Research on EEG Features in Different Emotional States

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Research

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Abstract

In order to improve the detection and treatment of neurological diseases effectively, it is a significant means to analysis EEG features. In this study, extrovert and stable persons were selected as the subjects according to the Eysenck Personality Questionnaire. Then set the subjects' EEG signals in a quiet state with eyes closed as a reference group. Four types of pure music were selected as stimulus materials to induce four different kinds of emotions: pleasure, sadness, irritability, and fear. During the period, evoked EEG signals was acquired. Then, some signal processing methods were used to de-noise for EEG and separate EOG artifacts from EEG signals. Finally, EEG signals' features in time domain, frequency domain and time-frequency domain were extracted, especially the method which combined Hilbert transform based on EMD with information entropy to calculate EEG signals' Hilbert spectrum entropy for four emotional states. The results showed that EEG signals' features in different emotional states changed with gender, brain and mood objectively, all differences mainly reflected in time domain features, frequency domain features and time-frequency domain features. All the results reveal that EEG signals' variation characteristics in the process of auditory stimulation, and can be an adjustment basis for detection and treatment of neurological diseases.

I. introduction

As social competition becomes more and more severe, various psychological stress factors increase sharply, mental disorders have already become one of the most prominent problems in society. According to statistics from the Ministry of Health, more than 16 million people suffer from severe mental and psychological disorders and there are also 6 million people with epilepsy, which occupies 1.69% of total population, and 190 million people with different levels of mental or psychological disorders that require professional intervention. Emotion is an integrated psychological process, including experience, physiology and expression, generated by the interaction between objective things and human needs[1-3]. Emotion can be expressed through facial expressions, psychological states, physiological responses[4] etc. and the brain, as the control center of the human body, dominates these neural responses, and 2019 Alzheimer's Disease Facts and Figures show that the brain changes that occur with Alzheimer's disease[5].

Therefore, the changes in emotions are ultimately reflected in the changes of EEG signals.

Researchers in neuroscience are using scientific methods to discover that human emotions can be triggered by a variety of external stimuli, such as static visual images, sound stimuli, and brain imagination. Research on EEG (Electroencephalogram, EEG) features during different emotional states, aims at using external stimulation to induce different emotions, via a variety of analysis methods, with the characteristic of the clear, significant differences to reflect the complex brain electrical changes, this research is not only benefit to development of brain mechanism, and has important significance for development of neuroscience and music therapy .

At present, many scholars devote themselves to research of the mechanism of brain action, and find that there are obvious differences in the brain's mechanism in different brain regions under different emotional states. However, there is a lack of uniformity in many research conclusions. In the previous doctoral thesis, it showed that happiness can induce stronger beta band and gamma band in the temporal lobe, the neural patterns of neutral and sad emotions are similar. Neutral emotion has stronger α band in the parietal and occipital lobe brain areas. Sadness can induce stronger delta band in the parietal and occipital lobe brain areas, but in the prefrontal brain area gamma band dominates[6]. Some scholars found that fearful stimuli evoked significantly larger LPP in right centro-parietal region than sad stimuli($P<0.05$), the regulation of sadness significantly increased the LPP in left and right frontal-central regions after the stimulation($P<0.05$), the regulation of sadness and fear both significantly enhanced the LPP in left frontal-central($P<0.05$)[7]. There are also some different thoughts in this field, for an instance, these scholars proposed a model named "Incentive-Inhibition" related to emotion by EEG analysis, and believed that the activity in the left frontal area of the brain was related to the incentive emotions of cheerful, interest, happiness and other behaviors, while the activity in the right frontal area was related to the inhibitory emotions of fear, disgust, sadness and other behaviors[8]. Since the power of a segment is contrary to brain activities[9], that is, the greater of the power represents, the less brain activities will induce, while the smaller of the power represents the more brain activities. Some summarize also validate by other scholars, they confirmed these results through their own research. When processing positive emotions, power in the left frontal region of the brain is lower than power in the right frontal region, while processing negative emotions, power in the left frontal region of the brain is higher than power in the right frontal region[10-11]. Numerous studies have found that there are obvious differences in the brain's mechanism at different emotional states in different brain regions, but the human body has physical and psychological changes at different life stages and different genders. Therefore, study on the changes of the basic rhythms of EEG signals caused by different brain regions and different emotions are not comprehensive for research on brain's mechanism, and parts of research only analyze the changes in a certain rhythm in different emotional states is lack of extensiveness—there are also inconsistencies in the results. To solve these problems, this study analyzed the average EEG and four basic rhythms of subjects in four age groups under five emotional states to explore the relationship between the brain's mechanism and emotional states, brain region, gender and age.

In addition, research by the Human Cognitive and Brain Science Research Center in Leipzig, Germany pointed out that the richness of musical activities determines that music is the most ideal tool to research brain function[12]. Its most important advantage lies in music which can trigger a fairly intense emotional response and these emotions can be induced consistently across different subjects; Music can induce not only unpleasant emotions, but also pleasant emotions, which are very difficult to induce by a static image. Therefore, music was selected as the stimulus source to induce different emotional states in this research. EEG signals were collected according to gender, age, emotion and brain region, and then extracted time domain, frequency domain and time-frequency characteristics of EEG signals and analyzed. The results show that the α segment and β segment of EEG are related to emotional processing, and the four segments of EEG are all involved in emotional cognition activity, and show

different activity levels in different brain regions quantitatively. Furthermore, Hilbert spectrum entropy is proposed as an objective indicator of emotion recognition which is an advanced direction in this field. These results provide a theoretical basis for exploring the mechanism of the brain, especially for music therapy, disease prevention and healthy life style.

II. Data Acquisition

A. EYSENCK PERSONALITY QUESTIONNAIRE (EPQ): SELECT SUBJECTS

Everyone has different personalities and their music appreciation abilities are diverse. Therefore, the selection of suitable subjects is crucial to the generality and reliability of the results. Before the experiment, Eysenck Personality Questionnaire (EPQ) was used to measure the personality type of the subjects, and the same type of people were selected as subjects due to EPQ can identify personality types from four scales and have been verified by a variety of psychological experiments conducted by the Department of Psychology and the Institute of Psychiatry of the University of London, all results are highly reliable and effective. EPQ consists of four subscales: E, N, P, L. E scale measures the internal and external tendencies of personality. The N scale measures emotional stability; Both E scale and N scale are bipolar scales, and there is no distinct boundary between the two poles, which can only be expressed as difference in degree. P scale is a unipolar scale, which is only meaningful when P score is high. L scale is a validity scale, which measures the authenticity of the answers. Itself also represents a stable personality function. Taking the E scale as the X axis and the N scale as the Y axis, the relationship between temperament types and E and N sales is shown in Fig.1. Melancholic type has too much black bile, which is usually characterized by melancholy and sadness, silence, unsociability, anxiety, rigidity and seriousness; choleric type has too much yellow bile, which is usually characterized by sensitive, easily irritated, easy to attack, restlessness and changeable; phlegmatic type has too much mucus, which makes people slow or lazy, do things carefully, good at thinking, calm, reliable and gentle; sanguine type has too much blood, which is always full of vitality and motivation, good at communication, talkative, leadership, easygoing and open-minded.

According to EPQ test results, people's personalities are divided into four types: extroverted unstable type (choleric type), extroverted stable type (sanguine type), introverted unstable type (depressive type) and introverted stable type (mucous type). Each type of personality is different. In the experiment, subjects of the same age group were selected according to their gender. Then, according to the test results, subjects of extroverted stable type (sanguine type) were selected as subjects for EEG collection.

B. MUSIC SELECTION

Psychological research shows that people's emotions are complex and difficult to be controlled by themselves, but can be alleviated and regulated by a variety of activities, and music plays the most unique role in this process. Music directly stimulates people's hearing through the melody and rhythm

sound generated by human voice or musical instrument, making people consciously or unconsciously accept the strong infection of thoughts and feelings or certain emotions to be expressed in music[13]. In addition, compared with static visual images, different emotional states were induced during music appreciation, which reduced the interference of eye movement artifacts.

According to various elements of music: melody, rhythm, timbre, intensity, harmony, body and form, music can be divided into different types according to the combination of its rich personalities. Due to the different effects of different music styles on the brain, according to the tune style, this research selected four types of pure music: cheerful, melancholy, fidgety and scary as stimulation sources, which can induce four different emotions: happy, sad, agitated, horrific, these four types of emotions as the basic forms of modern psychology can reflect the mood and passion changes of the subjects perfectly.

C. SIGNAL ACQUISITION AND EMOTION CLASSIFICATION

EEG signal contains lots of brain information, it's a very random physiological signal. A variety of different emotions and mindsets can affect the changes in brain waves. Therefore, EEG has high event sensitivity and is easily contaminated by irrelevant noise during the acquisition process, then generating various EEG artifacts.

In research of brain cognitive functions, specific EEG signal acquisition equipment or multi-functional physiological signal recording equipment are mostly used to collect EEG signals. At present, the most widely used are Neuroscan EEG/ERP EEG recording system and BIOPAC MP150 system. In this research, The MP150 multi-physiological signal acquisition equipment is used to collect EEG signals and positioned in frontal lobe and temporal lobe respectively, while recording horizontal and vertical EOG (electro-oculogram) signals during EEG acquisition process. We choose EEG100C amplifier and its gain is 5000, 2 shielded wires LEAD110(VIN+,VIN-) and 1 unshielded wire(GND) used to acquire EEG signals and sample rate sets as 200Hz. Meanwhile, the high-pass filter sets as 0.1Hz. Detailed acquisition method is shown in Fig.2.

The subjects are all non-music-related graduate students, aged 23-25, in good health, and has no family history related to brain disease, mental disorder or organic disease. Five males and five females are right-handed (EPQ tested and all are extroverted and stable). Before the experiment, subjects are required to ensure adequate sleep, avoid alcohol or coffee and other food that can lead to central excitement or inhibit central excitement. They cannot have vigorous exercise and their hair must ensure refresh to avoid excessive external interference.

During the signals' acquisition, the subjects keep their eyes closed and relaxed as much as possible. We wipe the surface of the skin with alcohol or saline in advance, then paste electrodes and acquire EEGs of the 10 subjects under the five emotional states: quiet, happy, sad, agitated, horrific (during music play, always follow the order: music which can induce positive polarity mood played at first, and then play music which can induce negative polarity mood) respectively. Before music evoked, each subject has to collect EEG signals during the quiet state and with eyes closed as a control group. Due to each

individual's taste to music appreciation, and music types' classification are different, so play 20 pieces of music randomly which are downloaded before (four types of pure music and every type has five pieces). According to the beat cognitive of the music[13,14], the 20 pieces of music with different lengths but similar and there is fixed 2 min interval during every 2 pieces of music (use programmable players and set interval as 120s between every 2 pieces of music), the subjects write down music's serial numbers and their type to classify if music's type match with defined style, then adjust themselves' moods recover from the former piece of music.

iii. Signal Processing And Feature Extraction

A. PREPROCESSING OF EEG

Acquiring EEG signals by physiologic recorder under different emotional states, the collected signals' frequency are greater than 0.1 Hz, containing EEG and other interference signals, because the frequency range of main ingredients of EEG's rhythm is 0.5 Hz ~ 50 Hz (δ rhythm 0.5~3.5Hz, θ rhythm 3.5~7.5Hz, α rhythm 7.5~13.5Hz, β rhythm 13.5~35Hz, γ rhythm 35~50Hz), the frequency of γ rhythm is too high and the people in this situation all the time will be life-threatening, so δ , θ , α , β rhythms are meaningful for this study. We use band-pass filter to extract EEG signals within range 0.5 ~ 35 Hz as the experimental data, at the same time avoiding the interference of 50 Hz power-line frequency.

In the process of EEG signals acquisition, it is inevitable to be interfered by acquired environment, equipment and other physiological signals. Because EOG signals have high amplitude and the frequency range overlaps with EEG signals, it's the main physiological signal which interface the acquisition of EEG signals. Independent Component Analysis (ICA)[15] can effectively remove eye movement artifacts. ICA assume different physical process will produce statistically independent signals, via the higher order statistical characteristic of signals to analysis non-gaussian structure of the data, to search a linear transformation to implement observe data's decomposition, and the ingredients broke down has the largest independence statistically, making it better and more effective than the classical factor analysis and principal component analysis[15], not only can eliminate the redundant component of mixed signal and has a strong resilience for source signal in mixed signal.

Fig.3 shows mixed EEG (2000 sample points) measured in frontal lobe, horizontal EOG_h (2000 sample points), and vertical EOG_v (2000 sample points) under quiet and eyes-closed condition. The EOG_h and EOG_v components in mixed EEG were separated by three-channel ICA separation, and the three ICA components - EEG, EOG_h and EOG_v were obtained. Due to uncertainty of ICA separation, it is necessary to distinguish the three components obtained by separation, two components are EOG signals and the other one is EEG signal, so this problem belongs to two classification issues. According to the fuzzy C-means algorithm, firstly, we extract the energy features of the three output components, then calculate the category of each feature, that is, the percentage of a certain signal, finally detect the coherent signal components and distinguish EEG signals and redundant signals(EOG signals). Fig.4 shows the EEG signals obtained after ICA separation.

B. FEATURE EXTRACTION

In this study, EEG signals' features are extracted in time domain, frequency domain and time-frequency domain respectively so that we can analyze these signals comprehensively.

1) Time domain feature extraction

Time domain amplitude histogram analysis is performed on the pre-processed EEG signals (2000 sample points' signals) acquired in five emotional states, and the processing results are shown in Fig.5. The amplitude range of the four basic rhythms of EEG signals is roughly as follows: rhythm δ (20~200 μ V), rhythm θ (10~40 μ V), rhythm α (30~50 μ V), rhythm β (5~30 μ V). This feature shows the changes in EEG signals in different genders, different brain regions, and the proportion of the four rhythms in each emotional state.

As the results shown in Fig.5, EEG signals and the four rhythms changed with gender, brain region and emotional state. In the quiet and eye-closed state, the rhythm α of EEG signals is dominant. With the increase of mood fluctuations, rhythm α decreases and rhythm β increases. When girls are in a state of sadness, their mood fluctuations are greater than those of boys, and rhythm α occupies a large part in EEG signals. Happy emotions activate rhythm β more easily than sad ones, and θ rhythm is scarce in all five emotional states.

2) Frequency domain feature extr-action

Power Spectral Density (PSD) is power distribution carried by each unit of frequency wave. This parameter can reflect the frequency which occupied a larger percentage in the spectrum and migration of whole EEG under different conditions. Therefore, the power spectral density analysis of EEG signals (2000 sample points' signals) in the five pre-processed emotional states was carried out, and the experimental results are shown in Fig.6.

From Fig.6, energy distribution of EEG signals under the five emotional states is significantly different, and rhythm distribution of EEG signals under each state is also different. The changed PSD frequency of EEG signals is concentrated in 0.5~35Hz, which involves the changes of four basic rhythms. Moreover, with the difference of gender, emotion and brain region, the energy distribution of EEG signals is also very different. The maximum power value of temporal lobe EEG signal lags behind that of frontal lobe obviously. No matter in the frontal lobe or temporal lobe, sadness is more likely to cause female students' mood swings, while irritability mood is more likely to cause male students' mood swings. The other four moods cause more brain activity in the temporal lobe than in the frontal lobe, except for the quiet and eye-closed state.

3) Time-Frequency DOMAIN feature extraction

Comprehensive analysis of time domain and frequency domain, as the change of mood, the four basic rhythm waves of brain electrical signals all can be changed, analysis one rhythm or any two rhythms can cause one-sidedness of experiment results, so extract four rhythms of all EEG signals evoked during different states, and then further analysis for the characteristics' changes of these four kinds of rhythm waves.

According to the frequency range of each EEG rhythm, set $[j,i]$ as the i th node of the j th layer in wavelet packet decomposition[16-18], then the decomposition node contained in the four EEG rhythms as below:

δ — $[6,1],[7,1],[7,4]$

θ — $[6,3],[6,4],[7,5]$

α — $[5,3],[6,5],[7,16]$

β — $[4,3],[5,8],[5,5],[6,9],[6,18],[7,18],[7,38]$

Fig.7 shows the four basic rhythms obtained by wavelet packet decomposition of the preprocessed EEG signals (as shown in Fig.4).

Due to the non-stationarity of EEG signals, traditional analytical methods are not applicable to EEG data analysis[19]. Considering the empirical mode decomposition (EMD) based on the Hilbert transform[20-22] does not need to pre-set the basic function, and it's an adaptive time-frequency analysis method, so it's very suitable for non-linear and non-stationary signals. In this study, four basic rhythms of EEG signals acquired under five emotional states are processed by EMD. Hilbert transform is performed for each IMF component to obtain the instantaneous frequency of signal. Thus Hilbert spectrum of original signals will be obtained by superposition all IMF Hilbert spectral. Then, Hilbert spectrum entropy of signals will be obtained by combining Hilbert transform based on EMD with information entropy, to analyze the differences of EEG signals in different emotional states from the perspective of time-frequency. The calculation process of Hilbert spectral entropy of the signal is shown in Fig.8.

Four rhythms of average EEG signals of male and female students in different brain regions under five emotional states were extracted respectively. Hilbert transformation based on EMD is performed for each rhythm to analyze the difference in Hilbert spectrum entropy of each rhythm under each emotional state. The analysis results are shown in Fig.9.

In Figure 9, a, b, c, and d respectively represent the Hilbert spectral entropy of the mean EEG signals in the frontal lobe of 5 female students, the temporal lobe of 5 female students, the frontal lobe of 5 male students, and the temporal lobe of 5 male students. As we see from Figure 9, Hilbert spectrum entropy of the four basic EEG rhythms showed the following trend under any emotional state, for both male and female students: $\beta > \alpha > \theta > \delta$, indicating that the complexity of the four rhythms also showed this trend. However, the dominant rhythm waves in EEG signals are different in different emotional states. The Hilbert spectrum entropy of the full frequency band showed that pleasure mood caused more frontal lobe

activity. Compared with the frontal lobe, the five emotions produced greater differences in brain activities in the temporal lobe. Especially for agitation mood and fear mood compared with the other three emotions. Compared with the approximate entropy (the ratio of high-frequency to low-frequency Hilbert spectrum entropy), the full-frequency Hilbert spectrum entropy is more intuitive to observe the changes in the complexity of EEG signals in the five emotional states.

IV. Results And Discussion

According to the above experimental data, the analysis results can be summarized as follows:

- (1) No matter time domain, frequency domain or time-frequency domain features of EEG signals change with gender, brain region and moods, there is a corresponding relationship between these parameters and brain mechanism.
- (2) In quiet and eyes-closed status, rhythm α of EEG signals are dominant, and with the increase of mood fluctuation, rhythm α decreases and rhythm β increases;
- (3) Pleasure mood triggers more rhythm β activities than sad mood, but sad mood triggers more θ rhythm than pleasure mood, that is, θ rhythm is directly proportional to inhibitory emotions and β rhythm is directly proportional to motivational emotions.
- (4) Under the state of sadness, the brain activities of female students are greater than male students and low-frequency wave is dominant, while the feeling of irritability can cause brain activities of male students easier than female students and low-frequency wave also is the main waveform, while the amplitude of male students' EEG signals is balance. In the view of physiology and psychology, it may be caused by the increased adrenalin in female subjects' bodies at this moment because the subjects felt scared and horrified;
- (5) Except for EEG signals acquired during quiet and eyes-closed state, the other four emotions caused more brain activities in the temporal lobe than in the frontal lobe;
- (6) In any emotional state, the Hilbert spectrum entropy of the four basic rhythms of EEG signals show a downward trend: $\beta > \alpha > \theta > \delta$
- (7) Compared with agitated mood, horrific mood and the other three emotions, the temporal lobe produces a greater difference in brain activities than the frontal lobe.

The Hilbert spectrum accurately describes how the amplitude of the signal varies with time and frequency over the entire frequency range, we try to analyze the differences in EEG signals' complexity under different emotional states by Hilbert spectrum entropy, which not only improves the efficiency of signal analysis, but also more reliable than approximate entropy, it will become an important means of signals' time-frequency analysis. In this study, Hilbert transform is combined with information entropy to analyze the Hilbert spectral entropy of EEG signals in different emotional states, different brain regions and

different genders. It has good objective statistical performance and represents the changes in the frequency domain complexity of EEG signals, it overcomes the one-sidedness of single frequency-domain analysis and single time-domain analysis.

V. Conclusion

In this study, the EPQ test was adopted as the criteria for subject selection to reduce the errors caused by individual personality differences. Four types of pure music (5 sections each type) are selected as the inducing source to induce four emotions, namely, happiness, sadness, irritability and fear, and the EEG signals under the state of quiet and eyes-closed are used as the reference group. The frontal lobe and temporal lobe EEG signals of 5 male and 5 female students are acquired. The time domain, frequency domain and complexity characteristics of EEG signals are analyzed, and the changes of EEG signals under different emotional states are revealed. In addition, a large number of experimental samples are needed to further verify these experimental results.

At present, research on EEG mechanism evoked by mood which induced by different types of music is less and not deep, but music contributes to mood disorder, behavior disorder and attention deficit hyperactivity disorder becomes more and more important obviously and increasingly. So, the results of this study have an important significance for the development of brain mechanism research, nervous disease prevention and music therapy, and we will continue to study in this direction deeply and comprehensively.

Declarations

A. ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

All tests are approved by the subjects and surface mounted electrodes are used for EEG signal acquisition, non-invasive, no harm to human body. It has nothing to do with ethics.

B. CONSENT FOR PUBLICATION

Not applicable.

This manuscript does not contain data from any individual person, and it does not involve personal privacy.

C. AVAILABILITY OF DATA AND MATERIALS

All original data was acquired by the article's authors and all is used for analysis and research. Part of the original data is shown in the article as an instance, all conclusions are drawn from the original data.

D. COMPETING INTERESTS

We declare that we have no competing interests, have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled.

E. FUNDING

No funding. All participants are voluntary.

F. AUTHORS' CONTRIBUTIONS

WXT was responsible for volunteer recruitment, signal acquisition and data recording, manuscript writing, signal processing and analysis. WZ took part in signal acquisition, processing and analysis. GJW also participated in signal acquisition, processing and analysis. Professor PCJ provided research guidance, experimental equipment and environment for EEG signal acquisition. LJK participated in the guidance in the process of research and provide some technic support.

G. ACKNOWLEDGEMENTS

All volunteers are non-music-related graduate students, we acknowledge them who contributed towards the article but not meet the criteria for authorship.

H. AUTHORS' INFORMATION

WXT received B.E. degree in biomedical engineering from Changchun University of Technology, Changchun, China, in 2011, and the M.S. degree from Changchun University of Science and Technology, Changchun, China, in 2014. The research interests include biomedical signal processing and optoelectronic medical equipment. Since 2014, She entered the electronics industry and worked at electronic product development for 6 years. In 2020, she joined in Ma'anshan University and severed as a teacher in college of OSAKA medical engineering. Her research interests include biomedical signal processing and optoelectronic medical equipment. She has authored two papers and four patents.

WZ received the B.E degree in Measurement and Control Technology and Instruments from Anhui University of Technology, Ma'anshan, China, in 2017, and the M.S degree in Detection Technology and Automation Equipment from China Jiliang University, Hangzhou, China, in 2020. Since 2020, he has worked at Ma'anshan University. He is the author of four research articles. His research interests include medical robot, cochlear implant robot, signal processing.

GJW received B.E.degree in mechanical design and manufacturing and automation from Shenyang architecture University, ShenYang, China, in 2014, the M.S.degree in mechanical engineering from Shenyang architecture University, ShenYang, China, in 2017, Since 2017, he has been engaged in the teaching of biomedical engineering courses in Ma'anshan College. Published 4 papers as the first author,

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PCY received the B.E.degree in optical technology and optoelectronic instruments from Zhejiang University, Zhejiang, China in 1995,the M.S. degree in optical engineering from Changchun University of Science and Technology, Changchun, China, in 1999,and the Ph.D. degree in optical engineering from Changchun Institute of Optics and Mechanics, Changchun, China, in 2007. From 1996 to 1999, she studied under professor Yin Fuchang in Changchun University of Science and Technology. From 2003 to 2007 she was a Research Assistant to professor Zhang Tao at Changchun Institute of Optics and Mechanics. From 2013 to 2019, she got Post-doc. in Changchun University of Science and Technology, and her cooperation tutor is Yang Huamin. She became a professor of biomedical engineering at Changchun University of Science and Technology in 1995 and is currently the dean of the School of Life Science and Technology. Professor Pang's main research direction is photoelectric medical instrument and signal processing. Her research interests include wearable intelligent monitoring equipment, analysis and processing of heart and brain electrical signals, etc., early diagnosis of cardiovascular diseases. She published many research articles, six of which were searched by EI, one invention patent, and she won the first prize of Jilin Province Science and Technology Award. She presided five Jilin Provincial Department of Science and Technology projects and a Guangdong Provincial Key Laboratory of Biomedical Engineering Testing and Ultrasound Imaging, three of which have been completed.

LJK received the B.S. degree in biomedical engineering from Taishan Medical University, Tai'an, China, in 2010, and the M.S. degree from Changchun University of Science and Technology, Changchun, China, in 2013. He is currently pursuing a Ph.D. degree in University of Chinese Academy of Sciences. His research interests include biomedical signal processing, biometrics and machine learning.

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Figures

Figure 1
Relationship between temperament types and E&N scales

Figure 2
Electrodes are positioned in the process of EEG and EOG acquisition

Figure 3

Frontal mixed EEG(upper), horizontal EOG(medium), vertical EOG(bottom)

Figure 4

Separated EEG(frontal) based on ICA

(a)

(b)

(c)

(d)

Figure 5

The amplitude histogram distribution of EEG in five emotional states. (a)The amplitude histogram distribution of 5 boys' mean frontal EEG (b)The amplitude histogram distribution of 5 girls' mean frontal EEG (c)The amplitude histogram distribution of 5 boys' mean temporal EEG (d) The amplitude histogram distribution of 5 girls' mean temporal EEG

(a)

(b)

(c)

(d)

Figure 6

Power Spectral Density distribution of EEG in five emotional states. (a)PSD of 5 girls' mean frontal EEG (b)PSD of 5 girls' mean temporal EEG (c)PSD of 5 boys' mean frontal EEG (d)PSD of 5 boys' mean temporal EEG

Figure 7

The basic rhythms of EEG frontal keep quiet and eyes closing

Figure 8

Time-frequency feature extraction flow chart

Figure 9

Hilbert spectrum entropy of EEG in five emotional states. (a) Hilbert spectral entropy of 5 girls' mean frontal EEG (b) Hilbert spectral entropy of 5 girls' mean temporal EEG (c) Hilbert spectral entropy of 5 boys' mean frontal EEG (d) Hilbert spectral entropy of 5 boys' mean temporal EEG