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The 9th International Conference on Cognitive Science

Classification of brainwave asymmetry influenced by mobile phone radiofrequency emission

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Abstract

A discriminant classification of human brainwave signals influenced by mobile phone radiofrequency (RF) emission is proposed in this paper. Brainwave signals were recorded using electroencephalograph (EEG) focusing on the alpha sub-band with frequency range from 8 to 12 Hz. The EEG test was divided into 3 sessions; Before, During and After with 5 minutes duration for each session. Analysis involved 95 participants from engineering students. The students were grouped into 3 groups according to the side of exposure; Left Exposure (LE), Right Exposure (RE) and Sham Exposure (SE). This work suggested that RF emit by the mobile phone give several effects to brainwave signals and there are significant different between the session of exposure. As result, the highest classification rate as high as 94.7% is achieved in session During.

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Keywords: EEG; alpha sub-band; asymmetry; RF; mobile phone radiation;

1. Introduction

Mobile phone has become one of the most important items in human daily lives in line with the increase in functionality and applications. However, the effect of mobile phone usage on human health is now become the subject of recent interest and study. Mobile phone operates in microwave range using Radiofrequency (RF) electromagnetic radiation. Data communication network and other digital wireless systems also emit the same radiation. Electromagnetic components have been shown to be directly and independently causing biological changes [1, 2]. Microwave radiation from mobile phones could modify certain brain electrical activity under both awake and sleep conditions and inducing abnormal slow waves in Electroencephalograph (EEG) of awake persons [3-5].

Due to the proximity of the antenna of the mobile phone to the user's ear and head, the brain is inevitably exposed to high frequency electromagnetic radiation with a relatively high Specific Absorption Rate (SAR) [6]. The farther the chassis and hand are from the head, the more the SAR in the head is reduced compared to the values without hand. However, the SAR in hands increased at the same time. At 900 MHz, when the distance increases

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doi:10.1016/j.sbspro.2013.10.270

from 2 to 14.5 mm, the SARs in the head are approximately 70%–60%. Correspondingly, at 1800 MHz the SARs in the head are approximately 95%–50% [7]. The RF emission from mobile phone also produces thermal and non-thermal effects. Thermal effects caused by holding mobile phones close to the body and extended conversations over a long period of time. There could also be possibly non-thermal effects from both phones and base stations whereby the affects could also be cumulative [8].

Electromagnetic emission such as those from mobile phones, alter regional cerebral blood flow on sleep and waking EEG and the exposure may provide a new, non-invasive method for modifying brain function for experimental, diagnostic and therapeutic purposes [9, 10]. Electroencephalograph (EEG) is a tool to measure human brainwave signals. It can be used to detect the magnitude of brain activity involved various in types of cognitive brain function. There are four sub-bands of brainwave signals which are beta, alpha, theta and delta. Beta has the highest frequency with the range between 13-32 Hz but lowest in amplitude. In contrast delta has the lowest frequency with the range of 0-3 Hz but highest in amplitude whereas frequency for alpha is from 8-12 Hz and 4-7 Hz for theta. Difference EEG characteristics brainwaves indicates different motional activities. Therefore, brain activity related to emotion can be analyzed through the EEG brainwave pattern [11].

The effects of mobile phone usage and the brainwave pattern after being exposed to mobile phone RF exposure have been studied [12-15]. The brain hemisphere dominance is also investigated by using Power Asymmetry Ratio (PAR) after exposed to RF at left and right side of the brain [14]. The widely used clustering algorithms, k-means clustering and agglomerative hierarchical techniques, suffer from well-known problems, whereas SPSS Two-Step clustering promises to solve at least some of these problems [16]. Classification is the process of finding a set of models or functions that describes and distinguishes data classes or concepts for the purpose of predicting the class of objects whose class labels are unknown [17]. Therefore, this research will observe more detail on the PAR pattern influenced by RF emission by using statistical classification technique.

2. Methodology

EEG data collection involved 95 participants from Universiti Teknologi MARA (UiTM), Malaysia. Participants are the undergraduate students from Faculty of Electrical Engineering aging from 18 to 25 years old. They were divided into 3 groups for the EEG experiments with 34 students for Left Exposure (LE) group, 31 students for Right Exposure (RE) group and 30 students for Sham Exposure (SE) group. Condition for LE group was strapped phone at left ear, while strapped phone at right ear for RE group. LE group was exposed to the RF from mobile phone at the left side of the head, whereas RE group was exposed to the RF from mobile phone at the right side of the head. The mobile phone was turn off for SE as the control group. All students were in healthy conditions and also not consuming any medicine or drugs prior to the EEG test.

The EEG test was carried out in a control environment at the laboratory. The duration taken for the EEG test was 17 minutes. The test was conducted in a dark room and divided in 3 sessions, 5 minutes for each session and 1 minutes rest in between sessions. The sessions are before, during and after the RF emission. The participants were asked to close their eyes and sit comfortably on a chair. A mobile phone with 0.69W/Kg of Specific Absorption Rate (SAR) was used as the source of RF exposure. The sampling frequency was 128Hz and the electrode impedance was maintained below 5kΩ. The position of the electrodes from Channel A and B is followed the International Standard 10-20 Electrode Placement System. 2 channels (Channel A and B) were selected to capture the frontal EEG signals using bipolar gold electrode cup.

Fig. 1 shows the flowchart of the methodology. From the EEG raw signals, prepossessing is the first stage. In this stage, the raw signals were filtered into the frequency range for each sub-band. Then cut-off data was done to get the 180 seconds recorded clean EEG data. The second stage is processing signals to get the time-frequency domain. Fast Fourier Transform (FFT) was used to originate the power spectral in order to get Power Spectrum Density (PSD) from the EEG time-series data. Next is feature extraction stage where Power Asymmetry Ratio (PAR) was applied to the EEG data after relative normalization. Feature extraction was performed in order to obtain a good EEG signal representation and the unique brainwave characteristics [14].

Statistical analysis was carried out to further investigate the PAR of EEG data. The analysis was done using Analysis of Variance (ANOVA) and Discriminant Classification. The normality of EEG brainwave signals was checked using Shapiro-Wilk test. EEG data normal distribution is a prerequisite for statistical discriminant classification. Normal data is an underlying assumption in parametric testing and numerical method of assessing is used to prove the normality of the EEG data. Shapiro-Wilk test is more appropriate for small sample size (<50 samples), but can also handle sample sized as large as 2000 samples. For this reason, the test is used as numerical means to assess normality in the dataset. After that, Duncan ANOVA test is used to compare the mean values of the groups within the session of exposure. The purpose of ANOVA is to analyze the mean of alpha PAR for the 3 groups. Statistical classification was carried out to discriminate the changes of brainwave signals in the groups of exposure. The number of dimension in discriminant analysis is the number of groups minus 1. Therefore, there are 2 discriminant dimensions observed in the PAR brainwave. Beta , alpha, theta and delta sub-bands were used as input to plot the discriminant functions in the 2 dimensions. The distribution of the scores from each function is standardized to have a mean of 0 and standard deviation of 1. The magnitudes of the coefficients indicate how strongly the discriminating variables affect the score.

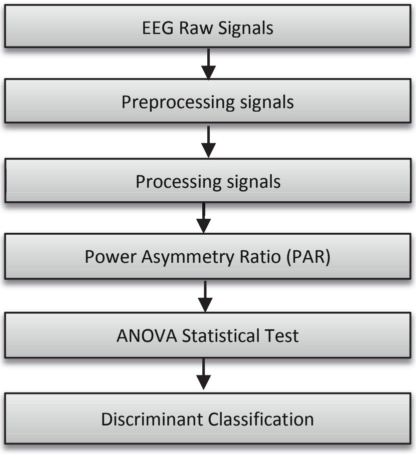

Fig. 1. Flow chart of the methodology

Initially, in the offline analysis, non-EEG signals with amplitude more than 100 µV were removed by deleting the sampled data in all channels. The recorded EEG brainwave signals will be filtered into 4 sub-bands which are beta, alpha, theta and delta. Fig. 2 shows the raw and normalized EEG signals for each frequency bands with power versus frequency. Delta in frequency 0-4 Hz, theta in frequency 4-8 Hz, alpha in frequency 8-12 Hz and beta in frequency 12-30 Hz.

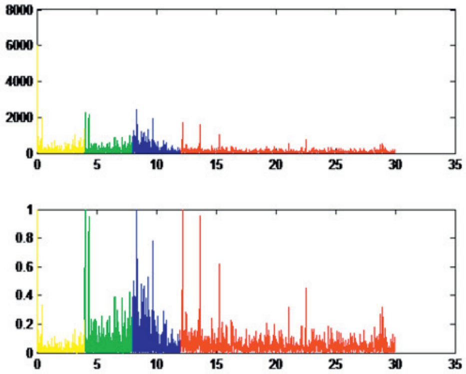

Fig. 2. Recorded EEG brainwave signals

Power Asymmetry Ratio (PAR) of the EEG signals is calculated by using the formula in equation 1. The positive value indicates right brain dominant whereas the negative value for left brain dominant.

$$\textit{Power Asymmetry Ratio (PAR)} = (PR - PL)/(PR + PL) \qquad (1)$$

where PL and PR are the PSD of the left and right brainwave respectively.

3. Results and Discussion

Table 1. Shapiro-Wilk Test for EEG Data

Group of Exposure	Statistic	df	Sig.
Left Exposure (LE)	0.966	34	0.691
Right Exposure (RE)	0.967	31	0.639
Sham Exposure (SE)	0.979	30	0.873

Table 1 shows Shapiro-Wilk test for alpha EEG data in LE, RE and SE group. The distribution of brainwave signals was observed by applying 95% Confidence Interval (CI) with significant level, p=0.05. The data is said to be normally distributed if significant values are greater than 0.05. Based on the results in the table, there is evidence that the EEG data was normally distributed.

3.1 Comparison Between Groups and Session

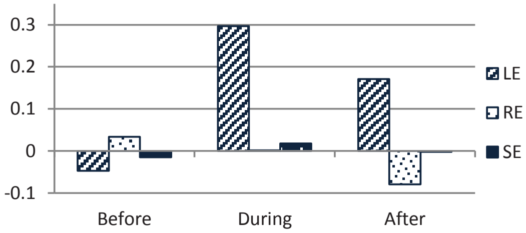

Fig. 3. Alpha PAR in session Before, During and After

Fig. 3 depicts alpha sub-band PAR in group LE, RE and SE. The comparison of groups was made between 3 sessions of the EEG test. It can be seen clearly that for LE and RE group, alpha hemisphere dominance changed after the exposure session. In contrast SE did not show the same pattern as having in real exposure group. This happened due to the RF exposure by the participants in during session because alpha synchrony would decrease during the trials. This might be the indicative of inhibitive activity in one hemisphere increasing unilaterally in response to the task and desynchronizing the hemispheres temporarily [11, 18].

Table 2. ANOVA Test for Alpha Power Asymmetry Ratio (PAR)

Exposure Session	Sum of Squares	Mean Square	F	Sig.
Before	0.106	0.053	1.482	0.232
During	1.885	0.942	25.461	0.000
After	1.034	0.517	10.318	0.000

Table 2 shows the output of the ANOVA analysis for alpha PAR in LE, RE and SE group. The significant level for exposure session Before is 0.232 (p=0.232), which are above 0.05 and therefore, there is no statistical significant different between group LE, RE and SE. However, the significant level is 0.000<0.05 in exposure session During and After. Thus explain that there is a statistically significant different between groups as determined by ANOVA for session During (F=25.461) and After (10.318). Duncan test revealed that alpha asymmetry in LE, RE and SE can be divided into different cluster due to the significant hemisphere different.

Table 3. Means for Groups in Homogeneous Subsets

Session	Group	Subset for α=0.05 (95% CI)	
		1	2
Before	LE	-0.047	-
	SE	-0.014	-
	RE	0.034	-
During	RE	0.001	-
	SE	0.004	-
	LE	-	0.297
After	RE	-0.079	-
	SE	0.020	-
	LE	-	0.171

Table 3 shows the means of alpha PAR within session for group LE, RE and SE. By applying 95% CI, subset for α is 0.05. There is only 1 cluster for alpha PAR in session Before. The 2 clusters in session During and After inform that the mean alpha PAR of exposure groups is different from each other. However, there are 2 groups having the same cluster for the data. Cluster 1 is for RE and SE and subset 2 is for LE group. Alpha would decrease during the exposure and resulted in unbalanced brainwaves.

3.2 *Power Asymmetry Ratio (PAR) Discriminant Classification*

Due to the abnormality occurred in the brainwave signals, classification was carried out to discriminate the changes of brainwave signals in the groups of exposure. There are 2 discriminant dimensions observed in the PAR brainwave. Both dimensions are statistically significant in session During with canonical correlation for the dimension 1 and 2 are 0.852 and 0.649 respectively and for session After is 0.879 for dimension 1 and 0.558 for dimension 2, whereas only dimension 1 is significant in session Before with canonical correlation of 0.458 and 0.089 for dimension 1 and 2 respectively.

Table 4. Classification of Predicted Group for Power Asymmetry Ratio (PAR)

Session of RF Exposure	Group	Original			Total %	Cross-validated			Total %
		LE	RE	SE		LE	RE	SE	
Before	LE	9	7	18	51.6	7	8	19	44.2
	RE	4	18	9		5	17	9	
	SE	6	2	22		10	2	18	
During	LE	32	1	1	94.7	32	1	1	93.7
	RE	1	29	1		1	28	2	
	SE	0	1	29		0	1	29	
After	LE	28	1	5	91.6	27	2	5	88.4
	RE	2	29	0		3	28	0	
	SE	0	0	30		1	0	29	

Table 4 explains the classification results for Power Asymmetry Ratio (PAR) using discriminant analysis. Cross validation is done only for those cases in the analysis. In cross validation, each group is classified by the functions derived from all groups other than that group. Session During has the highest percentage of classification with

94.7% of original groups and 93.7% of cross-validated. Predicted group membership is the predicted participants for group LE, RE and SE. The numbers going down each column indicate how many were correctly and incorrectly classified. For example, out of the 34 participants in LE group from session During, 32 were correctly predicted to be in the exact group whereas 1 in RE and SE group respectively. The participants were incorrectly predicted to be in RE and SE because of the characteristics is similar as the 2 groups.

Table 5. Canonical Discriminant Function Coefficient for LE, RE and SE Group

Input Variable	Before		During		After	
	1	2	1	2	1	2
Beta	-0.803	0.719	-1.987	0.048	0.172	-1.573
Alpha	0.120	0.722	2.130	0.263	-0.518	1.544
Theta	0.716	-0.527	0.548	-1.015	-1.562	0.018
Delta	0.833	-0.085	-0.589	1.101	2.110	0.409

Table 5 shows the standardized canonical discriminant function coefficient in session Before, During and After. For session After, the standardized coefficient for Delta in the first function is greater in magnitude with 2.110 than the other 2 variables. However, beta has the highest magnitude for function 2. Therefore, delta will have the greatest impact of the four variables on the first discriminant score and alpha on the second discriminant score as shown in Fig. 5.

Fig. 4, 5 and 6 show the scattergraph of canonical discriminant function for dimension 1 and 2 of session Before, During and After respectively. As illustrated in Fig. 4, the EEG PAR in groups are hardly discriminated either using function 1 or function 2 because the groups centroid are scattered nearby each other. However, as observed in Fig. 5, the PAR data can be discriminate between the groups in session During. LE group tend to be at the positive side of dimension 1; RE tend to be at the opposite side, with SE in the middle. On dimension 2, the results are not as clear ad dimension 1; however, scattered data in LE and RE tend to be higher than SE. The PAR data in session After also can be distinguishable as illustrated in Fig. 6. Function 1 in Fig. 5 and 6 can distinctly show the different data scattering in session During and After and this is due to the effects of RF exposed to the participants.

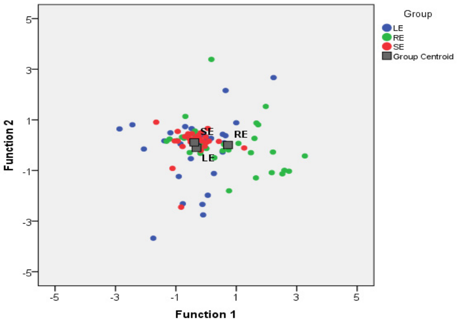

Fig. 4. EEG PAR of LE, RE and SE group in session Before

$$Function\ 1 = 0.12 * alpha + 0.716 * theta + 0.833 * delta - 0.803 * beta$$
$$Function\ 2 = 0.719 * beta + 0.722 * alpha - 0.527 * theta - 0.085 * delta$$

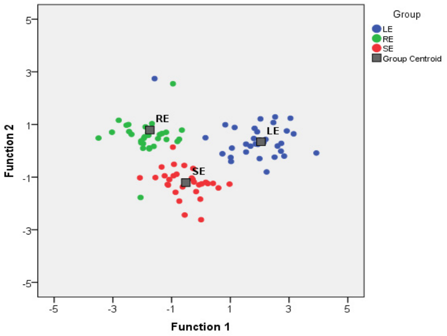

Fig. 5. EEG PAR of LE, RE and SE group in session During

$$Function\ 1 = 2.13 * alpha + 0.548 * theta - 0.589 * delta - 1.987 * beta$$
$$Function\ 2 = 0.048 * beta + 0.263 * alpha + 1.101 * delta - 1.015 * theta$$

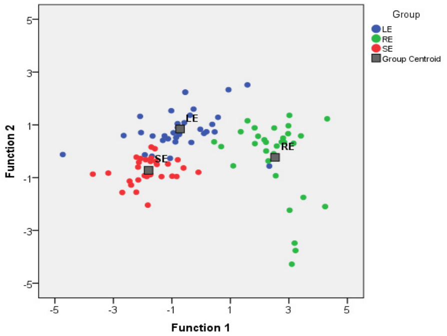

Fig. 6. EEG PAR of LE, RE and SE group in session After

$$Function\ 1 = 0.172 * beta + 2.11 * delta - 0.518 * alpha - 1.562 * theta$$
$$Function\ 2 = 1.544 * alpha + 0.018 * theta + 0.409 * delta - 1.573 * beta$$

4. Conclusion

Power Asymmetry Ratio (PAR) has been shown to be able to determine which brain will be dominant during a certain task. From the observation, brain hemisphere dominant changed after being exposed to the mobile phone RF for 5 minutes and the changes depend on the side of exposure. ANOVA statistical analysis also shows that there are significant different of Alpha PAR in 5 minutes exposure to RF and continue in 5 minutes after the exposure. The alpha sub-band in session During and After can be grouped into 2 clusters whereas only 1 cluster was found in session Before. Discriminant analysis of PAR gave highest classification percentage in session During with 94.7% and followed by session After with 91.6% as compared to 51.6% in session Before. Thus show that RF from mobile phone affected the human brainwave during the emission and the changes stay in 5 minutes duration after the emission.

This research will be continued with further analysis to investigate the effects of RF emission to human brainwave signals specifically on beta, theta and delta sub-bands. Other than that, the EEG data will also be analyzed on the statistical part as future work to obtain more significant different of the EEG signals influenced by the mobile phone RF emission.

Acknowledgements

The authors would like to thank staff and students from Universiti Teknologi MARA, Malaysia who have involved in this study and also to Research Management Institute UiTM and the government of Malaysia. This research is supported by the Fundamental Research Grant Scheme (FRGS), Ministry of Higher Education, Malaysia (project number 600-RMI/ST/FRGS5/3/Fst (33/2011).

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