalist*, 25:165–171.

PUBLICATIONS

Publication VI

Bachmann, M., Lass, J., Kalda, J., Säkki, M., Tomson, R., Tuulik, V., Hinrikus, H. (2006). Integration of differences in EEG analysis reveals changes in human EEG caused by microwave, Proceedings of the 28th IEEE EMBS Annual International Conference: IEEE, pp. 1597-1600, New York City, USA, 30 August – 3 September 2006.

PUBLICATIONS

Publication VII

Bachmann, M., Rubljova, J., Lass, J., Tomson, R., Tuulik, V., Hinrikus, H. (2007). Adaptation of human brain bioelectrical activity to low-level microwave, Conf Proc IEEE Eng Med Biol Soc, pp. 4747-4750, Lyon, France, 23-26 August 2007.

APPENDIX 2

ELULOOKIRJELDUS

1. Isikuandmed

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3. Hariduskäik

Õppeasutus (nimetus lõpetamise ajal)	Lõpetamise aeg	Haridus (eriala/kraad)
Tallinna Tehnikaülikool	2001	Infotehnoloogia teaduskond/tehnikateaduste bakalaureus
Tallinna Tehnikaülikool	2003	Infotehnoloogia teaduskond/tehnikateaduste magister
Tallinna Tehnikaülikool		Matemaatika-loodusteaduskond/doktorant

4. Keelteoskus (alg-, kesk- või kõrgtase)

Keel	Tase
Eesti	Kõrgtase
Inglise	Kõrgtase
Soome	Algtase
Itaalia	Algtase
Vene	Algtase

5. Täiendusõpe

Õppimise aeg	Täiendusõppe läbiviija nimetus
2003	*Politecnico di Milano*

6. Teenistuskäik

Töötamise aeg	Tööandja nimetus	Ametikoht
2001-2002	Tallinna Tehnikaülikool	Tehnik
2003-2003	Tallinna Tehnikaülikool	Insener
2004 – k.a.	Tallinna tehnikaülikool	Teadur

7. Teadustegevus

   Madala tasemega elektromagnetkiirguse mõju inimese EEG-le

8. Kaitstud lõputööd

   Eve Kukka, BSc. EEG muutuste dünaamika mikrolaine toimel, TTÜ, 2006

   Anna Suhhova, MSc. Moduleeritud mikrolaine mõju depressiooni EEG-le, TTÜ, 2007

   Jekaterina Rubljova, MSc. Inimese aju võimalik adaptatsioon moduleeritud mikrolainekiirguse toimel, TTÜ, 2007

9. Teadustöö põhisuunad

   SF0142084As02, Bioelektriliste signaalide interpreteerimine, 2002-2006

   SF0140027s07, Biosignaalide interpreteerimine meditsiinitehnikas, 2007-2012

   G5143, Elektromagnetvälja bioloogilise koosmõju mehhanismid, 2002-2005

   ETF6173, Mikrolainekiirguse mõju kognitiivsetele funktsioonidele, 2005-2008

   ETF6632, Elektromagnetvälja mõju aju rütmidele, 2006-2009

APPENDIX 3

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3. Education

Educational institution	Graduation year	Education (field of study/degree)
Tallinn University of Technology	2001	Faculty of Information Technology/BSc.
Tallinn University of Technology	2003	Faculty of Information Technology/MSc.
Tallinn University of Technology		Faculty of Science/PhD Student

4. Language competence/skills (fluent; average, basic skills)

Language	Level
Estonian	fluent
English	fluent
Finnish	basic skills
Italian	basic skills
Russian	basic skills

5. Special Courses

Period	Educational or other organisation
2003	*Politecnico di Milano*

6. Professional Employment

Period	Organisation	Position
2001-2002	Tallinn University of Technology	technician
2003-2003	Tallinn University of Technology	engineer
2004 –	Tallinn University of Technology	researcher

7. Scientific work

   Low-level microwave radiation effect on human EEG

8. Defended theses

   Eve Kukka, BSc. Dynamics of changes in EEG caused by microwave, TUT, 2006

   Anna Suhhova, MSc. Effect of modulated microwave exposure on depression EEG, TUT, 2007

   Jekaterina Rubljova, MSc. Possible adaptation of human brain to modulated microwave exposure, TUT, 2007

9. Main areas of scientific work/Current research topics

   SF0142084As02, Bioelectrical signals interpretation, 2002-2006

   SF0140027s07, Interpretation of Biosignals in Biomedical Engineering, 2007-2012

   G5143, Mechanisms of Biological Interaction of the EMF, 2002-2005

   ETF6173, Microwave effects on cognitive functions, 2005-2008

   ETF6632, Effect of electromagnetic radiation on brain oscillations, 2006-2009