THE CHARACTERISTIC FREQUENCY BANDS ANALYSIS OF BRAIN WAVE DURING LEARNING

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Abstract

The traditional E-learning often offers the online examination to assess the learning effect of a student after completion of the online learning. Basically, this traditional learning assessment mechanism is a passive and negative assessment mechanism, which cannot provide an real-time learning warning mechanism for teachers or students to find out problems as early as possible (including such learning conditions as "absence of mind" resulting from poor learning stage or physical or psychological factor), and the post-assessment mechanism also cannot assess the learning effectiveness provided by the online learning system. This research paper attempts to acquire the electroencephalogram to analyze the characteristic frequency band of the brainwave related to learning and formulate the learning energy index (LEI) for the learner at the time when the learner is reasoning logically via the brain-wave detector based on the cognitive neuroscience. With the established LEI, the physical and psychological conditions of an online leaner can be provided instantly for teachers for assessment. Given that the learning system is integrated into the brainwave analytic sensing component, the system not only can provide learners an instant learning warming mechanism, but also help teachers and learning partners to further understand the causes of learning disorder of learners, and can also provide relevant learning members with timely care and encouragement. This research will discuss and analyze such subjects as the electroencephalogram difference between the traditional print textbooks and the multi-medium textbooks, whether the development of exercise habit will be help to learning by means of a view of cognitive neuroscience except for the analysis of characteristic frequency band of the brainwave represented at the time when learners adopt diverse learning methods.
Key words: *cognitive neuroscience, electroencephalogram, learning energy index*.

Introduction

The cognitive neuroscience is mainly to explore the relationship between brain and noema. In fact, it is difficult to make a distinction among cognitive neuroscience, cognitive science and neuroscience. The cognitive neuroscience based on the neuroscience uses the special structure and signal of the neural system to interpret its cognitive function. In other word, it, which is to understand how the nerve cells transmit messages and communicate with each other from the view of biology when we study the brain system and cognition, is a functional neuroscience on the basis of cognitive science and neuroscience (Albright, & Neville, 1999). The cognitive science, which is a concept containing wide meaning, covers the sociology, the psychology, the pedagogy, artificial intelligence, linguistics, bioengineering, etc. and therefore is an interdisciplinary science (Eysenck, & Keane, 1990). The research range of cognitive science includes the method of storing and displaying messages and knowledge in brain, the way of human understanding languages and expressing thoughts and feelings by languages, the way of understanding images and generating consciousness, thoughts and feelings, the way of learning new knowledge, reasoning and judging, solving problems, establishing and implementing plans, which are the psychological activity caused by the intelligent mechanism of brain.

Cognition means that the noema development of individuals is closely related to knowledge, learning and intelligence, and must be transmitted via brain and mental activities. The cognitive psychologists emphasized that learning is a process of initiatively receiving messages and creative thinking, and found that the formation of human cognition could be considered as a process of processing data by computer. They attempted to use the human brain to simulate the operation flow of computer, view individuals as a data processing system, which can actively select messages generated by environment and can process and store further through mental activities so as to be ready for information retrieval and extraction when required. The relevant information process mode is as shown in Figure 1 (Atkinson, & Shffirn, 1968; Gagne, 1985).

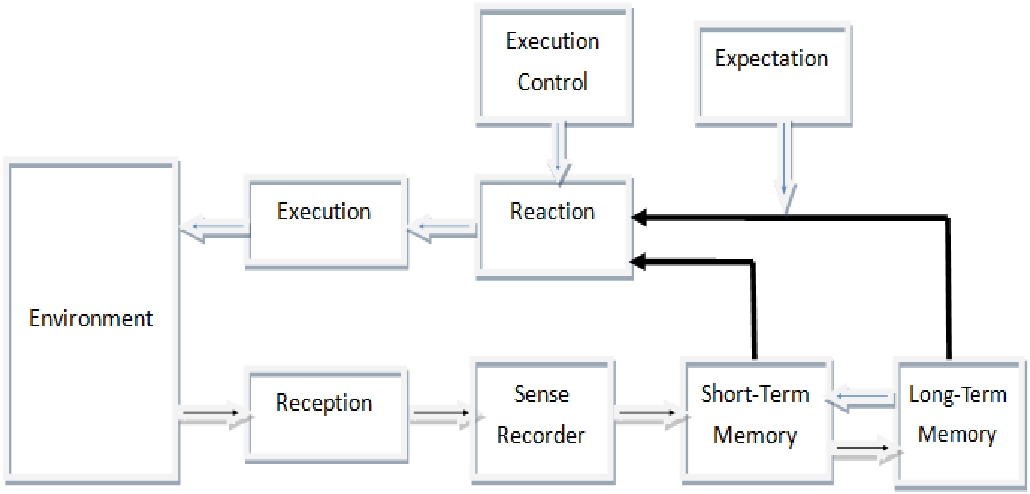


Figure 1: Information processing model.

Consisting of neuron, colloid and other sustenticular cells, the cerebrum suspends in the cerebrospinal fluid of the cranial cavity and is the most stringent guarded organ. The cerebrum is also considered as the central nervous system, which is the sensorium controlling all thinking and receives messages generated by the external environment so as to give out commands related to various activities and external behaviors through the integration of the neural system of the cerebrum and the complex thoughts and actions in the brain. In recent years, with the rapid development of the medical technologies and the improvement of the detection instruments, all parts of the cerebrum and their relevant functions have been further known. Through observation of the function and the sensory perception of the brain, we can know that every part of the brain controls a different task. The relevant functional parts of the brain contain the parietal lobe, the occipital lobe, the temporal lobe and the frontal lobe, of which the parietal lobe is located at the top of the head and the recognition center of the algesia and the feeling, the occipital lobe is located at the after brain and responsible for the visual recognition and related to the abilities of word recognition and geometry learning, and the frontal lobe is located at the forehead and responsible for motion coordination, thinking and judgment and problem solving and is the commander in chief of the brain.

Based on the neuroscience, the cognitive neuroscience uses the network structure and signal transmission of the neural system to interpret the cognitive function. In other word, it is a functional neuroscience for interneuronal information transmission and communication when the cognitive behavior of the brain is researched. With the development of the neuroscience, technologies and instruments for research of human brain have been significantly improved in recent years. Scientists use advanced instruments such as magnetic resonance imaging (MRI), functional magnetic resonance imaging (FMRI), computerized tomography (CT), positron emission tomography (PET), magneto encephalography (MEG), electroencephalogram (EEG), etc. to explore the cerebral activities so that researchers can further know the relationship between brain and mental activities (Jensen, 2008) when human is carrying out a special action. The application of the electroencephalogram in the human body is approximately 40 years earlier than the MEG. The electroencephalogram is mainly used for recording the potential difference of the brain, and the MEG is used for recording the magnetic field of the brain. Both of them are often applied for exploration of the potential excitement source of the brain. The electroencephalogram is characterized by noninvasive measurement, non-radiation, higher time resolution, transplantability and low cost, so this research adopts the electroencephalogram to study its characteristic frequency brand.

Electroencephalogram Measurement

The electroencephalogram is the electromagnetic signal generated by the neural activities of the brain, which is the message transmitted by the cranial nerve using the electrochemical process. The nerves convert the chemical signal into the electric signal through release of the chemical substance. These electric signals are mainly generated by the ion permeability. The neurons consisting of nerves are cells specially for transmitting electric signal. The neurons will produce the action potential to transmit message when the receptors on the cell surface have received the neurotransmitters. Different stimulations will have different transmission signals. Rhythmic potential changes will occur when the nerve impulse is transmitted between the nerves and the nerve fibers. These weak potential changes consist of the electrical rhythms and the transient discharge. It is the so-called electroencephalogram when these neurons generate the resultant potential changes.

The energy of electroencephalogram action is far less than other psychological signals of the human body (e.g. electrocardiogram and electromyogram), so it is difficult to record the electroencephalogram. The main reason is that its signal is so weak that the measurable brainwave is about 1 to 100μV and the frequency range is from 0.5 to 100Hz [J. G. Webster, 1988] when the brainwave signals pass through the meninges, the cerebrospinal fluid and skull and reach the scalp. The electroencephalogram basically has the synchronization, and will be affected by different waking states and also have different characteristics in different sleeping periods. The electroencephalogram is continuously generated and still keeps active even if a person is in a state of unconsciousness or falling asleep.

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. The α wave is a brainwave with frequency between 8Hz and 13Hz, and with amplitude of about 50μV. Generally the periodic wave appears in a time when people regain consciousness and are in a quiet and rest state and is most significant in the occipital region and the parietal region. In such conditions, however, the energy consumption of the mind and body will be kept lowest. If the energy obtained by the brain is relative high, the motion will be quicker, smoother, and the inspiration and the intuition are also a bridge between the consciousness and the subconsciousness. The β wave has a main frequency between 13Hz and 22 Hz and a potential of about 5-20 μV. In the case of keeping a clear mind and alert, it often appears in the parietal region and the frontal region. And this wave will be more obvious especially when the brain is in the case of logical thinking, computation, reasoning or sensory stimulus. Because the body at that time is in a nervous state, and is ready for response to the outside at any time. Under this condition, the consumption of the physical strength and the psychic energy is more intensified. The θ wave has a frequency between 4Hz and 8 Hz. Generally speaking, its amplitude is lower. This wave often appears in the parietal region and temporal region of the children, and will occur when the emotion of adult is suppressed or the consciousness of a person is interrupted, the body is relaxed or in the case of meditation. In addition, the θ wave is also found in many patients suffering from brain disease. The δ wave has a frequency between 0.2Hz and 4Hz. It will become more obvious when people fall asleep deeply or babies fall asleep, and patients suffering from severe organic brain disease. This wave is mainly found in the occipital region of the children, and the frontal region of the adults. For relevant functional parts of the brain, refer to Figure 2 (Hu, 1991).

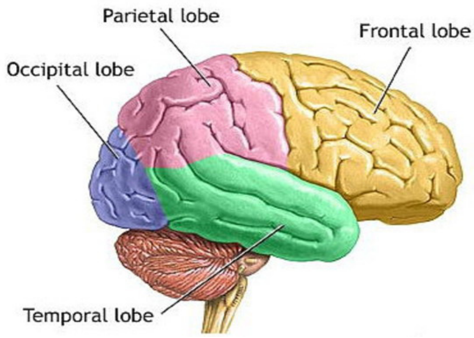


Figure 2: Four functional areas of the brain.

The brainwave measurement is basically divided into the monopolar type, the average type and the bipolar type. The position of the electrodes for the brainwave measurement has a direct influence on amplitude, phase and frequency of the brainwave signal, so the brainwave signals measured at different electrode positions cannot be compared with each other. The International Federation of Societies for Electroencephalography and Clinical Neurophysiology established a set of 10-20 electrode system. The top view of the relevant electrode positions are as shown in figure 3 (Schaul, 1998). The distance between electrodes is marked in accordance with the head structure. Some of marks are in the nasion, the inion and the mastoid. The central line from the nasion to the inion is perpendicular with the line of the mastoid at the point of Cz. The distance of each electrode point is spaced based on 10% or 20% of the vertical and horizontal lengths of the head circumference. Each electrode point is expressed by the combination of letters and digits. The first letter A represents the earlobe, C represents the central sulcus of the frontal lobe, P represents the parietal lobe, F represents the frontal lobe, T represents the temporal lobe and O represents the occipital lobe. If the second place is an even number, it is in the right cerebrum, and if an odd number, it is in the left cerebrum. If the second place is the letter Z, it means the electrode point is located on the central line of the nasion to the inion. Fp1 and Fp2 are respectively located in the left and right frontal lobe.

When the brainwave is measured, waves not belonging to the brain will be recorded. Such waves will have interference on the judgment of the normal brainwave, and are named as the artifact (Guan, 2002). Most of artifact is from the physiological reaction, equipment or external environmental interference. The interference of the physiological reaction comes from electrocardiogram, electromyogram, pulse, breath, eye movement, and body or head movement. The equipment interference is caused by the poor contact of the electrode patches or the 60Hz socket. The external environmental interference is caused by electrostatic, grounding of plug, etc. When the interference wave is produced, the source of the artifact shall be found out and then the possibility of solutions shall be put forward. If the interference cannot be avoided due to external factors, the filter or filtration function shall be added to the hardware and the software separately to eliminate such influence. This research adopts a simple there-electrode measurement to carry out the application study of relevant brainwaves based on the considerations of the transplantability and development, etc.

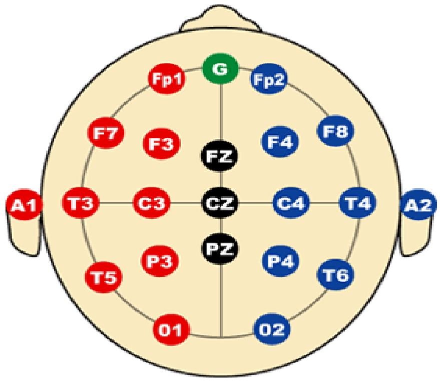
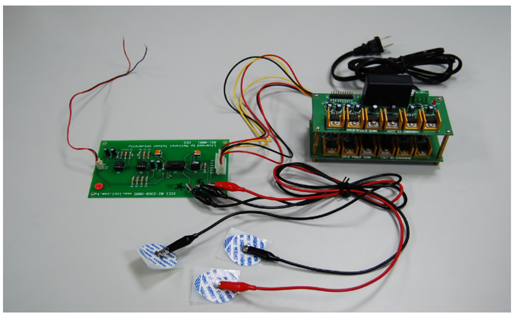


Figure 3: T-20 standard electrode International Location.

Design of EEG Measuring Module

With the continuous improvement of material technology and measuring technology, the measuring technology of the brainwave has been accelerated in recent years. A medical grade electroencephalograph, however, is huge, expensive and complicated in processing signals of the backend. Therefore, it is required that the operation shall be carried out by professional staff during the measurement. The brainwave measuring module proposed in this research is shown as in figure 4, which 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. This research uses a simple bipolar system to measure the brainwave. The relevant electrode positions are respectively in the forehead and the lower earlobe and used for recording signals at Fp1, Fp2, A1, etc. of which the A1 is the reference potential. The measuring positions are as shown in Figure 5



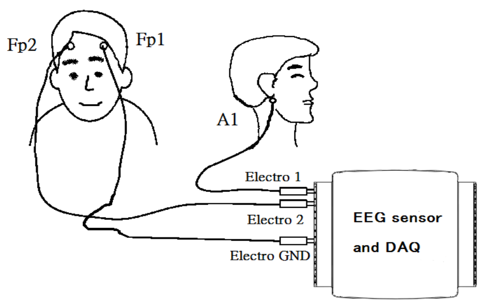


Figure 4: EEG measurement module design. **Figure 5: Two-electrode measurement Schematic.**

Design of Brainwave Measuring Circuit

During measurement, hair on the head will prevent the electrodes from being stuck, so it is difficult for the participants to stick the electrodes on the scalp. Therefore, the measurement of electrodes is carried out at positions of the forehead Fp1 and Fp2 and the lower earlobe A1. A1 is used as a reference potential. An isolation measure shall be taken so as to avoid electric shock due to the electric leakage of the power supply or instrument. The block diagram of relevant brainwave measuring circuit and the brainwave sensor board are described in figure 6 and figure 7. The preamplifier uses the instrument amplifier to capture the vector signal of the electroencephalogram as the monopolar signal with a magnification of 50, and uses the JFET operational amplifier to increase the impedance match between electrodes and circuit. The isolation circuit is used for separating signals and power supply so as to protect the circuit against damage. Optical isolation or transformer isolation is usually adopted. The bandwidth of the band-pass filter is set as 1Hz to 20Hz, of which the purpose is to screen out the four frequency-band signals such as α, β, δ and θ, and the signals passed through the filter are amplified to 1000 times gain. The signals are transmitted to PC and displayed as the brainwave signals after being converted by the Data Acquisition Card (DAQC). The DAQC (USB-6009) adopted has 8 analog input channels, 2 analog output channels, 12 digital output-input channels and USB 1.1 ports as shown in figure 8 ("User guide and specifications NI USB-6008/6009",1999). The resolution of USB-6009 analog input can be up to 14 digits. When measuring with a single channel, the sample rate can be up to 48kSamples/sec. When measuring with multiple channels, the sample rate can be up to 42 k Samples/sec.

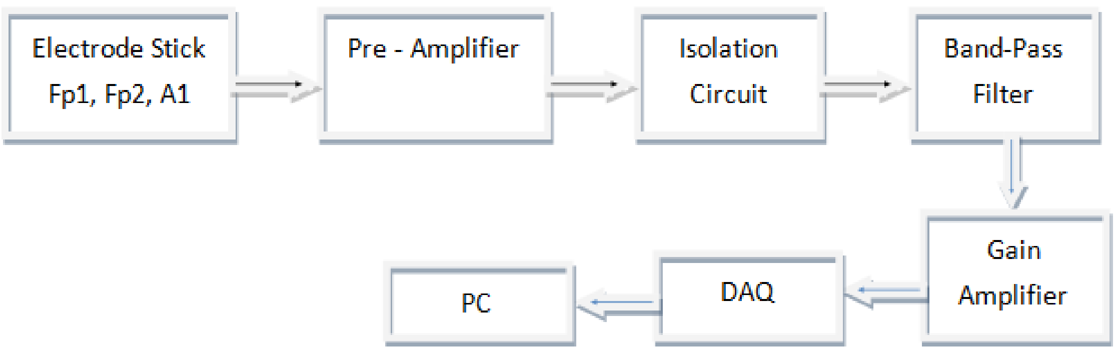


Figure 6: EEG functional block diagram of measuring circuit.

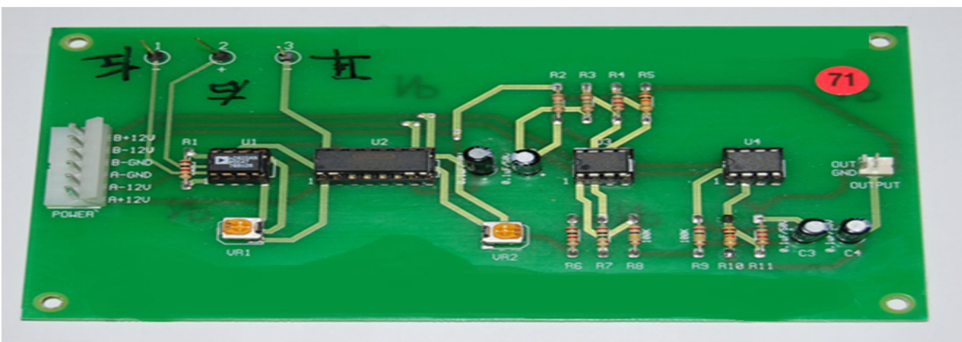


Figure 7: EEG measurement circuits.

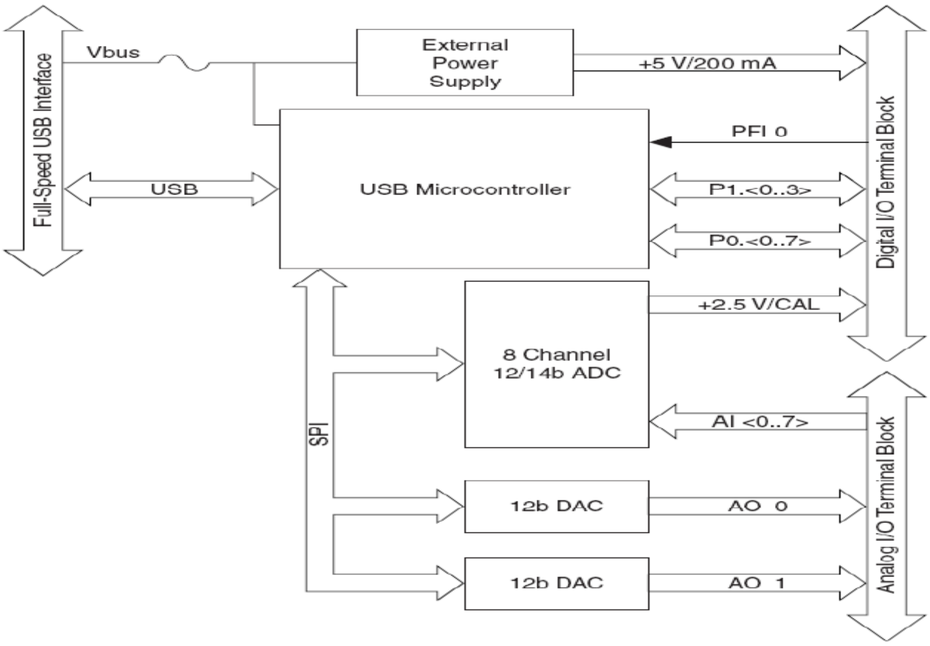


Figure 8: USB-6009 device block diagram.

System Implementation and Statistic Analysis

This research establishes a LEI from the point of view of the cognitive neuroscience. This LEI is expected to provide the teachers and learners with the capabilities of observing the physiological condition of learners or the learning members of the same group if they are appropriate to the online learning so as to avoid the absence of mind and to improve effective the learning results when the future online learning cooperation is conducted. Furthermore, the establishment of the LEI also needs the analysis of the brainwave characteristic frequency band. The relevant analysis of the brainwave characteristic frequency band can also provide you with a basis for R&D of the hardware of the quick-detecting module for the brainwave energy in the future learning. In this research, not only the relevant brainwave-measuring modules and the brainwave characteristic analysis programs are actually made, but also discuss the following subjects: (1) Analysis of the brainwave characteristic frequency band for human under different physiological statuses (falling asleep, deep sleep, logical reasoning, reading, etc.); (2) Comparison analysis of brainwave difference when reading the print textbooks and the multi-medium textbooks; (3) Whether habit formation is helpful to learning; (4) Whether game-base learning is the positive learning.

Framework of Analysis System

The system framework proposed in this research includes the front brainwave-sensing module for capturing brainwave signals and the rear brainwave-analysis program for analyzing the characteristics of brainwave frequency band. After the brainwave signals of the participants are acquired by the front brainwave-sensing module, the digitalized brainwave signals will be sent a computer and saved as a specified format and provided the rear brainwave-analysis program for the characteristics analysis of brainwave frequency band through the analog to digital converter (ADC) of the DAQC. The relevant framework for characteristics analysis

of the brainwave frequency band is as shown in figure 9. 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 LabVIEW acquisition program is used to capture brainwave signals.
(2).After being converted by the ADC module of the sensor, the brainwave signals are sent to PC and saved as Excel or Txt format through the USB port of the DAQC.
(3).The EEG Analysis GUI 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 brainwave signals. After the brainwave signals have been processed by FFT formally, the percentage of amplitude to energy of each brainwave frequency band on the frequency domain. In this research, the percentage of amplitude to energy of main brain frequency band is used to calculate the LEI.

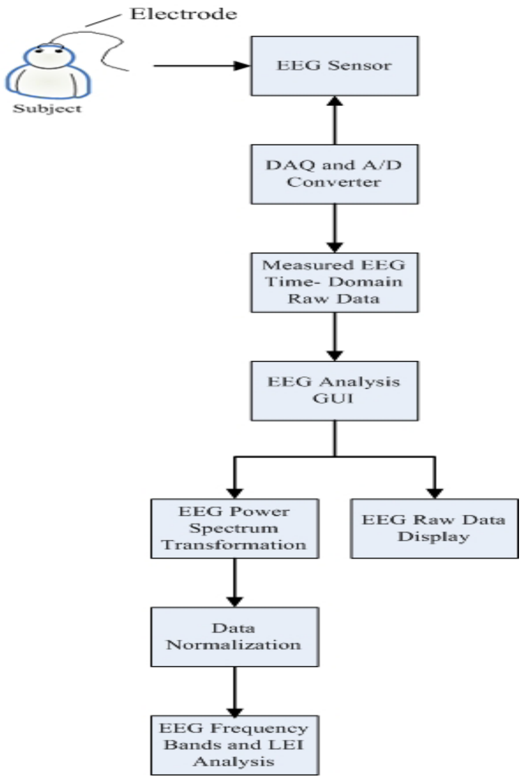


Figure 9: Analysis of EEG frequency band features of the system architecture diagram.

Method of Brainwave Signal Analysis

In this research, a brainwave analysis system with GUI was developed by the MATLAB program language. The system uses the fast Fourier transform (FFT) to convert the time-domain signals into the corresponding frequency spectrum signals, and uses the event-related coherence (ERCoh) to divide the brainwave frequency band. After calculation of the energy percentage, it is used to analyze the distribution of brainwave energy of every learning status. The analysis interface is shown as in Figure 10.

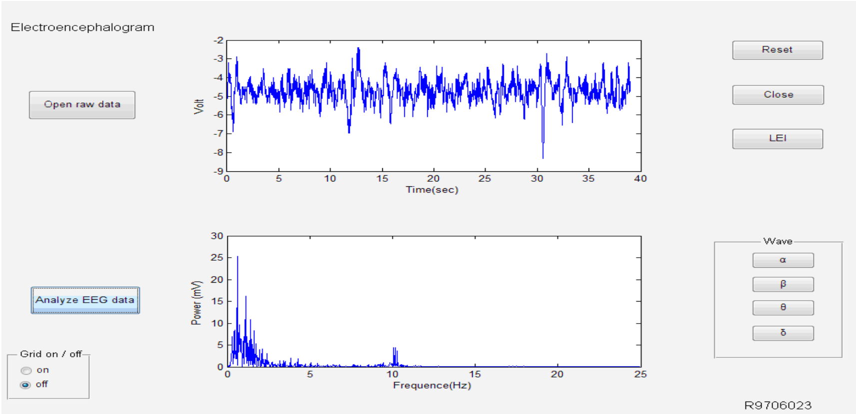


Figure 10: EEG analysis interface.

Learning Energy Index (LEI)

In this research, 50 students from the Department of Computer Science were tested for their brainwave signals for the logical reasoning of professional books. Based on the energy distribution of main brainwave characteristic frequency band by analyzing learners' logical reasoning ability, it establishes the LEI. The energy distribution of the tested brainwave characteristic frequency band is listed in Table 1. Based on the α, β, θ and δ in Table 1, 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 "Probability and Statistics" of the professional discipline. The test results showed that 46 students whose subzone characteristic frequencies of the α and β apparently increased in energy, the frequency of relevant subzones for α is 9Hz to 11Hz and for β is 19Hz to 21Hz, the main frequencies of the subzones for α are α2 and α3 and for β are β7 and β8, and the energy percentage of relevant subzones is apparently higher than that of other subzones when the 50 students were reasoning logically in a state of consciousness (see Table 1). From the Tables1, 2 and 3, we can know the characteristic frequency bands of the subzone are the frequency bands at δ1, δ2, θ1 and θ2 at the time when people fall asleep or are in deep sleep, which are apparently different from those generated by logical reasoning in the case of consciousness, and the energy of the frequency bands of α and β is obviously lower than that acquired in the case of consciousness. Therefore, in order to consider the brainwave energy of the quick-detecting learning, the total energy percentage related to frequencies of main zones (α2 and α3, and β7 and β8) is specified as the LEI, and the LEI is used as the basis for teachers to understand the physiological status of studying alone or cooperatively of learners.

The frequency domain in the said tables is divided into 4 zone frequency bands according to the α, β, θ and δ frequencies. The average of the total potential amplitude of different frequency bands for 50 participants is calculated so as to obtain the energy of the zone frequency band and the total energy using equations (1) and (2)

$$E_B = \sum_{f}^{n} Power_f \qquad (1)$$

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

In the above equations, B are the zone frequency bands of α, β, θ and δ, 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. Δ is the frequency band of δ1, δ2, δ3, …, β9 as shown in equation (3):

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

Table 1. Energy distribution of frequency band for the learning brainwave.

Status	Brain wave type	Zone frequency (Hz)	Subzone frequency (Hz)		Subzone energy/ total energy (E_Δ%)	Frequency at max. amplitude, (Hz)	Total energy percentage of zone (E_B/E_T %)	Characteristic frequency of subzone
Learning	Delta (δ)	0.2 ~ 4	δ1	0.2 ~ 1	2.38	0.2	8.11	
			δ2	1 ~ 2	1.93			
			δ3	2 ~ 3	1.77			
			δ4	3 ~ 4	2.03			
	Theta (θ)	4 ~ 8	θ1	4 ~ 5	1.95	7.4	9.34	
			θ2	5 ~ 6	2.05			
			θ3	6 ~ 7	2.40			
			θ4	7 ~ 8	2.93			
	Alpha (α)	8 ~ 13	α1	8 ~ 9	3.27	10.4	43.23	**α2 α3**
			α2	9 ~ 10	12.92			
			α3	10 ~ 11	20.93			
			α4	11 ~ 12	3.56			
			α5	12 ~ 13	2.55			
	Beta (β)	13 ~ 22	β1	13 ~ 14	3.44	19.6	39.32	**β7 β8**
			β2	14 ~ 15	2.88			
			β3	15 ~ 16	3.03			
			β4	16 ~ 17	2.97			
			β5	17 ~ 18	2.72			
			β6	18 ~ 19	3.09			
			β7	19 ~ 20	12.70			
			β8	20 ~ 21	5.64			
			β9	21 ~ 22	2.84			
LEI, %	**$_{LEI}=\alpha_{2-3}+\beta_{7-8}$ = 52.19, α_{2-3}=33.85, β_{7-8} = 18.34**							

Table 2. Energy distribution of frequency band before falling asleep.

Status	Brain wave type	Zone frequency (Hz)	Subzone frequency (Hz)		Subzone energy/ total energy (E_{Δ}%)	Frequency at max. amplitude (Hz)	Total energy percentage of zone (E_B/E_T %)	Characteristic frequency of subzone
Period of falling asleep	Delta (δ)	0.2 ~ 4	δ1	0.2 ~ 1	26.74	0.3	83.02	δ1 δ2
			δ2	1 ~ 2	16.75			
			δ3	2 ~ 3	23.51			
			δ4	3 ~ 4	16.03			
	Theta (θ)	4 ~ 8	θ1	4 ~ 5	4.58	5.9	13.83	θ1 θ2
			θ2	5 ~ 6	4.45			
			θ3	6 ~ 7	4.00			
			θ4	7 ~ 8	0.80			
	Alpha (α)	8 ~ 13	α1	8 ~ 9	0.62	9.6	2.22	
			α2	9 ~ 10	0.61			
			α3	10 ~ 11	0.30			
			α4	11 ~ 12	0.40			
			α5	12 ~ 13	0.29			
	Beta (β)	13 ~ 22	β1	13 ~ 14	0.13	13.2	0.92	
			β2	14 ~ 15	0.15			
			β3	15 ~ 16	0.17			
			β4	16 ~ 17	0.10			
			β5	17 ~ 18	0.10			
			β6	18 ~ 19	0.10			
			β7	19 ~ 20	0.06			
			β8	20 ~ 21	0.06			
			β9	21 ~ 22	0.05			

Table 3. Energy distribution of frequency band during deep sleep.

Status	Brain wave type	Zone frequency (Hz)	Subzone frequency (Hz)		Subzone energy/ total energy (E_{Δ}%)	Frequency at max. amplitude (Hz)	Total energy percentage of zone (E_B/E_T %)	Characteristic frequency of subzone
Deep sleep	Delta (δ)	0.2 ~ 4	δ1	0.2 ~ 1	48.52	0.4	99.03	δ1 δ2
			δ2	1 ~ 2	43.53			
			δ3	2 ~ 3	6.38			
			δ4	3 ~ 4	0.59			
	Theta (θ)	4 ~ 8	θ1	4 ~ 5	0.34	4.1	0.68	θ1 θ2
			θ2	5 ~ 6	0.17			
			θ3	6 ~ 7	0.08			
			θ4	7 ~ 8	0.09			
	Alpha (α)	8 ~ 13	α1	8 ~ 9	0.06	12.2	0.19	
			α2	9 ~ 10	0.04			
			α3	10 ~ 11	0.04			
			α4	11 ~ 12	0.02			
			α5	12 ~ 13	0.03			
	Beta (β)	13 ~ 22	β1	13 ~ 14	0.00	14.6	0.0009	
			β2	14 ~ 15	0.00			
			β3	15 ~ 16	0.00			
			β4	16 ~ 17	0.00			
			β5	17 ~ 18	0.00			
			β6	18 ~ 19	0.00			
			β7	19 ~ 20	0.00			
			β8	20 ~ 21	0.00			
			β9	21 ~ 22	0.00			

Comparative Analysis of Brainwave Difference when Learning by Print Textbooks and Multi-medium Textbooks

In this research, the textbook “probability and statistics” and the puzzle “sudoku” are adopted in exploring the comparative analysis of brainwave difference, and the change in brainwave difference of logical reasoning for participants is compared and analyzed under different media when learners study by print textbooks and multi-medium textbooks. The print textbooks for measuring the logical reasoning brainwave include the professional textbooks and the Sudoku, and their relevant brainwave measurement is as shown in figures 11 and 12. The test results showed that the peak value of brainwave at the frequencies 10Hz and 20Hz can be observed when the participants were logically reasoning using the professional textbooks and the Sudoku. From the electroencephalogram, we can know the amplitude at 10Hz decreases and that at 20Hz increases, and the energy of β will increase during reasoning when the participants do exercises from the professional textbook. When playing the puzzle “Sudoku”, both α and β will generate peak values, but their amplitude energy is higher than reading professional textbook. The energy of the characteristic frequency band of the two brainwaves is listed in table 4. For the print textbooks, whether it is the professional textbook or the Sudoku game, the characteristic frequency band of the two brainwaves is located at α2 and α3 of α and at β7 and β8 of β. When reading the professional textbooks, the energy of the zone frequency band of α and β is respectively 31.74% and 48.45%, and when playing the Sudoku of paper type, the energy of the zone frequency band of α and β is respectively 58.18% and 38.83%. The test results showed that the LEI (91.22%) of logical reasoning by playing the Sudoku of paper type is obviously higher than the LEI (51.3%) of learning by the professional textbook. From the said results, we can know that the game-based learning not only has the positive learning property of learning by the professional textbook, but also its game-designing way can enhance the LEI of brainwave of learners.

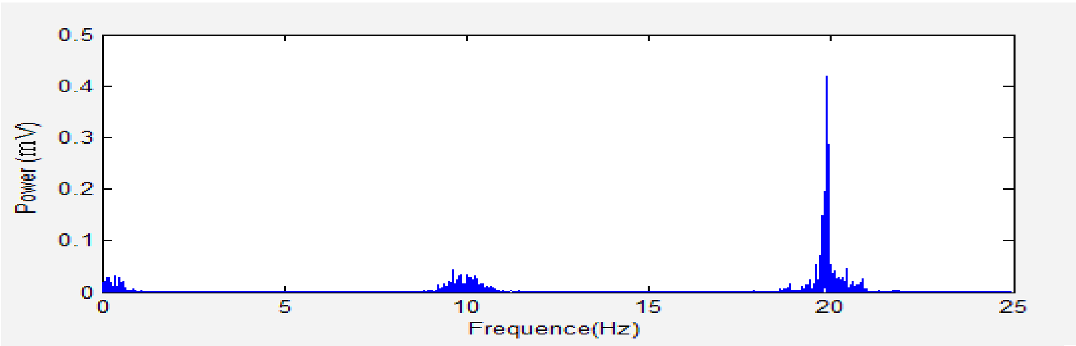


Figure 11: Professional books to read on paper, the average EEG frequency domain.

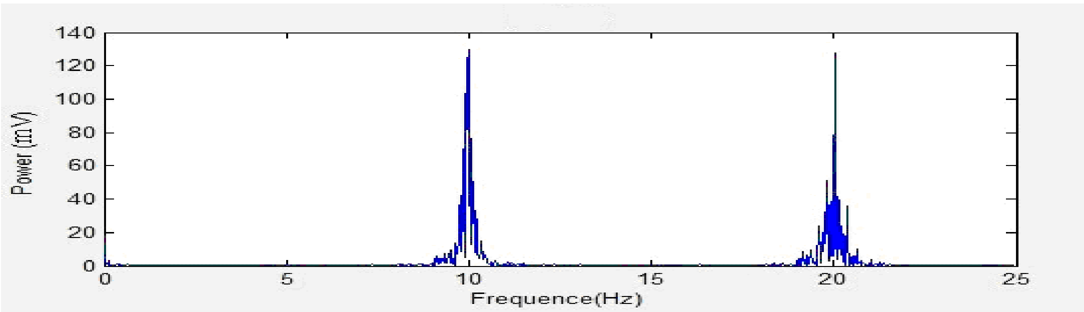


Figure 12: Paper Sudoku average EEG frequency domain.

Table 4. Comparison of main energy distribution of logical reasoning by print textbooks (%).

Print textbook	LEI	Characteristic frequency band, α_{2-3}	Characteristic frequency band, β_{7-8}
Professional textbook	51.3	23.75	27.55
Sudoku	91.22	54.69	36.53

The energy distribution of the characteristic frequency band is as shown in figures 13 and 14 when using the digital textbooks to study. The results show that both of them will generate two peaks at 20Hz brainwave when the participants use the multi-media textbooks to drill the logical reasoning. As shown in figure 5, the difference of both LEIs is not higher. The LEI of the professional textbook is 51.78 % and higher than 45.14% of the LEI of the Sudoku. The main characteristic frequency bands for both of them are located at α_{2-3} and β_{7-8}. The energy of the β frequency band measured by the multi-media Sudoku is slightly higher than that measured by the professional multi-medium textbook. We can know from the interview that the participants feel nervous when they are playing the multi-medium Sudoku due to the lack of pen and paper for recording and analyzing. After completion of the interview, a new test with pen and paper was conducted. From the new test, we found that the LEI is 78.55% such that the characteristic frequency band α_{2-3} increases to 39.64% from the 8.34% without the pen and paper. The above-mentioned tests show that a test with or without pen and paper has a remarkable influence on the LEI distribution of logical reasoning by the digital textbooks.

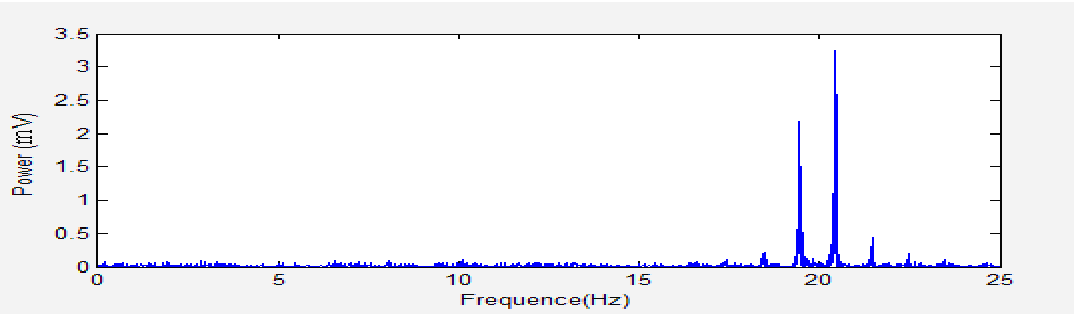


Figure 13: For professional digital content subjects the average EEG frequency domain.

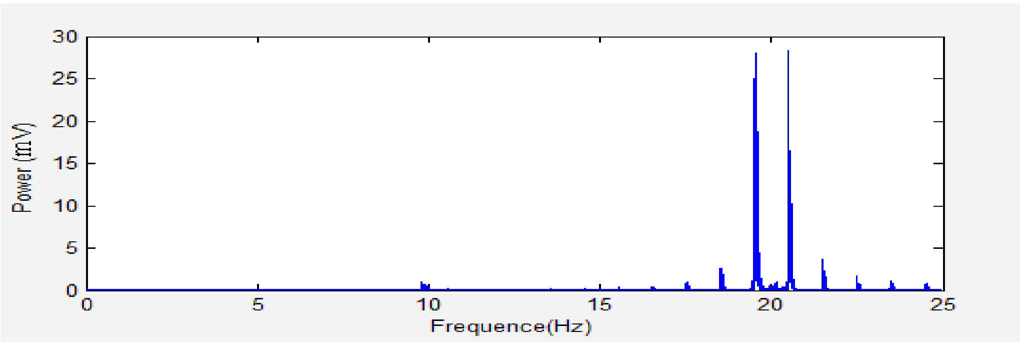


Figure 14: Sudoku games multimedia average EEG frequency domain.

Table 5. Comparison of main energy distribution of logical reasoning by multi-medium textbooks (%).

Multi-medium textbook	LEI	Characteristic frequency band, α_{2-3}	Characteristic frequency band, β_{7-8}
Professional textbook	51.78	18.43	33.35
Sudoku	45.14	8.34	36.8

Influence of Exercise Habit Formation on Brainwave

It will consume a large amount of energy when the brain works. The brain, therefore, must have enough blood to supply nutrients. The brain approximately receives 20% of the total blood from the heart. The brain cannot save nutrients such as oxygen, glucose, etc., so it shall get oxygen and glucose from the blood circulation. Appropriate exercise can enhance the function of the cardiovascular and facilitate blood circulation of the whole body so that the brain can obtain sufficient nutrients to speed up the activation of the cranial nerves. From the view of physiology, exercise not only can enhance the function of the cardio-pulmonary, but also can facilitate the metabolism of the brain and activate the brain cells. The test divides 10 people into 2 teams. One of the team has the exercise habit and the other one has no exercise habit. The comparative analysis of the brainwave difference is conducted for both teams when they read books. The exercise for the test is mainly the aerobic exercise (fast walking or run). Based on the physical ability of the participants, the fast walking and run are implemented alternately for 30 minutes per day. This kind of exercise has been kept for 3 months prior to measuring the brainwave. In the test, the brainwave energy is analyzed through the learning with and without exercise habit so as to observe the energy change in brainwave when people from both teams have been learning for a long time. The purpose of the test is to observe if the brainwave will effectively improve the strength and continuity of the learning energy due to the exercise habit formation when the participants are reading.

The book read by the participants is “the facts of life”. The brainwave is measured every half an hour for continuous two hours. Before the test, the brainwave characteristics of the participants reading a relaxing book are as shown in figure 15. the results showed that LEI is 49.13%, the energy in α_{2-3} zone is 27.21%, the energy in β_{7-8} zone is 21.92%, the peak value appears when the brainwave is at 10Hz and 20Hz, and the α is higher than the β in amplitude. It means the participants are relaxed and have thinking activities. The LEI change for people from both teams reading book for a long time (2 hours) is listed in Table 6. The test results showed that the team with exercise habit is higher than the team without exercise habit in LEI, and the energy of the characteristic frequency band of α_{2-3} and β_{7-8} are different during every measurement. With the extension of reading time, the energy of the characteristic frequency band of β_{7-8} for the team without exercise habit reduces gradually, which also means the concentration decreases apparently with the extension of reading time.

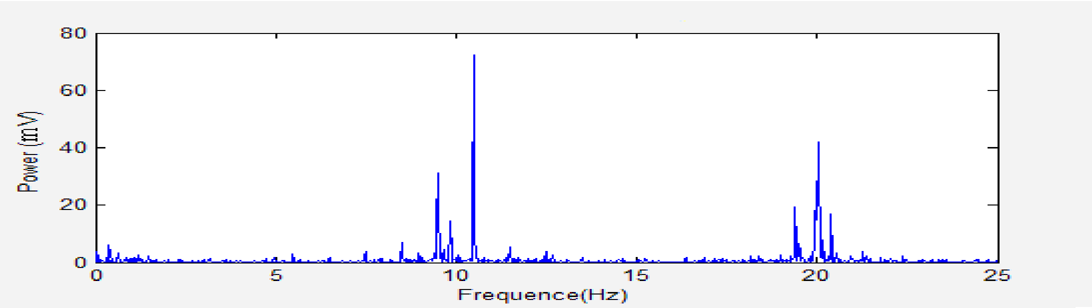


Figure 15: Leisure to read books before the experiment the average EEG frequency domain.

Table 6. Influence of the relaxing book reading on the brainwave for people with and without exercise habit (%).

Elapsed time	LEI		Characteristic frequency band α2–3		Characteristic frequency band β7–8	
	Without exercise habit	With exercise habit	Without exercise habit	With exercise habit	Without exercise habit	With exercise habit
30m	50.79	62.35	25.87	27.25	24.92	35.10
60m	53.13	59.67	26.56	31.35	26.57	28.52
90m	37.9	55.51	18.83	29.43	19.07	26.08
120m	38.45	54.16	19.38	27.97	19.07	26.19

Conclusion

In this research, the graphic processing software tool LabVIEW and the program development software MATLAB are used to develop a brainwave analysis system for analyzing the brainwave energy of frequency band of learners. Based on the analysis of the acquired brainwave signals and the brainwave energy through the brainwave sensor, the LEI for learners is established for observing the learners or learning members of the same group whose physiological status to see if the are appropriate to the online learning so as to avoid the absence of mind and to improve effective the learning results when the future online learning cooperation is conducted. Furthermore, the establishment of the learning energy index also needs analysis of the characteristic frequency band of the brainwave. The relevant characteristic frequency band of the brainwave can also be the basis for the quick-detecting module for the brainwave energy in the future learning. In this research, various frequency spectrum properties of brainwave are not only analyzed and discussed for learners conducting diverse learning, but also the brainwave difference caused by using the traditional print textbooks and the multi-medium textbooks from the view of the cognitive neuroscience. As for exercises being helpful to learning, the experimental data of relevant researches also prove that the LEI of the team with exercise habit is higher than that of the team without exercise habit, and the energies of the characteristic frequency band of α_{2-3} and β_{7-8} are the same. With the extension of reading time, the energy of the characteristic frequency band of the team with exercise habit is obviously better than that of the team without exercise habit. This research also proves that good exercise habit can help learners to extend the concentration from the view of the cognitive neuroscience.

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