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The effect of GSM-like ELF radiation on the alpha band of the human resting EEG

Nicholas Perentos, Rodney J. Croft, Raymond J. McKenzie, Dean Cvetkovic, and Irena Cosic, *Senior Member, IEEE*

***Abstract*—Mobile phone handsets such as those operating in the GSM network emit extremely low frequency electromagnetic fields ranging from DC to at least 40 kHz. As a subpart of an extended protocol, the influence of these fields on the human resting EEG has been investigated in a fully counter balanced, double blind, cross-over design study that recruited 72 healthy volunteers. A decrease in the alpha frequency band was observed during the 20 minutes of ELF exposure in the exposed hemisphere only. This result suggests that ELF fields as emitted from GSM handsets during the DTX mode may have an effect on the resting alpha band of the human EEG.**

I. Introduction

There is ongoing concern regarding possible health and biological effects that can arise from the exposure of users to the electromagnetic emissions that personal telecommunication devices such as Global System for Mobiles (GSM) handsets emit. Investigations seem to detect biological effects associated with the exposure in equal frequency with investigations that do not. This fact combined with the absence of any acceptable physical mechanism that could explain any of the observed effects requires empirical tests of the possibility to continue.

We have previously examined the effects of continuous and pulsed mobile phone like radiation on the human resting EEG [1], and so have many others [2]. One aspect of mobile phone exposure, which remains sidelined in current research in comparison to RF, is that caused by the Extremely Low Frequency (ELF) field which is produced by the flow of currents inside handset devices. The sole influence of this exposure on human brain variables has yet to be studied. Some relevant works are those that used real handsets for their investigations, and as such combine RF and ELF exposures. Examples are the works of Russel and Cosic [3], Curcio et al. [4], and Croft et al. [5], but are difficult to compare due to the combination of exposures. The works of Cook et al. are also relevant where changes in brain activity after and during exposure to pulsed ELF fields were observed [6, 7]. However, field characteristics in the works of Cook et al. significantly differed from those of mobile phones. Differences lie in the intensity, frequency content and spatial distribution of the fields.

These characteristics have been studied by a few independent laboratories. The radiation is found to be spatially confined in close proximity to the source and spatial field decay is rapid, dropping significantly by the time it reaches the centre of the brain [8, 9]. The radiation dose associated with these ELF exposures has also been assessed and was found to be well below relevant exposure guidelines.

So while technical and dosimetric aspects of the fields have been the subject of investigations it remains to determine whether they are capable of causing any measurable changes in brain variables.

The statistical variation and contradictory nature of previous results in RF bioeffects literature can be avoided by employing robust experimental protocols. A similar approach was followed in our earlier study where we adjusted the experimental protocol accordingly, partly building on previous research, to avoid most methodological limitations. However one such limitation remained, that of small sample size, which led us to view those results with caution.

In fact very few studies have used sample sizes greater than 30 and just two studies have recruited more than 50 volunteers [5, 10]. The significance of large samples is also stressed in a recent review by Valentini et al. [2].

To address this issue and the relative lack of large sample size studies we performed an extended double blind study where we recruited 72 healthy participants and studied their resting brain activity under three different electromagnetic radiations, pulse modulated RF, continuous RF and ELF fields. In this paper we present results pertaining to the ELF exposure, and specifically the resting brain activity in the alpha band region.

II. Materials and Methods

A. Subjects

Seventy two healthy volunteers (35 female and 37 male) participated in the study. The mean age of the sample was 24.5 years and the standard deviation was 5.4 years. Participants were instructed to abstain from alcohol

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N. Perentos is with RMIT University, Melbourne, VIC 3000, Australia (phone: +61 4 2192 5572; fax: +61 3 9925 2954; e-mail: n.perentos@student.rmit.edu.au).

R. Croft is with Swinburne University, Melbourne, Australia (e-mail: RCroft@groupwise.swin.edu.au).

R. McKenzie is with RMIT University, Melbourne, Australia (e-mail: Ray.McKenzie@rmit.edu.au).

D. Cvetkovic is with RMIT University, Melbourne, Australia (e-mail: Dean.Cvetkovic@rmit.edu.au).

I. Cosic is with RMIT University, Melbourne, Australia (e-mail: Irena.Cosic@rmit.edu.au).

consumption within the 24 hours before the experiment, and abstain from mobile phone use and caffeine consumption within the six hours before the experiment. The Human Research Ethics Committees of RMIT and Swinburne Universities approved the study protocol. Written informed consent was obtained from all participants prior to any experimental procedures. A monetary reimbursement was made available to participants who concluded the experiment.

B. Protocol

Participants attended a two hour recording session which included four 30 minute intervals of EEG recordings, Fig 1. In each interval participants received one of four conditions, sham, continuous RF, pulsed RF and pure ELF electromagnetic exposures. The order of exposure was randomly assigned in a fully counter balanced, double blind cross-over design. In each 30 minute interval, the first five minutes were stressor-free serving as a baseline, followed by a twenty minute exposure, and lastly, a five minute post exposure period. Electrophysiological readings were recorded continuously throughout while participants were seated comfortably with eyes open. Although the characteristic alpha peak is suppressed during eyes open when compared with eyes closed, due to the long recording intervals the eyes open condition will help avoid large fluctuations in alertness. Four minute breaks were introduced between the 30 minute intervals where participants were asked to complete an activation deactivation adjective checklist (AD-ACL) and then were allowed to stretch and drink water.

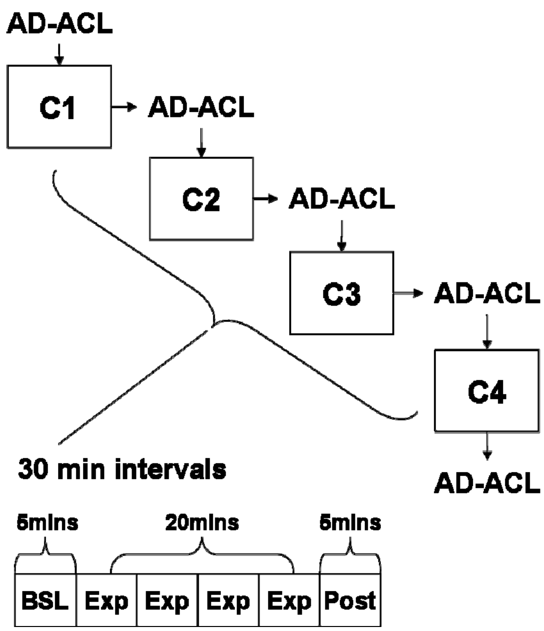

Fig1. The protocol. Each Condition (C1-C4) is randomly assigned to one of four radiation sources CW-RF, PM-RF, ELF and Sham and lasts for 20 minutes. Before and after each condition an AD-ACL questionnaire is administered.

TABLE I
SUMMARY OF STATISTICAL ANALYSES

	Comparison		F	df	*P*
During Exposure	Main Effect	S vs. ELF	1.676	71	0.340
	Ipsi vs. Contra	S vs. ELF	5.493	71	*0.020**
After Exposure	Main Effect	S vs. ELF	1.676	71	0.198
	Ipsi vs. Contra	S vs. ELF	1.811	71	0.634

The summary of statistical analysis is shown. Since comparisons are hypothesis driven the critical level is kept at $\alpha = 0.05$. The P values of significant comparisons are marked with an asterisk. S, Sham; ELF, Active ELF radiation condition; Ipsi, Ipsilateral to exposure; Contra, Contralateral to exposure.

C. Data Acquisition

Participants were fitted with a Compumedics Neuroscan 19 Channel Tin Quick EEG Cap employing the standard 10/20 international electrode positioning system. Reference levels were recorded from unlinked mastoids (M1 and M2). In addition the vertical and horizontal components of the EOG were monitored. Data were recorded through the Synamps^2 system (Compumedics, Ltd) with a sampling frequency of 250 Hz. Electrode impedances were kept below 5 kΩ. Recordings took place in an electromagnetically semi-shielded room. Apart from the subject under test the experimenter was present in the same room, but no visual contact was possible

D. Electromagnetic exposure

Exposures were delivered through a specially constructed model handset which included both RF and ELF radiating elements within a Nokia 3110 mobile phone housing. The real mobile phone housing was chosen so as to preserve ecological validity. The plastic casing was stripped from any metallic coatings so as to influence the radiating properties of the antennae as little as possible. The ELF exposure source was a wire loop of 9mm radius carrying enough current to produce a magnetic field of 25 μT at a distance of 10 mm from the outer surface of the handsets casing. Preliminary results through numerical simulations show that absolute peak currents generated within participants' heads do not exceed 100 $\mu A/m^2$ or 1% of ICNIRP exposure limits. Compliance of exposure with the ICNIRP limits is also

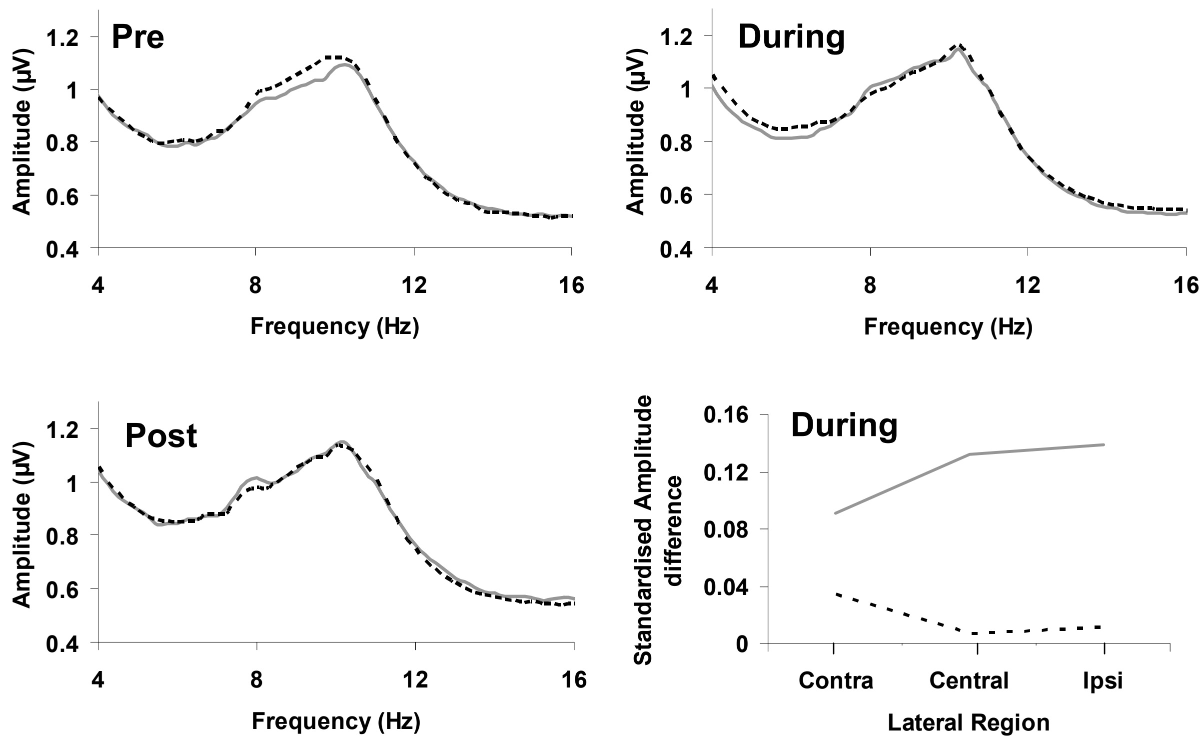

Fig.2 Grand Mean EEG spectral amplitude data are shown in panels (a) pre exposure, panel (b) during exposure and panel (c) after exposure. Panel (d) is the standardized difference of amplitude data during exposure as a function of lateral region. ELF condition, dotted black line; Sham condition, solid grey line; Contra, Contralateral to exposure, Mid, Midline; and Ipsi, Ispilateral to exposure.

suggested indirectly through the works of Jokela et al., where fields three times as large were assessed against ICNIRP basic restrictions and were shown to only reach the 28% mark. As such, we are sufficiently confident that compliance with exposure guidelines was achieved. Currents inside the loop were set to simulate the DTX frame structure thus include 2, 8, 217 Hz and harmonics. The handset was positioned according to the standard ear to mouth position on the right hemisphere, and was held in place with a specially constructed cradle. Additionally, another non radiating handset was placed on the left side so as to avoid lateralisation of participants' attention.

A. Data Analysis

First, channels containing large amplitude, continuous artifact were excluded from the analysis through visual inspection. Data were subsequently re-referenced to the numerical average of M1 and M2 and submitted through the RAAA automated artifact reduction routine [11]. EOG corrected data were epoched in 4 second intervals and spline-fitted to 1024 samples. Epochs were baseline corrected throughout the entire length. Epochs which included data of voltages greater than 200 µV were considered as containing artifacts and were automatically rejected. Epochs were then grouped into six 5-minute intervals (pre, during 1, during 2, during 3, during 4 and post), and average spectral amplitudes were calculated for each 5-minute interval. Spectra were divided in the nominal EEG bands: Delta (0 - 3.74634), Theta (3.99609 - 7.74243), Alpha (7.99219 - 12.7375) and Beta (12.9873 - 25.3252) Hz.

B. Statistical Analysis

The statistical analysis was based on difference values computed from the average spectral amplitude data of EEG bands pre exposure to those during and post exposure. Electrodes were grouped by averaging to reduce noise and the amount of statistical comparisons. Electrode groups were: Left Frontal (LF = mean (Fp1, F3, F7)), Mid Frontal (Fz), Right Frontal (RF = mean (Fp2, F4, F8), Left Central (LC = mean (C3, T7)), Mid Central (Cz), Right Central (RC = mean (C4, T8), Left Posterior (LP = mean (P3, P7, O1)) Mid Posterior (Pz), and Right Posterior(RP = mean (P4, P8, O2).To remove any effects associated with the duration of experiment, data were grouped according to time intervals i.e. 1st 30 minutes 2nd, 3rd and 4th and corresponding z-scores were calculated for each interval. As such data of each interval have identical means of 0 and standard deviations of 1. Subsequently, statistical significance was tested with Repeated Measures Analysis of Variance (RM-ANOVA).

The alpha band of the human EEG seems to be the most sensitive to electromagnetic exposures. Here we test the specific finding reported in literature of alpha activity either increased or decreased [6, 7]. Through the ANOVA design, we test for main effects of Exposure (Sham vs. Active) and the interaction of exposure with Laterality (ipsilateral vs. contralateral to exposure). This statistical analysis is performed for the periods during exposure as well as after exposure. Since these hypothesis driven tests are designed to test specific findings in literature the overall significance criterion is kept at the $\alpha = 0.05$ level.

III. Results

The results of the statistical analysis are listed in Table 1, and grand means for each experimental condition are depicted in Fig 2(a), (b) and (c). No significance was observed for the main effect of exposure either during or after exposure. During exposure, the interaction of exposure condition with laterality reached significance ($p = 0.022$) where Ipsilateral to exposure the alpha band difference value was lower in the active exposure in comparison to the sham, Fig 2(d). There was no effect for the interaction of exposure condition and laterality after exposure cessation.

IV. Discussion

The reported result arises due to a larger increase in alpha activity in the sham exposure interval in comparison to the ELF exposure, Fig 2(a). As such, the effect can be interpreted as a suppression of the tendency of alpha activity to increase throughout the half hour interval.

The reported decreased alpha activity during ELF exposure is consistent with the finding of Cook et al. [7] where a general posterior decrease is observed. The bilateral nature of that finding does not contradict the unilateral nature of the finding reported here since a homogeneous exposure throughout the head was used by Cook et al. as opposed to the mobile phone related field used here which is spatially confined to at most within the exposed hemisphere.

The no-effect result for the post exposure period again is partly in line with the latter results of Cook et al [7], where only trend levels of alpha increase were detected but is contradictory to the earlier result where an increase in alpha activity was observed [6].

Some studies that investigated the effects of GSM like RF fields on the human resting EEG, for example those of Russell and Cosic, Croft et al. and Curcio et al., used real GSM handsets [3-5]. For this reason their reported results could be viewed as a combination of RF and ELF exposures since in real handsets the two cannot be separated. It would be difficult to draw comparisons with those findings due to the presence of the RF stressor.

Despite the large sample size, there are two main reasons why a limited interpretation of this result is warranted. Firstly the same day protocol employed combined with the 14 minute interval between exposures leaves a possibility of carry over effects. However full counterbalancing, and a moving baseline were employed, which should generally guard against this possibility. In addition, the conversion or results to z-scores provides guards further against carry over effects. Since four exposure conditions were part of the experiment, a detailed analysis taking into account individual exposure condition permutations and the effect of previous exposure to subsequent ones might reveal more information on this effect. Secondly due to the extended duration of each exposure session (30 minutes) an increased degree of variability of alertness would be expected in comparison with studies with shorter protocols. Such variability can lead to an increase in error variance and potentially mask a condition related effect.

In conclusion, for the first time, the effect of the GSM handset generated ELF field on the human resting EEG has been assessed. The field was designed to mimic that emitted by GSM handsets during DTX conditions and replicates it in terms of frequency content spectral and spatial distribution as well as intensity. A decrease in the alpha frequency band was observed during ELF exposure in the exposed hemisphere only. This result suggests that ELF fields as emitted from GSM handsets during DTX mode may have an affect on the resting alpha band of the human EEG.

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