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The Effects Of Mobile Phone Electro-Magnetic Field On Functional Connectivity Of The Brain

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Abstract: The change in functional connectivity between different regions of the brain can affect the performance of various cognitive processes. Because of this, subjects having neurological disorders have shown a significant change in the functional connectivity as compared to control subjects. Therefore the study of functional connectivity have become an important tool for the diagnosis and research of various neurological disorders. EEG-based coherence function is one of useful signal processing for examining the functional connectivity between various regions of the brain.

The major aim of this study is to investigate the effects of electromagnetic fields (EMF) emitted by cellular phones on functional connectivity existing between various regions of the brain. The functional connectivity was assessed by comparing the magnitude square coherencies (MSCs) of both groups of subjects who were performing visual attention experiment with and without the exposure to a digital 902 MHz field. The subjects were instructed to detect change in the two-picture stimulus presented before them through the computer screen. For the group of subjects with the exposure to EMF, the significant difference in MSC function between change detection and no-change detection trials was examined using the two-way ANOVA statistical test. However for group of subjects without the exposure of EMF, the two-way ANOVA did not reveal the significance level of difference between change detection and no-change detection trials. The considerable loss in the significance level of MSC difference between change detection and no-change detection trial for the group of subjects with the exposure to EMF indicates that EMF may affect the functional connectivity of the brain.

Keywords: EEG, electromagnetic field, mobile phone, coherence function.

1. INTRODUCTION

The cell phones emit radio waves which are composed of both electric and magnetic fields. The radio waves of cell phone can affect the brain by its interaction with the electric field generated inside the brain. Literature reports changes in EEG of healthy subjects over midline posterior sites of the brain (Croft 2002; Huber, 2002; Cook 2004; Regel; 2007) and over frontal and temporal areas (Kramareko; 2003) when subjects were exposed to mobile phone EMF ranging from 30minutes to 60 minutes. Various studies have reported effects of mobile phone EMF on event related potentials (ERPs) which are time-locked EEG signals recorded while subject is busy in performing either visual or audio tasks. Hamblin *et al.,* (2004) reported changes in the amplitude and latency of N_{100} component of event related potentials in healthy subjects exposed to mobile radio waves of 895 MHz for 30 minutes during the auditory oddball task. However the group of same authors comparatively in well-designed study reported no evidence of radio waves effects on human brain during the auditory and visual tasks. Maby *et al.,* 2006; Papageorgiou *et al.,* 2006 reported changes in P_{50} and P_{200} components of ERPs in healthy subjects exposed to mobile radio waves 0f 1000 MHz for 30 minutes during the auditory tasks respectively.

EEG literature reports various signals processing methods such as power spectral density function which describes the energy distribution of signal. Literature provides substantial amount of evidence that subjects exposed to mobile phone EMF exhibit increased spectral power spectral density function (Reiser and Dimpfel, 95; Heitanan *et al.,* 2000; Huber *et al.,* 2002; Regal *et al.,* 2007; Curcio *et al.,* 2005; Hinikus *et al.,* 2008). EEG-based coherence function is another signal processing method which is ueseful tool for examining the functional connectivity between regions of the brain. Relatively few studies have examined effects of mobile phone EMF on functional connectivity of the brain using the EEG coherence function (Vecchio *et al.,* 2006; Vecchio *et al.,* 2007 Stefanics *et al.,* 2008).

The major disadvantage of studies reported in literature for the effects of mobile phone EMF on EEG-coherence function (functional connectivity of the brain) is that it is limited to the frequency domain analysis of EEG signals. Whereas most kind of EEG signals are time-varying and might contain important information both in time and frequency domain. Moreover literature does not discuss the issue of volume conduction on EEG coherence analysis for the effects of mobile phone EMF. The issue of volume conduction is important

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because volume conduction effects can introduce the artificial coherence into the real coherence value (Nunez and Srinivasan, 2005). In view of the above limitations, the major aims of this study are following. (1) It detects the effects of mobile phone EMF on EEG coherence function by minimizing the effects of volume conduction. (2) It uses wavelet analysis to study EEG coherence function. The advantage of wavelet analysis is that it provides time-frequency analysis of signals at optimal time-frequency resolution. Finally it examines the effects of mobile phone EMF on EEG coherence in the context of working memory process. For this purpose, the event related potential, elicited during the visual oddball experiment, were used in this study.

2. METHODS

ERPs were recorded from 12 healthy subjects performing visual oddball task. It was obtained from the the laboratory of the brain and psychological sciences research centre, Swinburne University of technology Melbourne Australia. For further details on this data set, see Hamblin et al., (2004) where ERP analysis using this data set has been published. The brief detail of this data set is given below. 12 healthy aged between 19-44 years were recruited as paid volunteers for the recording of the ERP data set. Subjects were asked to be in relax position as well as to avoid any unnecessary movement . International 10/10 system of electrode's position based on 62 electrodes was used for recording the ERP data at the sampling rate of 1000Hz. The GSM digital mobile phone was held inside the cradle which was fixed at the electro-cap.

Subjects were shown two types of pictures: (1) Pictures of squares (2) Pictures of circles through the monitor of computer. Any picture out of these pictures shown to the subjects is called stimulus. The trial consists of two picture stimuli and two blank displays. Each trail started from a 500 ms blank display followed by 500 ms picture stimulus. After this picture stimulus another 500ms blank display appeared following another stimulus. The subjects were asked to recognize the picture of circles in case if they are repeated in trial by pressing the mouse key. The trial was called the correct trial if the subjects were successful in recognizing the pictures of circles otherwise it was called missed trial. The GSM digital mobile phone of Nokia 6110 with average output power of 250mW was used. The transmitted signal was RF carrier pulse modulated at 217 Hz. The experiment was divided into two sessions: during the first session subjects were asked to perform visual oddball task without the exposure to mobile phone EMF. During the next session, subjects were exposed to mobile phone EMF for the 45 minutes of duration while performing the visual oddball experiment.

Coherence Analysis

Computation of Wavelet-based coherence

The wavelet transform is used to transform given discrete time series *x(n)* into time-frequency domain using the following relation:

$$X_n^x(a,b) = \frac{1}{\sqrt{a}} \sum_{n=1}^{N} x(n)\psi_{a,b}^*(n) \quad (1)$$

The alphabetical symbols a and b are called scaling and position parameters which are used to stretch or expand the mother wavelet and to change the position of the mother wavelet respectively. The $\psi_{a,b}^*(n)$ is wavelet function and for $a = 1$ and $b = 0$, it is called mother wavelet.

If $X_n^x(a,b)$ and $Y_n^y(a,b)$ are wavelet transforms of signals $x(n)$ and $y(n)$ respectively, the wavelet cross and auto spectra are given by following relations:

$$C_n^{xy}(a,b) = X_n^x(a,b) \cdot Y_n^{*x}(a,b) \quad (2)$$

$$P_n^{xx}(a,b) = X_n^x(a,b) \cdot X_n^{*x}(a,b) \quad (3)$$

$$P_n^{yy}(a,b) = Y_n^y(a,b) \cdot Y_n^{*y}(a,b) \quad (4)$$

The wavelet coherence is given by

$$\Upsilon_n^{xy}(a,b) = \frac{C_n^{xy}(a,b)}{\sqrt{P_n^{xx}(a,b) \cdot P_n^{yy}(a,b)}} \quad (5)$$

The square of absolute value of equation (5) is called magnitude square coherence and it is abbreviated as MSC. In this study, the MSC of each trial for each pair of electrodes was estimated using the Morlet mother wavelet with non-dimensional frequency $\omega_0 = 6$ as it provides nearly equivalent relationship between scaling parameter of the wavelet Fourier period, therefore providing a useful definition of frequency for wavelets. Then the average of MSCs across repeated trails was obtained then mean band MSC was estimated by averaging that MSC across the time-frequency domain of $[t_1 - t_2]$ $[f_1 - f_2]$. The mean band MSC is defined here for assessing the effects of standard frequency bands across particular period of time by using the two-way ANOVA statistical test. The time-frequency region for mean band MSCs are defined for four frequency regions [4-7 Hz], [8–12], [15-26Hz], and [30-50Hz] and mean band MSC corresponding to each of these frequency regions are called in this study theta, alpha, beta, and gamma band MSCs respectively.

Statistical Analysis

The statistical significance of MSC was assessed using the confidential interval based on the method of Gish, H., and Cochran as following

$$Z_t = 1 - (1 - d)^{N-1} 0 \leq d \leq 1 \quad (6)$$

where d represents the detection threshold for N number of repeated trials to achieve Z_t level of confidence. For a 95 % confidence interval, the equation (6) can be written as

$$d_{95\%} = 1 - 0.05^{\frac{1}{N}-1} \quad (7)$$

The MSC values less than $d_{95\%}$ were excluded from the further analysis since they were considered non-significant values.

3. RESULTS AND DISCUSSION

The Volume conduction effects due to the uncorrelated sources (VCUS) present in the brain introduces a biased estimates into the true value of MSC (Nunez and Srinivasan., 2005). The MSCs affected by the VCUS effects were excluded from further analysis after being detected using the characteristic that VCUS effects on MSC are independent of both time and frequency (Memon and Kalhoro, 2012).

The alpha band MSC

The two-way ANOVA statistical test revealed significant increase in correct trial alpha band MSC as compared to the missed trial alpha band MSC irrespective of whether the subjects were exposed to mobile phone EMF or not. This effect was observed for parietal, frontal and occipital regions of the brain. This result provides an evidence that functional connectivity might play an important role in understanding the neurophysiological mechanism of change detection. For the time-durations of pre-stimulus, first stimulus and inter-stimulus intervals, this study detected various increased correct trial alpha band MSCs as compared to the corresponding missed trial alpha band MSCs while subjects were not exposed to mobile phone EMF. However statistical significance difference in alpha band MSC between correct trial and missed trial MSC was examined only for the time duration of second stimulus. This might be due to the reason that decision making process takes place during the time duration of second stimulus and therefore significant difference in this time interval was observed. The non-significance difference in MSC for other time durations, might be due to the reason that alpha band is related to the intelligence and subjects who detected the correct trials might be assumed more intelligent than those who could not detect correct trials and therefore an increase in MSCs for these time duration was observed. The number of correct trials while the subjects were exposed to mobile phone EMF was found lower than those when subjects were not exposed to mobile phone EMF. This result provides an evidence that mobile phone EMF might affect the performance of detecting correct trial. The alpha band MSCs for correct and missed trials while subjects were not exposed to mobile phone EMF were compared to those corresponding MSCs while subjects were exposed to mobile phone EMF. Various subjects exhibited decrease in missed trial MSC due to the mobile phone EMF as compared to those when subjects were not exposed to the mobile phone EMF. But no significant decrease in the missed trial MSC due to the mobile phone EMF was observed using the ANOVA test. However as shown in (**Table 1**) that the statistically significant decrease in MSC due to mobile phone EMF was observed only for correct trial MSCs. This finding leads to the conclusion that mobile phone EMF might affect the functional connectivity which is related to the change detection or detection of correct visual stimulus.

The gamma band MSC

The gamma band of frequency revealed statistically significant increase in correct trial gamma band MSC as compared to missed trial gamma band MSC for trials without the exposure of mobile phone EMF and with the exposure of mobile phone EMF. This effect was observed for frontal, central, and parietal regions of the brain. Correct trial MSCs for subjects performing trial without the exposure of mobile phone EMF were significantly found larger as compared to those corresponding MSCs when subjects were exposed to the mobile phone EMF. As shown in (**Table1**) that for different positions of electrodes and for the time duration of second stimulus, the two-way ANOVA test reveals significant decrease in correct trial MSCs due to the exposure of the mobile phone EMF.

The beta band MSC

In contrast to the alpha and gamma band of frequencies, the beta band of frequency revealed statistically significant decrease in correct trial beta band MSC as compared to missed trial beta band MSC for trials without the exposure of mobile phone EMF and for trials with the exposure of mobile phone EMF. This effect was observed for frontal, central, and parietal regions of the brain. The MSCs for subjects performing correct trial with the exposure of mobile phone EMF were compared to the missed trial MSCs for same subjects performing missed trial without the exposure of mobile phone EMF. As shown in (**Table 1**) that correct trial beta band MSCs during the trial without the exposure of mobile phone EMF were found significantly lower as compared to the corresponding missed trial beta band MSCs with the exposure of mobile phone EMF. However ANOVA test revealed significant difference only for frontal-occipital regions of the brain. No significant increase in beta band MSC due to mobile phone EMF was examined for frontal and parietal regions of the brain. The reduce in correct trial beta band MSC as compared to the corresponding correct trial alpha band MSC is due to the fact that particular cognitive functions such as work load of visual short term memory(VSTM), intelligence, cognitive binding, and matching of (VSTM) are related to particular frequency band and therefore they reflect different neuropsychological mechanism.

Table 1: The two-way ANOVA test shows significant increase in correct trial MSCs for subjects exposed mobile phone EMF (denoted by EMSC) as compared to those MSCs when subjects were not exposed mobile phone EMF(denoted by NEMSC).

Electrode positions	ANOVA results for gamma band		ANOVA results for beta band		ANOVA results for alpha band	
	F	P-value	F	P-value	F	P-value
	5.9	0.034	4.91	0.734	4.78	0.027
	EMSC	NEMSC	EMSC	NEMSC	NEMSC	NEMSC
FZ-PZ	0.33+0.04	0.47+0.03	0.56+0.04	0.53+0.07	0.31+0.05	0.49+0.03
FZ-P3	0.62+0.05	0.35+0.05	0.64+0.05	0.60+0.04	0.22+0.91	0.37+0.08
FZ-P4	0.80+0.05	0.85+0.02	0.35+0.07	0.38+0.05	1.63+0.02	1.19+0.07
FZ-P7	0.23+0.07	0.38+1.01	0.77+0.07	0.80+0.05	1.15+0.08	1.19+0.03
FZ-P8	0.71+0.02	0.56+0.05	0.04+1.03	0.14+1.03	0.76+0.05	1.23+0.08
F3-PZ	0.82+1.02	0.85+0.03	0.84+1.02	0.82+1.02	0.51+0.07	0.72+1.02
F3-P3	0.23+0.05	0.37+0.08	1.11+1.03	1.12+0.09	1.23+0.02	0.80+1.01
F3-P4	0.56+0.04	0.67+1.01	0.85+0.09	0.64+0.04	1.73+0.02	0.74+0.05
F3-P7	0.28+1.02	0.31+0.02	0.19+0.08	0.24+1.03	0.41+0.07	0.42+0.05
F3-P8	0.38+0.05	0.51+0.05	0.14+0.04	0.19+0.04	0.08+1.02	1.01+1.01
F4-PZ	0.89+1.03	1.02+1.01	0.57+0.04	0.01+0.08	0.09+0.07	1.27+0.06
F4-P3	0.23+0.07	0.42+0.05	0.35+0.08	0.39+0.03	0.06+0.08	0.18+0.06
F4-P4	0.30+0.09	0.51 +0.07	1.15+0.07	1.24+1.02	0.46+1.01	1.55+0.01
F4-P7	0.18 +0.04	0.41+0.08	0.81+0.06	0.85+0.09	0.70+0.05	1.06+0.04
F4-P8	0.87+1.03	1.02+0.03	1.55+1.03	1.02+0.04	0.34+1.02	0.42+0.05
F7-PZ	0.69+0.07	1.04+0.03	0.78+0.06	0.64+0.09	0.08+1.02	0.19+0.04
F7-P3	1.02+0.09	1.45+0.08	1.19+0.05	1.06+0.12	0.12+0.07	0.31+1.01
F7-P4	0.18+0.07	2.01+1.02	0.51+0.05	0.48+0.05	0.23+0.08	0.46+0.08
F7-P7	0.80+0.05	1.05+1.01	0.35+0.08	0.34+0.14	0.31+0.06	0.34+0.03
F7-P8	0.69+0.11	1.02+0.08	0.09+0.05	0.51+0.07	1.01+1.01	1.06+1.01
F8-PZ	0.31+1.02	0.46+0.02	1.09+1.02	1.02+1.02	0.65+0.08	1.01+0.02
F8-P3	0.26+0.05	0.33+0.01	0.62+0.08	0.67+1.12	0.51+0.06	0.64+0.04
F8-P4	1.02+0.09	0.69+1.01	0.72+0.02	0.69+0.04	1.08+0.05	1.32+1.02
F8-P7	1.55+1.01	1.73+0.05	0.37+0.03	0.31+0.07	0.60+0.02	1.63+0.02
F8-P8	1.48+0.02	1.63+0.03	1.01+1.02	0.92+0.06	1.06+0.02	1.02+1.01
OZ-F7	0.23+0.06	0.65+0.01	0.74 +0.07	0.47+0.02	0.25+1.03	0.38+0.06
OZ-F3	0.38+0.02	0.78+0.06	0.85+0.03	0.80+1.01	0.33+0.03	0.43+1.01
OZ-FZ	0.49+1.01	0.53+1.03	0.65+0.07	0.74+0.02	0.47+0.06	0.87+0.01
OZ-F4	0.54+0.01	0.69+0.02	1.19+0.01	1.08+1.03	0.78+0.02	1.12+0.01
OZ-F8	0.43+1.02	0.64+0.03	0.26+0.01	0.38+0.06	0.27+0.01	0.37+0.06
O1-F7	1.42+0.01	1.08+1.01	1.63+0.02	1.12+0.06	1.23+1.03	1.05+0.05
O1-F3	0.42+1.03	0.64+1.03	2.19+1.02	1.73+1.02	0.72+0.01	0.39+0.05
O1-FZ	0.43+0.06	0.56+0.06	1.15+1.01	0.85+0.01	0.43+0.02	0.87+0.02
O1-F4	0.33+0.06	0.43+1.03	0.31+1.04	0.37+1.01	0.02+0.01	0.14+0.02
O1-F8	0.46+0.02	0.50+0.04	0.34+1.02	0.31+0.02	0.27+1.01	0.14+1.03
O2-F7	0.62+1.02	1.03+0.02	0.74+0.07	0.12+1.03	1.06+1.03	1.15+0.01
O2-F3	0.05+0.02	0.41+0.02	0.87+1.03	0.54+0.03	0.38+0.01	0.42+1.01
O2-FZ	0.19+0.01	1.06+0.06	1.84+1.01	1.08+1.01	0.35+0.01	0.31+0.01
O2-F4	1.27+1.03	0.72+1.03	1.32+0.01	1.15+0.03	0.09+0.03	0.30+1.03
O2-F8	0.60+0.02	0.62+1.01	1.63+0.02	1.48+1.02	0.30+0.06	1.27+0.03
O1-FC1	0.43+0.01	0.64+1.02	1.05+0.01	0.85+0.04	0.43+1.01	0.57+1.01
O2-FC2	1.12+0.03	1.02+0.06	2.08+0.06	1.32+0.01	0.49+0.03	0.71+0.01
OZ-FC1	0.05+1.01	0.13+1.03	0.69+0.01	0.19+1.05	0.18+0.02	0.13+0.06
OZ-FC2	0.37+0.01	0.42+1.05	0.50+0.02	0.49+1.04	0.89+0.01	1.06+0.03
O1-FC5	0.62+1.02	1.27+1.01	0.19+0.01	0.69+1.03	0.31+0.01	0.11+1.03
O2-FC5	1.05+0.06	1.08+0.01	0.69+1.01	1.48+0.01	0.64+1.01	1.01+0.01
OZ-FC5	0.09+1.02	0.18+0.01	1.08+0.01	0.89+0.02	0.28+0.06	0.25+0.06

4 CONCLUSION

The two-way ANOVA statistical test revealed the significant decrease in MSC for subjects performing the correct trial during the exposure of mobile phone EMF as compared to those correct trial MSCs when subjects were not exposed to mobile phone EMF while performing the same correct trial experiment. This effect was observed for alpha and gamma band of frequencies for the time duration of second stimulus. However in contrast to alpha and gamma band of frequencies, the beta band showed significant increase in MSC due to the effects of mobile phone EMF. In addition to this, the number of correct trials were reduced while subjects were performing the visual oddball experiment during the exposure of mobile phone EMF. The ANOVA test could not reveal significant difference in MSCs for subjects performing missed trial experiment even though various subjects exhibited decrease in MSC due to the mobile phone EMF. These important findings lead to the conclusion that mobile phone EMF might affect the cognitive functions related to visual discrimination task via functional connectivity of the brain.

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