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Detecting Effects Of Mobile Phone EMF On Electric Potentials Of The Brain−A Nonlinear Analysis Based On Approximate Entropy Function.

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Abstract: Mobile phones are frequently used in most parts of the world but most of us are not aware of its dangerous effects on human health. The mobile phone emits electromagnetic radiation which can affect the human brain. The major aim of this study is to examine the mobile phone electromagnetic effects (EMF) on human brain by studying the nonlinear dynamical changes in EEG. The EEG which are the electric potentials produced inside the brain were recorded from the 12 subjects in two sessions. In first session, the subjects were given the exposure of mobile phone EMF for 45 minutes during the EEG recording. In next session, EEG was recorded form same subjects without the exposure of mobile phone EMF for 45 minutes. The nonlinear changes in EEG were studied using the signal processing tool called approximate entropy (ApEn) function. The ApEn function which is the measure of complexity in information process was found significantly low in group of subjects who were exposed to mobile phone EMF. In addition to this, the energy function corresponding to same group of subjects was found significantly larger at frontal position of electrodes. Since no study has been carried out to investigate the nonlinear effects on EEG due to mobile phone EMF, the results of this study might be proved useful in improving the further understanding about the effects of mobile phone EMF on brain.

Keywords: Mobile phones EMF on human brain by studying.

1. INTRODUCTION

The use of Mobile phone has been extensively increasing around the world. However its extensive use might produce harmful effects on human health according to various studies (Huber *et al.,* 2002; Volkow *et al.,* 2011). The mobile phone emits electromagnetic waves which can transfer heat to the human brain but this amount of heat is not large enough to produce any brain damage. However these electromagnetic waves can affect the brain by their interaction with the electric field generated inside the brain. The current imaging techniques such as functional magnetic resonance imaging (FMRI), and positron emission technique (PET) have been used to investigate the mobile phone EMF effects on human brain (Schönborn *et al.,* 1998; Kleinlogel *et al.,* 2008; Volkow *et al.,* 2011). However these studies do not mention the significant effect of mobile phone EMF on human brain except the study of (Volkow *et al.,* 2011) in which increase in glucose metabolism on the brain side have been reported.

The event related potentials (ERPs) are time-locked EEG signals which are recorded while subject is busy in performing either visual or audio tasks. The study of ERPs provides useful information about the neurophysiological mechanism of various cognitive and neurological disorders. Literature reports number of studies about the effects of mobile phone EMF on human brain using the ERPs. N100 ERP component in subjects who were exposed to mobile phone EMF for 30 minutes. The N100 ERP component reflects the auditory response and significant decrease in its amplitude shows that mobile phone EMF might produce changes in auditory system of human brain. Koivisto *et al.,* 2000 reported significant decrease in P300 ERP component due to mobile phone EMF in subjects performing visual discrimination tasks. P300 ERP component reflects the brain activity related to attention and therefore significance decrease in its amplitude shows that mobile phone EMF might produce changes in visual attention mechanism of brain. Apart from these studies, various other ERP studies about the effects of mobile phone EMF on human brain have been reported and most of these studies have mentioned a decrease in ERP components due to mobile phone EMF (Maby *et al.,* 2006; Krause *et al.,* 2000; Krause *et al.,* 2004; Vecchio *et al.,* 2012).

The effects of mobile phone EMF on EEG has been studies using some advance signal processing techniques such as power spectral density (Reiser and Dimpfel,1995; Huber *et al.,* 2002; Regal *et al.,* 2007; Curcio *et al.,* 2005; Hinikus *et al.,* 2008) and coherence function. These studies report increase in both power spectral density and coherence function due to the mobile phone EMF. The approximate entropy (ApEn) is nonlinear signal processing method which is used in EEG-based studies to investigate both complexity and increase in information process of the brain (Andreas, 2000). Over the years, it has provided various

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important clinical applications. For example, it has been used to study the effects of Alzheimer's disease on information process of the brain (Jeong *et al.,* 2001; Stam *et al.,* 2003; Pijnenburg *et al.,* 2004). It has been used in the investigation of different sleeping stages and underlying brain activity (Andreas, 2000; Fell *et al.,* 1994) . One of important clinical applications observed for ApEn function is based on the seizure predication system. Literature reports changes in intracranial EEG based ApEn function 10-20 minutes before the onset of seizure (Xu *et al.*,2003; Golpayegani *et al.*,2009; Aarabi and He, 2012).

EEG literature about the effects of mobile phone EMF on human brain is limited to only linear methods of signal processing and the nonlinear changes in EEG using nonlinear measures including the ApEn function have not been investigated to date to the best of our knowledge. Therefore keeping in view the important contribution of EEG-based ApEn analysis in neurology for various neurological disorders, this study examines the effects of mobile phone EMF on EEG using the ApEn function.

This paper is divided as follows, Section 2 presents the methodology for the recording of EEG data. The ApEn and energy functions are introduced in Section 2. In Section 3, results have been presented. The clinical implications of the results have been also discussed in Section 3. Finally Section 4 presents the important conclusions drawn from the results.

2. MATERIAL AND METHODS

EEG recording

This study uses the ERPs which were recorded from 15 subjects. ERPs were recorded from 12 healthy subjects performing visual discrimination task. It was obtained from 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. The subjects were recruited as the paid volunteers. The GSM digital mobile phones were held inside the cradle which were fixed at the electro-cap for each subject. The mobile phones of similar company and same specifications were used with average output power of 250mW. Subjects were asked to detect changes in visual stimulus shown to them through the computer monitor while recording their ERPs. The ERP recording was divided into two sessions. For the first session, the ERP was recorded while subjects were busy in detecting changes in visual stimulus with the 30 minutes exposure of mobile phone EMF. During the second session, the ERPs were recorded without the exposure of mobile phone EMF. The trial was called hit trial in case if subjects were correct in detecting either the changes or no changes in visual stimulus. The trial was called miss trial in case if subjects were failed to show correct response while detecting changes in visual stimulus.

Estimation of Approximate Entropy (ApEn)

The ApEn function is the measure of both complexity and increase in information process and it was estimated using the following relation

$$ApEn(s,z,N) = \Phi^m(z) - \Phi^{s+1}(z) \quad (1)$$

Where parameter s is called the embedding dimension which is used to find out number of previous points in making the another time series and the parameter z is the tolerance threshold for having the resemblance between two sets of equal data points. The values of s and z was set to 1.5 and 15% of standard deviation as recommended in the studies of Fell et al. 1994; Sammer, 1998 . The parameter $\Phi^m(z)$ was computed using the following equation

$$\Phi^m(z) = \frac{1}{N-(s-1)} \sum_i^{N-(s-1)} \ln[C_i^m(z)] \quad (2)$$

and

$$C_i^m(z) = \sum_i^{N-(s-1)} \sum_{j=i+1}^{N-(s-1)} \Theta(r - d[y(i) - y(j)]) \quad (3)$$

The parameter $C_i^s(z)$ is called the correlation integral and it depends upon the distance between number of new data points created by the original time series and $\Theta(x)$ is the Heaviside function which is defined in the interval $\Theta(x) = 1$ if $x > 0$, $\Theta(x) = 0$ if $x < 0$. For estimating the correlation integral, first new time series was produced by using the relation $y(t) = x(t), x(t+\tau), x(t+2\tau), \ldots, x(t+(s-1)\tau)$, where $x(t)$ and τ are original time series and time lag respectively. After finding the new time series, the distance between vectors $y(i)$, and $y(j)$ was estimated such that i,j = 1,…,N-(s-1). Finally correlation integral $C_i^s(z)$ was calculated using these distances values.

Estimation of Energy function

The energy function of ERPs was calculated using the following relation

$$E = \sum_{n=1}^{N} |x(n)|^2 \quad (4)$$

where N is the total number of data points.

2. RESULTS AND DISCUSSION

The frontal, temporal, parietal and occipital regions of the brain were shown by following representations respectively [FZ, F3, F4, FP1, FP2, FC1, FC2, FC5], [PZ, P3, P4, P7, P8], [T7, T8] and [OZ, O1, O2]. Kolmogorov-Smirnov statistical test revealed non-normal distribution for both sets of EEG data and therefore non-parametric statistical test was applied for comparing the difference of EEG activity during the exposure of mobile phone EEG and EEG

activity without the exposure of mobile phone EMF. The Table 1 shows the values of ApEn function (mean ± SD) for the EEG in the presence of EMF and for the EEG in the absence of EMF. The p-values showing the statistical significance of difference between both conditions of EEG are also shown in this table.

As shown in **(Table 1)** that EEG in presence of EMF shows significant lower ApEn values as compared to the corresponding EEG without the presence of EMF. The difference in ApEn values is statistically significant only at the frontal position of electrodes. In addition to this, the pre-frontal positions of electrodes shows more significant.

In order to correctly interpret this result, the neurophysiological meaning of ApEn function needs to be further discussed. As discussed earlier that ApEn function is the measure of both complexity and increase in information process of brain. In this point of view, this result implies that mobile phone EMF significantly decreases complexity in information processes and processing of information both taking place on frontal side of the brain.

Table 1: Scores of Mann–Whitney *U* test for significant difference of both ApEn and energy functions between EEG activity in presence of EMF l And EEG without the presence of EMF and values (mean (SD)) of both ApEn and energy functions.

Position of electrodes	Values of ApEn function (mean (SD)) and p-values			Values of energy function (mean (SD)) and p-values		
	Trials with EMF	Trials without EMF	P-value	Trials with EMF	Trials without EMF	P-value
FZ	1.34(0.25)	1.51(0.13)	0.02	15.61(0.49)	15.20(0.53)	0.01
F3	1.39(0.23)	1.52(0.14)	0.03	15.80(0.52)	15,41(0.51)	0.01
F4	1.43(0.24)	1.50(0.22)	0.03	15.90(0.52)	15.62(0.49)	0.01
FP1	1.45(0.24)	1.63(0.19)	0.00	14.84(0.51)	14.53(0.45)	0.03
FP2	1.36(0.16)	1.52(0.21)	0.00	14.52(0.52)	14.11(0.52)	0.01
FC1	1.41(0.18)	1.53(0.24)	0.06	12.71(0.54)	12,40(0.58)	0.08
FC2	1.51(0.19)	1.64(0.25)	0.05	13.92(0.54)	13.61(0.57)	0.06
FC5	1.42(0.17)	1.52(0.20)	0.06	12,34(0.53)	12.33(0.58)	0.37
CP1	1.23(0.34)	1.29(0.20)	0.48	14.72(0.54)	14.62(0.52)	0.06
CP2	1.28(0.20)	1.29(0.27)	0.97	15.21(0.51)	14.90(0.52)	0.76
CP5	1.70(0.27)	1.73(0.35)	0.81	11.59(0.51)	11.54(0.51)	0.38
PZ	0.79(0.15)	0.89(0.11)	0.07	12.27(0.49)	12.13(0.55)	0.66
P3	1.44(0.25)	1.49(0.21)	0.42	17.49(0.49)	17.42(0.55)	0.70
P4	1.43(0.27)	1.48(0.22)	0.49	17.79(0.51)	17.73(0.53)	0.56
P7	1.47(0.24)	1.49(0.16)	0.82	17.10(0.49)	16.50(0.52)	0.09
P8	1.52(0.25)	1.53(0.14)	0.83	16.97(0.52)	16.70(0.49)	0.41
T7	0.84(0.04)	0.88(0.10)	0.50	20.11(0.51)	19.38(0.50)	0.18
T8	1,10(0.09)	0.87(0.09)	0.58	18.63(0.52)	18.42(0.51)	0.75
0Z	1.01(0.12)	1.01(0.12)	0.99	18.69(0.52)	18.64(0.52)	0.14
01	1.01(0.13)	1.03(0.12)	0.83	18.12(0.51)	17.89(0.55)	0.65
02	1.70(0.34)	1.71(0.29)	0.96	13.28(0.59)	13.15(0.65)	0.65

As mentioned earlier that pre-frontal position of electrodes showed comparatively larger significant level as compared to the other positions of the electrodes. This shows the possibility that deficits in information process due to the EMF in brain were stronger in the brain process related to working memory tasks. This is because prefrontal regions of human brain are strongly correlated to working memory process (Isseroff *et al.,* 1982).

Next we studied the energy difference between EEGs in presence of EMF and EEG in absence of EMF. The energy function was calculated using the Equation 4. Table 1 summarizes the energy values (mean ± SD) for both types of EEGs (EEG in presence of EMF and EEG without the presence of EMF) and p-values showing the difference between both kind of EEG. As shown in Table 1 that subjects who were exposed to EMF exhibited significantly larger values of energy function as compared to those when subjects not exposed to mobile phone EMF.

4. CONCLUSION

The subjects who were exposed to mobile phone EMF exhibited significantly lower values of ApEn function and larger values of energy function at frontal position of electrodes as compared to those when subjects were not exposed to mobile phone EMF. Keeping in view the neurophysiologic meanings of both these functions, these findings lead to the conclusion that mobile phone EMF might introduce significant effects in both complexity and rate of information process taking place in brain. Moreover the larger values of energy function shows increase of energy in EEG signals due to the mobile phone EMF.

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