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The possible effects of the UMTS mobile phone exposure on human cognitive functions

PhD thesis

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1 Introduction

Theres has been an exponential increase of mobile phone (MP) use in the recent decades resulting in substantially increased exposure to various high frequency electromagnetic (EM) fields. This may interfere with the physiology of the human body alone or combination with other environmental factors (Kwon and Hämäläinen, 2011). Experimental radio-frequency (RF) dosimetry data indicate that approximately 40 to 55 % of the MP RF output power is absorbed in the user's head which may cause electric and, as a consequence, physiological interference in the normal functioning of the brain (Gandhi, 2002).

According to a statistical survey by the International Telecommunication Union (ITU), to date, there are an estimated 5 billion subscriptions globally[1]. Furthermore, around 4 billion out of 5 billion MP subscribers use the third generation (3G) Universal Mobile Telecommunication System (UMTS) technology. Before the rapid spreading of the UMTS mobile phone technology, no systematic studies investigated the effects of the UMTS MP emitted EM fields on human brain function. Because of the large number of subscribers, any observable (even small) physiological effects of the EM fields may cause general public health problems.

Recently, several major European projects have been launched to close the gap and provide essential basic and applied scientific data on how EM fields may (adversely) interfere with brain information processing (measured with EEG). The two major research projects were the GUARD and the EMFnEAR. The latter was launched in 2004 to study the potential adverse effects of the newly introduced and rapidly spreading Universal Mobile Telecommunications System (UMTS) technology on the auditory system. In this project, one of the aims was to design and build an UMTS exposure system for use in human provocation studies (Stefanics et al., 2008; Parazzini et al., 2009). Several further studies investigated the potential effects of MPs exposure on human EEG. However the findings on potentially adverse or beneficial neurological effects together with numerous studies reporting no such biological effects make the field apparently non-converging and contradictory (van Rongen et al., 2009; Kwon and Hämäläinen, 2011).

[1] http://www.itu.int/en/ITU-D/Statistics/Documents/statistics/2014/stat_page_all_charts_2014.xls

In the presents research programme, first, we aimed at investigating the potential effects of UMTS MP exposure on human spontaneous EEG (sEEG) and automatic auditory deviance detection. Second, we conducted a novel experiment which was based on the so called "interaction approach". Namely, we proposed that, if the acute UMTS MP exposure alone would not reach the threshold for evoking measurable biological effects, then MP exposure combined with know facilitatory agent caffeine, may exert additive (or even, superadditive or synergistic) effects on facilitation of cognitive function. Thus, we systematically tested the possible acute combined action of simultaneous UMTS MP EMF exposure and caffeine intake on visual information processing.

2 Aim

In the present research programme our aims were to test the possible effects of UMTS MP exposure

- on spontaneous EEG activity indexed by delta (1-3 Hz), theta (4-8 Hz), alpha (9-12 Hz) and beta (13-32 Hz) frequency bands;
- on neural correlates of processing statistical regularities of environmental stimuli as automatic auditory deviance detection indexed by the mismatch negativity event related brain potential;
- on executive functions tested in a visual odd ball paradigm indexed by reaction time and the P300 event related brain potential, alone or in combination with caffeine intake.

3 Materials and Methods

3.1 Exposure system

Radiofrequency EMF exposure was administered using a standard UMTS Nokia 6650 MP. The RF source was controlled via an external software (Phoenix Service Software, Nokia, Espoo, Finland). The MP was connected to an external patch antenna, which was mounted on a plastic

headset. We performed specific absorption rate (SAR) validation measurements to determine possible differences between main parameters of the MP internal antenna and the patch antenna. We found no differences between the SAR values in the two cases, therefore, we used the patch antenna in the human studies. The patch antenna was mounted on a plastic headset in a position mimicking the normal use of a mobile phone. Throughout the study the distance between the antenna and the participant's head was 4-5 mm which correspods to the distance of the antenna from the phantom head as used in the SAR validation measurements.

3.2 Spontaneous EEG and automatic deviance detection

The subjects' head was exposed to either genuine or sham UMTS EMF irradiation for 30 min in two separate sessions with at least one week interval between the two sessions. Both experiments (sEEG, ERP) were designed in a double-blind fashion. During exposure, the patch antenna was unilaterally placed at a distance of 4-5 mm from the right ear above the tragus, mimicking the most frequent normal position of MP in use as reported by the subjects. Each session (either Genuine or Sham) comprised of two recording blocks before and after the irradiation (hereafter Pre and Post blocks, respectively). Each experiment lasted 50 min and comprised of 10 min for the first recording block, 30 min exposure to EMF and 10 min for the second recording block.

In the sEEG study, spontaneous brain activity was recorded for 10 min in each condition (Genuine/Sham - Pre/Post). During the recording sessions the participants' task was to watch a documentary clip in a relaxed fashion with sounds turned off and they were informed that details of the clip will not be debriefed later in the session.

In the MMN study in each block, a total of 1000 tone stimuli (900 standards and 100 deviants) were delivered. Similarly to the sEEG study, participants were instructed to ignore the auditory stimuli and watch a documentary clip with sound turned off.

EEG was recorded from three Ag/AgCl electrodes at midline Fz, Cz and Pz sites according to the international 10-20 system. The impedance at the start of each session was under 5 kOhm at all electrodes. EEG was recorded continuously at a sampling rate of 1 kHz with an analog band-pass filter of 0.16-150 Hz and a 50 Hz notch filter. Data were stored on a personal computer for off-line analysis. Data were analyzed off-line on a personal computer using built-in and self-

developed functions as well as the freeware EEGLAB toolbox (http://sccn.ucsd.edu/eeglab/) under the Matlab (MathWorks, Natick, MA) programming environment. In both sEEG and ERP analyses trials exceeding $\pm 100\ \mu V$ uV were rejected from further analyses.

Spontaneous EEG. Spontaneous (sEEG) data were analyzed on all three recording sites. Continuous data were filtered between 0.5-40 Hz and segmented into 2 s epochs (300 epochs per recording block, altogether). Fast Fourier Transform (FFT) algorithm was applied on the epoched data using 1024 FFT size. Log-transformed power values were calculated for pre-defined (delta: 1-3 Hz, theta: 4-8 Hz, alphaI: 9-10 Hz, alphaII: 11-12 Hz, betaI: 13-18 Hz, betaII: 19-32 Hz) frequency bands for each block for statistical analysis.

First, EEG spectral power was analyzed with three-way repeated-measures of ANOVAs (rANOVA). Second, to investigate any possible short-term effects, which might have occurred within the 10 min recording session, post-exposure recording blocks were divided into five two-min time intervals. Then, the putative EMF effects which may have developed or attenuated in a relatively short duration after the termination of exposure were analyzed by rANOVAs on the five intervals and after that, we compared the two first intervals in the post-sessions.

Automatic deviance detection. First, 600 ms epochs (100 ms before and 500 ms after tone onset), were extracted from raw data. Individual waveforms were baseline-corrected against the mean of the 100 ms pre-stimulus period. Amplitude and latency data of the four experimental conditions (Genuine/Sham and Pre/Post) were pooled together to determine grand average peak intervals for standard and deviant conditions separately.

Difference waveforms were calculated by subtracting ERP responses to standards from those to deviants, which revealed a prominent negative-going component (MMN) in the 80-190 ms latency range. To confirm the presence of the MMN component we compared ERP amplitudes to standard and deviant stimuli in the 126-176 ms, 127-177 ms and 134-184 intervals at Fz, Cz and Pz electrodes, respectively. The statistical analysis showed significant difference between the response to the standard and deviant stimuli at Fz and Cz, but not on Pz electrodes sites (verifying the MMN component). Thus, further analyses of the P50, MMN and P3a ERPs were carried out on the Fz and Cz electrodes.

3.3 Possible combined effects of caffeine and UMTS exposure on visual target detection indexed by P300

EEG was recorded with a 32-channel BrainAmp amplifier (Brain Products GmbH, München, Germany) using 30 Ag/AgCl electrodes mounted on an elastic cap (Easycap, Munich, Germany) according to the International 10-20 system.

In a double blind, crossover design volunteers took part in four experimental sessions, each corresponding to one of the four exposure conditions: 1) Control - placebo caffeine and sham UMTS, 2) UMTS alone - placebo caffeine and genuine UMTS, 3) Caffeine alone - genuine caffeine and sham UMTS, and 4) Combined - genuine caffeine and genuine UMTS) with a minimum two and maximum seven days between sessions.

EEG experiments started at 45 minutes after 3 mg/kg b.w. caffeine or placebo ingestion. In the visual oddball paradigm, simple geometrical shapes were presented to the subjects on a computer screen in the center of the visual field subtending 5o both in vertical and horizontal directions. A square served as the frequent standard (p=0.8) and a circle as the rare target (p=0.2) stimulus. The subjects' task was to press a button when a target was detected, while reaction time (RT) and EEG were recorded. Each recording session consisted of three consecutive recording blocks: 1) A block which preceded the exposure (Pre), followed by 2) a recording block during exposure (Exp), and 3) a post exposure block (Post) with no breaks in between blocks.

4 Results

4.1 Effects of UMTS exposure on spontaneous EEG and automatic deviance detection

Spontaneous EEG. First, the entire 10 min long blocks were analyzed. The results of the rANOVAs on spectral power data from the different frequency bands showed no significant effects of genuine UMTS EMF irradiation on EEG power in any of the studied frequency bands. However we found electrode main effects in each frequency band which indicated the different ongoing activities of different cortical areas.

Second, to investigate any possible short-term effects of the UMTS exposure, the 10 min recording blocks were divided into five consecutive 2-min intervals. Neither the analysis of EEG power data by rANOVA on five consecutive 2-min intervals nor the comparison of the two first 2-min intervals in the post sessions yielded significant effects of UMTS EMF exposure in any of the frequency bands.

Automatic deviance detection. Analysis of the latency of the P50 component evoked by standard stimuli yielded a significant SESSION $\times$ BLOCK interaction [F(1,25)=4,598; p=0,041; partial η^2=0,155]. However, the interaction did not survive the post-hoc test (Tukey's HSD, all p>0.19).

We found marginal SESSION $\times$ BLOCK interactions on the standard N100 [F(1,25)=3.485; p=0.073; partial η^2=0.122] and P200 [F(1,25)=3.568; p=0.07; partial η^2=0.124] amplitude. However the individual post-hoc Tukey HSD comparisons did not reveal any significant differences between the genuine and sham UMTS exposures.

The analyses of the P3a latency of the difference wave showed a marginal SESSION main effect [F(1,25)=3.564, p=0.07, partial η^2=0.124].

4.2 Combined effects of UMTS exposure and caffeine on visual information processing

Reaction time. We performed two different statistical analyses on the data of the Exp block. First, we tested the overall treatment effect on RT in the Exp block by comparing RTs during the whole block.

The analysis of RT during the Exp block yielded a significant treatment effect (F(3,66)=3.0, p<0.037, partial η^2=0.12). Post hoc Tukey's HSD showed that RT in Caffeine treatment (mean: 399 ms, SEM: 12.18) was significantly shorter (p<0.038) than in the Control treatment (mean: 419 ms, SEM: 9.8). However, RTs in the Combined treatment (mean: 405 ms, SEM: 10.61) did not differ from RTs in any other treatments (p>0.25). To further test for possible linear interaction between caffeine and UMTS exposures, we applied the summative model. As we did not find significant difference between the summed data in individual exposures ([Caffeine

- Control] + [UMTS - Control]) and the data in simultaneous exposures (Combined - Control), [F(1,22)=0.535, p=0.47, partial η^2=0.02], we do not suggest attenuating effects of the UMTS signal on caffeine-induced decrease of RT (Combined treatment).

Second, to investigate possible short-term effects during exposure, we divided the Exposure block into six equally long consecutive sub-blocks. Significant Pearson's correlations showed that RTs were increased over time from the first Exp sub-block in each treatment. Furthermore, we found significant Treatment [F(3,66)=3.001, p<0.037, partial η^2=0.12] main effects on RT. The Tukey HSD post hoc test revealed that the RT in the Caffeine treatment (mean: 399 ms, SEM: 12.2) was significantly shortened (p<0.039) compared to Control (mean: 419 ms, SEM: 9.8). No other significant differences were found between different treatments.

Event related potential. Similarly to the RT analysis here we applied also two different statistical analyses on the data of the Exposure block.

In the first analysis, the ANOVA of target P300 during the whole exposure yielded significant treatment effect on late area under the curve (AUC) [F(3,54)=3.65, p<0.018, partial η^2=0.169]. The post hoc analysis of the late AUC showed that caffeine significantly decreased the P300 AUC relative to the control treatment. Furthermore, neither the Tukey HSD test nor the analysis of the summative model showed significant differences between Caffeine and Combined treatments.

In the second analysis, the analysis of the segmented Exp. block showed significant sub-block effect on the P300 fractional area latency (FAL) [F(5,80)=12.54, p<0.001, partial η^2=0.44]. Post-hoc test revealed that P300 FAL significantly increased from the second to the last (6th) sub-block compared to the first one. This sub-block effect on the P300 FAL was further confirmed by Pearson's correlation (Control: R=0.89, p=0.02; UMTS: R=0.95, p<0.01; Caffeine: R=0.79, p=0.06; R=0.85, p=0.03). Furthermore, significant treatment effect was found on late AUC [F(3,48)=6.32, p=0.001, partial η^2=0.28]. Post hoc Tukey HSD revealed that the late AUC decreased in either Caffeine (mean: 2092.92 μV^2, SEM: 200.8) or Combined (mean: 2053.88 uV2, SEM: 198.22) treatments compared to Control (mean: 2437.24 μV^2, SEM: 226.72). Neither the Tukey HSD post-hoc test nor the analyses of the summative model of the P300 measures showed significant differences between the Caffeine and Combined treatments in each

sub-block.

5 Summary

Since there are an estimated 5 billion MP subscriptions globally the brain is exposed to high frequency EM fields which may cause electric and physiological interference with brain function. Although a large number of scientific studies have already investigated the effects of different MP related EMF exposures [continuous wave, Global System for Mobile Communications (GSM), UMTS] on the human brain the findings so far make the field apparently non-converging and sometimes contradictory. In addition, only a few studies have investigated the possible effects of the recently emerged third generation (3G) UMTS telecommunication signal on higher order human brain functions.

In the present research, we investigated the possible effects of 3G UMTS mobile phone like exposure on electroencephalography (EEG) and behavioral measures of human cognitive function.

In the first experiment, the effects of the UMTS exposure were tested on spontaneous EEG which is a precise measurement of the actual mental state. We found no modulatory effects of the UMTS EMF on the amplitudes of major frequency bands in the EEG. In the second experiment, the effects of 3G UMTS exposure were investigated on EEG correlates of automatic deviance detection and automatic attention shifting indexed by the event related potentials (ERP) MMN and P3a. In line with previous findings of other laboratories, we did not find any measurable modulatory effects of the 3G UMTS signal on auditory information processing. In the third experiment, we further hypothesized that if the 3G UMTS signal itself does not alter brain physiology it may still interact with environmental factors other than the EMF, which may result in additive or syngergistic excitatory effects in the level of the neurons. Thus, we developed a new experimental design to test the possible interaction of 3G UMTS exposure and a neuropharmacological intervention on higher order visual information processing. Here, caffeine was chosen, because it is one of the most widely consumed stimulants to the central nervous system and, in addition, it is common to take caffeine containing beverages (coffee, tea) and make phone calls at the same time on the daily basis. The present results indicate no effects of 3G UMTS exposure

in modulating known stimulant action of caffeine on reaction time or P300 ERP correlates of visual information processing.

In conclusion, 3G UMTS exposure alone does not alter cognitive performance and brain physiology indexed by spontaneous EEG, auditory or visual event related potential and reaction time. Furthermore, the 3G UMTS mobile phone signal does not interact additively with known behavioral and neurophysiological effects of caffeine.

The possible explanations of the present findings may be that the UMTS signal has 1) low output levels and/or 2) an ineffective modulation type to reach the threshold for observable biological effects (Binhi and Rubin, 2007; Juutilainen et al., 2011). Although the present results do not confirm any measurable UMTS MP effects on information processing in the brain, based on known physiological effects of the GSM MP signal, MP EMFs, in general, cannot be considered as biologically ineffective. Thus, we suggest that more research is needed to draw a final conclusion on whether and how different EMFs may cause interactive effects with brain function alone or in combination with other environmental factors.

6 Bibliography

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7 Publications

Publications related to thesis

1. **Trunk, A.**, Stefanics, G., Zentai, N., Kovács-Bálint, Zs., Thuróczy, Gy., Hernádi, I. (2013). No effects of a single 3G UMTS mobile phone exposure on spontaneous EEG activity, ERP correlates, and automatic deviance detection. *Bioelectromagnetics*, 34(1):31–42. **IF: 1,859**

2. **Trunk, A.**, Stefanics, G., Zentai, N., Bacskay, I., Felinger, A., Thuróczy, Gy., Hernádi, I. (2014). Lack of interaction between concurrent caffeine and mobile phone exposure on visual target detection: An ERP study. *Pharmacology, Biochemistry and Behavior*, 124C:412:420. **IF: 2.82**

Posters related to thesis

1. **Trunk, A.**, Stefanics, G., Kovács-Bálint, Zs., Thuróczy, Gy., Hernádi, I. (2010). The effect of a single thirty-minute 3G mobile phone irradiation on auditory evoked potentials. 7th Forum of Neuroscience (FENS), Amsterdam, Netherlands. (Poster presentation, abstract)

2. **Trunk, A.**, Stefanics, G., Kovács-Bálint, Zs., Thuróczy, Gy., Hernádi, I. (2010). The effect of 3G EMF exposure on auditory evoked potentials and automatic deviance detection: an EPR study. International Brain Research Organization (IBRO), Pécs, Hungary. (Poster presentation, abstract)

3. Stefanics, G., **Trunk, A.**, Kovács-Bálint, Zs., Thuróczy, Gy., Hernádi, I. (2010). The effect of thirty-minute 3G mobile phone exposure on auditory evoked potentials and the MMN response. 15th World Congress of Psychophysiology Budapest, Hungary. (Poster presentation, abstract)

4. **Trunk, A.**, Stefanics, G., Thuróczy, Gy., Hernádi, I. (2011). The effect of thirty-minute UMTS RF exposure on human auditory evoked potentials and the MMN response. 10th International Conference of the European Bioelectromanetics Association (EBEA), Rome, Italy. (Poster presentation, abstract)

5. **Trunk, A.**, Stefanics, G., Zentai, N., Kovács-Bálint, Zs., Thuróczy, Gy., Hernádi, I. (2011). The effect of a single 30 minute long 3G EMF exposure on auditory evoked potentials, automatic deviance detection and spontaneous EEG (sEEG). 13th Conference of the Hungarian Neuroscience Society (MITT), Budapest, Hungary. (Poster presentation, abstract)

6. **Trunk, A.**, Stefanics, G., Zentai, N., Hernádi, I. (2011). A koffein hatása az emberi auditoros és vizuális eseményhez kötött kiváltott potenciálokra ingerdiszkriminációs paradigmában. Magyar Farmakológus Anatómus Mikrocirkulációs Élettani Társaságok Közös Tudományos Konferenciája (FAME), Pécs, Magyarország. (Poszter előadás, absztrakt)

7. **Trunk, A.**, Stefanics, G., Zentai, N., Bacskay, I., Felinger, A., Thuróczy, Gy., Hernádi, I. (2012). Novel experimental design to test potential synergistic effects of caffeine and 3G mobile phone exposure on human visual evoked potentials. 8th Forum of Neuroscience (FENS), Barcelona, Spain. (Poster presentation, abstract)

8. **Trunk, A.**, Stefanics, G., Zentai, N., Bacskay, I., Felinger, A., Thuróczy, Gy., Hernádi, I. (2012). Possible synergistic effects of caffeine and 3G mobile phone exposure on human reaction time and visual event-related potentials. International Brain Research Organization (IBRO), Szeged, Hungary. (Poster presentation, abstract)

9. **Trunk, A.**, Zentai, N., Stefanics, G., Bacskay, I., Felinger, A., Thuróczy, Gy., Hernádi, I. (2012). Combined effects of caffeine and 3G mobile phone exposure on predictive coding in the human brain. ERNI-HSF, Brain oscillations in health and disease, Budapest, Hungary. (Poster presentation, abstract)

10. **Trunk, A.**, Zentai, N., Stefanics, G., Bacskay, I., Felinger, A., Thuróczy, Gy., Hernádi, I. (2013). No combined effects of caffeine and 3G mobile phone exposure on predictive coding in the human brain. 14th Conference of the Hungarian Neuroscience Society (MITT), Budapest, Hungary. (Poster presentation, abstract)

11. **Trunk, A.**, Stefanics, G., Zentai, N., Bacskay, I., Felinger, A., Thuróczy, Gy., Hernádi, I. (2013). No evidence of interactions between caffeine intake and 3G mobile phone exposure on target expectancy in the human brain. II. Interdisciplinary Doctoral Conference, Pécs, Hungary. (Poster presentation, abstract)

12. **Trunk, A.**, Stefanics, G., Zentai, N., Bacskay, I., Felinger, A., Thuróczy, Gy., Hernádi, I. (2013). Investigation of possible synergistic effects of caffeine intake and UMTS mobile phone-like exposure on predictive coding in the human brain. 11th International Conference of the European Bioelectromanetics Association (EBEA), Thessaloniki, Greece. (Poster presentation, abstract)

13. **Trunk, A.**, Zentai, N., Csathó, Á., Hernádi, I. (2014). Koffein vizuális figyelmet javító hatása: eseményhez kötött potenciál vizsgálat. A Magyar Kísérletes és Klinikai Farmakológiai Társaság Experimentális Farmakológiai szekciójának VIII. szimpóziuma és az MBKE

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14. **Trunk, A.**, Stefanics, G., Zentai, N., Bacskay, I., Felinger, A., Thuróczy, Gy., Hernádi, I. (2014). Investigation of possible synergistic effects of caffeine intake and UMTS mobile phone-like exposure on human visual attention. 7th COURSE: "Biological effects of combined exposures to EMF and other chemical and physical agents", Erice-Sicily, Italy. (Poster presentation, abstract)

15. **Trunk, A.**, Zentai, N., Csathó, Á., Gács, B., Hernádi, I. (2014). Modulatory effects of caffeine on human visual attention indexed by the N200 event related potential. 9th Forum of Neuroscience (FENS), Milan, Italy. (Poster presentation, abstract)

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1. Kovács-Bálint, Zs., Stefanics, G., **Trunk, A.**, Hernádi, I. (2014). Automatic detection of trustworthiness of the face: a visual mismatch negativity study. *Acta Biologica Hungarica*, 65(1), pp. 1-12. **0,504**.

2. Zentai, N., Csathó, Á., **Trunk, A.**, Fiocchi, S., Parazzini, M., Ravazzani, P., Thuróczy, Gy., Hernádi, I. (2014). No effect of acute Wi-Fi electromagnetic field exposure on spontaneous EEG activity and psychomotor vigilance in healthy human volunteers. (*under review*).

3. Zentai, N., Fiocchi, S., Parazzini, M., **Trunk, A.**, Juhász, P., Ravazzani, P., Hernádi, I., Thuróczy, Gy. (2014). Exposure to RF emitted by commercial WLAN system: dosimetry assessment for human provocation studies. (*under review*).

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1. Dénes, V., Hernádi, I., **Trunk, A.** (2010). Biológiai laboratóriumi alapismeretek IV. Élettani gyakorlatok. Egyetemi elektronikus jegyzet.

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