International Journal of Engineering

Journal Homepage: www.ije.ir

Investigating The Effects of Modem Electromagnetic Waves (2.4 GHz) on Electroencephalogram

R. Javanrouh Givi, A. M. Aminian Modarres*, M. Kafaee Razavi

Department of Electrical Engineering, Sadjad University of Technology, Mashhad, Iran

PAPER INFO

Paper history:
Received 25 October 2018
Received in revised form 15 May 2019
Accepted 05 July 2019

Keywords:
Microwave Wave
Average Power
Brain Signal
Coherence

ABSTRACT

With respect to the dramatic increasing use of electronically communicators and wireless modems, concerns have been raised about the possible effects of emitted electromagnetic radiation on human brain. In this paper, the effects of high-frequency wireless modem waves on the brain signal are investigated. To this end, the Electroencephalograph (EEG) recording of 15 volunteers is examined in four different bands. The experiments are designed to cover in four steps. Average power statistical analysis in different frequency bands and magnitude-squared coherence function shows significant changes in some bands.

***doi**: 10.5829/ije.2019.32.08b.11*

1. INTRODUCTION

Nowadays, the effect of electromagnetic waves on human health has become an important health problem. It is shown in research that being exposed to electromagnetic radiation has a negative impact on devices including impulse generators, implantable cardiovascular defibrillators, pacemaker and on men fertility, and in general, to the whole body and head [1].

These radiations can be mainly divided into two categories: 1) ionizing radiation, 2) non-ionizing radiation. The first one has a high frequency in the electromagnetic spectrum which has enough energy to separate electrons from atoms or molecules and ionize them [2]. This type of radiation with high power could damage DNA structure which may lead to birth defects in newborns [2, 3]. The second type of electromagnetic radiation, the non-ionizing one, has an extremely low frequency. Although it does not have enough energy to break down the molecules and atoms, it is able to vibrate them [2].

*Corresponding Author Email: *aminian.mod@gmail.com* (A. M. Aminian Modarres)

The biological effects of non-ionizing radiations can be divided into two different groups which are the thermal effects [4] and effects on human brain signals.

The thermal effect is actually caused by the amount of the electromagnetic energy absorbed by the body and could be quantified by Specific Absorption Rate (SAR) [2].

These thermal effects can lead to heating of tissue and burns, sterility and blindness [5].

In 2011, Khalid [6], reported the highest emitted power density at a 0.5-meter distance from the wireless modem about 220 $\mu w/m^2$. Also, the highest SAR was measured in a 10-year-old child with a distance of 34 centimeters rom the antenna, which was reported as 80 μW/kg.

Non-thermal effects may lead to changes in body rhythm, disturbing the operation of medical instruments, cancer susceptibility for human, and changes in the essence of chemical and electrical signals. Therefore, these alterations can also have effects on human brain signals, which can be detected in the electroencephalogram (EEG). The EEG contains electrical activity information of the brain's cortical

Please cite this article as: R. Javanrouh Givi, A. M. Aminian Modarres, M. Kafaee Razavi, Investigating The Effects of Modem Electromagnetic Waves (2.4 GHz) on Electroencephalogram, International Journal of Engineering (IJE), IJE TRANSACTIONS B: Applications Vol. 32, No. 8, (August 2019) 1155-1162

neuronal cells that can be measured at various frequencies [4, 7, 8].

It should be noted that in order to extract the required information from the Electroencephalography, the recorded data need to be processed. In recent years, much research has been conducted in EEG process field which can embody a unique protocol for EEG record depending on the type and condition of the test. In each study, regarding the data recording protocol and different data analysis methods, the results are different. Hence, differences are common in study results.

In this paper, brain connectivity and the average power tools are utilized to show variations in the brain signals. Investigating brain connectivity has attracted attention since 1960s decade. According to the latest research, these connections are divided into three main categories: neuroanatomical, functional and effective [9]. The neuroanatomical connectivity, in fact, indicates the physical connectivity. Effective connectivity shows dynamic interactions between different brain regions.

The third category (functional connectivity) is in fact a connection of two brain regions due to the existence of a particular function between these two regions. Investigation and analysis of this brain connectivity category, which is not necessarily physical connectivity, are based on temporal correlation estimation between different distant neurophysiologic events during diverse central neurological system activities [10, 11].

Most of neurophysiologic signals (including recording local field potential, Electroencephalography, Magnetoencephalography, Positron Emission Tomography, and Functional Magnetic Resonance Imaging) can be diagnosed using functional connectivity-based analysis [11]. As an example, it is reported in literature [11], it is claimed that the reduction in harmony and connectivity of one's brain signals can be effective in early diagnosis of Alzheimer disease.

In 2005, Curcio et al. [12] compared the effect of mobile electromagnetic waves (902.40 MHz with an average power of 0.25 watts), on EEG signals of 20 volunteers, before and during the radiation. They showed that the power spectrum during radiation in the alpha band is increased at a higher rate than pre-radiation. In another experiment, subjects were exposure by electromagnetic radiation in 30 minutes with the frequency of 900 MHz in both continuous wave and pulse modulation modes. during the experiments, some cognitive tests were conducted. In this experiment also the EEG signal was recorded in three steps which are immediately after radiation, 30 and 60 minutes after radiation respectively. Their result represented that electromagnetic field radiation in pulsed modulation mode reduced the reaction speed and increased accuracy in memory tests. That was accompanied by increasing power spectrum in the EEG signal of 10.5-11 Hz. However, in continuous wave mode, no effect was observed [13].

In 2009, electromagnetic field exposure from wireless modem (2400MHz) and cordless phone (900MHz) were tested [14]. Moreover, It is reported in literature [15, 16] their results stated from exposure with 900 MHz and 1800 MHz. None of them showed a significant difference in frequency bands.

The aim of this paper is to illustrate the non-thermal effects of high-frequency wireless modem waves on human brain signals.

For this purpose, in section 2, data recording protocol along with information of volunteers and radiation apparatus are stated. After that, pre-processing methods for signal preparation are explained, and in section 3, the proposed analytical methods are explained in detail. Finally, the results are reported in the last two sections.

2. MATERIALS AND METHODS

2. 1. Data Acquisition Fifteen female volunteers (21-30 years of age) participated in this study. The participants were healthy and without any mental problems. The radiation device used in this experiment is the Siemens Wireless Modem SL2-141 / SL2-141-I model with 802.11 standard. The standard 802.11 specifies the maximum radiation power in transmitting devices [6]. The output power of this modem is -17.6 dBm which was measured using a spectrum analyzer. The Lutron portable frequency meter (the FC-2500 A model) was used to measure the frequency of radiations, which was 2.476 GHz.

In this study, 8-channel power lab was used to record the brain signals. The electrodes were embedded in Ag / AgCl according to standard 20-10 electrode-placement strategy. The International Electroencephalography and Clinical Neurophysiology Federation have proposed the setting of electroencephalography for 21 electrodes, called the 20-10 standard. The data was recorded in five channels using a differential manner. The position of the electrodes is shown in Figure 1.

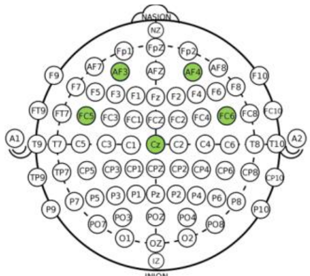

Figure 1. Electrodes location

The brain signal is recorded in four steps due to Table 1. Before radiation (step R1, 5 minutes), Radiation with a distance of 20 cm (step R2, 15 minutes) Radiation with a distance of 70 cm (step R3, 15 minutes) and after Radiation (step R4, 5 minutes). To isolate the laboratory environment, a Faraday cage (made of galvanized wire) was used to reduce the noise. During the experiment, all subjects with open eyes were placed in the comfortable chair. The laboratory environment is represented in Figure 2. (which includes the Faraday cage, EEG recorder and etc.).

2. 2. Preprocessing Raw brain signals have a range of micro-volts and frequencies up to about 100 Hz. Due to biological artifacts and external environmental noise, it is hard to analyze them and extract some proper features [17]. Physiological artifacts can be caused by various activities of the body [18].

In order to obtain valuable information and to analyze correctly, raw brain signals need to be filtered prior to processing [8]. These filters should be designed in order to minimize alternations in the original information. A high-pass filter with 1 Hz cutoff frequency was used to remove biological signals, such as cardiac and respiration artifact, and a low-pass filter with 40 Hz cutoff frequency to remove EMG artifacts.

The effective bandwidth of the brain signals is approximately 100 Hz. But depending on the applications, it can be halved. Therefore, the sampling frequency of 200 samples per second can satisfy the Nyquist criterion [8]. In this study, the sampling frequency is 250 samples per second. To accurately analyze the EEG signal in research applications or medical diagnoses, removing extra-cerebral artifact sources is essential. Thus, the Blind Resources Separation assumption (BSS) which is based on the autonomy of brain resources from artifact sources, is used. In fact, the goal is to obtain the main sources of the brain and remove artifact resources. In the last decades, different separating blind sources algorithms have been proposed such as high order statistics (HOS), second order statistics (SOS), and independent component analysis (ICA) [17, 19]. An independent component analysis is usually used for linear separating a multidimensional data into independent statistical components. It is assumed that each processed signal is composed of a linear combination of independent signals [20] . An independent component analysis for removing artifacts was done using the EEGLAB toolbox in MATLAB software. In this way, the desired signal for features extraction can be captured by identifying and removing the sources of artifact.

TABLE 1. Steps

Step	Name
Before radiation	R1
Radiation with a distance of 20 cm	R2
Radiation with a distance of 70 cm	R3
After Radiation	R4

Figure 2. Lab environment and Faraday Cage

3. INVESTIGATED FACTORS

3. 1. Average Power The average power of the brain waves was calculated separately for four-band frequencies (theta (4-8 Hz), Alpha (8-12 Hz), High Alpha (12-15 Hz) and beta (15-35 Hz)). It should be noted that band power method in MATLAB software was used in each step for all individuals.

This method calculates the average power at a specified frequency range through a modified periodogram. In this method, the signal, sampling rate and frequency range will be given as inputs. Due to the difference between the brain signals of the subjects, the ratio of the power of the four steps was calculated to personalization the results. This means that, in each individual, for example the average power of mode R1 was divided by the average power of mode R2 in each frequency band.

3. 2. Brain Signals Asymmetry In this study, brain signals are recorded symmetrically in two channels. Regarding the fact that some frequency bands are normally asymmetric in different brain regions, symmetry extent in mutual brain regions like AF3 and AF4 is measured. Three brain normal patterns in beta, gamma and theta bands which are called briefly as BAT, are as follows:

Left lobe beta≥ right lobe beta

Right lobe alpha ≥ left lobe alpha

Right lobe theta ~ left lobe theta

The existence of these normal patters are essential in a healthy brain, so that the difference in either of these inequalities can be a sign of a disease. For example, in order to examine the susceptibility to anxiety, depression and internalizing psychopathology, frontal EEG alpha asymmetry has been employed. Also, the same method has been incorporated to externalize disorders including addiction, attention-deficit hyperactivity disorder (ADHD) and mania [21, 22]. In addition, beta asymmetry is used to diagnose individuals' anxiety [23].

As a result, if the right lobe to the left lobe ratio is calculated, the resulting number should be less than or equal to unity in the beta frequency band, and greater than or equal to unity in the second condition for the alpha frequency band. This number should approximately be about unity in the third condition for the theta frequency band. The extracted results of this rule can be observed in the results section.

3. 3. Cerebral Connectivity and Coherence

Brain connectivity measurement could lead to evaluate and perception of connections between brain different areas.

Coherence states linear statistical correlations between two time series in a certain frequency band, in neurons group activities between two regions of the brain [9, 11] Coherence is a precise measurement which can demonstrate accurate aspects of the brain network scan. It is stated as the connectivity measurement or functional dependency between two brain regions [24] and shows to which extent those two structures are literally related together [25].

Many different methods have been adopted for brain connectivity measurement so far. One of these methods is to investigate brain connectivity via functional connectivity in the frequency domain [9].

One of the most commonly used methods for functional connectivity analysis is Magnitude Squared Coherence (MSC) which is used from in this research [11, 26].

For coherence study, data were initially recorded differentially using the same reference [27]. Then coherence was used to measure the linear connectivity in the frequency domain. Coherence is sensitive to both power and phase alterations. In other words, the coherence value varies with changes either in power or phase of one of the signals. If the two signals remain constant and unchanged over time, the coherence value remains constant. So, it can be concluded that coherence does not give direct information from the actual connections between the two signals, but rather its essence is the stability of these connections [11, 24, 28]. Consider two discrete time signals x_n and y_n, n=1,…,N. The cross-correlation function is calculated using (1) [11]:

$$C_{xy}(\tau) = \frac{1}{N-\tau}\sum_{n=1}^{N-\tau}((x_n - \bar{x})/\delta_x))((y_{n+\tau} - \bar{y})/\delta_y)) \quad (1)$$

In which $\bar{x}$, δ_x, and τ are mean, variance and time lag, respectively, and magnitude squared coherence or coherence is in fact equation 1 in the frequency domain, which is the same as cross spectral density function S_{xy}, which is normalized using autocorrelation functions of each series. Equation 2 shows magnitude squared coherence.

$$\gamma_{xy}(f) = \frac{|<S_{xy}(f)>|^2}{|<S_{xx}(f)>||<S_{yy}(f)>|} \quad (2)$$

In which < . > is window averaging. The obtained value is a number ranges between 0 and 1, in which 0 indicates independency and 1 is the representative for maximum linear dependency [11].

4. RESULTS

In this section, the results from the introduced methods in section 3 are investigated. Subsection 4.1 is dedicated to explaining results obtained from the average power ratio method. In subsection 4.2, brain signals symmetry is assessed and subsection 4.3 deals with calculating and analysis of brain connectivity and coherence.

4. 1. Average Power

Variations in average power ratio through CZ, FC5 and FC6 channels for different frequency bands in two steps with respect to each other are shown in Tables 2 to 4. In Table 2. from FC5 channel, the value 1.314 from the alpha frequency band represents a 1.314 times increase in mean average power in R2/R1 mode. In this mode, there has been growth in both CZ and FC5 channels for all bands and FC6 channel in the theta band.

Regarding Table 3. the mean average power in R3/R1 mode has been increased in all bands and channels excluding the high alpha band in CZ channel and the beta band in FC6 channel.

TABLE 2. The ratio of mean average power R2/R1

R2/R1	FC5	FC6	CZ
Alpha	1.314	0.976	1.098
High Alpha	1.262	0.792	1.084
Beta	1.356	0.880	1.132
Theta	1.292	1.014	1.006

TABLE 3. The ratio of mean average power R3/R1

R3/R1	FC5	FC6	CZ
Alpha	1.158	1.425	1.018
High Alpha	1.661	1.612	0.985
Beta	1.331	0.786	1.078
Theta	1.230	1.157	1.137

According to Table 4. the ratio of mean average power in R4/R1 mode for all bands except the alpha and theta in FC5 channel and beta in FC6 channel has been increased.

As discussed before, one of the most important effects of electromagnetic radiation on the human body is to disturb the natural body rhythm. Either reduction or increment in the average power of brain waves can disturb the natural rhythm of cerebral waves which in turn may lead to lack of concentration, anxiety, and stress in long term.

4. 2. Brain Signals Asymmetry The ratio of the average power for the mentioned four frequency bands in the frontal region was calculated. In the paper published by Allen, the analysis of brain signals asymmetry in the frontal lobe is applicable for diagnosis of disorders like depression, anxiety, and ADHD [21].

Regarding Table 5. the mean ratio of alpha average power in R1 step is a number greater than unity which confirms asymmetry. It should be mentioned that as it was stated in section 3-2, if the beta ratio is greater than unity, it can be a sign of anxiety which is normal in signal recording.

This ratio has averagely been reduced in R2 and R3 steps (Tables 6 and 7) and does not follow the asymmetry pattern. The results from R4 step show that (Table 8) this effect vanishes after electromagnetic waves removal. This means that electromagnetic waves have a short term effect on disturbing asymmetry.

TABLE 4. The ratio of mean average power R4/R1

R4/R1	FC5	FC6	CZ
Alpha	0.925	1.190	1.528
High Alpha	2.392	1.062	1.254
Beta	1.049	0.886	1.054
Theta	0.928	1.241	1.054

TABLE 5. Brain waves ratio in step R1

R1	AF4/AF3
Alpha	1.84
High Alpha	1.64
Beta	1.10
Theta	1.08

TABLE 6. The ratio of brain waves in step R2

R2	AF4/AF3
Alpha	1.07
High Alpha	0.85
Beta	1.58
Theta	1.14

TABLE 7. The ratio of brain waves in step R3

R3	AF4/AF3
Alpha	0.81
High Alpha	0.66
Beta	0.92
Theta	0.74

TABLE 8. The ratio of brain waves in step R4

R4	AF4/AF3
Alpha	3.15
High Alpha	2.87
Beta	1.66
Theta	1.73

4. 3. Brain Connectivity And Coherence Figure 3 illustrates the Magnitude Squared Coherence in different frequency bands. Comparing coherence in different steps and also comparing two signals together in the alpha, beta, and theta frequency bands, it is concluded that the amount of coherence has been diminished in all bands through R4 step.

In a study conducted by Locatelli on Alzheimer patients, it is shown that coherence is reduced in alpha, beta and theta bands in Alzheimer patients [29].Therefore, it is likely for electromagnetic waves radiation to create effects similar to Alzheimer disease even in short term.

5. STATISTICAL ANALYSIS

In this research, two different statistical tests have been used. First, one-way ANOVA is used to analyze the average power. ANOVA is a statistical analysis method for examining the effect of a factor (such as radiation) among different groups. It can be applied to both intra-group variances and between groups variances. The groups considered here are the ratio of average power in two channels at one frequency band in one subject. Then, it can be calculated in two steps, before and during radiation. In other words, if:

$$a_{i1} = \frac{\text{The average power of alpha band in channel A before radiation in subject } i}{\text{The average power of alpha band in channel B before radiation in subject } i} \quad (3)$$

$$a_{i2} = \frac{\text{The average power of alpha band in channel A during radiation in subject } i}{\text{The average power of alpha band in channel B during radiation in subject } i} \quad (4)$$

Then:

$$\beta_i = \alpha_{i1}/\alpha_{i2} \qquad i = 1,2,\ldots,15 \quad (5)$$

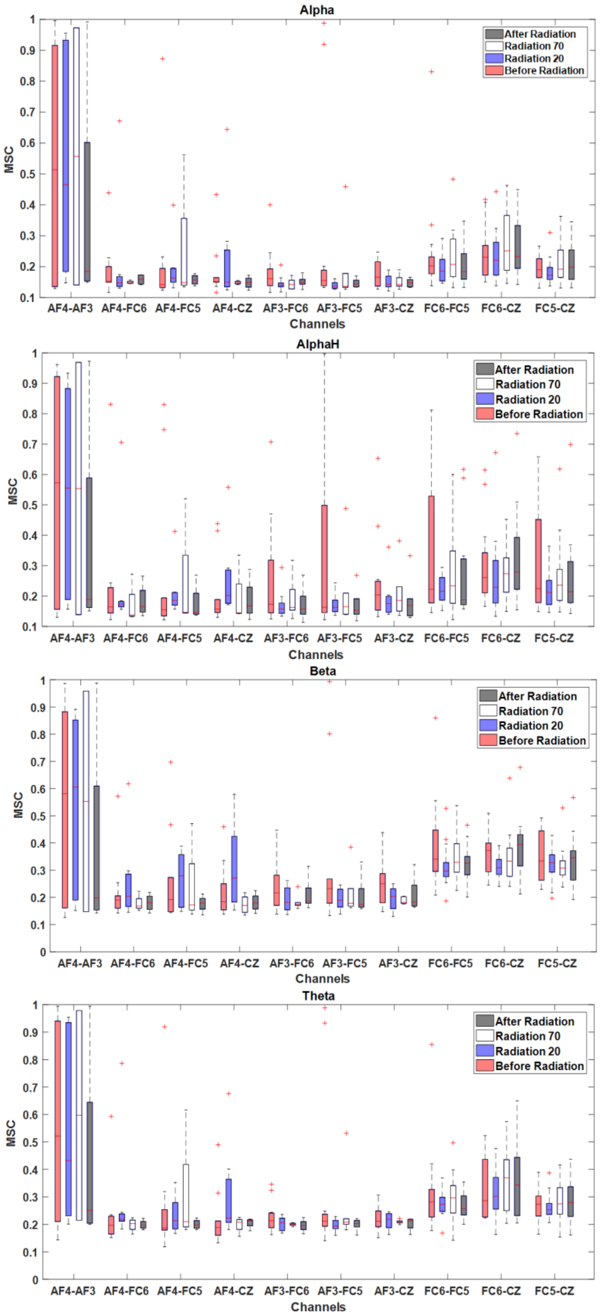

Figure 3. Magnitude Squared Coherence in different frequencies for diverse brain regions

It should be noted that we calculate the channel ratio symmetrically as follows: the ratio of the channel AF4 to AF3, FC6 to FC5, (AF4 + FC6)/2 to (AF3 + FC5)/2. Eventually, it became clear that statistical analysis of β_i by ANOVA method cannot show statistically significant changes in any of the groups. Meanwhile, in the results obtained by Yaqing HE in 2016, no changes were reported in the results for subjects before or during the short-term exposure to electromagnetic waves [30].

The Paired t-test was used in SPSS software to compare the average power of alpha, high alpha, beta, and theta bands in each channel, in steps R1, R2, R3, R4 on the same subjects. Paired t-test is a statistical test that statistically examines the difference between the mean of the two groups of dependent observations.

The columns of Table 2. (P*v) is the values of p-value obtained from the paired t-test.

Regarding Table 10. the results from the paired t-test have a statistically meaningful difference in the following cases:

Beta frequency band in AF4 channel and high alpha frequency band in AF4 channel through R1, R2 steps. The beta frequency band in FC5 channel in steps R1, R3. Theta frequency band in FC6 channel through R1, R4 steps. Theta and alpha frequency bands in FC6 channel though steps R3, R4.

TABLE 10. Average power ratio to channel difference and frequency band in paired t-test. (. p-value≤0.05)

R1, R2

	$P^*_{v\text{-}AF4}$	$P^*_{v\text{-}AF3}$	$P^*_{v\text{-}FC6}$	$P^*_{v\text{-}FC5}$	$P^*_{v\text{-}CZ}$
Alpha	0.0805	0.0824	0.4385	0.1094	0.9443
High Alpha	0.1183	0.0320	0.5319	0.0982	0.5772
Beta	0.0179	0.1566	0.3165	0.0880	0.4322
Theta	0.0654	0.1013	0.5011	0.1692	0.4760

R1, R3

	$P^*_{v\text{-}AF4}$	$P^*_{v\text{-}AF3}$	$P^*_{v\text{-}FC6}$	$P^*_{v\text{-}FC5}$	$P^*_{v\text{-}CZ}$
Alpha	0.9421	0.8115	0.9491	0.6267	0.2379
High Alpha	0.9379	0.7448	0.8624	0.3654	0.3840
Beta	0.8759	0.9035	0.2322	0.0128	0.4290
Theta	0.8918	0.7193	0.6437	0.5817	0.8080

R1, R4

	$P^*_{v\text{-}AF4}$	$P^*_{v\text{-}AF3}$	$P^*_{v\text{-}FC6}$	$P^*_{v\text{-}FC5}$	$P^*_{v\text{-}CZ}$
Alpha	0.9750	0.8586	0.0755	0.2210	0.9681
High Alpha	0.8952	0.8525	0.5124	0.1662	0.9688
Beta	0.9920	0.9129	0.1154	0.1395	0.3096
Theta	0.9981	0.5949	0.0299	0.6189	0.3246

R3, R4

	$P^*_{v\text{-}AF4}$	$P^*_{v\text{-}AF3}$	$P^*_{v\text{-}FC6}$	$P^*_{v\text{-}FC5}$	$P^*_{v\text{-}CZ}$
Alpha	0.5759	0.8278	0.0468	0.2769	0.3530
High Alpha	0.5252	0.8446	0.4217	0.3868	0.3272
Beta	0.5573	0.9160	0.8933	0.3153	0.8172
Theta	0.5866	0.9963	0.0378	0.8700	0.0633

6. CONCLUSIONS

This study assessed the biological effects of non-thermal high-frequency wireless modem waves on human EEG signals by using average power in important frequency bands and magnitude-squared coherence function. Our results as mentioned in section five, showed evidence about significant differences in some bands or channels for every step.

The average power and coherence analysis for different steps shows that radiated wireless waves to individuals have caused reduction or increment in power and also alterations in coherence between different brain regions. It means a change in the brain signals' natural rhythm which can affect the natural course of the brain that can have incurable consequences in long term.

7. ACKNOWLEDGMENT

The research was in part supported by the Cognitive Sciences and Technologies Council of Iran. Special thanks to Ali Asghar Zarei for his assistance.

8. REFERENCES

1. R. Acharya, D. Kumar, and G. Mathur, "Study of Electromagnetic Radiation Effects on Human Body and Reduction Techniques," in Optical and Wireless Technologies, ed: Springer, (2018), 497-505.
2. Y. Lu and Y. Huang, "Biological effects of mobile phone radiation," in 2012 International Conference on Microwave and Millimeter Wave Technology (ICMMT), (2012), 1-4.
3. A. V. Kramarenko and U. Tan, "Effects of high-frequency electromagnetic fields on human EEG: a brain mapping study," ***International Journal of Neuroscience***, Vol. 113, (2003), 1007-1019.
4. C. Smitha and N. Narayanan, "Entropy analysis to study the effects of mobile phone radiation on brain," in 2015 International Conference on Information and Communication Technology Research (ICTRC), (2015), 254-257.
5. B. Awada, G. Madi, A. Mohsen, A. Harb, A. Diab, L. Hamawy, *et al.*, "Simulation of the Effect of 5G Cell Phone Radiation on Human Brain," in 2018 IEEE International Multidisciplinary Conference on Engineering Technology (IMCET), (2018), 1-6.
6. M. Khalid, T. Mee, A. Peyman, D. Addison, C. Calderon, M. Maslanyj, *et al.*, "Exposure to radio frequency electromagnetic fields from wireless computer networks: duty factors of Wi-Fi devices operating in schools," ***Progress in Biophysics and Molecular Biology***, Vol. 107, (2011), 412-420.
7. L. V. Moran and L. E. Hong, "High vs low frequency neural oscillations in schizophrenia," ***Schizophrenia Bulletin***, Vol. 37, (2011), 659-663.
8. S. Sanei and J. A. Chambers, "EEG signal processing," (2007).
9. A. A. Fingelkurts, A. A. Fingelkurts, and S. Kähkönen, "Functional connectivity in the brain—is it an elusive concept?," ***Neuroscience & Biobehavioral Reviews***, Vol. 28, (2005), 827-836.
10. R. E. Greenblatt, M. Pflieger, and A. Ossadtchi, "Connectivity measures applied to human brain electrophysiological data," ***Journal of Neuroscience Methods***, Vol. 207, (2012), 1-16.
11. V. Sakkalis, "Review of advanced techniques for the estimation of brain connectivity measured with EEG/MEG," ***Computers in Biology and Medicine,*** Vol. 41, (2011), 1110-1117.
12. G. Curcio, M. Ferrara, F. Moroni, G. D'inzeo, M. Bertini, and L. De Gennaro, "Is the brain influenced by a phone call?: an EEG study of resting wakefulness," ***Neuroscience Research***, Vol. 53, (2005), 265-270.
13. S. J. Regel, J. M. Gottselig, J. Schuderer, G. Tinguely, J. V. Rétey, N. Kuster "Pulsed radio frequency radiation affects cognitive performance and the waking electroencephalogram," ***Neuroreport***, Vol. 18, (2007), 803-807.
14. K. Wu, A. Sajad, and S. Omar, "The effect of high frequency radio waves on human brain activity: an EEG study," University of Toronto Journal of Undergraduate Life Sciences, Vol. 3, (2009).
15. H. Danker-Hopfe, T. Eggert, H. Dorn, and C. Sauter, "Effects of RF-EMF on the Human Resting-State EEG—the Inconsistencies in the Consistency. Part 1: Non-Exposure-Related Limitations of Comparability Between Studies," ***Bioelectromagnetics***, Vol. 40, (2019), 291-318.
16. M. Hietanen, T. Kovala, and A.-M. Hämäläinen, "Human brain activity during exposure to radiofrequency fields emitted by cellular phones," ***Scandinavian Journal of Work, Environment & Health***, Vol. 26, (2000), 87-92,.
17. A. Darroudi, J. Parchami, M. K. Razavi, and G. Sarbisheie, "EEG adaptive noise cancellation using information theoretic approach," ***Bio-medical Materials and Engineering***, Vol. 28, (2017), 325-338.
18. M. Fatourechi, A. Bashashati, R. K. Ward, and G. E. Birch, "EMG and EOG artifacts in brain computer interface systems: A survey," ***Clinical Neurophysiology,*** Vol. 118, (2007), 480-494.
19. R. R. Vázquez, H. Velez-Perez, R. Ranta, V. L. Dorr, D. Maquin, and L. Maillard, "Blind source separation, wavelet denoising and discriminant analysis for EEG artefacts and noise cancelling," ***Biomedical Signal Processing and Control***, Vol. 7, (2012), 389-400.
20. D. P. Subha, P. K. Joseph, R. Acharya, and C. M. Lim, "EEG signal analysis: a survey," ***Journal of Medical Systems***, Vol. 34, (2010), 195-212.
21. J. J. Allen, P. M. Keune, M. Schönenberg, and R. Nusslock, "Frontal EEG alpha asymmetry and emotion: From neural underpinnings and methodological considerations to psychopathology and social cognition," ***Psychophysiology***, Vol. 55, (2018), e13028.
22. G. E. Bruder, J. W. Stewart, and P. J. McGrath, "Right brain, left brain in depressive disorders: clinical and theoretical implications of behavioral, electrophysiological and neuroimaging findings," ***Neuroscience & Biobehavioral Reviews***, Vol. 78, (2017), 178-191.
23. J. N. Demos, *Getting started with neurofeedback*: WW Norton & Company, (2005).
24. R. W. Thatcher, "Coherence, phase differences, phase shift, and phase lock in EEG/ERP analyses," ***Developmental Neuropsychology***, Vol. 37, (2012), 476-496,.
25. L. A. Baccalá and K. Sameshima, "Partial directed coherence: a new concept in neural structure determination," ***Biological Cybernetics***, Vol. 84, (2001), 463-474.
26. V. Sakkalis, C. D. Giurc, P. Xanthopoulos, M. E. Zervakis, V. Tsiaras, Y. Yang "Assessment of linear and nonlinear synchronization measures for analyzing EEG in a mild epileptic paradigm," ***IEEE Transactions on Information Technology in Biomedicine***, Vol. 13, (2008), 433-441.

27. T. Bullock, M. McClune, J. Achimowicz, V. Iragui-Madoz, R. Duckrow, and S. Spencer, "EEG coherence has structure in the millimeter domain: subdural and hippocampal recordings from epileptic patients," ***Electroencephalography and Clinical Neurophysiology***, Vol. 95, (1995), 161-177.
28. K. M. Ropella and O. A. Imas, "Coherence," Wiley Encyclopedia of Biomedical Engineering, (2006).
29. T. Locatelli, M. Cursi, D. Liberati, M. Franceschi, and G. Comi, "EEG coherence in Alzheimer's disease," ***Electroencephalography and Clinical Neurophysiology***, Vol. 106, (1998), 229-237.
30. Y. He, Y. Diao, W. Sun, S. W. Leung, and Y.-M. Siu, "Impact of magnetic-field generated by wireless power transfer of electric vehicles on brain waves and neuro-psychological changes," in 2016 Asia-Pacific International Symposium on Electromagnetic Compatibility (APEMC), (2016), 639-641.

Investigating The Effects of Modem Electromagnetic Waves (2.4 GHz) on Electroencephalogram

R. Javanrouh Givi, A. M. Aminian Modarres, M. Kafaee Razavi

Department of Electrical Engineering, Sadjad University of Technology, Mashhad, Iran

P A P E R I N F O

Paper history:
Received 25 October 2018
Received in revised form 15 May 2019
Accepted 05 July 2019

Keywords:
Microwave Wave
Average Power
Brain Signal
Coherence

چکیده

با توجه به گسترش روزافزون استفاده از وسایل ارتباط جمعی و مودم‌های بی‌سیم، بررسی تاثیرات امواج ساطع شده از این وسایل بر روی مغز به‌خصوص سیگنال‌های مغزی حائز اهمیت است. این مقاله تاثیرات امواج فرکانس بالای مودم بی‌سیم را بر روی سیگنال مغز بررسی می‌کند. در این آزمایش الکتروانسفالوگراف برای ۱۵ داوطلب در چهار باند فرکانسی ثبت شد. این آزمایش در ٤ مرحله انجام شد. بررسی‌های آماری توان متوسط در باندهای فرکانسی مختلف و اندازه مربع همدوسی تغییرات معنی‌داری را در برخی باندها نشان می‌دهد.

doi*: 10.5829/ije.2019.32.08b.11*