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Impact of Mobile Phone Electromagnetic Waves on Brainwaves

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Abstract

In the era of wireless communication, cellular phone becomes an indispensable accessory to most people. People use cellular phone to interact with others, perform commercial and financial transactions, or conducting recreational activities, etc. The advance in wireless technology and escalate of broadband networks not only flourish communications industry and application service providers but also encourage people perform prolonged wireless network activities under the risk of over exposing themselves in long term high frequency electromagnetic waves. For example, some people conduct excessive phone-trading activities, as it is necessary to the job, and some people exercise the non-stop e-learning or recreation activities on mobile devices with long hours. However, would prolonged exposure to high frequency EMW environment bring adverse effects on human health? This research from the perspective of cognitive neuroscience investigates the effect of EMW from cellular phone to the energy distribution of human brainwave characteristic band by examine brainwave changes of test subjects when exposing to high frequency EMW environment. Experiment uses left ear and right ear to answer the phone separately. The calling session is divided into three stages: the instant of call connection, during the call, and after the call. On each ear, the brainwave signal of each calling stage is extracted and analyzed. The experiment shows at the instant of call connection stage, resulting maximum EMW strength, having extreme effect on the energy distribution of the human brainwave characteristic band, and causing severe changes on the energy of human brainwave.

Keywords: electromagnetic waves (EMW), cognitive neuroscience, brainwave

1. Introduction

What is electromagnetic field or electromagnetic waves? There are three types of man-made electromagnetic waves surround us and affect our health. They are Radio Waves (RF, also known as Radio Frequency), Extremely Low Frequency (ELF) electric field, and Electric Magnetic Field (EMF) magnetic field. The electromagnetic wave from the cellular phone is RF, and the 50/60 Hz electromagnetic wave from the household electricity falls into the categories of ELF and EMF. Mobile phone is operating using the high frequencies to transmit and receive signals. With a distance of within 2cm from a user's head, mobile phones can radiate radiofrequency (RF) signals in the range of 450 to 2500 MHz [1]. In a mobile phone, there are already built in antenna to receive and transmit signals. Radiated power from an antenna is approximately up to 125mW [2]. Part of the radio waves which emitted by a mobile phone are absorbed by the human heads. The radio waves emitted by a GSM mobile phone can have a peak power of 2 watts [2]. Some users of mobile phone have reported feeling several unspecific symptoms during and after its use, ranging from burning and tingling sensations in the skin of the head and extremities, fatigue, sleep disturbances, dizziness, loss of mental attention, headaches, heart palpitations, to disturbances of the digestive system [3]. Reports have noted that all of these symptoms can also be attributed to stress and that current

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research cannot separate the symptoms from nocebo effects [3].

Some medical applications use electromagnetic fields in the RF range. Therapeutic applications such as soft tissue healing appliances, hyperthermia for cancer treatment, or diathermy expose the patient well above the recommended limit values to achieve the intended biological effects [4]. In 1935 Burr and Northrop examined and published the effects of stable voltage gradients on various biological systems. They were followed by a lot of scientists who found that stable voltage gradients led to many drastic changes in the organism, including growth and local injury. Studies have shown that these effects were associated with changes in distribution of ions [5]. According to some authors, there is connection with electromagnetic fields and disappearance of bees known as colony collapse disorder in Europe and the US, and that it could also interfere with bird migration [6-7].

Electromagnetic waves generated by many natural and human-made sources can travel for long distances and play a very important role in daily life. In particular, the electromagnetic fields in the Radiofrequency (RF) zone are used in communications, radio and television broadcasting, cellular networks and indoor wireless systems. Resulting from the technological innovations, the use of electromagnetic fields gradually increases and thus people are exposed to electromagnetic waves at levels much higher than those present in the nature [8]. Along with the widespread use of technological products in daily life, the biological effects of electromagnetic waves started to be discussed. Particularly, the dramatically increasing number of mobile phones users rise significant concerns due to its potential damage on people exposed by radiofrequency waves. Since mobile phones are used in positions very close to the human body and require a large number of base station antennas, the public and the scientists have question marks in their mind about the impact of mobile phone networks on health [9].

This research from the perspective of cognitive neuroscience investigates the effects of EMW from cellular phone to the energy distribution of brainwave characteristic band of human being.

2. EMW Specifications and Measurement

Cellular base stations at Taiwan are spreading all over the island. Many base stations locate in populated residential area that causing health concern for the electromagnetic waves they emit. As result, the issue brings frequent protesting and confrontation between Cellular service provider and public. Major controversy lies on lack of solid government regulation over the amount of allowable EMW emission. This agitates speculations about government being partial to the Cellular service provider and further enhanced the confrontation. Henceforth, to avoid further confrontation, the government should, based on rigorous scientific research data, issue regulation on permissible EMW emission to protect public health. Moreover, with the expansion of industrialization and infrastructure, the electromagnetic waves emitted by the industry, transportation, power grid, scientific research and medical facilities should be evaluated rigorously to maintain a healthy environment for the public.

A wide frequency range of radio wave (3 kHz – 300 GHz) and microwave scattering in our living environment affect our daily life. Most of these EMW are man-made byproducts of broadcasting, radar communications, satellite communications, medical and industrial manufacturing. More specifically, EMW sources form household microwave oven, cellular phone (including base station), radio broadcasting, computer terminal equipment, medical rehabilitation devices, plastic cutting and molding high frequency industrial machinery, etc. EMW is ubiquitous to our daily life. As the result, the effect of EMW to human health has becoming a concern to the public.

World Health Organization (WHO) in 1996 formally categorized the range of EMW world widely. The categorization is based on the strength of EMW at range of 0 Hz to 300 GHz. EU and International Commission on Non-Ionizing Radiation Protection (ICNIRP) further issues EMW exposure limitation of human body as shown in the Table 1[10].Most

countries follow ICNIRP regulations and set theirs' own industrial and household EMW permissible value. The 2005 annual report by International EMF Project of WHO also endorses the ICNIRP regulation. The current permissible EMW exposure regulations for different working environment in Taiwan are given in Table 2 and 3[11]. In general, electric magnetic fields distribute over a wide range of frequencies. For non-ionizing radiation, the frequency starts from extreme low frequency (0 Hz) to nanometer wave (300 Hz) are all in the category of EMW.

There are controllable and uncontrollable EMW surrounding. Example of controllable EMW surrounding includes laboratory where strength of EMW can be measured and adjust by professionals for protection. The protection measures at these locations are mainly for the safety of the professionals on site. Examples of uncontrollable EMW surrounding are airports, hotels, auditoriums, and other public places. The EMW of these public places are commonly generated extraneously that difficult to trace and control. The safety measures at these locations are mainly for the public. The above tables indicate that the human body acceptable EMW exposure values vary along with frequency. Among them, the 1 Hz acceptable EMW exposure values that under the column title - Current density for head and trunk is setup to prevent damaging cardiovascular and central nerve system. The acceptable EMW exposure values of 1~10 MHz are mainly for protecting functionality of central nerve system. The SAR value given at the frequency ranges 100 KHz to 10 GHz are setup to prevent overheating human surface tissue. Altogether, the above regulations establish a strong correlation between health concerns and the frequency and the strength of EMW.

Table 1 The acceptable EMW exposure values to the health of human body by EU and ICNIRT

Frequency range	Magnetic flux density (mT)	Current density for head and trunk J(mA/m^2) r.m.s	Whole body average SAR (W/kg)	Localized SAR (head and trunk) (W/kg)	Localized SAR (limbs) (W/kg)	Power density S(W/m^2)
0Hz	40	-	-	-	-	-
> 0~1Hz	-	8	-	-	-	-
1~4Hz	-	8/f	-	-	-	-
4~100Hz	-	2	-	-	-	-
1000~100kHz	-	f/500	-	-	-	-
100kHz~10MHz	-	f/500	0.08	2	4	-
10MHz~10GHz	-	-	0.08	2	4	-
10~300GHz	-	-	-	-	-	10

Table 2 The suggested susceptible non-ionizing radiation exposure value of personnel by Taiwan ICNIRP

IRPA		Frequency	Recommended Value
Object	Professionals	50/60Hz	5000 mG
		1-400MHz	1 mW/cm^2
		400-2000MHz	f/400 mW/cm^2
		2000-300000M/Hz	5 mW/cm^2
	General public	50/60Hz	1000 mG
		1-400MHz	0.2 mW/cm^2
		400-2000MHz	f/2000 mW/cm^2
		2000-300000M/Hz	1 mW/cm^2

Table 3 The suggested susceptible non-ionizing radiation exposure value of environment suggested by Taiwan ICNIRP

Frequency Range	Electric field strength E(V/m)	Magnetic field strength H(A/m)	Magnetic flux density B(uT)	Power density Seq(W/m^2)
<1Hz	-	3.2×10^4	4×10^4	-
1-8Hz	10,000	$3.2\times10^4/f^2$	$4\times10^4/f^2$	-
8-25Hz	10,000	4,000/f	5,000/f	-
0.025-0.8KHz	250/f	4/f	5/f	-
0.8-3KHz	250/f	5	6.25	-
3-150KHz	87	5	6.25	-
0.15-1MHz	87	0.73/f	0.92/f	-
1-10MHz	$87/f^{0.5}$	0.73/f	0.92/f	-
10-400MHz	28	0.073	0.092	2
400-2000MHz	$1.375f^{0.5}$	$0.0037f^{0.5}$	$0.0046f^{0.5}$	f/200
2-300GHZ	61	0.16	0.20	10

This research adopts TES-92 high-frequency electromagnetic meter as shown in Figure 1. TES-92 monitors high-frequency radiation over the frequency range of 50MHz to 3.5GHz and equips a high sensitivity 3-axis non-directional sensor which make it capable of measuring not only electric fields but also strength of electro-magnetic fields of cross electromagnetic chamber (TEM cells) and electromagnetic anechoic chamber (Absorber rooms). It supports different measurement units and operating modes, and complies most known regulations. Operating mode determines measuring types such as intensity of electro-magnetic field or power density and so on.The supporting units of measurement include mV/m, V/m, uA/m, mA/m, uW/m2, mW/m2, W/m2, uW/cm2, mW/cm2 ,etc. Measurement of the high frequency power density is crucial for the measurement can be used to calculate absorbed EMW power by human body. The exposure to the high frequency EMW should be minimum for healthy consideration. Especially the high frequency has a greater adverse effect on human health that compares to the low frequency counterpart..

Fig. 1 TES-92 EMW Meter

3. Brainwaves Measuring

There are enormous numbers of nerve cells operating constantly inside the brain. These cells emit Faint EMW when they are operating. Using scientific instruments, we can visualize movement of the emitted EMW on screen, and it appears as sea wave like waveform and hence the name "brainwaves". Brainwave and human consciousness are highly correlated and they operate in accordance with rhythmic cell activity. Cerebral cortex can be divided into several functional regions; the frontal region is responsible for reasoning, planning, and portions of languages, sports, and emotion; the parietal region is responsible for tactile, pressure, temperature, and pain; the temporal region is related to perception, auditory stimuli recognition and memory; and the occipital region mainly concerns visual sensory [12].

The brainwave is defined as arrhythmic of electric potential between brain cells called neurons and proficiently captured by EEG equipments. Brainwave signals are grouped into four types which are Alpha, Beta, Theta, and Delta. The

frequency of alpha wave is from 8 to 12 Hz and significantly presents when the person is in a relaxed condition or reflecting with closed eyes [13-14]. During this state, a person is still awake yet resting. Slightly higher from alpha, beta wave's frequency, ranges from 12 to 30 Hz. Beta wave is indicative of active, busy or anxious thinking and active concentration [13]. Thus, related to the alert or working state. Delta wave is the lowest frequency range starting from almost zero and can be only up to 4 Hz. It is higher during sleeping mode, whereas Theta ranges from 4 to 7 Hz. It is dominant when someone is feeling tired and depressive. EEG is the recording of electrical activity along the scalp produced by the firing of neurons within the brain. In clinical contexts, EEG refers to the recording of the brain's spontaneous electrical activity over a certain period of time [13-14]. EEG test is harmless and painless and can be repeated. Electrodes are placed on specific sites on the scalp to detect and record the electric signal impulses within the brain. EEG electrodes transform ionic current from cerebral tissues into electrical current used in EEG preamplifier. This device will detects and amplifies the electrical signals and record them onto software in the computer. Some applications of EEG are as diagnostics tools for the case of epilepsy, coma and brain death [15-16].

This research will analyze and identify the brainwave patterns due to the usage of mobile phone on human brainwave particularly the alpha and Beta waves. Furthermore, we compare the results between three stages which are before, during and after usage. Finally, the energy distribution analysis of brainwaves is performed to show the difference for the three stages. In addition, this research is also to help and bring awareness to the public on the effects of radiation from mobile phone so that users can take precautions and realize about the side effects of the mobile phone usage.

3.1. EEG Measuring Experiment

The time frame protocol of the experiment involving three stages were before (the moment of connecting), during and after usage of mobile phone. Initially, samples will undergo the interview sessions to answer questioners related to the usage of mobile phones. The interview session is normally conducted between five to ten minutes. The EEG recording duration was five minutes for each stage with one minute rest period in between, giving a total of approximately 20 to 25 minutes for each sample. The same mobile phone was used and fixed to the ear of the sample. During EEG recordings, samples were asked to close their eyes, relax and not allowed to talk to reduce interference in the EEG signals. The EEG signals were recorded under three stages which are before (the moment of connecting), during and after call using mobile phone. Figure 2 is the adopted EEG module and a demonstration of EEG measuring is shown in figure 3.

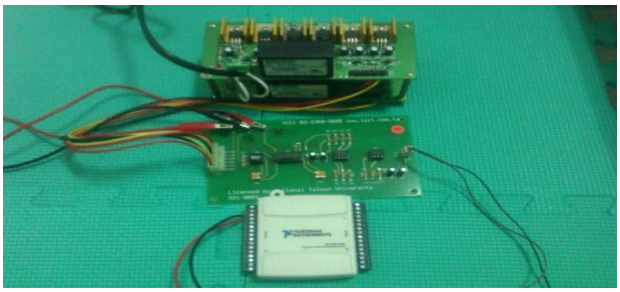

Fig. 2 EEG Sensor

Fig. 3 Brainwaves Recording

4. Measurement and Comparison of Brainwaves Differences

This research analyses the characteristic frequency bands of brainwave from the point of view of the cognitive neuroscience. This research from the perspective of cognitive neuroscience investigates how Electromagnetic waves can influence users' brainwave distribution of characteristic frequency bands. The research experiment accomplishes this by extracting subjects' brainwave while using mobile phone. The extracted measurements are then analyzed and compiled statistics for its distribution over the brainwave characteristic frequency bands with respect to Electromagnetic waves strength.

4.1 Proposed framework of Brainwave analysis system

The system structure proposed in this research includes the brainwave sensor which is used to capture brainwave signals and the brainwave analysis interface in the back-end which is used to analyze the brainwave frequency bands. The proposed framework of brainwaves analysis is shown in Fig. 4. The related steps are described as follows:

(1) Attach electrode patches to the subjects after installation of a brainwave sensor and capture brainwave signals, as shown in Fig.5.

(2) Digital brainwave signals are sent to PC and saved as Excel or Txt format through the USB port after being converted by A/D Converter.

(3) Brainwaves analysis interface provides brainwave analysis for the data in the prescribed format. The time-domain part of the brain analysis interface provides the strength change in time for the original brainwave signals. The brainwave signals are then processed by FFT formally as shown in Figs.6-9. In this study, the percentages of amplitudes of sectional brainwave frequency band are used to calculate the sectional brainwave energy.

(4) Statistics and analysis of the corresponding characteristic frequency bands energy under different electromagnetic waves strength.

(5) Compare the difference of brainwave characteristic bands under different electromagnetic waves strength.

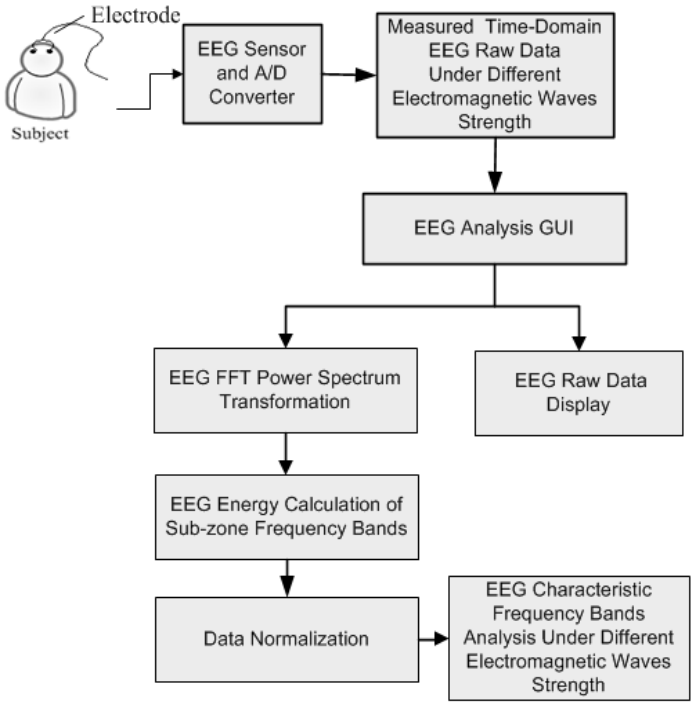

Fig. 4 Brainwave analysis structure under different electromagnetic waves strength

Fig. 5 Electrode attachment position

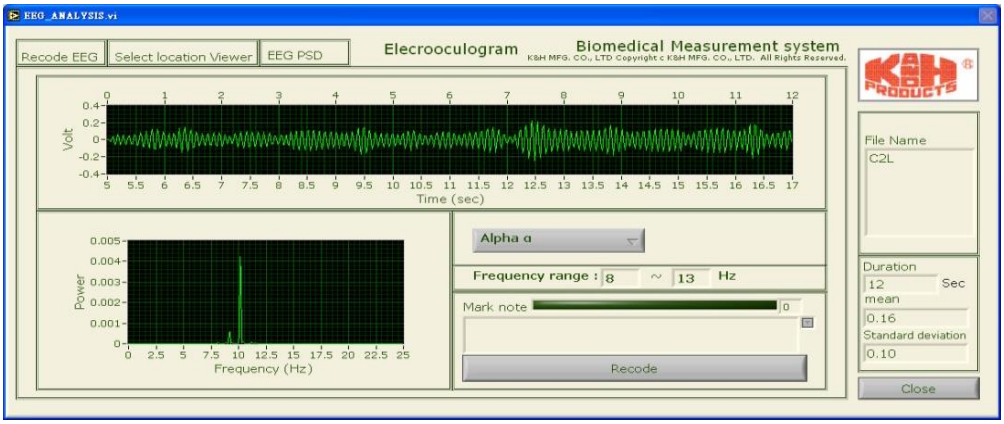

Fig. 6 α brainwave at the instant of the call connection

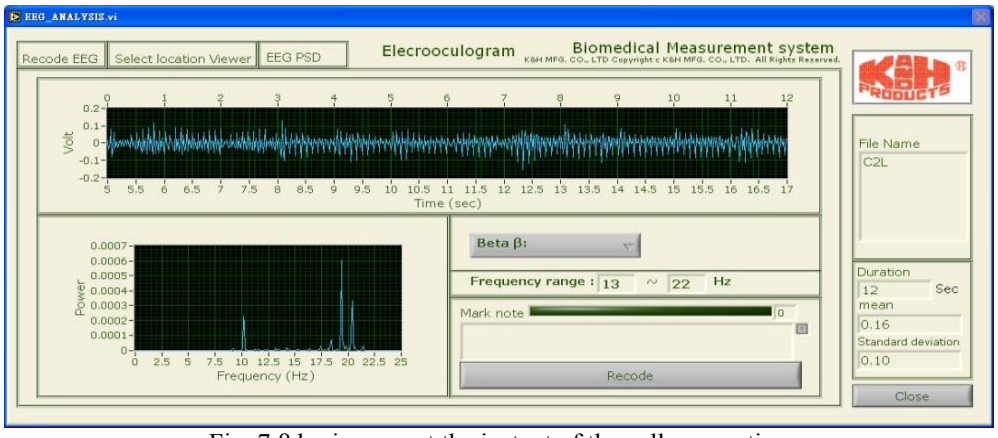

Fig. 7 β brainwave at the instant of the call connection

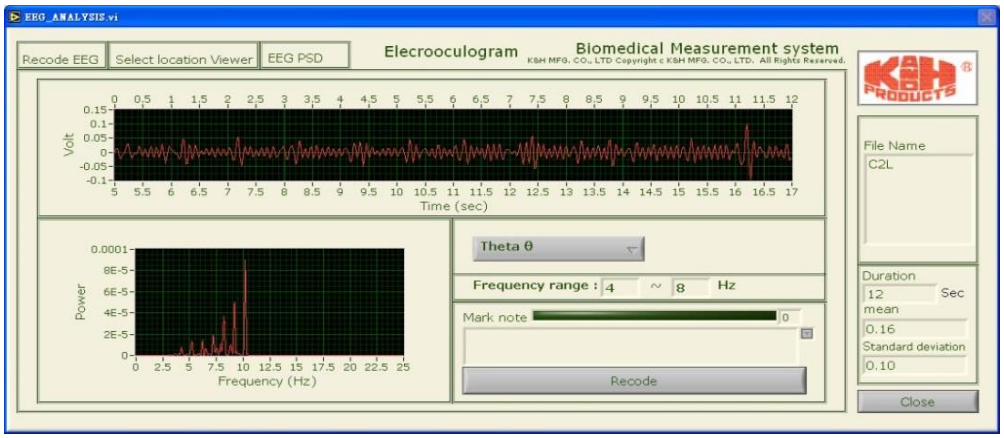

Fig. 8 θ brainwave at the instant of the call connection

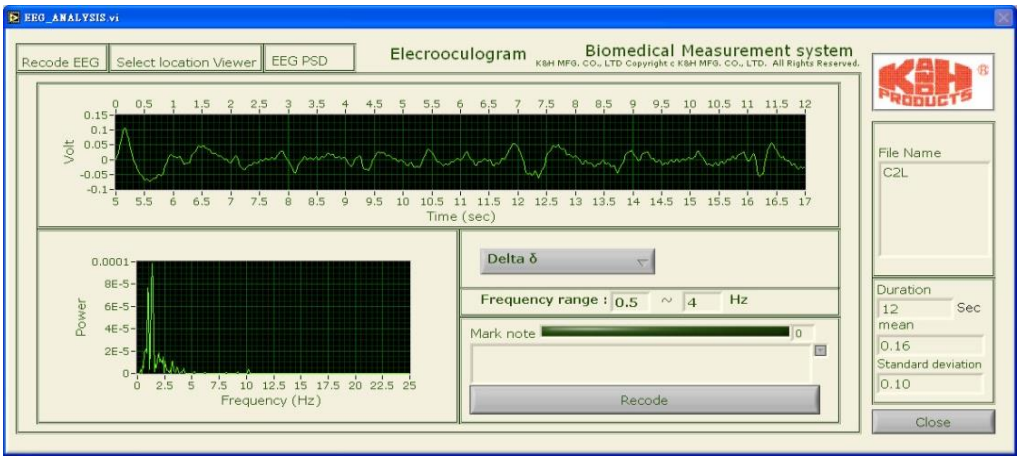

Fig. 9 δ brainwave at the instant of the call connection

4.2 Analysis of Brainwaves differences

The averaged values of the total amplitude of different frequency bands for 15 normal subjects are calculated so as to obtain the energy of the sectional frequency bands and the total energy using Eq. (1) and (2). In the above equations, B is the sectional frequency bands, f is the start frequency of each frequency band, n is the end frequency of each frequency band, and E is energy of each frequency band. ET is the total energy of the four sectional frequency bands from 0.2Hz to 25Hz. The brainwave energy percentage of α, β, θ and δ is respectively (EB/ET) %. The energy percentage of the sub-sectional frequency EΔ is namely the percentage of the energy in the individual subsection and the energy in the total frequency band, as shown in Eq. (3) [17].

$$E_B = \sum_{f}^{n} Power_f \tag{1}$$

$$E_T = \sum_{f=0.2}^{25} Power_f \tag{2}$$

$$E_\Delta(\%) = \frac{E_\Delta}{E_T} \tag{3}$$

The averaged energy distribution of 15 subjects under different usage stages of mobile phone are listed in Table 4, Table 5 and Table6.The whole call session of the experiment consists of three stages: the instant of call connection, during the call, and after the call. Experiment data shows when making a phone call using the right ear, the distribution of brain wave characteristic bands during the whole call session (starts from the instant of call connected to the end of call) mainly resides at 9 ~ 10 Hz and 10 ~ 11 Hz of the α wave, and 19 ~ 20 Hz and 20 ~ 21 Hz of the β wave. More interestingly, an additional band of 6~7 Hz θ waves shows up at the instant of the call connection.The brainwave energy distribution from the above table shows energy distribution varies with the calling stages. When using the right ear, extreme brainwave energy distribution take place at the instant of call connection where δ wave and β wave are the lowest among the three calling stages, and θ and αare the highest among the three calling stages. Furthermore, the measured EMW at the instant of call connection is the strongest among the tree calling stages. The average EMW strength of the three calling stages are shown in Table 7.

Experiment shows, at the instant of call connection effect of EMW to human brain wave is evidently, as the severe transition of brainwave energy band. This strongly suggests caller should avoid holding phone too close to ear when the call is connected. When using the left ear and repeating the experiment, it also shows energy distribution varies with calling stages. Especially, the distribution of brainwave energy band at the instant of call connection is quite different to the distribution obtained from normal awakening situation. At the instant of call connection, both energy of δ wave and θ wave

are higher than other calling stages, and energy of β wave is the lowest among the three calling stages. This is quite different to the brainwave of an awake and calm person. The difference of brainwave energy band between using right and left ears at the instant of connection is shown in Table 8. As shown in the Table, the most intense change of brainwave at the instant of call connection take place when using right ear, which is even more severe than using left ear.

Table 4 Averaged Brainwave Energy distribution at the instant of the call connection (Right ear to answer)

Status	Brainwave type	Subzone frequency (Hz)		Subzone energy/ total energy (E_Δ%)	Freq. at max. amplitude (Hz)	Total zone energy percentage (E_B/E_T %)	Char. Freq. of subzone
Right ear to answer	Delta (δ)	δ1	0.2 ~ 1	3.02	2.09	13.37	
		δ2	1 ~ 2	3.05			
		δ3	2 ~ 3	3.16			
		δ4	3 ~ 4	3.06			
	Theta (θ)	θ1	4 ~ 5	3.96	6.17	17.81	θ3
		θ2	5 ~ 6	3.44			
		θ3	**6 ~ 7**	**5.15**			
		θ4	7 ~ 8	2.79			
	Alpha (α)	α1	8 ~ 9	3.79	10.20	27.59	α2 α3
		α2	**9 ~ 10**	9.17			
		α3	**10 ~ 11**	10.14			
		α4	11 ~ 12	3.88			
		α5	12 ~ 13	3.58			
	Beta (β)	β1	13 ~ 14	3.89	17.94	41.23	β7 β8
		β2	14 ~ 15	2.79			
		β3	15 ~ 16	3.70			
		β4	16 ~ 17	4.14			
		β5	17 ~ 18	2.59			
		β6	18 ~ 19	3.78			
		β7	**19 ~ 20**	7.95			
		β8	**20 ~ 21**	9.84			
		β9	21 ~ 22	3.13			

Table 5 Averaged Brainwave Energy distribution during calling (Right ear to answer)

Status	Brainwave type	Subzone frequency (Hz)		Subzone energy/ total energy (E_Δ%)	Freq. at max. amplitude (Hz)	Total zone energy percentage (E_B/E_T %)	Char. Freq. of subzone
Right ear to answer	Delta (δ)	δ1	0.2 ~ 1	2.86	2.12	13.40	
		δ2	1 ~ 2	3.07			
		δ3	2 ~ 3	3.20			
		δ4	3 ~ 4	3.45			
	Theta (θ)	θ1	4 ~ 5	3.43	6.27	16.70	
		θ2	5 ~ 6	3.85			
		θ3	6 ~ 7	3.84			
		θ4	7 ~ 8	3.54			
	Alpha (α)	α1	8 ~ 9	4.22	10.47	27.28	α2 α3
		α2	**9 ~ 10**	7.32			
		α3	**10 ~ 11**	10.32			
		α4	11 ~ 12	3.94			
		α5	12 ~ 13	4.19			
	Beta (β)	β1	13 ~ 14	3.70	17.49	42.62	β7 β8
		β2	14 ~ 15	3.54			
		β3	15 ~ 16	3.77			
		β4	16 ~ 17	3.99			
		β5	17 ~ 18	3.63			
		β6	18 ~ 19	3.63			
		β7	**19 ~ 20**	6.89			
		β8	**20 ~ 21**	10.25			
		β9	21 ~ 22	3.39			

Table 6 Averaged Brainwave Energy distribution after calling (Right ear to answer)

Status	Brainwave type	Subzone frequency (Hz)		Subzone energy/ total energy (E_Δ%)	Freq. at max. amplitude (Hz)	Total zone energy percentage (E_B/E_T %)	Char. Freq. of subzone
Right ear to answer	Delta (δ)	δ1	0.2 ~ 1	3.38	1.98	15.83	
		δ2	1 ~ 2	3.50			
		δ3	2 ~ 3	3.78			
		δ4	3 ~ 4	3.66			
	Theta (θ)	θ1	4 ~ 5	3.59	6.28	16.63	
		θ2	5 ~ 6	3.64			
		θ3	6 ~ 7	3.77			
		θ4	7 ~ 8	3.40			
	Alpha (α)	α1	8 ~ 9	3.82	10.47	25.31	α2 α3
		α2	**9 ~ 10**	**6.65**			
		α3	**10 ~ 11**	**10.33**			
		α4	11 ~ 12	4.02			
		α5	12 ~ 13	3.81			
	Beta (β)	β1	13 ~ 14	4.06	17.85	42.23	β7 β8
		β2	14 ~ 15	3.61			
		β3	15 ~ 16	4.06			
		β4	16 ~ 17	3.61			
		β5	17 ~ 18	3.87			
		β6	18 ~ 19	4.00			
		β7	**19 ~ 20**	**7.78**			
		β8	**20 ~ 21**	**7.69**			
		β9	21 ~ 22	3.96			

Table 7 Averaged Electromagnetic Strength

Type	Instant ($\mu W/cm^2$)	During ($\mu W/cm^2$)	After ($\mu W/cm^2$)
HTC Wildfire S	3.793	0.779	0.338

Table 8 Averaged Brainwave Energy distributionat the instant of the call connection

Status	Total Zone Frequency Bands Energy (%)				
	δ	θ	α	β	Char. Sub-Zone Frequency Bands
Listen by right ear	13.37 (Min)	17.81 (Max)	27.59 (Max)	41.23 (Min)	θ_3 , α_2, α_3, β_7, β_8
Listen by left ear	16.99 (Max)	17.04 (Max)	26.0	39.97 (Min)	α_2, α_3, β_7, β_8

5. Conclusions

This research from the prospective of Cognitive Neuroscience investigates the effect of high frequency EMW to the energy distribution of human brainwave characteristic band. The experiment extracts energy of brainwave characteristic band of a caller and analyze its changes according to the three stages of the call: at the instant of call connection, during the call, and after the call. The experiment established that the distribution of brain wave energy band will change with the above calling stages. In particular, the instant of connection stage generates the most distinguishable energy distribution of brainwave band. When using the right ear, it has lowest δ and β waves of the three stages and the strongest θ and α waves of the three stages. The EMW measurement is also the highest among the three. When using the left ear, the experiment also shows unusual energy distribution of brainwave band. The strongest EMW effect to the brainwave takes place at the instant of call connection from which the transition of the energy distribution of brainwave band is also the most significant. Also,

using right ear has more severe EMW effect than using left ear. All these suggest caller should use left ear to answer the phone and avoid holding the phone too close to the ears.

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