Brainwaves Analysis of Positive and Negative Emotions

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Abstract: - Emotions, is the generic term for various subjective cognitive experiences and a psychological and physiological synthesized state generates under a variety of perceptions, thoughts, and behaviours. In general, emotion can be categorized into Joyful, Angry, Protected, Sad, Surprised, Fear, Satisfied and Unconcerned eight types of positive-negative emotions. More subtle and delicate emotions include jealousy, humiliation, shame, pride and other emotions. Emotion is often under influence of mood, personality, temperament, purpose and other factors. It can also be affected by hormones and neuro transmitters. Whether positive or negative emotions are all motivations and trigger action. Although some emotional behaviour seems take place inadvertent, however conscious plays an important role in producing emotion. This paper from the perspective of cognitive neuroscience investigates difference of human brainwave of 8 types of positive and negative emotions i.e. Joyful, Angry, Protected, Sad, Surprised, Fear, Satisfied and Unconcerned. The experiment uses acoustic stimuli to stimulate the positive and negative emotions of the test subjects and uses Electroencephalogram (EEG) to extract test subjects' frontal lobe brainwave. The extracted brainwave is further transformed into frequency domain signal where sub-band energy is calculated, characterized, and finally digital encoded for analysis. The encoded characteristic brainwaves of positive and negative emotion are compared for theirs difference. It shows 8 different positive and negative emotions can be effectively identified by the proposed emotional brainwave digital encoding technique and the technique is promising for developing future emotion identification technique.

Key-Words: - Brainwave, Cognitive Neuroscience, Emotion Recognition

1 Introduction

Emotions can be classified into innate "basic emotions" and "complex emotions" which acquired through learning. Basic emotions are innate and closely relates to human survival instinct. In contrasting, complex emotional has to be learned through human interaction and hence each individual owns different number of complex emotions and has different definition of them. Emotion has being described as abrupt response to the internal or external important events and a person always takes the same response to the same event. Emotion lasts for a very short duration; it collaborating actions of language, physiological, behavioural and neural mechanism [1]. Human emotions also derive from biological functionalities/survival instinct and strengthen through evolution. It provides simple solutions to frequent problems that early human have to confront, such as fear causes evasion [2, 3].

Emotions are both a subjective experience and an objective physiological response. It is has its purpose and also a social expression. Emotions are divisive complex comprehensive events [4]. From the component-processing model, emotion consist five basic elements that must be coordinated in a short time, synchronous manner [5]. The five basic elements are cognitive assessment, physical reactions, feelings, tendencies, expression, and action. These elements are described as follow:

Cognitive Assessment: Observing external incident (or people), cognitive system automatically evaluates its emotion, thereby triggering subsequent emotional response (for instance, seeing the beloved pet dies, the cognitive system of the owner assesses the incident as a significant negative event). Physical reaction: a physiological component of emotion and a spontaneous reaction of the body that makes the subject adapt to the sudden event (for example, realizing irreparable death of the pet, pet owner's nervous system becomes less sensitive,

body experiencing malaise, heart rate slow down, and other physiological reactions).
Feelings: subjective emotions of person (for example, after the death of their loved ones, family members produced a series of physical and psychological reactions. Subjective consciousness picks up these changes that collectively referred to as "sad").
Expression: a facial and voice variations show subject's emotions to convey subject's opinion and intention to the others (for example, seeing the death of relatives, family members frown and dropping of the lip corners to convey a crying expression.) There are expressions common to all and some are private [6].
Tendencies: emotions generate motivation (for example, people tend to find somebody to talk to when feeling sad and will do something unusual when feeling anger.)

Beside the subject who is experiencing emotion shift, bystanders can also learn subject's emotion shift through observation. However, are there any other ways to learn people's emotion shift beside observation and interaction? Is there an effective scientific approach to identify the inner emotion shift of people? This study identifies positive and negative psychological emotions using brainwave variation. It focuses on analysing eight types of positive and negative emotions: Joyful, Angry, Protected, Sad, Surprised, Fear, Satisfied and Unconcerned. Figure 1 depicts the relation between the above emotions in three dimensions. The figure expands the emotions into three-dimensional space using three orthogonal axes: the positive or negative, the strength, and the shift of the emotion.

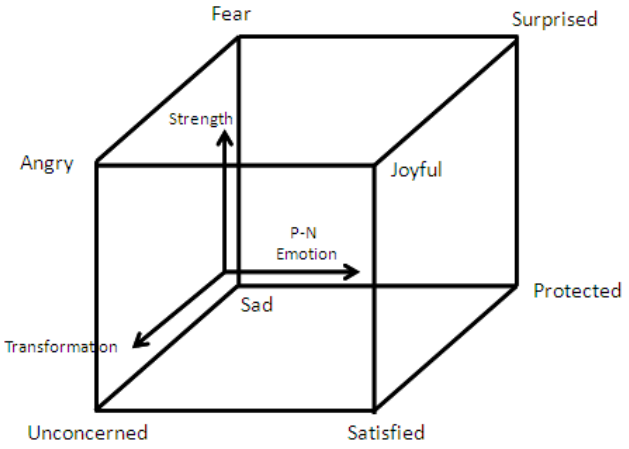

Figure 1 3D Emotions Graph

Brainwave is an electromagnetic signal generated by electrochemical process of the nerve system inside the Brain. The nerve system, by discharging ironic chemical substance and through ion permeability transforms chemical signal into electrical signal. The neuron, core of nerve system is responsible of generating electric signal. When the receptor which locates at the surface of the neuron receives ironic substance from the nerve system, an action voltage is built up and hence an electric signal is fired. Different excitations will generate different types of signal patterns. Rhythmic potential variation that consists of Electrical Rhythms and Transient Discharge is generated when nerve system conducting signal and this aggregative rhythmic potential variation from billions of neuron constitutes what we called the Brainwave [7].

Recent brainwave identification technique has been widely adapted in Brain-computer Interface (BCI) design, where human intention/thoughts is extracted and identified by brainwave instrument and feeds directly to the computer interface circuit for interaction [8]. Clinically, brainwave signal analysis is a common practice to diagnosis non-structural brain lesions diseases (such as Epilepsy, Alzheimer's disease, Sleep dysfunction, and etc.) [9]. This research, based on the cognitive neuroscience, uses brainwave sensor to extract brainwave signal of the test subjects while they are performing the induction of emotions. The extracted measurements are further analysed, compiled statistics for its distribution over the brainwave characteristic frequency bands, and finally the characteristic frequency bands of emotional brainwaves are digitally encoded to come up with a metrics for human emotions identification.

2 Design of EEG Sensor Module

There are four frequency bands such as Alpha (α), Beta (β), Theta (θ) and Delta (δ) according to the data provided by the International Federation of Societies for Electroencephalography and Clinical Neurophysiology [10]. The α wave is a brainwave with frequency between 8Hz and 13Hz, and with amplitude of about 50μV. The β wave has a main frequency between 13Hz and 22 Hz and a potential of about 5-20 μV. The θ wave has a frequency between 4Hz and 8 Hz. The δ wave has a frequency between 0.2Hz and 4Hz.Brainwave technique was originally for medical purpose such as diagnosing epilepsy and other brain related diseases. For medical purposes, brainwave measurements are taken under T-20 standard electrode position and the measurements are used to diagnosis brain related diseases such as epilepsy, Alzheimer's disease and other brain related diseases. The adopted relevant brainwave EEG functional block diagram and

sensor module is shown as in Fig.2and Fig.3 [11]. The brainwave sensor proposed in this research is not only small in size, convenient to carry and easy to operate but also is low in price, and is applicable to being used in various industries in the future compared to the medical grade electroencephalograph.

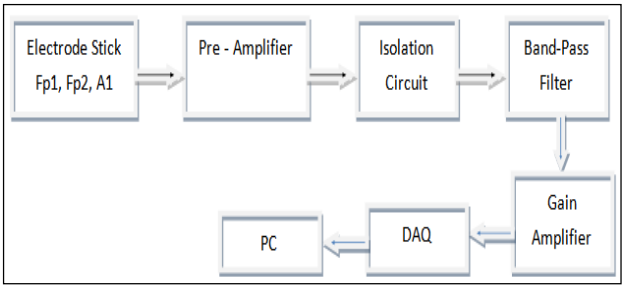

Figure 2 EEG functional block diagram

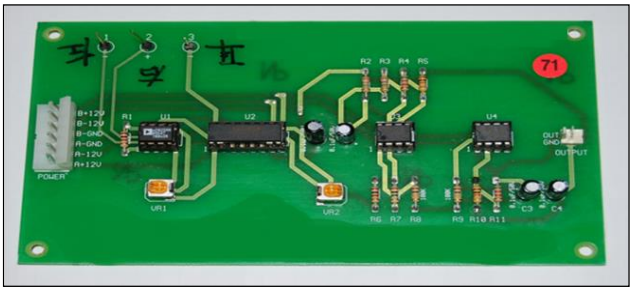

Figure 3 EEG sensor module

3 System Implementation and Statistic Analysis

This research follows the perspective of cognitive neuroscience, develops characteristic frequency bands of brainwave for identifying positive and negative emotions of human brain. The research experiment accomplishes this by extracting test subjects' brainwave under different emotion response. The extracted measurements are then analyzed and compiled statistics for its distribution over the brainwave characteristic frequency bands with respect to different emotional brainwaves, and finally the digital codes of the emotional brainwaves are encoded.

3.1 Framework of Analysis System

The relevant framework for characteristics analysis of the emotional brainwave frequency bands is shown in Fig.4. The relevant steps are described as follows:

(1).After installation of a brainwave sensor, the electrode patches are attached to the participants and then the acquisition program is used to capture emotional brainwave signals.

(2).After being converted by the ADC module of the sensor, the emotional brainwave signals are sent to PC and saved as Excel or Txt format through the USB port.

(3).The emotional EEG Analysis GUI (as shown in Fig. 5) provides brainwave analysis for the data in the format of Excel or Txt. The time-domain part of the GUI provides the strength change in time for the original emotional brainwave signals. The emotional brainwave signals are then processed by Fast Fourier Transform (FFT) formally, as shown in Fig.6, Fig. 7. In this research, 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.

(5).Difference comparison and digital encoding of brainwave characteristic frequency bands.

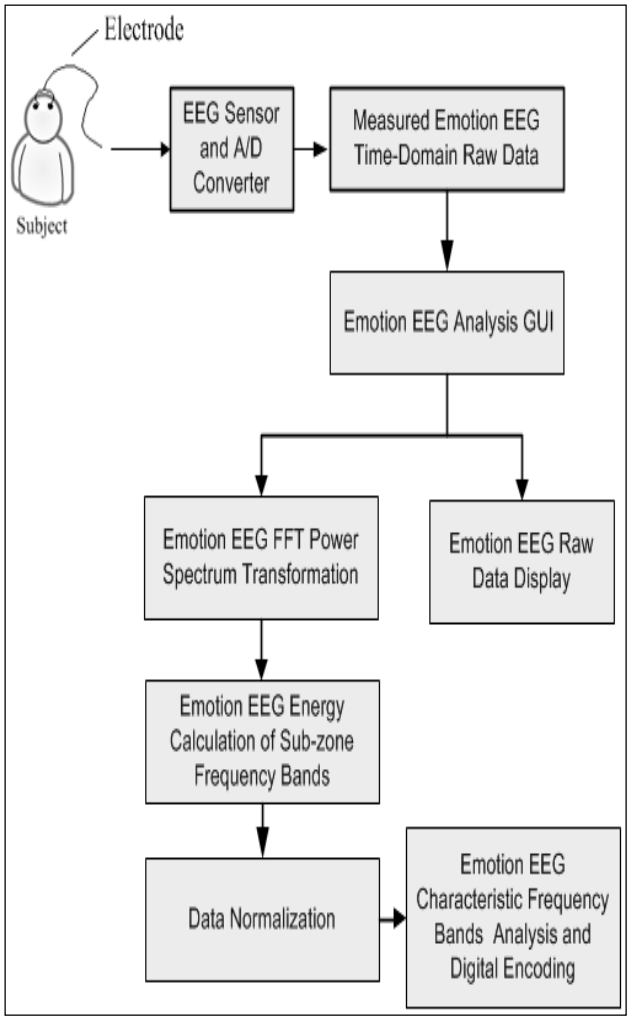

Figure 4 Analysis structure of emotional braiwaves

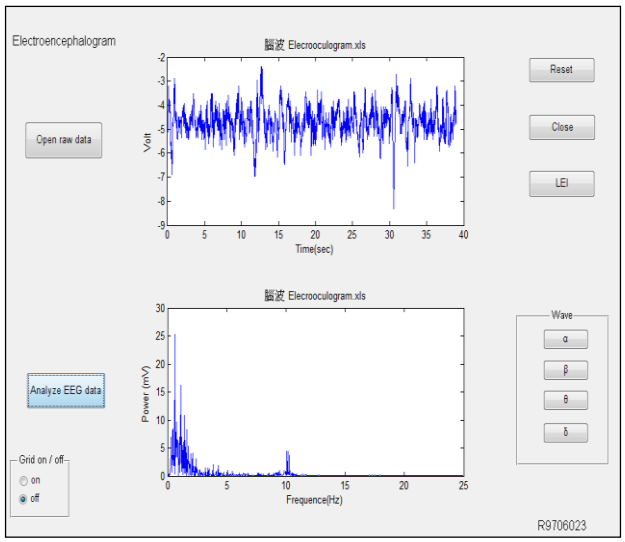

Figure 5 GUI of emotional braiwaves analysis

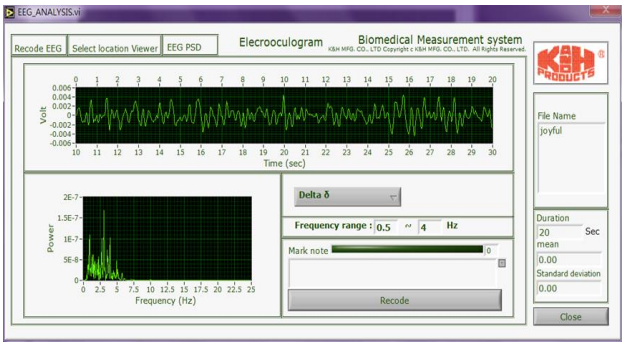

Figure 6 δ brainwave of Joyful emotion

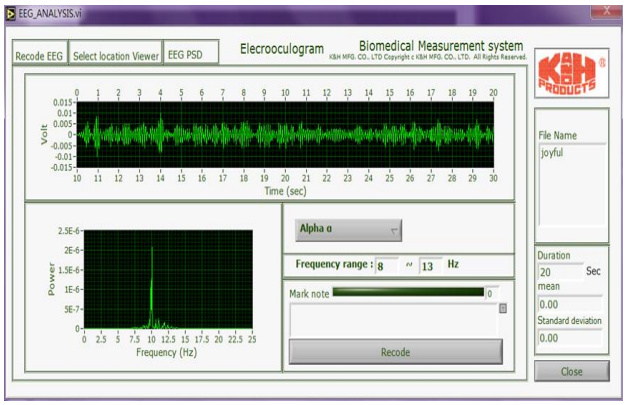

Figure 7 α brainwave of Joyful emotion

3.2 Analysis Method of Emotional Brainwaves

This research develops a brainwave concentration analysis system to identify human's direction perception. The system performs Fast Fourier Transform (FFT) to transfer time domain brainwave signal into frequency domain spectrum. It then applies Even-Related coherence (ERCoh) to divide brainwave spectrum into sub-bands, calculates the energy ratio and performs normalization on each derived sub-band, and finally constructs brainwave frequency characteristic bands of the test subject by analyzing its brainwave energy distribution [13].

The relevant emotional brainwave energy calculation method is described as follows. The average of the total potential amplitude of different frequency bands for 15 participants is calculated so as to obtain the energy of the zone frequency band and the total energy using Eq. (1) and (2). In the above equations, B are the zone frequency bands, f is the start frequency of each frequency band, n is the end frequency of each frequency band (the frequency sampling interval is 0.01Hz), and E is energy of each frequency band. E_T is the total energy of the four zone frequency bands from 0.2Hz to 25Hz. The energy percentage of α, β, θ and δ is respectively (E_B/E_T) %. The energy percentage of the subzone frequency E_Δ is namely the percentage of the energy in the individual subzone and the energy in the total frequency band, as shown in Eq. (3) [14].

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

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

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

3.3 Analysis of Emotional Brainwave Characteristic Bands

This research conducts the experiment in a coherent environment, applies a set of acoustic emotional stimuli to stimulate emotional shift and measures brainwave variation with respect to different stimuli of the test subject. The acoustic stimuli are for medical experiment purpose and have to be registered for downloading, it contains 8 types of stimuli for emotions: Joyful, Surprised, Protected, Satisfied, Angry, Fear, Sad, and Unconcerned [12]. It takes 3 different sounds to stimulate each emotion shift for the required brainwave measurement. The whole experiment requires 8 different set of acoustic stimuli and a total of 24 stimuli. Before the experiment started, 15 subjects are set to listen three different stimuli, then subjects pick a stimuli that best fit his/her current emotion and uses the stimuli to perform necessary test stimulation. In the

experiment, a sound is played three times consecutively for each emotion. It takes approximately 100 seconds for each emotional test. Before the test, the subject takes a 10 seconds' break to calm down. The test starts by playing a 20 seconds of acoustic stimuli and having the brainwave of the subject recorded at the same time, it then immediately followed by a 10 seconds break. The above sequel is repeated for three times and a total of 100 seconds for the complete test.

A total of 15 males and females junior students participate the experiment. A total 45 emotional brainwaves data are collected. This research analysis eight different acoustic stimulated emotional brainwaves. The research analysis δ、θ、α、β sub-bands brainwave data of emotions including Joyful、 Surprised、 Protected、 Satisfied、 Angry、 Fear、 Sad、 Unconcerned. Furthermore, emotions are grouped into 4 pairs of positive-negative emotion groups: Joyful-Angry、 Surprised-Fear、 Protected-Sad、 and Satisfied–Unconcerned.

Based on the energy distribution of main brainwave characteristic frequency band by analyzing subject's emotions characteristics, it establishes the digital encoding of emotional brainwaves. The energy distribution and characteristic frequency bands of the tested different emotional brainwaves are listed in Table 1, Table 2, Table 3 and Table 4. Based on the α, β, θ and δ in the above Tables, the average energy percentage of the frequency band of each zone is calculated and the relevant characteristic frequency bands are found out according to the energy level when the participants were tested for their emotion response. Table 5 shows brainwave characteristic band encoding of positive and negative emotions that Joyful and Angry. Encoding is done by dichotoming the sub-band to 1 if its sub-band energy exceeds 4% of overall brainwave energy, and 0 if its energy is less than 4%. As shown in Table 5, the measured negative emotion (Angry) has greater average total brainwave energy than the positive emotion (Joyful). In addition, there is a distinguishable α band encoding between the two emotions.

Table 1 Averaged Brainwave Energy Distribution under Joyful Emotion

Status	Brainwave type	Zone frequency(Hz)	Subzone frequency (Hz)		Subzone energy/ total energy (E_Δ%)	Total energy percentage of zone (E_B/E_T %)	Characteristic frequency of subzone
Joyful	Delta (δ)	0.2 ~ 4	δ1	0.2 ~ 1	3.63	15.21	δ4
			δ2	1 ~ 2	3.52		
			δ3	2 ~ 3	3.62		
			δ4	3 ~ 4	4.44		
	Theta (θ)	4 ~ 8	θ1	4 ~ 5	4.92	16.75	θ1 θ2
			θ2	5 ~ 6	4.50		
			θ3	6 ~ 7	3.56		
			θ4	7 ~ 8	3.76		
	Alpha (α)	8 ~ 13	α1	8 ~ 9	3.76	31.45	α2 α3
			α2	9 ~ 10	9.38		
			α3	10 ~ 11	11.39		
			α4	11 ~ 12	3.62		
			α5	12 ~ 13	3.31		
	Beta (β)	13 ~ 22	β1	13 ~ 14	3.71	36.59	β7 β8
			β2	14 ~ 15	3.24		
			β3	15 ~ 16	3.78		
			β4	16 ~ 17	3.51		
			β5	17 ~ 18	3.25		
			β6	18 ~ 19	3.75		
			β7	19 ~ 20	5.75		
			β8	20 ~ 21	6.01		
			β9	21 ~ 22	3.60		

Table 2 Averaged Brainwave Energy Distribution under Angry Emotion

Status	Brainwave type	Zone frequency(Hz)	Subzone frequency band (Hz)		Subzone energy/ total energy (E_Δ%)	Total energy percentage of zone (E_B/E_T %)	Characteristic frequency band of subzone
Angry	Delta (δ)	0.2 ~ 4	δ1	0.2 ~ 1	3.53	16.04	δ4
			δ2	1 ~ 2	3.86		
			δ3	2 ~ 3	3.99		
			δ4	3 ~ 4	4.67		
	Theta (θ)	4 ~ 8	θ1	4 ~ 5	5.11	16.68	θ1 θ2
			θ2	5 ~ 6	4.53		
			θ3	6 ~ 7	3.70		
			θ4	7 ~ 8	3.34		
	Alpha (α)	8 ~ 13	α1	8 ~ 9	3.55	31.86	α2 α3 α4
			α2	9 ~ 10	9.27		
			α3	10 ~ 11	11.63		
			α4	11 ~ 12	4.13		
			α5	12 ~ 13	3.27		
	Beta (β)	13 ~ 22	β1	13 ~ 14	3.30	35.41	β7 β8
			β2	14 ~ 15	3.58		
			β3	15 ~ 16	3.25		
			β4	16 ~ 17	3.17		
			β5	17 ~ 18	3.28		
			β6	18 ~ 19	3.68		
			β7	19 ~ 20	5.43		
			β8	20 ~ 21	6.10		
			β9	21 ~ 22	3.63		

Table 3 Averaged Brainwave Energy Distribution under Surprised Emotion

Status	Brainwave type	Zone frequency(Hz)	Subzone frequency band (Hz)		Subzone energy/ total energy (E_Δ%)	Total energy percentage of zone (E_B/E_T %)	Characteristic frequency band of subzone
Surprised	Delta (δ)	0.2 ~ 4	δ1	0.2 ~ 1	4.24	16.51	δ1 δ4
			δ2	1 ~ 2	3.75		
			δ3	2 ~ 3	3.81		
			δ4	3 ~ 4	4.72		
	Theta (θ)	4 ~ 8	θ1	4 ~ 5	4.66	15.19	θ1 θ2
			θ2	5 ~ 6	4.05		
			θ3	6 ~ 7	3.08		
			θ4	7 ~ 8	3.39		
	Alpha (α)	8 ~ 13	α1	8 ~ 9	3.66	30.88	α2 α3
			α2	9 ~ 10	10.21		
			α3	10 ~ 11	9.68		
			α4	11 ~ 12	3.78		
			α5	12 ~ 13	3.55		
	Beta (β)	13 ~ 22	β1	13 ~ 14	3.17	37.42	β7 β8
			β2	14 ~ 15	3.14		
			β3	15 ~ 16	3.38		
			β4	16 ~ 17	3.18		
			β5	17 ~ 18	3.33		
			β6	18 ~ 19	3.61		
			β7	19 ~ 20	6.68		
			β8	20 ~ 21	7.20		
			β9	21 ~ 22	3.73		

Table 4 Averaged Brainwave Energy Distribution under Fear Emotion

Status	Brainwave type	Zone frequency(Hz)	Subzone frequency band (Hz)		Subzone energy/ total energy (E_Δ%)	Total energy percentage of zone (E_B/E_T %)	Characteristic frequency band of subzone
Fear	Delta (δ)	0.2 ~ 4	δ1	0.2 ~ 1	4.45	16.23	δ1 δ4
			δ2	1 ~ 2	3.75		
			δ3	2 ~ 3	3.95		
			δ4	3 ~ 4	4.07		
	Theta (θ)	4 ~ 8	θ1	4 ~ 5	4.89	16.08	θ1 θ2
			θ2	5 ~ 6	4.21		
			θ3	6 ~ 7	3.38		
			θ4	7 ~ 8	3.60		
	Alpha (α)	8 ~ 13	α1	8 ~ 9	3.61	31.32	α2 α3
			α2	9 ~ 10	10.89		
			α3	10 ~ 11	9.80		
			α4	11 ~ 12	3.59		
			α5	12 ~ 13	3.42		
	Beta (β)	13 ~ 22	β1	13 ~ 14	3.43	36.67	β7 β8
			β2	14 ~ 15	3.29		
			β3	15 ~ 16	3.32		
			β4	16 ~ 17	3.15		
			β5	17 ~ 18	3.22		
			β6	18 ~ 19	3.59		
			β7	19 ~ 20	5.68		
			β8	20 ~ 21	6.84		
			β9	21 ~ 22	3.86		

Table 5 Difference Comparison of Joyful and Angry Emotions Brainwaves

P-N Emotion / Freq. Bands		Joyful emotion			Angry emotion		
		Energy (%)	Energy	Digital code	Energy (%)	Energy	Digital code
δ Delta (1~4)	0.2~1	3.63	0.20	δ(0001)	3.53	0.26	δ(0001)
	1~2	3.52	0.20		3.86	0.29	
	2~3	3.62	0.20		3.99	0.29	
	3~4	4.44	0.25		4.67	0.35	
θ Theta (5~8)	4~5	4.92	0.28	θ(1100)	5.11	0.38	θ(1100)
	5~6	4.50	0.25		4.53	0.34	
	6~7	3.56	0.20		3.70	0.27	
	7~8	3.76	0.21		3.34	0.25	
α Alpha (9~13)	8~9	3.76	0.21	α(01100)	3.55	0.26	α(01110)
	9~10	9.38	0.53		9.27	0.69	
	10~11	11.39	0.64		11.63	0.86	
	11~12	3.62	0.20		4.13	0.31	
	12~13	3.31	0.19		3.27	0.24	
β Beta (14~22)	13~14	3.71	0.21	β(000000110)	3.30	0.24	β(000000110)
	14~15	3.24	0.18		3.58	0.26	
	15~16	3.78	0.21		3.25	0.24	
	16~17	3.51	0.20		3.17	0.23	
	17~18	3.25	0.18		3.28	0.24	
	18~19	3.75	0.21		3.68	0.27	
	19~20	5.75	0.32		5.43	0.40	
	20~21	6.01	0.34		6.10	0.45	
	21~22	3.60	0.20		3.63	0.27	

3.4 Digital Encoding of Emotional Brainwaves

The 8 digital encoding of emotional brainwave characteristic band are shown in Table 6. The Table shows negative emotion Fear shares the same digital encoding of Surprise. Therefore, digital encoding along cannot effectively identify these two different emotions. As result, this research further proposes using highest energy sub-band to identify emotions. The result is shown in Table 7, it shows sub-band δ4 and δ1 of the δ band can provides effective emotion identification.

Table 6 Digital Encoding of Positive-Negative Emotional Brainwave Characteristic Bands

Frequency Bands / Emotions	δ	θ	α	β
Joyful	0001	1100	01100	000000110
Angry	0001	1100	01110	000000110
Surprised	1001	1100	01100	000000110
Fear	1001	1100	01100	000000110
Protected	1001	1000	11100	000000110
Sad	0001	1000	11110	000000111
Satisfied	1000	1100	01110	000000110
Unconcerned	1001	1000	01100	000000110

Table 7 Comparison of Highest Brainwave Sub-band Energy of Emotion Surprise and Fear

Brainwave Frequency Bands	Surprised emotion		Fear emotion	
	the highest energy sub-band of emotional brainwave		the highest energy sub-band of emotional brainwave	
δ	δ4 (3~4Hz)	0.24	δ1 (0.2~1Hz)	0.25
θ	θ1 (4~5Hz)	0.24	θ1 (4~5Hz)	0.27
α	α2 (9~10Hz)	0.52	α2 (9~10Hz)	0.60
β	β8 (20~21Hz)	0.37	β8 (20~21Hz)	0.38

4 Conclusions

This research form the perspective of cognitive neuroscience, extracts and computes the emotional brainwave energy using brainwave sensor. The emotional brainwave energy data are further analysis and characterize for different emotions. The experiment use medical acoustic stimuli to stimulate brainwave responses of different types of positive and negative emotions. The experiment shows among 4 pairs of positive and negative emotions (Joyful-Angry、 Surprised-Fear、Protected-Sad、 Satisfied–Unconcerned), all negative emotions have a greater energy compared to the positive emotion. There are three pairs of characteristic band encoding carry distinguishable difference and can be effectively identify through emotional brainwave digital encoding. However, the positive and negative emotion of Surprise and Fear shares the same emotional brainwave characteristic digital encoding and using the proposed highest energy brainwave sub-band comparison scheme can resolve these two different emotions effectively. The research shows the processed brainwave characteristic band digital encoding technique and highest sub-ban energy scheme can effectively identify brainwave of 8 types' positive and negative emotions.

Acknowledgements

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