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Impacts of Radio Frequency Interference on Human Brain Waves and Neuro-psychological Changes

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Abstract: This study investigates the neuro-psychological impacts of radio frequency interference (RFI) by correlating the brain waves under RFI exposure. In our experiments, twelve participants were tested under controlled RF exposure at 1.8 GHz in an anechoic chamber under one-blind condition. The electroencephalograph (EEG) were recorded for each 5-minute time trial before, during and after RF exposure with an intensity of 10% of the ICNIRP Guideline exposure limits. The psychological responses of the participants are inquired with psychometric scales before and after the experiment to analyze the correlationship between RFI and the emotional reaction of humans. Statistical tests indicate that theta and alpha waves were able to be characterized, and the significant differences were observed in both alpha waves and theta waves between the data before and after exposure from the consequence of paired t-tests. This initial study indicated that short term exposure to RFI may cause impacts on brain waves, but may not lead to any direct emotional changes by the participants.

Keywords: EEG, Radio frequency interference, RF exposure, Brain waves, Neuro-psychological changes

I. INTRODUCTION

In back-propagation, for example if a fully trained must learn a new training vector, it may disrupt the weights so badly that complete retraining is required. In a real-world case, the network will be exposed to a constantly changing environment; it may never see the same training vector again twice [1]. Under such circumstances, a back-propagation network will often learn nothing; it will continuously modify its weight to no avail, never arriving at satisfactory setting [2].

In the latest 50 years, with the exponentially increasing use of electromagnetic technology, especially wireless communication devices such as cell phones and Wi-Fi transmitters, there has been a growing awareness that radio frequency interference (RFI) may affect human health. In an attempt to address awareness of this, Studies have been done on the impact of RFI to Specific Absorption Rate (SAR), temperature rise in the cells, blood glucose level, and the change in DNA/ RNA structure to quantify the effects of electromagnetic interference (EMI) on human safety and to apply the research outcome to develop a system to reduce the impact of RFI on human beings [1]–[3], and they have confirmed that there is a certain effect on the objectives mentioned above in some situations and conditions. Electroencephalography (EEG) has also been utilized to explore the impacts the radio frequency (RF) emissions to brain activities, a large number of arguments have been made in order to try to draw a conclusion as to whether the RF of wireless networks affect human brain activities [4]–[8] - opposite conclusions were drawn and no persuasive verdict can yet been reached.

A lot of research has been done to study the effects RF/EF from mobile phones to the human body. As for the investigations where subjects were required to be awake and seated and exposed under the radiofrequency field emissions from mobile phones, the conclusions reached to tend to be the same [9], [10]. In one study, a method of discriminant classification of human brainwave signals influenced by mobile phone emissions was proposed to illustrate the influence. R.M. Isa, *et al*. [10] exposed 95 subjects divided into 3 groups to the RF emissions of a mobile phone from left or right side, and one group of sham exposure was the control group. A mobile phone with 0.69W/kg of SAR was used and the sampling frequency was 128Hz. This work suggested that the RF from mobile phones affected the human brainwave during the emissions and the changes stayed for 5 minutes duration after the emissions and the highest classification rate, as high as 94.7%, was achieved during exposure. Furthermore, the

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impact of Wi-Fi on brainwaves under different conditions were made and the results have just been published in the past two years [11], [12], and the conclusions support that the intensity of EM exposure will affect people's brainwaves in some situations.

However, the existing researches neglect possible neuro-psychological impacts of RF emission on human beings. Indeed, there have been reports on psychological impacts including anxiety and depression, although little research to date could provide conclusive or persuasive evidence on this, things have at least been regional social worries. There are frequent complaints from the general public in Hong Kong of psychological discomforts such as headache and anxiety when near radiation sources such as a transmission line or base stations [13]. Therefore, this investigation focuses primarily on the psychological impacts of RFI by correlating the brain wave activity. The objective is to explore whether there is any impact of RF on brain activities and to try to find out the possible correlationship between the RF interference and psychological emotional changes.

II. METHODOLOGY

A. Subject Selection

The participants involved included twelve postgraduate students from City University of Hong Kong with an average age of 24.6 (min=22.3, max=29.3). Only males were selected due to reducing impacts from gender differences. All students were informed to maintain a healthy condition and without taking any medication, alcohol or drugs 24h prior to the EEG test, and a declaration confirming the above requirements had to be signed as confirmation.

B. Source of Exposure

A system of signal generators was selected as the source of RF exposure, including a generator (Hewlett-Packard 8664A synthesized signal generator), an amplifier (Amplifier Research, 25M1G4A) and a bilog-antenna. A non-modulated 1.8GHz sine signal was adopted to simulate a realistic RF environment, which was reported that the SARs were approximately 95%-50% in the head when the distance from a cell phone to the head was from 2 to 14.5 mm [14]. The emitter was placed 3m straight from the subjects, and the height of the emitter was approximately at equal distance from the head when people sat on a chair to the ground floor.

The field intensity should be adopted below the limitation in ICNIPR Guidelines. Therefore the maximum value of field intensity with frequency spectrum of 1800MHz is approximately equal to 58.3V m-1 [15]. For safety considerations, 10% of the maximum intensity value—5.8Vm^{-1} was finally adopted. A broadband high frequency field strength meter (Narda test solutions, NBM series) was used to monitor the intensity of the electric field each time, before the exposure was started.

C. Psychological Scale in the Experiment

Questionnaires were used to evaluate the emotion change ‘before’ and ‘after’ the RF exposure in psychological scale - eight common emotions were organized to be assessed; four positive emotions including exciting, happy, enjoyment and calm, and four negative emotions including tension, anxiety, depression and dysphoric. The eight emotions were interleaved in the questionnaires to avoid any resultant psychological hints. The subjects were asked for the evaluation before, and immediately after the experiment to quantity their emotion status in seven degrees from 1 to 7; where 1 represented “absolutely no” whereas 7 illustrated “definitely yes”.

D. Procedure of Experiment & Data Acquision

To maintain a controlled EM environment, the experiments were accomplished in an EMI anechoic chamber in our Applied Electromagnetic Laboratory in City University of Hong Kong. Electric gel was fully applied between the electrodes of the EE-GO cap and the scalp to ensure good connection with the head surface, to improve the electrical conductivity and reduce impedance. As illustrated in Fig. 1, participants who wore the electrode cap after several minutes rest were asked to sit in a soft comfortable chair, and to start reading a given book which would not arouse emotional changes.

There are 3 intervals in the experiment. Each interval lasted for 5 minutes, and in the second interval the electromagnetic wave was emitted as the RF exposure. A two-minute break were arranged in between each two intervals, thus, the whole experiment would continue for 19 minutes in total.

During the whole procedure, participants were requested to try not to move their limbs, especially their legs. During the tests, leg movements were not allowed as movements could cause drastic EEG wave fluctuation - the fluctuations could be several times those of the normal patterns.

EEGs were recorded with eegoTM sports system from 9 (F3, F4, Fz, C3, C4, Cz, P3, P4 and Pz) out of 32 sintered Ag/AgCl electrodes distributed according to the International 10/20 Standard in an elastic cap [16], [17]. GND electrode was the ground point. Cpz electrode was set as a reference to get differential voltage by subtracting the same voltages so that the potential voltages could be collected. The effective approved records started when impedances were in the range of 20 k□ - 200 k□. High-pass filter (>0.3Hz) was used for removing low-frequency noise mostly caused from the instrument, as well as a low-pass filter (<50Hz) which was used for removing high-frequency noise. Once a time interval finished, the corresponding record was saved as a single file.

In order to prevent any influence from subjects' awareness or worry of any existing RF, the experiments were organized as single-blind trails - that is, participants didn't know when the experimental conditions were being changed.

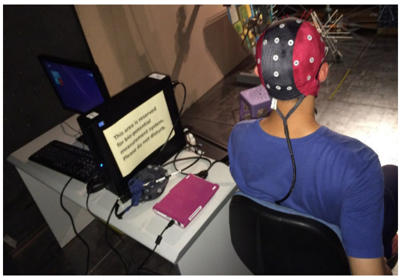

Fig. 1 One example of experiment

III. RESULTS AND DISCUSSION

A. Brain Wave Analyses

Three sections of EEG data were made up for one subject dataset, and twelve datasets were made up of all EEG recordings. Then the data were filtered again with a low-pass filter (<30Hz). Fast Fourier transformation (FFT) completed by ASATM analyzing software was performed for each filtered EEG recording with the sampling frequency of 500Hz and the epoch length of 0.256s. After the transformation was finished, 32 groups of power spectrum density (PSD) value for each brain wave spectrum were acquired. As by its definition of how the power of time series or signals distribute with frequency changes, the value can be used for comparison and analysis. Here the spectrum divisions in the software are: 0.5 to 3.5 Hz for Delta, 3.5 to 7.5 Hz for Theta, 7.5 to 12.5 Hz for Alpha and 12.5 to 30 Hz for Beta, and the initial settings could not be altered by users. Thus in the subsequent analyses, the spectra division standard followed the aforementioned division method.

All of the statistical analyses were carried out with statistic software, The R Programming Language. The analyses were primarily analyzed horizontally in each dataset of each individual subject. A two-way analysis of variance (two-way ANOVA) was conducted to statistically investigate whether there were any significant differences affecting the mentioned factors where the p-values of less than 5% (p=0.05) were considered to be significant. The factors named 'test time' (levels: before/during/after) and 'bands name' (levels: delta/theta/alpha/beta) as well as their interactions were analyzed. The results of the two-way ANOVA are listed in table I.

Table.1 results of two-way ANOVA of all groups' data

Number	Subject	Pr(>F)	Sig.
A	bands name	< 2e-16	***
	Test Time	3.84E-10	***
B	bands name	< 2e-16	***
	Test Time	0.00998	**
C	bands name	<2e-16	***
	Test Time	0.666	
D	bands name	< 2e-16	***
	Test Time	0.00016	***
E	bands name	< 2e-16	***
	Test Time	1.29E-05	***
F	bands name	<2e-16	***
	Test Time	0.0752	.
G	bands name	<2e-16	***
	Test Time	0.435	
H	bands name	9.59E-07	***
	Test Time	0.558	
I	bands name	<2e-16	***
	Test Time	0.947	
J	bands name	< 2e-16	***
	Test Time	6.70E-07	***
K	bands name	< 2e-16	***
	Test Time	0.000715	***
L	bands name	< 2e-16	***
	Test Time	0.000787	***

a. (Pr (>F) refers to *p*-value; Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1)

The results of the two-way ANOVA where the factor “time interval”, and “bands name” (delta, theta, alpha and beta) were considered indicates that there were statistically significant differences (p=0.001) in “bands name” in all 12 groups (100%), and there were significant levels of “time interval” in 7 out of 12 (58.33%) groups with the statistically significant level of 0.01 (p=0.01), which is better than general p=0.05, or in 8 out of 12 (66.67%) groups (6 of p=0.001, 1 of p=0.01, 1 of p=0.1) with the statistically significant level of 0.1 (p=0.1), which may tolerate some possible errors.

Table.2 Tukey’s HSD test for paired bands

Paired Bands	Diff	Lwr	Upr	P-Value
Beta-Delta	0.00027524	0.0260236	-0.026574	0.999992
Alpha-Delta	0.04043722	0.0141384	0.0667361	0.000592
Theta-Delta	0.17430277	0.1480039	0.2006016	0.000000
Alpha-Beta	0.04016199	0.0138631	0.0664608	0.000656
Theta-Beta	0.17402754	0.1477287	0.2003264	0.000000
Theta-Alpha	0.13386556	0.1075667	0.1601644	0.000000

Consequently, the method of Tukey's honest significance test (Tukey’s HSD) was adopted to distinguish the more significant factors affecting the recording results of the experiments. Table II illustrates the relationships of each of the two sub-bands of the whole frequency spectra. This illustrates that with the 95% family-wise confidence level, the largest difference is between the two levels of Theta - Alpha, and Beta-Delta has no significant difference; there are significant differences between other paired levels. Based on the result of data analyzing listed in table II, a box-plot is used to explain the factors in Fig. 2

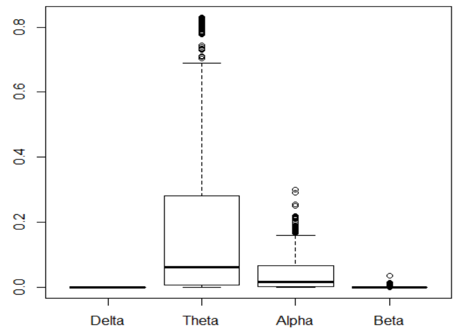

Fig. 2 Corresponding distribution of four bands

Therefore, a new graph could be printed out consequently in Fig. 2 according to foregoing outputs, which indicates the distribution of four sub-bands. It is obvious that the sub-bands of theta waves take the large presence, which suggests that theta waves produce the dominant impacts, while alpha waves take the second place. In contrast, delta waves as well as beta waves exert negligible influence. As a result, theta and alpha sub-bands are primary factors in the following analyses. Consequently, paired t-tests which aim at the two primary factors described in last paragraph conducted to the 7 groups which were affected by testing time significantly. As the different exposure conditions in three time intervals, each two of the data segments were tested respectively to detect whether there are any impacts among the situation of before, during and after RF exposure. The output are listed in the following table 3.

Table 3. Paired t-test for theta and alpha waves

Spectrum	Paired	T	Df	P-Value	95 % Confidence Interval		Mean Of The Differences
					lwr	upr	
theta	B-D	-8.7667	91	9.71E-14	0.082078	0.151633	-0.1530
	B-A	-3.7288	91	0.000334	0.082078	0.151633	-0.0811
	D-A	4.6523	91	1.11E-05	0.219914	0.319867	0.0718
alpha	B-D	-8.8643	91	6.07E-14	0.016911	0.032346	-0.0347
	B-A	-3.95625	91	0.000151	0.016911	0.032346	-0.0195
	D-A	4.3955	91	2.99E-05	0.048358	0.070442	0.0152

The results of paired t-test for both theta and alpha waves are listed in table III where the p-value of less than 5% (p=0.05) is concerned to be significant. As noted below the table, “B” refers to “before exposure”, “D” refers to “during exposure” and “A” refers to “after exposure”. The table indicates that the difference between each two different time intervals of two spectra, there are six tests processed and all of six p-values are far less than 0.05(p=0.05), that is, there are statistical significant differences in between each paired two time intervals.

B. **Psychometric Scales Analysis**

All the values of scales shall be computed subsequently. According to the property of them, all emotions are divided into two categories which were named after their properties—"positive" and "negative" in all rows divided from the before-after experimental sequence in each test, then the gross values of each category were calculated respectively.
The result of chi-square distribution for estimating the correlationship between two opposite emotions is exhibited in table 4.

Table 4 Pearson's Chi-squared test for two emotions

X-Squared	Df	*P*-Value
1.9967	1	0.1576

All the values of scales shall be computed subsequently. According to the property of them, all emotions are divided into two categories which were named after their properties—"positive" and "negative" in all rows divided from the before-after experimental sequence in each test, then the gross values of each category were calculated respectively.
The result of chi-square distribution for estimating the correlationship between two opposite emotions is exhibited in table IV.
With 95% confidence interval (CI) applied, referring to the *p* value of 0.1576 which is larger than 0.05 (*p*=0.05), the result illustrates that there is no correlationship between the two opposite emotions. Thus, the subsequent two paired t-tests were conducted respectively on each mean value of emotion estimation between before-after sequences to assess whether a significant difference exists or not. Results are listed as follow.

Table 5 Paired t-test for the comparison of each emotion

Name	T	Df	*P*-Value	95 % Confidence Interval		Mean Of The Diff.
				lwr	*upr*	
Pos	2.3174	6	0.0596	-0.1438	5.2866	2.1667
Neg	-0.607	6	0.5662	-7.9086	4.7658	-1.5714

[b] ("Pos" refer to "Positive emotions"; "Neg" refer to "Negative emotions")

Table 5 lists the output of the variation of emotion before and after exposure. From the demonstration, it is considered that positive emotion definitely changed after exposure, and statistical significance could exist because the significant level was lowered to 0.1(*p*=0.1) which recognizes an ordinary significant level. The negative emotion changed before and after the experiment, however the statistical significance was not significant, so it could not be justified that negative emotions were changed. Thus, it can be inferred that there is an ordinarily significant difference of positive emotion between tests before and after exposure, whereas there is inappreciable significant difference of negative emotions. The comparison is shown clearly with the following box-plot in Fig 3.

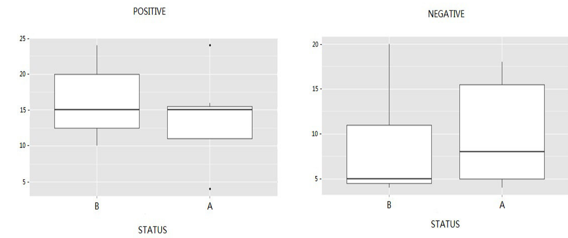

Fig 3 Box-plot of positive emotion change (left) and box-plot of negative emotion changing (right)

In Fig. 3, the detailed changes of two groups of emotions are exhibited as a visualized evidence. It shows that with median immovability, the box of trial "after" narrows down with the maxmum value decrease.conrary to illustration in the left figure, with the median increased, the range of box "after" heighten with both of maximum and minumun values increased.

IV. CONCLUSION

It can be concluded that from our study that RFI which followed settings in the experiment of five-minute-list may cause brain wave changes (58% with the significant level of p=0.05 or 66.7% with the significant level of p=0.1). Two-way ANOVA as well as Tukey's HSD test were also supported that results indicated that the sub-band of theta and alpha are the only two major analyzing parameters in the EEG signals recorded in the test periods. Outcomes of the paired t-tests for two of the three time trial data segments also suggested that there are significant brain wave changes produced by RF exposure. Outcomes of the scales analyzing suggested that the degree of positive emotions is reduced after RF exposure, and there is no significant changes in the degree of negative emotion.

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