A STUDY OF BRAIN WAVE PATTERN WITH THE TOUCHING LEARNING OF BLINDED PEOPLE

WACHIRA LAWPRADIT

DOCTOR OF PHILOSOPHY
IN
COMPUTER ENGINEERING

SCHOOL OF INFORMATION TECHNOLOGY
MAE FAH LUANG UNIVERSITY

2021

A STUDY OF BRAIN WAVE PATTERN WITH THE TOUCHING LEARNING OF BLINDED PEOPLE

WACHIRA LAWPRADIT

THIS DISSERTATION IS A PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
IN
COMPUTER ENGINEERING

SCHOOL OF INFORMATION TECHNOLOGY
MAE FAH LUANG UNIVERSITY
2021

A STUDY OF BRAIN WAVE PATTERN WITH THE TOUCHING LEARNING OF BLINDED PEOPLE

WACHIRA LAWPRADIT

THIS DISSERTATION HAS BEEN APPROVED
TO BE A PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY
IN
COMPUTER ENGINEERING
2021

EXAMINATION COMMITTEE

S. Promwong ....CHAIRPERSON
(Asst. Prof. Sathaporn Promwong, Ph. D.)

Yooyativong T. ....ADVISOR
(Asst. Prof. Gp. Capt. Thongchai Yooyativong, Ph. D.)

..........CO-ADVISOR
(Asst. Prof. Roungsan Chaisricharoen, Ph. D.)

..........CO-ADVISOR
(Asst. Prof. Phakkharawat Sittiprapaporn, Ph. D.)

..........EXAMINER
(Asst. Prof. Nattapol Aunsri, Ph. D.)

Chayapol Kamyod ....EXAMINER
(Chayapol Kamyod, Ph. D.)

ACKNOWLEDGEMENTS

Successful completion of this dissertation could not have achieved without kindness and encouragement from many people.

Firstly, I would like to express my gratefulness to my supervisors, Asst. Prof. Gp. Capt. Dr. Thongchai Yooyativong and my co-operative advisors, Asst. Prof. Dr. Roungsan Chaisricharoen, and Asst. Prof. Dr. Phakkharawat Sittiprapaporn, for their valuable advice, continuous guidance, strong patience, and pushing me the great opportunity to explore this dissertation.

Secondary, my sincere thanks to my supporters, teachers from Lampang Eye Foundation and Lampang School for the Blind for providing technical and useful suggestion of blinded learning and tools. I would like to thank the cute students for their school throughout the development of this dissertation. Thanks go to all the instructors and the officers at the School of Information Technology, Mae Fah Luang University, for giving me timeline, knowledge and experience for studying. I appreciate the reviewers of my publications for their helpful advice and suggestions for improvement. I am grateful to all the professionals for checking the patterns and research tools, as well as for their expedient suggestions. And, I would like to thanks for Mae Fah Luang University that granted my graduate school dissertation and research publication grant. These grants made me operate research with agility and flexible.

Finally, I would like to express my thankfulness my parents and my family for their constant encouragement and support me along my Ph.D. degree and my lifetime. Furthermore, I would like to thank myself for throughout all the work hard and difficult time that I devoted myself to this dissertation.

Wachira Lawpradit

Dissertation Title	A Study of Brain Wave Pattern with The Touching Learning of Blinded People
Author	Wachira Lawpradit
Degree	Doctor of Philosophy (Computer Engineering)
Advisor	Asst. Prof. Gp. Capt. Thongchai Yooyativong, Ph. D.
Co-Advisor	Asst. Prof. Roungsan Chaisricharoen, Ph. D.
	Asst. Prof. Phakkharawat Sittiprapaporn, Ph. D.

ABSTRACT

Thailand was one of countries give precedence to care of blinded people. Thailand had increased the number of blinded persons continuously by born or accidents. The government and some private companies established organizations that educate for blinded students in several ages. Blinded people must learn in the different ways, such as tactile graphics or talking calculator. Nowadays, author have a question about blinded people understand the meaning of contents of the tactile pictures or the objects they touched like normal people or not?

The brain computer interfacing (BCI) is the technology that describe leaning patterns of the human. This technology can observe the synapse and chemistry movement in brain. Electroencephalogram (EEG) collecting is easy and inexpensive method to collect the dataset from brain. In this dissertation, researcher used NeuroSky MindWave device, inexpensive device, to collect EEG datasets from blinded and normal people. Datasets were the voltage power of the brain wave signal, such as delta, theta, alpha, beta and gamma that derive from touching learning behaviors. Then, datasets were converted to the meaningful values by Fast Fourier Transform algorithm (FFT). After that, author compared results of normal and blinded people to respond researcher questions. This dissertation was designed into three main experiments include 1) find the main important EEG brain waves 2) find patterns of blinded and normal people when touch on tactile pictures and 3) find patterns of blinded and normal people when touch on tactile pictures with different positions.

From results, most important waves when touching learning are delta, theta, high-alpha and mid-gamma. In addition, normal people got high value waves in delta, theta, high beta and low gamma when touching on circle shape tactile pictures but blinded people got high value in every wave. This result showed that blinded people use more brain when touching on circle shape pictures. Another, normal people got higher in delta, theta and high gamma when touching on hexagon shape tactile pictures. However, blinded people get higher in delta, theta and low alpha. These results show blinded people use the brain more about the imagination when touching on more angle picture learning. In the same way, blinded people got higher in low alpha when touching on square shape tactile pictures like normal people. The result showed blinded people use the brain more about the conscious when touching on angle picture learning like normal people. Normal people got higher in delta, theta, high beta and low gamma when touching on triangle shape tactile pictures. However, blinded people got higher in delta, theta, alpha, high beta and low gamma when touching on triangle shape tactile pictures. These results showed blinded people use the brain more about the imagination, conscious and thinking when touching on picture learning more than normal people.

Keywords: Brain-Computer Interface, Blinded People, Brain Wave Pattern, Touching Leaning

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

Table **Page**

LIST OF TABLES (continued)

Table **Page**

LIST OF TABLES (continued)

Table **Page**

LIST OF TABLES (continued)

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF FIGURES (continued)

Figure **Page**

LIST OF FIGURES (continued)

Figure **Page**

LIST OF FIGURES (continued)

Figure **Page**

CHAPTER 1

INTRODUCTION

This dissertation mentions about patterns of electroencephalography signal of human brain. Researcher focus on normal and blinded people signals to compare and generate EEG signal patterns of each sample group. This chapter provided on the significance of the problem, objectives, research scopes, and dissertation structure.

1.1 Significance of the Problem

With mentions of blinded people, several countries in the world had a greater number of them. Thailand was one of countries give precedence to care of blinded people. Thailand had increased the number of blinded persons continuously by born or accidents. The group types of them usually been with some visual impaired, blinded on one side or blinded on two sides. In the most cases of Thailand, the government and some private companies established the organizations that educate for the blinded students in the several ages. Samples of organization were the foundation for the blind in Thailand under the royal patronage of H.M. the queen, the Bangkok school for the blinds the skills development center for the blinded, the blind and education technology center for the blind and more.

If we looking at the way to learn of the blinded people, they must learn in the different ways (Gierach, 2009), such as tactile graphics or talking calculator. In primary, learning tools for understand the contents of blinded persons were Braille alphabet and listen to the speakers mainly. In pictures or shaped acknowledgement, they usually learn with tactile pictures or touch on the objects. From the reason, researcher did not know what the blinded people understand the meaning of the contents of the tactile pictures or the objects they touched truly. When they accessed to the Internet, they got the problem about pictures that show in the webpage. With the exist technology, pictures were skip. The problem made them cannot get information from pictures. The technology can speech only text on websites like JAWS screen reader programs (Freedom Scientific, Inc., 2012).

There are several learning media that make aware of learning patterns and outcomes of blinded peoples to understand meaning of things. For this dissertation, researcher will use the technology that interacts to the brain signal to observe the neurotransmitters working. Nowadays, world has the technology which interact with the brain such as electroencephalography (EEG) which placed the electrode on the scalp, electrocorticography (ECoG) which placed the electrode on the surface of the brain, magnetoencephalography (MEG), positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and functional Near InfraRed (fNIR). However, MEG, PET, fMRI, and fNIR are still technically demanding and expensive but EEG and ECoG are still inexpensive and simple. In this dissertation, researcher chooses EEG technology.

In this research, researcher mentions to the learning method for tactile pictures and shaped objects touching. With the reason, we do not know what blinded people learn and understand content of pictures or objects like normal people can. Therefore, we will be looking for ways to recognize pictures or objects and find patterns of the EEG brain signal. Thus, researcher addresses to study and analysis brain signals with EEG by using the brain wave devices such as, NeuroSky Mindwave, Emotive Epoc and Emotive Insight. There consist of a headset, an ear-clip, and a sensor arms with different number of electrodes. The most inexpensive and simple device is NeuroSky Mindwave of NeuroSky Inc.

The initial experiment discuss at the study and analysis of normal person and blinded person brain signals by focus on the inexpensive device to find patterns of touching learnings. In the first step, researcher discuss on the touching of the normal people on geometric shape objects in the suitable environment for search baseline importance waves that we focus on. Afterwards, we compared experiment results between normal person and blinded person brain signals to find the brain wave patterns of the touching activity on tactile pictures. In the third stage, we focus on the blinded people, so we find brain wave patterns to describe the position of tactile pictures when they touch. With all results, we can find patterns of the brain wave when blinded people learning from tactile pictures.

1.2 Research Objectives

This dissertation has three main objectives as follows:

1.2.1 To analyze and describe electroencephalography (EEG) brain wave patterns that blinded people use when they want to understand pictures.

1.2.2 To compare electroencephalography (EEG) brain wave patterns between normal people and blinded people when they want to understand pictures.

1.3 Scopes of Research

The overall purpose of dissertation is patterns of the brain wave when blinded people learning from pictures by using the inexpensive device such as NeuroSky Mindwave device. Results will help us to know brain signal patterns when blinded people touch and identify meaningful pictures like normal people can. Researcher hope to address the following research questions:

1. What are important waves we focus when we touch?
2. Are normal people signals and blinded people signals different?
3. What are the touching brain wave signal patterns?
4. Can one electrode inexpensive devices identify the reliable wave signals?
5. What is the best feature extraction algorithm for the one electrode device?

There are three main part experiments for find patterns: (1) find important EEG brain signal bands from normal people when touching of the objects, (2) compare EEG signals of normal people and blinded people when touching on tactile pictures with suitable algorithm, and (3) create EEG signals patterns of normal people and blinded people when touching on several position tactile pictures with suitable algorithm.

1.3.1 Find Important EEG Brain Signal Bands from Normal People when Touching of the Objects

Researcher find important brain signals which collect from the brain when touching on surfaces and shapes of objects. Thus, we address to study and analysis of the brain signal with electroencephalography (EEG) by using the NeuroSky MindWave which consists of one sensor electrode. The headset has reference and ground electrode is on the ear clip and the EEG electrode is on the sensor arm by connect to forehead above the eye (FP1 position). The experiment discusses on study and analysis of the normal people brain signal that is collect from surfaces, smooth and rough, and geometric shapes, sphere and cube, of the objects touching in the suitable environment. Afterwards, we analyze experiment results with important brain signals which refer to the future works on normal and blinded people.

1.3.2 Compare EEG Signals of Normal People and Blinded People when Touching on Tactile Pictures with Suitable Algorithm

Researcher lead important brain wave result from 1.3.1 experiment to find EEG signals of normal people and blinded people when touching on tactile pictures. Researchers focus on tactile pictures of three normal form geometry type. We collect EEG data from participants with NeuroSky MindWave device. The device connects to the computer via Bluetooth channel. We use OpenVIBE program to record datasets and MATLAB to analyze datasets by FFT algorithm.

1.3.3 Create EEG Signals Patterns of Normal People and Blinded People when Touching on Several Position Tactile Pictures with Suitable Algorithm

Researcher lead important brain wave result from 1.3.1 experiment to find EEG signals of normal people and blinded people when touching on tactile pictures in several positions. Researchers focus on tactile pictures of nine position normal form geometry type. We collect EEG data from participants with NeuroSky MindWave device. The device connects to the computer via Bluetooth channel. We use OpenVIBE program to record datasets and MATLAB to analyze datasets by FFT algorithm.

1.4 Dissertation Structure

Following with the Figure 1.1, the structure of this dissertation has five chapters. In Chapter 1, the researcher introduces the overview scope of dissertation. Chapter 2 mention about the literature reviews. The research experiments and methodology are illustrated in Chapter 3 and Chapter 4. The conclusion is mentioned in Chapter 5

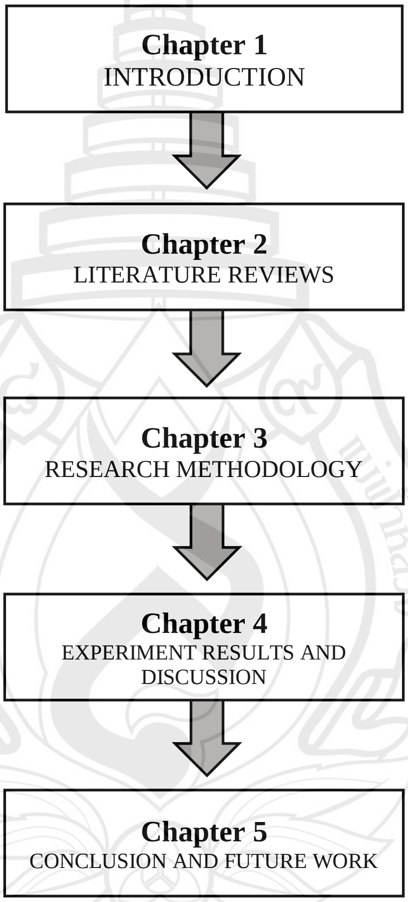


Figure 1.1 The dissertation structure

CHAPTER 2

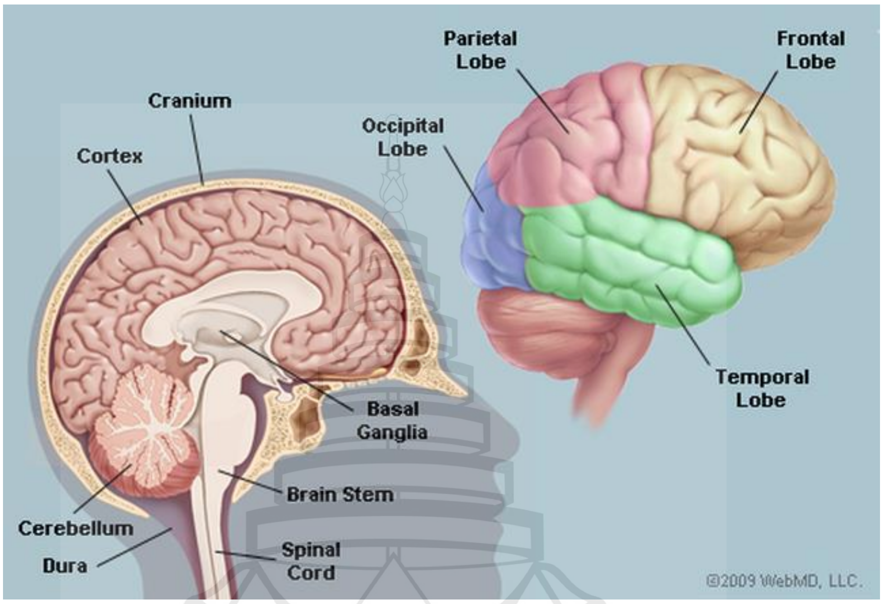
LITERATURE REVIEWS

In this section, several theories that relate to the field of brain computer interfacing will presented. Contents of this chapter focus on the brain mechanism, neurotransmitter, brain wave signal which illustrate to electroencephalography or EEG and algorithms which analyze the wave and describe waves. Researcher reviews and mention about following topics:

1. The brain
2. The brain functions
3. The vertical cross-section motor and sensory cortical areas in brain
4. Neurotransmitters
5. The multi-modal perception
6. Auditory pathway
7. Somatosensory pathway
8. The brain wave signals
9. EEG brain wave bands
10. The 10-20 scheme for brain electrode
11. BCI signal processing model
12. Brain computer interface devices
13. Fast Fourier Transform algorithm
14. Blinded people learning tools

2.1 The Brain

This research focus on each brain area positions and their functions. The brain is one of large organ which contain of complex components (WebMD, 2014). One of important brain features has one hundred billion nerves which communicate between them with synapses. The brain has the complex structures and functions that show in figure 2.1



Source WebMD (2014)

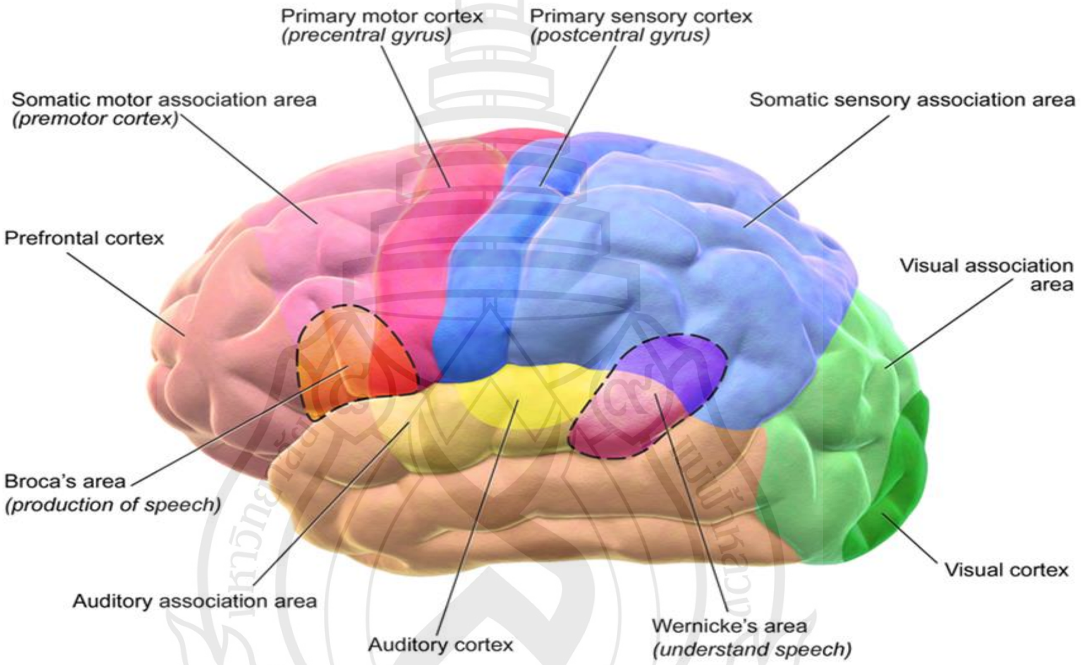
Figure 2.1 The brain components and positions

From the figure 2.1, the cortex area does a task about thinking and movements. The brain stem works about the breathing and sleeping control. The coordination between other area is the function of basal ganglia. And the last component is cerebellum function about responsive of coordination and balance.

The brain divides into four parts, including frontal lobe, parietal lobe, temporal lobe and occipital lobe. First, the frontal lobe response to problem solving, judgement and motor function. Second, the parietal lobe response to sensation, handwriting and body position. Next, temporal lobe controls about memory and hearing. Last, the visual processing system communicate with the occipital lobe.

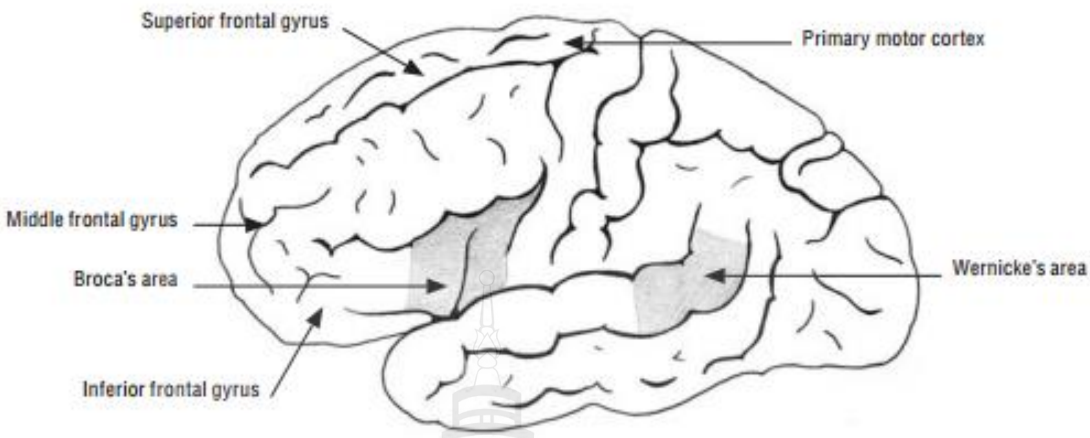
2.2 The Brain Functions

The several areas of the brain control with different functions. For example, the frontal lobe area controls motor functions, the parietal lobe function about sensory activities, the temporal lobe work about hearing system and the occipital lobe control the vision system. The brain area is show in figure 2.2.



Source Blausen Medical (2014)

Figure 2.2 Functional areas of the human brain



Source OECD (2007)

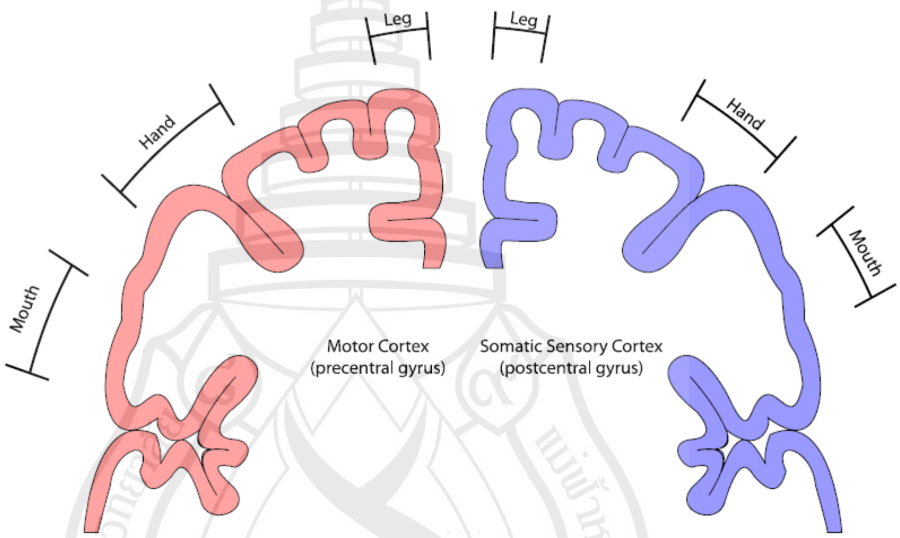
Figure 2.3 The frontal lobe

The frontal lobe associates with cognitive functions, including planning, judgment, memory, problem-solving, and motor behavior. The parietal lobe associates with mathematics learning, sensory information and visual processing. The temporal lobe associates with naming, comprehension, and other language functions. Ant the last, the occipital lobe is located at the back of the brain above the cerebellum is associated with visual processing, color and movement discrimination (OECD, 2007).

This research focus on the frontal lobe. The frontal lobe is in front of cerebrum. This area includes the primary motor cortex, the superior frontal gyrus and the middle frontal gyrus. The primary motor cortex controls the movement of the body. The superior frontal gyrus can plan and execute the activities. The middle frontal gyrus works with the decision-making processes. The Broca’s area controls activities about the speech of the human and the Wernicke’s area is the main recognition about the speech or hearing brain area.

2.3 The Vertical Cross-section Motor and Sensory Cortical Areas in Brain

The different brain areas control with different functions of human body. The frontal lobe area usually associates with thinking, judgment, memory and motor functions. This part of brain can function the motor and sensory of the human.



Source Schalk and Melinger (2010)

Figure 2.4 The frontal lobe functions

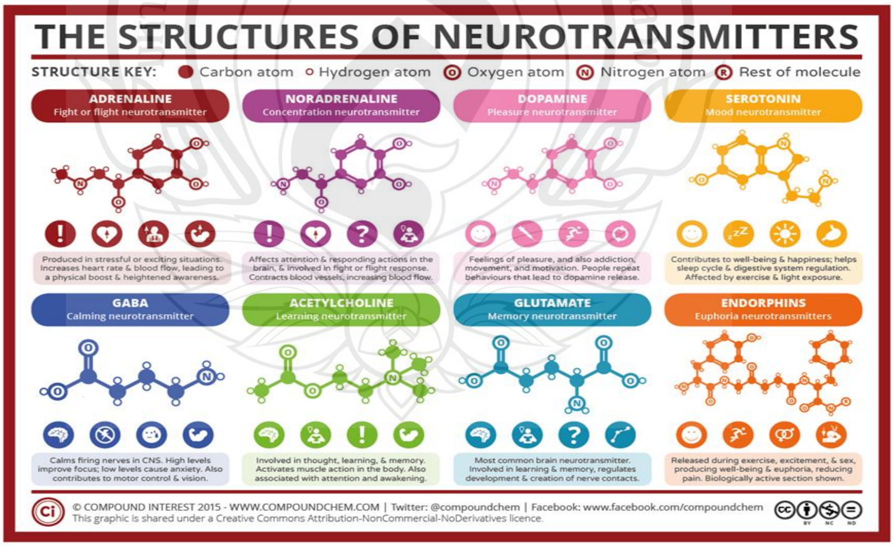
The picture of brain area in figure 2.4 shows the vertical cross-section along motor and sensory cortical areas (Schalk et al., 2010). The motor cortex is displayed in red color (left). This area associates with functional of the motor parts of the human body like mouth, hands. The sensory cortex is show in blue color (right). Particular areas in sensory cortex associate with sensory function of limbs. The area of the motor cortex and sensory cortex are located in the mid-brain like figure 2.2.

2.4 Neurotransmitters

Neurotransmitters are endogenous substances from neurons in nervous system (Squire et al., 2008). The general agreement for substance designates a neurotransmitter by following:

1. A neurotransmitter must be synthesized by and released from neurons
2. The substance should be released from nerve terminals in a chemically identifiable form
3. The neurotransmitter should reproduce at the postsynaptic cell the specific events
4. The effects of a putative neurotransmitter should be blocked by competitive antagonists of the receptor for the transmitter in a dose-dependent manner
5. There should be active mechanisms to terminate the action of the putative neurotransmitter

There are very different types of neurotransmitters with the different functions. We showed them in figure 2.5.



Source Compound Interest (2017)

Figure 2.5 The structure of neurotransmitters

Adrenaline is a hormone that produce a high stress or exciting situations. It can increase heart rate, contracts blood vessels, and dilates airways. Noradrenaline is a neurotransmitter that affects attention and responding actions in the brain. Dopamine is associate with feelings of pleasure, satisfaction, addiction, movement and motivation. Serotonin is a contributor to feelings of well-being and happiness, sleep cycle along with melatonin and intestinal movements. GABA can increase levels improve mental focus and relaxation. Acetylcholine involve in thought, learning and memory. Glutamate involve in cognitive functions, such as learning and memory and Endorphins release in the brain with exercise, excitement, pain and sexual activity (Compound Interest, 2015).

The synapses that transmit neurotransmitters from neuron to neuron or neuron to peripheral targets is the primary place for start coordination in neurotransmission system. These synapses generate the action potential from neurotransmitters that transport from neuron to others. Researcher can record brain signals from this action on the brains with several types of electrode.

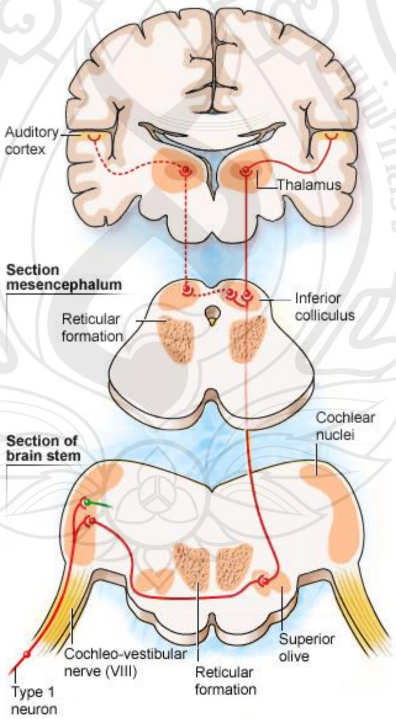
2.5 The Multi-modal Perception

Most of the time, the human usually unifies multiple sensory modalities in the same time. The several component of brain regions in the middle brain and cerebral cortex relate to multimodal perception. These regions contain many neurons that respond to stimuli from multiple sensory modalities. The superior temporal sulcus contains single neurons that respond to both the visual and auditory components of speech (Lachs, n.d.).

2.6 Auditory Pathway

The auditory pathway is the pathway of the auditory sensory. In this research, researcher focus on the blinded people. The auditory sensory is the best way of the study about learning behavior of them. Experiments were designed for knowing about brain wave signals and ways their work. Auditory messages convey to the brain via two types of pathway, including the primary auditory pathway which carries messages from the cochlea and the non-primary pathway which carries all types of sensory messages (Pujol, 2017).

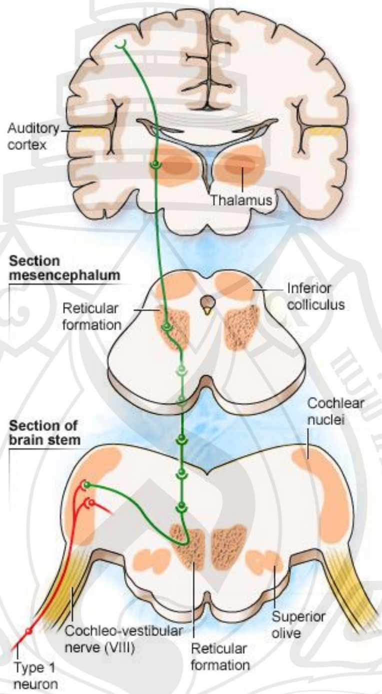
The primary auditory pathway produces in the cochlear nuclei in the brain stem that show in figure 2.6. At this layer, the important decoding of signals, such as duration, intensity and frequency will occur. The second pathway is in the superior olivary complex. The neuron carries the message up to the layer of the superior colliculus. These two pathways play an essential role in the localization of sound. And the next one, this pathway occurs in the Thalamus. This system prepares for the motor response. The final neuron of the primary auditory pathway links the thalamus to the auditory cortex. This neuron decodes the passage from the previous neurons in the pathway. The auditory cortex can recognize, memorize and perhaps integrated into a voluntary response (Pujol, 2017).



Source Pujol (2017)

Figure 2.6 Primary auditory pathways

The non-primary pathway occurs in the cochlear nuclei like figure 2.7. The first pathway locates in the cochlear nuclei, has the small fibers rejoin the ascending reticular pathway. Several synapses occur in the reticular pathway of the brainstem and the mesencephalus. In this pathway, the auditory information integrates with the other sensory modalities. In other words, the reticular pathway is the center that will wake and motivate the information which sequences the priority by the brain. After the reticular formation, the non-primary pathway leads to the non-specific thalamus then to the polysensory cortex.

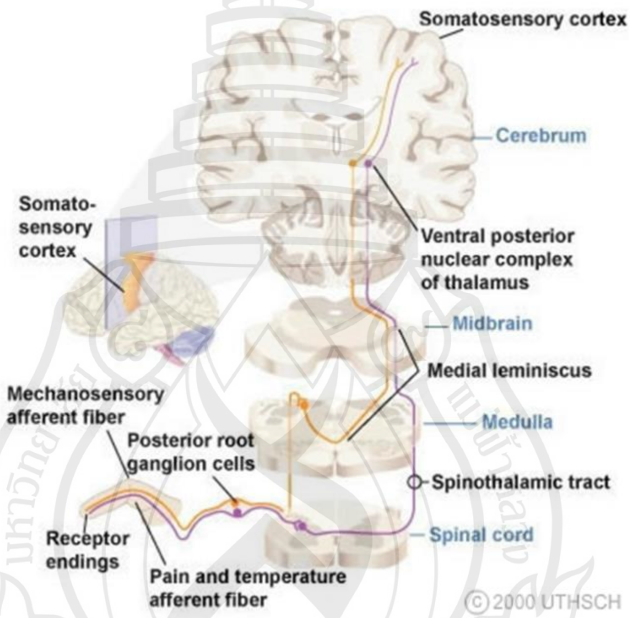


Source Pujol (2017)

Figure 2.7 No-primary auditory pathways

2.7 Somatosensory Pathway

The somatosensory pathway is the pathway of the sensory in human brain. This pathway consists of many neurons from receptor organ to cerebral cortex. The structure of pathway shows in figure 2.8. The start pathway is a pseudounipolar neuron which locate in a peripheral ganglion on cell body. This neuron has the axon that connect to the somatosensory receptors on spinal cord. The second pathway connects to the next pathway with neurons in spinal cord and thalamus (Dougherty, 2017). Thalamic neurons send their axons in the posterior limb of internal capsule to end in the cerebral cortex. Somatosensory pathways are at the end of the parietal lobe of the cerebral cortex.



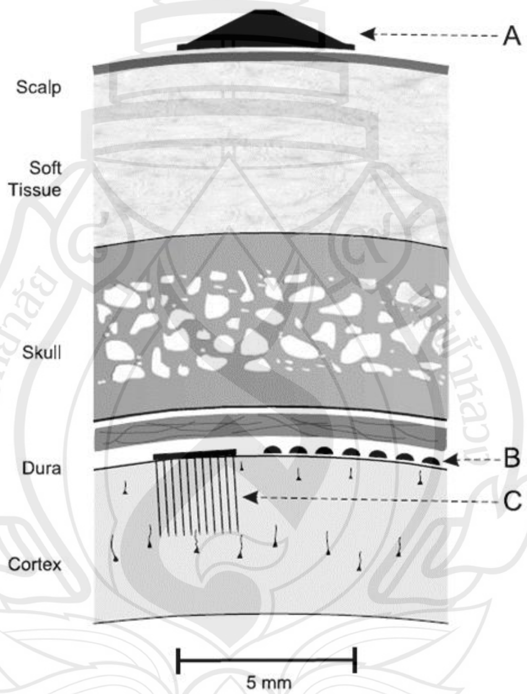
Source Dougherty (2017)

Figure 2.8 Common anatomical features of spinal somatosensory pathways

2.8 The Brain Wave Signals

Now, the world has many varieties of technology for monitoring brain activity and provide the basis for a brain-computer interfacing. The technology can interact with the brain by several types of device, such as electroencephalography (EEG) which placed the electrode on the scalp, electrocorticography (ECoG) which placed the electrode on the surface of the brain, magnetoencephalography (MEG), positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and functional Near InfraRed (fNIR) (Schalk & Melinger, 2010). However, MEG, PET, fMRI, and fNIR are still technically demanding and expensive but EEG and ECoG are inexpensive and simple to use.

The EEG is the alternative use. The EEG devices can record the brain wave signals from the scalp. The placement of electrode shows in figure 2.9. These BCI technology are high performance for collecting the data but EEG technology has less spatial resolution which limit the amount of information that can extract.



Note A showed the placement area of electroencephalography (EEG). B showed the placement area of electrocorticography (ECoG) and C showed the placement area of single-neuron recordings

Source Schalk and Melinger (2010)

Figure 2.9 The different types of sensor in BCI research

2.9 EEG Brain Wave Bands

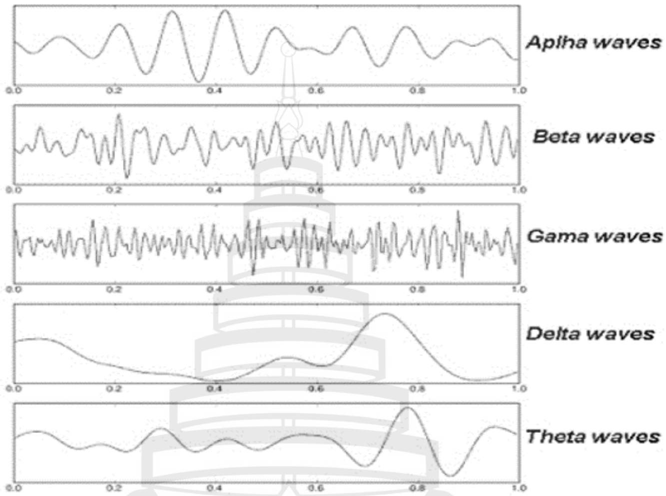
The EEG brain signals was discovered by German scientist named Hans Berger. The EEG brain signals are captured from specific devices that armed with the electrodes. In this research, researcher focus on the device that can connect to computer. The EEG signals is many frequencies. The different waves perform different tasks like figure 2.10.

Brainwave Type	Frequency range	Mental states and conditions
Delta	0.1Hz to 3Hz	Deep, dreamless sleep, non-REM sleep, unconscious
Theta	4Hz to 7Hz	Intuitive, creative, recall, fantasy, imaginary, dream
Alpha	8Hz to 12Hz	Relaxed, but not drowsy, tranquil, conscious
Low Beta	12Hz to 15Hz	Formerly SMR, relaxed yet focused, integrated
Midrange Beta	16Hz to 20Hz	Thinking, aware of self & surroundings
High Beta	21Hz to 30Hz	Alertness, agitation
Gamma	30Hz to 100Hz	Motor Functions, higher mental activity

Source NeuroSky, Inc (2015)

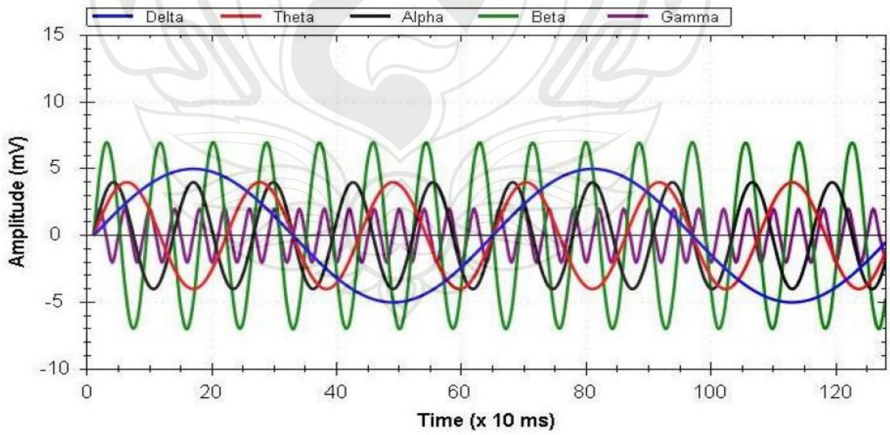
Figure 2.10 EEG frequency bands and brain states

From figure 2.10, the five main frequency bands are different frequency ranges (Larsen, 2011). Each frequency shows in Figure 2.11. The highest frequency is gamma wave. The gamma wave is in the frequency range of 31 Hz and up. This wave associates with the attention, perception and cognition. The Beta wave is in the frequency range between 12 Hz and 30 Hz. This wave associates with focus, concentration, movement and solving a math task. Beta wave defines in central and frontal areas of the brain. Next, the alpha wave is range between 7.5 Hz and 12 Hz. This wave associates with relaxation and disengagement. Sometime, alpha wave can increase with the thinking of something peaceful with eye closed. This wave usually found in the back of head or the frontal lobe. The next wave is theta wave which is ranging in 3.5 Hz to 7.5 Hz. This wave associate with awake or in a sleep state, emotional stress, especially frustration or disappointment, unconscious material, creative inspiration and deep meditation. The last one, the delta wave is ranged in 0.5 Hz to 3.5 Hz. This wave associate with dreamless sleep, non-REM sleep and unconscious states (NeuroSky, Inc., 2009). The relations of the wave are showed in figure 2.12.



Source NeuroSky, Inc (2009)

Figure 2.11 The five EEG main waves



Source NeuroSky, Inc (2009)

Figure 2.12 The relationships of five main frequency bands

2.10 The 10-20 Scheme for Brain Electrode

The standard positioning scheme for EEG signals record is the 10–20 international system. This scheme bases on iterative subdivision of arcs on the scalp which start positioning from reference points at earlobe (Schalk at al., 2010). Forehead to nape positions start from Nasion (NS) to Inion (IN). Left to right positions are pre-auricular points (PAL and PAR). All electrode placement points show in figure 1.13-A and figure 1.13-A B. Original points of this system are nineteen electrode placement points but points can extend to seventy electrodes placement points and rename T3, T5, T4, and T6 positions into T7, P7, T8, and P8 positions. This system uses the earlobe which is the reference position and mastoid which is the ground positions. In this research, researcher uses this system to refer to place the electrode.

Refer to 10–20 international system, there are several important positions. First, the pair of CPz-C2-C4 and CPz-C1-C3 points are the line points that divide the brain to two parts, the frontal lobe and parietal lobe. Other important points are CP6-C6-FT8-FT10 and CP5-C5-FT7-FT9 positions that divide the brain part to temporal lobe area. For more information look at the figure 1.13-C (Schalk & Mellinger, 2010).

In this paragraph, researcher collected information about the placement of electrodes on the scalp and summarize them by following step. In this research, author use the device name NeuroSky Mindwave that electrode point is Fp1 position.

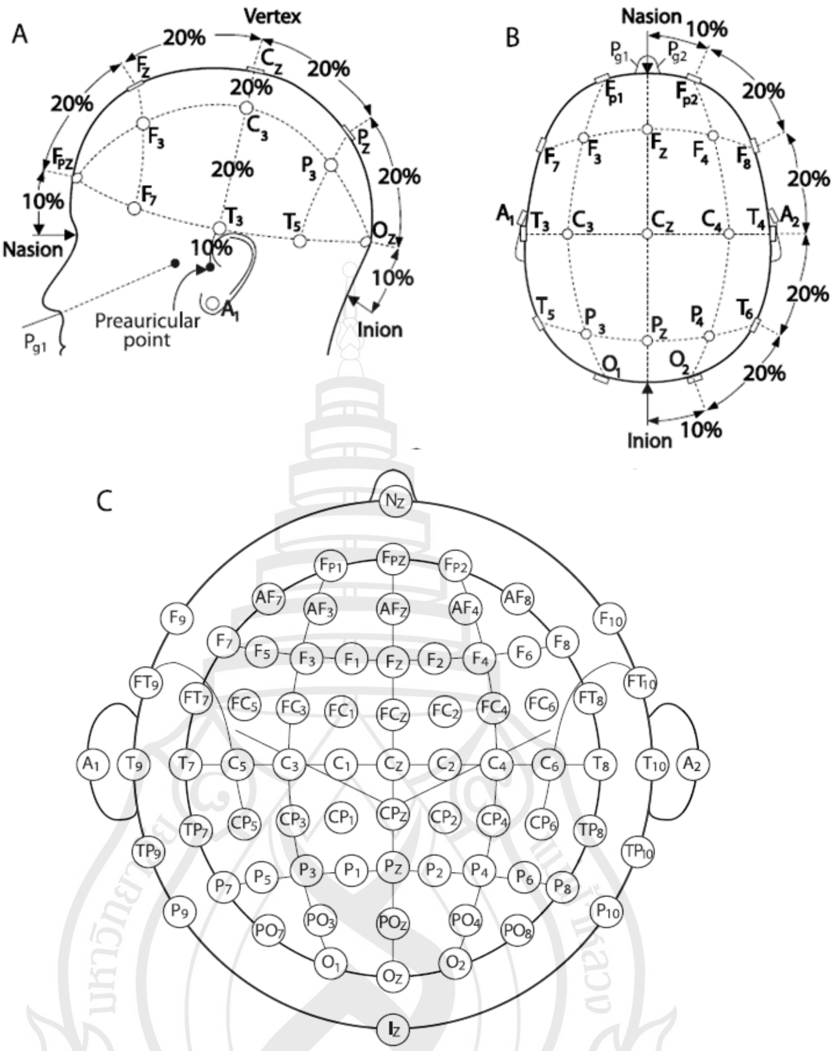
1. Find the nasion and inion point, then find the middle position between the points. The finding point is vertex.

2. Find the Fpz and Oz positions. Fpz is above nasion 10% from nasion to inion point and Oz is above inion point about 10% from the same distance.

3. Identify the Cz point and make it to vertex of the head.

4. Adjust the electrodes to the positions that the device support and ensure that Cz point not move.

5. Fix the reference and ground position, attach reference electrode to one earlobe and the ground electrode to the mastoid on the same side if device has this electrode.



Note A showed the placing electrodes point from NS to IN by lateral. B showed the placing electrodes point from NS to IN by top and C showed the extensions of this scheme define more than seventy locations

Source Schalk and Melinger (2010)

Figure 2.13 Electrodes on the original 10–20 scheme

2.11 BCI Signal Processing Model

The EEG brain wave signals usually record in raw data which consist of artifacts, including eye blink, eye movement or muscle movement signals. With the BCI methodology reason, the methodology is divided into five stages (Ilyas, 2015). First stage is a brain activity measurement. This step is the process that sensor capture the EEG signals. The second stage is pre-processing. This method is the process that clean and remove noisy data like eye blink or muscle movement. Third stage is feature extraction, i.e., the method identifies discriminative information, reduce the computational complexity and maintain the important information from loss. Fourth stage is classification that obtain the data from the previous stage. This stage is important for reflect the user's intentions. Final stage is control interface that connect to other devices. Researcher selects the suitable algorithm in each method.

In the method of pre-processing, this method has many algorithms to eliminate artifacts of the raw signals. There are Common Spatial patterns (CSP), Principle Component Analysis (PCA), Common Average Referencing (CAR), Surface Laplacian (SL), adaptive filtering, Independent Component Analysis (ICA) and digital filter algorithm. The advantages and disadvantages of pre-processing algorithm show in table 2.1.

Table 2.1 The advantages and disadvantage of pre-processing algorithms

No	Approach	Advantages	Disadvantages
1	Common Spatial Patterns	Works well for Motor Imagery data	Needs multiple electrode
2	Principle Component Analysis	Reduction of feature dimension	Not as good as ICA
3	Common Average Referencing	Outperforms all the reference methods	Needs sufficient head coverage

Table 2.1 (continued)

No	Approach	Advantages	Disadvantages
4	Surface Laplacian	Robust against the artifacts at uncovered electrode	Sensitive to artifacts Sensitive to spline pattern
5	Adaptive filtering	Works well for the signals with overlapping spectra	Need two signals (including reference signal)
6	Independent Component Analysis	Computationally efficient High performance for large data sized	Require more computational for decomposition
7	Digital Filter	Easily remove electrical grounding noise	Requires EEG signal and artifact occupy distinct frequency bands

In the method of feature extraction, there are many of algorithm, such as Principal Component Analysis (PCA), Independent Component Analysis (ICA), Wavelet Transformations (WT), Wavelet Packet Decomposition (WPD), Auto Regressive (AR), and Fast Fourier Transform (FFT). There advantages and disadvantages show in table 2.2.

Table 2.2 The advantages and disadvantage of feature extraction algorithms

No	Approach	Advantages	Disadvantages
1	Principal Component Analysis	Dimension reduction without losing data	Unable to process complicated set of data
2	Independent Component Analysis	Computationally efficient High performance for large data sized	Require more computational for decomposition

Table 2.2 (continued)

No	Approach	Advantages	Disadvantages
3	Wavelet Transform	Suitable for nonstationary signals Able to analyze signal in time and frequency domain	Lacking of specific methodology to apply to pervasive noise
4	Wavelet Packet Decomposition	Able to analyze the nonstationary signals	Increase computational time
5	Auto Regressive	Require short duration of data Reduce spectra loss problems and give better frequency resolution	Not applicable to stationary signals
6	Fast Fourier Transform	Works well for stationary signals	Not applicable for non-stationary signals Unable to measure both time and frequency

Mention to feature extraction method, the extraction vectors are classified by Artificial Neural Network (ANN), k- Nearest Neighbour (k-NN), Linear Discriminant Analysis (LDA) and Support Vector Machine (SVM). The difference of each algorithm shows in table 2.3

Table 2.3 The advantages and disadvantage of classification algorithms

No	Approach	Advantages	Disadvantages
1	Artificial Neural Network	Fast Operation Ease of implement	Performance depends on the number of neurons in hidden layer

Table 2.3 (continued)

No	Approach	Advantages	Disadvantages
2	k-Nearest Neighbor	Simple to understand Easy to implement	Sensitive to irrelevant and redundant features
3	Linear Discriminant Analysis	Simple to use Low computational complexity	Usually allied for two classes
4	Support Vector Machine	Performance in better compare to another linear classifier	High computational complexity

2.12 Brain Computer Interface Devices

In the researches of brain computer interfacing, they have many devices that connect to the brain by several methods. The EEG device that connect the brain signal are expensive price follow by the number of electrodes. In this part, author discuss on some devices that we interested in. The devices that we interested in are EMOTIV Epoc, EMOTIV Insight and NeuroSky MindWave Mobile because there has a low price. NeuroSky MindWave device we mentioned to has the inexpensive device.

EMOTIV Epoc device is the EEG brain signal capture device with fourteen channels of electrode. The device can connect to AF3, F7, F3, FC5, T7, P7, 01, 02, P8, T8, FC6, F4, F8, AF4, with common mode sense and driven right Leg (CMS/DRL) references in P3/P4 locations of the 10–20 scheme system. These device uses a sampling rate of 128 samples per seconds (SPS) and connect to the computer with Bluetooth connection. This device shows in figure 2.14

Source Emotive (n.d.)

Figure 2.14 EMOTIV Epoc device with fourteen channel electrodes

EMOTIV Insight is the EEG brain signal capture device with five channels of electrodes. This device uses five channel electrodes in AF3, AF4, T7, T8, Pz positions and CMS/DRL references. These device uses a sampling rate of 128 samples per seconds (SPS) and connect to the computer with Bluetooth connection. This device shows in figure 2.15

Source Emotive (n.d.)

Figure 2.15 EMOTIV Insight device with five channel electrodes

NeuroSky MindWave Mobile device is the most inexpensive device than others device. The device connects to the brain via Bluetooth channel. This device connects to the brain with single Fp1 position electrode that place on the scalp. NeuroSky MindWave device measures and output EEG power spectrums, including alpha waves, beta waves, etc, NeuroSky eSense meters (attention and meditation) and eye blinks signals. This device consists of a headset, an ear-clip, and a sensor arm. The headset's reference and ground electrodes are on the ear clip. The EEG electrode is on the sensor arm like figure 2.16

Source NeuroSky, Inc (n.d.)

Figure 2.16 NeuroSky MindWave Mobile with single channel electrode

2.13 Fast Fourier Transform Algorithm

Fourier Transform algorithm is the tool of conversion between the time domain and the frequency domain of wave or signal (Huang, n.d.). Fourier Transform converts signal in time domain to spectrum of frequency. However, Inverse Fourier Transform convert frequency domain back to the time domain (Heckbert, 1995). Fourier Transform function show with the following equation (2-1):

$$F(\omega) = \int_{-\infty}^{\infty} f(x)e^{-i\omega x}dx \tag{2-1}$$

Next, Inverse Fourier Transform function show in the next equation (2-2)

$$f(x) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F(\omega)e^{i\omega x}d\omega \tag{2-2}$$

With above equations, $F(\omega)$ is the signal spectrum. $f(x)$ is input signal data before process by f or F function. f function is the impulse response of a filter which process the input data to output data. F function is the filter's frequency response.

Fast Fourier Transform is the fast algorithm. This algorithm can compute Discrete Fourier Transform faster. The computation of DFT of N-Point by equation take $O(N^2)$ multiplies and adds but FFT use $O(N \log N)$ multiplies and adds. The equation of FFT show in the following equation (2-3) (Huang, n.d.):

$$X(k) = \sum_{n=0}^{N-1} x[n]e^{-2\pi jnk/N} \tag{2-3}$$

In this dissertation, author use Fast Fourier Transform algorithm to analyze signal dataset and convert to signal spectrum for find touching learning brain signal patterns.

2.14 Blinded People Learning Tools

Blinded people were found many numbers in the world. Some people blinded by born or accidents. They learn by different ways, such as tactile picture. The use of the assistive technology for blinded people must consider by following area (Gierach. 2009).

1. Desk space
2. Classroom space

3. Location
4. Visual access of classroom presentations
5. Type of light and level of illumination
6. Type of learning medium
7. External noise
8. Assistive Technology: past and present
9. Sensory Considerations

There are many organizations that try to help leaning method of blinded people. in the condition of Lampang Education for the Blind School in Lampang of Thailand, blinded students are learning by tactile pictures. The school uses the Thermoform machine, swell paper, silk screen, color prints on paper, pictures of different materials and low or high relief in tactile images that show in figure 2.17 to 2.18. The blinded people can learn and get the knowledge from the internet only text reader, i.e., JAW program (Freedom Scientific, Inc., 2012) but they cannot get the knowledge from the pictures in the internet because this program cannot process pictures. In this research, researcher focus on the brain wave of blinded people when they touch on objects or tactile pictures and analyze signals of them.

Figure 2.17 Thermoform machine

Figure 2.18 Swell paper and use

2.15 Summary

According to related work, this dissertation aims to three experiments that focus on the EEG brain wave patterns which related to tactile picture learning of blinded people. There are three main experiments consist of (1) the EEG brain signal representation for surfaces and shapes touching behavior with an inexpensive device, (2) the EEG brain signal patterns for touching learning of blinded people on tactile pictures by the inexpensive device and (3) the EEG brain signal patterns for touching learning of blinded people on tactile pictures with several positions by the inexpensive device. The research methodology relates to three experiments and compare results between normal people and blinded people to explain the hypothesis. Details of dissertation methodology and experiments will be explained in the Chapter 3.

CHAPTER 3

RESEARCH METHODOLOGY

This section mentions in overview of all process of the dissertation methodology with three experiments which explain the EEG of normal people and blinded people when they learn about the tactile pictures by touching.

3.1 Research Methodology

Researcher focused on methods which find EEG signal patterns. The methodology was separated into three major parts. First, the method explored important waves, usually appeared in high amplitude ranges. These experimental objects were three types of basic shape and two types of surface. Second, author started to collect the data with four sample groups and extract the feature by using suitable algorithm, Fast Fourier Transform algorithm. Researcher used tactile pictures for this experiment. The last stage, author used other tactile pictures that have difference positions with twenty-seven different locations.

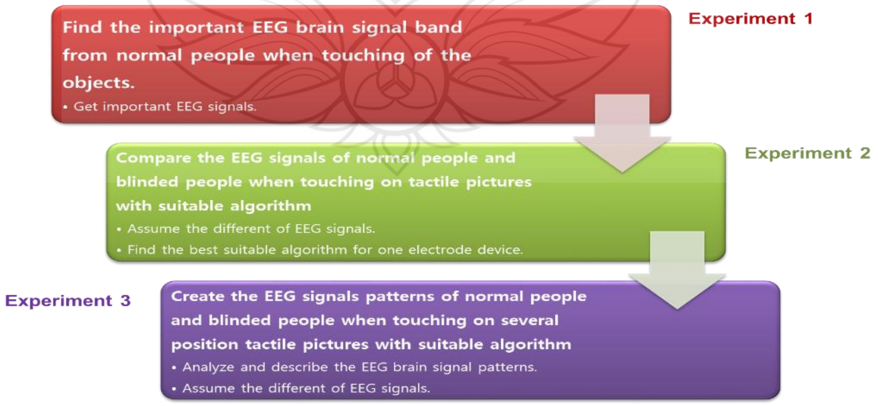


Figure 3.1 Dissertation framework

3.2 Experimental Method

Researcher design the experimental method for each experimental by BCI signal processing model. NeuroSky MindWave device is the main BCI device, connect to computer by Bluetooth. Then, author design experiment to record EEG brain signal and store datasets to MATLAB with .csv filename. After that, researcher find the best algorithm for feature extraction method to denoise the signal. Next, researcher seeks for the best algorithm that support to classification method to create EEG signal patterns for each experiment like figure 3.2

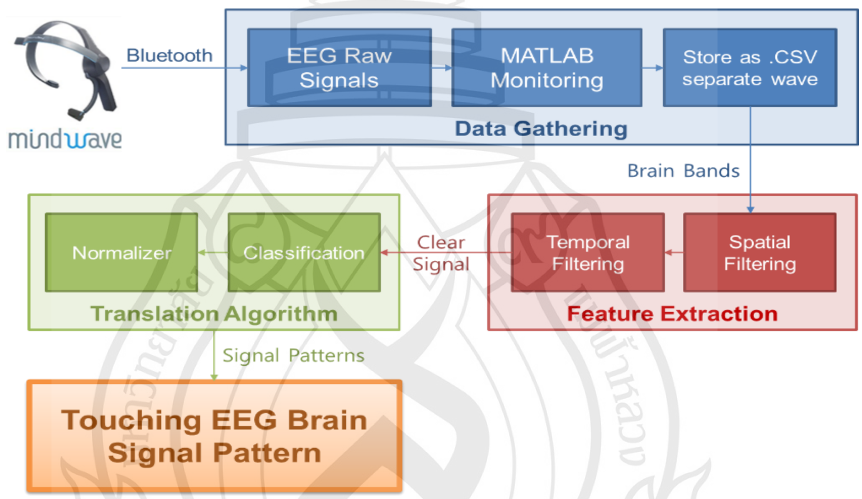


Figure 3.2 Experimental method

This dissertation separated experiments to three parts, show in figure 3.1. For the first part, researcher focused on important wave which affect to touching behavior. Second, author designed the experiment for capture and analyze the wave that compare between normal people and blinded people when they touch on tactile pictures and know them. Third, researcher tried to analyze the wave when volunteers touch on tactile pictures with different positions.

3.3 Research Experiments

3.3.1 Aim 1: The EEG Brain Signal Representation for Surfaces and Shapes Touching Behavior with an Inexpensive Device

Aim 1 proposes to find important wave bands by use the inexpensive device. Author focuses on the electroencephalography (EEG) brain wave signals. Author uses the NeuroSky MindWave to connect to four normal people that touch on three different types of smooth surface shapes, sphere, pyramid and cube. Researcher decides to connect this device to the computer via Bluetooth with MATLAB code and record the dataset for sixty seconds and analyze the wave between twenty-one to forty seconds that the time for touching, showed in figure 3.3. Finally, researcher uses mathematic methods, Mean and Standard Deviation for analyze the highest wave values. With this case, author can know what the important waves of EEG signal when touch.

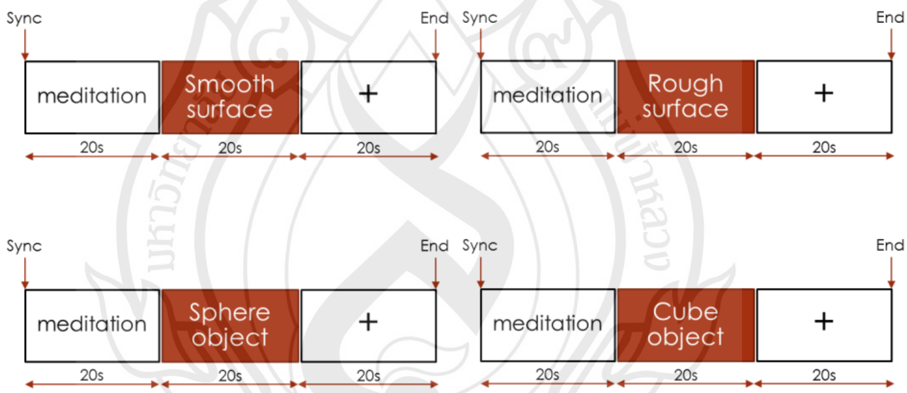


Figure 3.3 Aim 1 timeline

3.3.2 Aim 2: The EEG Brain Signal Patterns for Touching Learning of Blinded People on Tactile Pictures by the Inexpensive Device

This aim, researchers focus on the tactile pictures of three types of normal form geometry. Thus, we will connect the device to the computer and record the data, blinded people touch on the triangle, square and circle tactile picture in center position of paper. After that, we will use MATLAB for analyze the data with suitable algorithm. This aim purpose will show brain wave patterns of the blinded people when they touch on the paper by NeuroSky Mindwave headset. The timeline of this aim will show in figure 3.4.

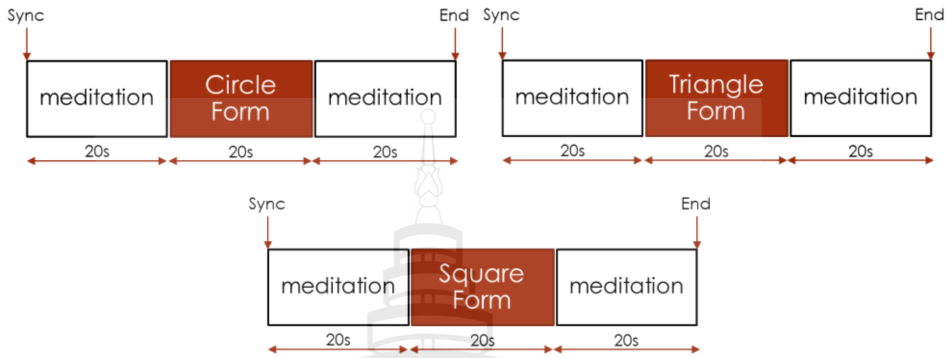
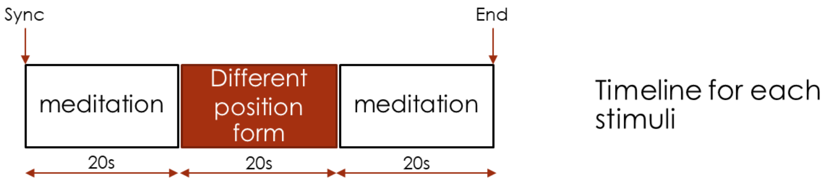


Figure 3.4 Aim 2 timeline

3.3.3 Aim 3: The EEG Brain Signal Patterns for Touching Learning of Blinded People on Tactile Pictures with Several Positions by the Inexpensive Device

Aim 3 focuses on brain wave patterns of the blinded people when they find the position and perceive meaning of tactile pictures. Experimenter will use triangle, square and circle tactile pictures, separate to twenty-seven positions for each. We will use suitable algorithm to analyze the data in feature extraction and classification method. With the reason, MATLAB can help us the do this. The timeline of this experiment will show in figure 3.5. Finally, we will find the EEG wave patterns for touching learning behaviors.



The touching stimuli	The touching stimuli (cont.)	The touching stimuli (cont.)
1. Upper-left Circle	10. Upper-left Triangle	19. Upper-left Square
2. Center-left Circle	11. Center-left Triangle	20. Center-left Square
3. Lower-left Circle	12. Lower-left Triangle	21. Lower-left Square
4. Upper-center Circle	13. Upper-center Triangle	22. Upper-center Square
5. Center Circle	14. Center Triangle	23. Center Square
6. Lower-center Circle	15. Lower-center Triangle	24. Lower-center Square
7. Upper-right Circle	16. Upper-right Triangle	25. Upper-right Square
8. Center-right Circle	17. Center-right Triangle	26. Center-right Square
9. Lower-right Circle	18. Lower-right Triangle	27. Lower-right Square

Figure 3.5 Aim 3 timeline

3.4 The EEG Brain Signal Representation for Surfaces and Shapes Touching Behavior with an Inexpensive Device

This experiment used to find important waves which extract from the brain signal of the touch on surfaces and shapes of some objects. The first experiment methodology showed in figure 3.6

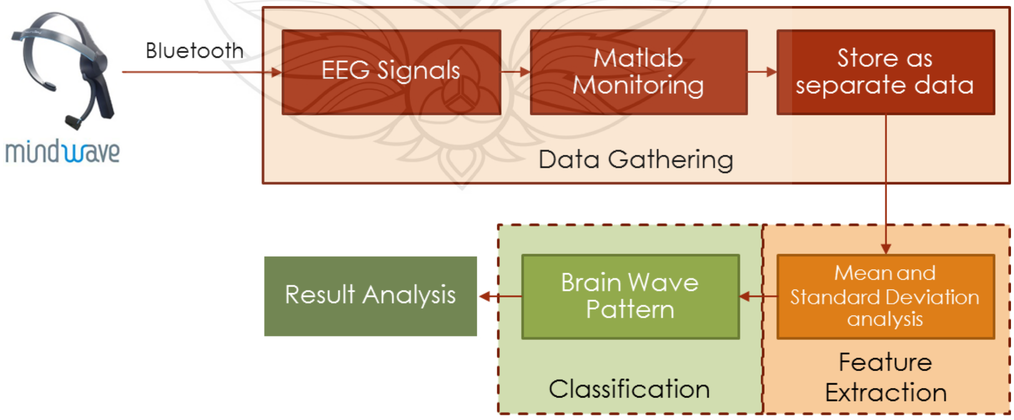


Figure 3.6 Overview of experiment workflow

Researcher started with capturing the EEG signals from four volunteered students from the same major in the one university. They had ages between twenty and twenty-two with two males and two females. The experiment was captured EEG brain waves which affect to volunteers while they touching on the surface and shape objects. Researcher selected four objects with two topics to observe the touching brain wave. The first and second object we focus on the surface of the objects. First objects are a smooth surface and the second one is a rough surface. The third and the last object we focus on the shape of them, sphere and cube objects. The objects show in figure 3.7

(a) (b) (c) (d)

Note (a) Smooth surface gypsum board, (b) Rough surface tile, (c) Sphere rubber ball and (d) Cube wood piece with rough surface

Figure 3.7 Stimulus

The experiment method shows in figure 3.8. Researcher started with verbal instruction for volunteers. Then, we wear NeuroSky MindWave and blindfold to each person. After that, we start the touching experiment by timer sound for touch objects and we connect the device to computer via Bluetooth and monitor in MATLAB.

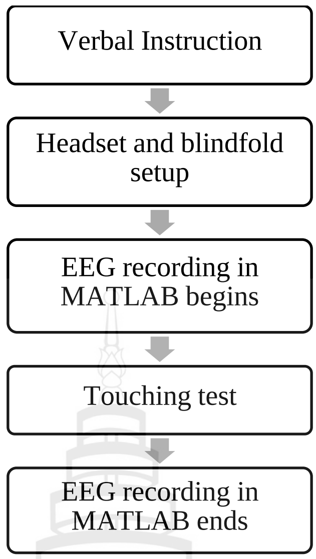


Figure 3.8 Data collection procedures

Researcher designed the step of data gathering that show in figure 3.9 by the following steps.

1. The subjects got the verbal instruction about the research and methods.
2. The subjects used NeuroSky Mindwave to FP1 position of 10/20 System and blindfold to cover the eye of a test taker and move him to the experimental room by assistant.
3. The subjects got the instruction to meditate themselves for 20s.
4. The subjects got the sound alert to touching on the first smooth object for 20s. Then record the EEG brain signal to MATLAB. After that, they got the sound alert for meditate again in 20s.
5. The assistant moved the subjects to the next position and meditate for 20s before the next touching by the instruction.
6. The subjects got the sound alert to start the next touching with the next object for 20s.
7. The subjects got the sound alert to meditate for 20s before move to the next objects.
8. Did these three steps for other objects repeatedly.

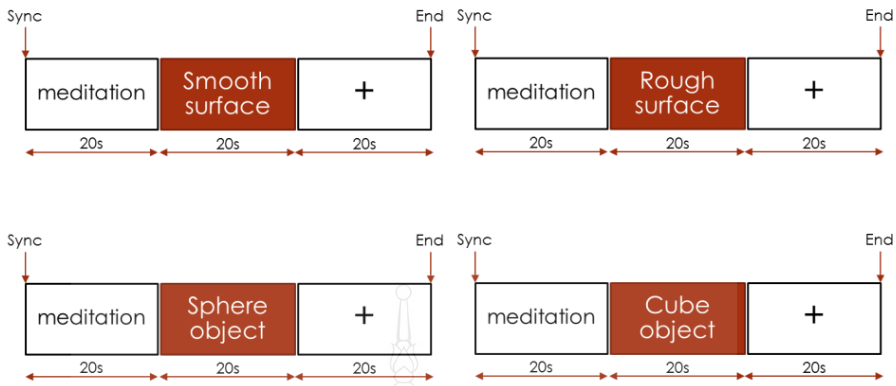


Figure 3.9 Timing diagram for experiment 1

This experiment used the Mean values (x̄) and Standard Deviation values (S.D.) to analyze the important waves. The Mean values is the sum of the dataset values divided by the number of datasets. These variables identify central values of the dataset. The standard deviation can mention the measure of variability. These values can show the spread of the dataset and the relationship of the mean to the rest of the data.

1. Mean Values

The Mean values (x̄) denote to the sum of the dataset values divided by the number of datasets. The X values is an individual data points of brain wave in each type of them. The N values show the number of dataset size of each brain wave. The Mean show with the following equation (3-1):

$$\bar{x} = \frac{\sum X}{N} \qquad (3\text{-}1)$$

When x̄ is the Mean, X relate to a sum of an individual data of each matrix in the same second, N relate to the number of subjects.

2. Standard Deviation Values

The Standard Deviation Values (S.D.) is the values use for calculate the measure of variability. It can show the spread of the dataset and the relationship of the mean to the rest of the data. The X values is an individual data points of brain wave in each type of them. The M values is Mean. The N values show the number of dataset size of each brain wave. The Standard Deviation show with the following equation (3-2):

$$S.D. = \sqrt{\frac{\sum(X-M)^2}{N-1}} \tag{3-2}$$

When S.D. is the Standard Deviation, X relate to a sum of an individual data of each matrix in the same second, M relate to the Mean of the dataset at the same time, N relate to the number of subjects.

At last, the result of Mean and Standard Deviation Values can show the different of the signal in each wave form. They can show the highest values at the same time.

3. EEG Voltage Calculation

The values of 8 wave EEG frequency bands were standard big-endian IEEE 754. The values of EEG signals usually convert to the voltage by the following equation (3-3):

$$EEG\ Voltage = \frac{(\bar{x} \times \left(\frac{1.8}{4096}\right))}{2000} \tag{3-3}$$

When $\bar{x}$ is the Mean of raw values, 1.8 value relate to 1.8V input voltage, 4096 value relate to value range and 2000 value is gain.

As mentioned, this experiment illustrates the important wave when people learn about shape and surface from touching. The result shows in the next chapter.

3.5 The EEG Brain Signal Patterns for Touching Learning of Blinded People on Tactile Pictures by the Inexpensive Device

For this experiment, this work illustrated EEG signals pattern of learning pictures for normal people and blinded people by touching on four geometry shape tactile pictures, such as square, triangle, circle and hexagon like figure 3.10. Researcher designed method of this experiment showed in figure 3.11

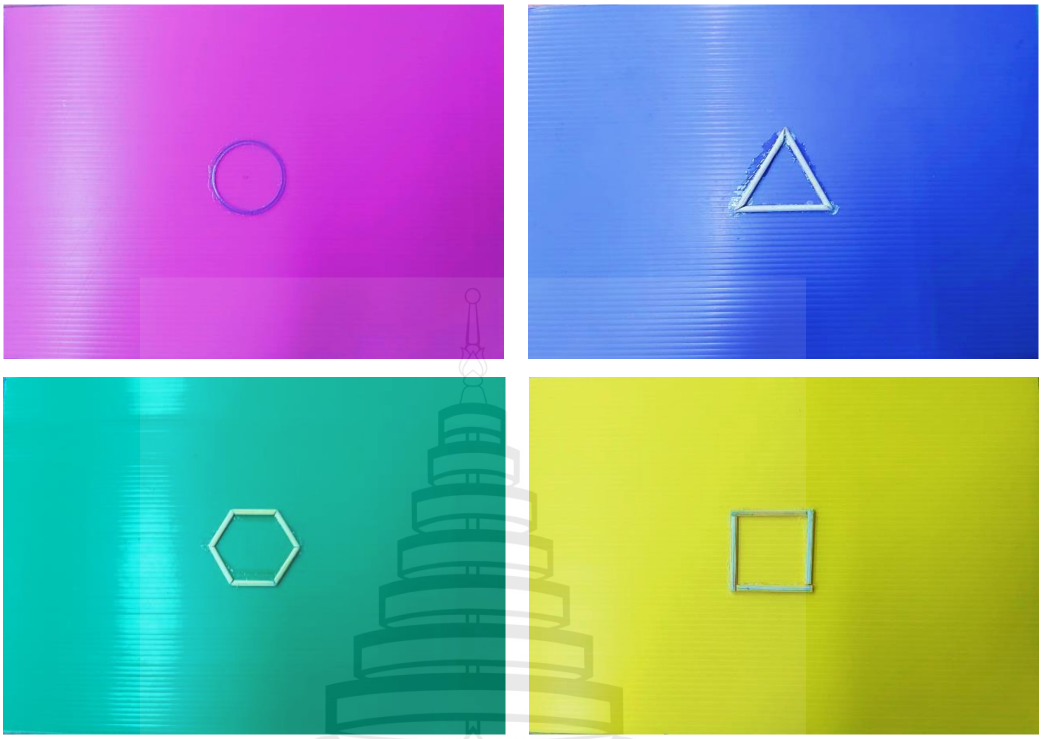


Figure 3.10 Stimulus in experiment 2

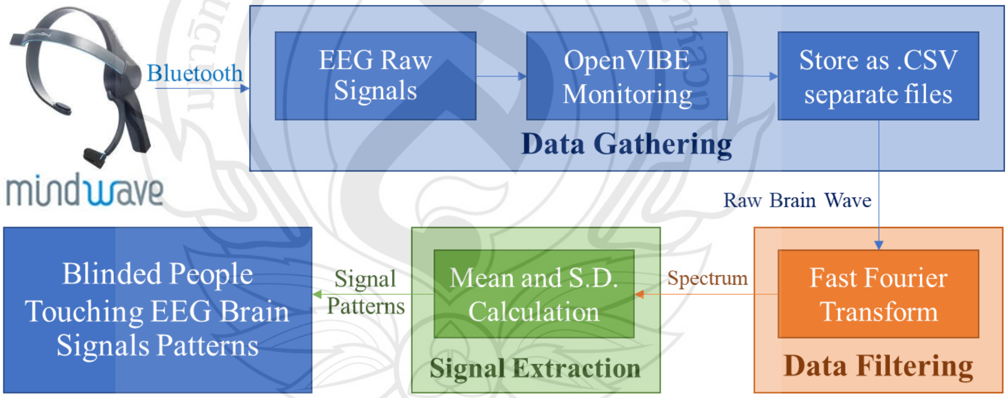


Figure 3.11 Methodology of experiment 2

This experiment based on NeuroSky MindWave device EEG capturing with in OpenVIBE program.MATLAB will be integrated to analyze the dataset. Then, researcher analyze spectrum of the wave from raw EEG signal by fast fourier transform algorithm (FFT) by 3-4 equation. The experiment result mentions in Chapter 4. The timeline of this method was showed in figure 3.12.

$$X(k) = \sum_{n=0}^{N-1} x[n]e^{-2\pi jnk/N} \qquad (3\text{-}4)$$

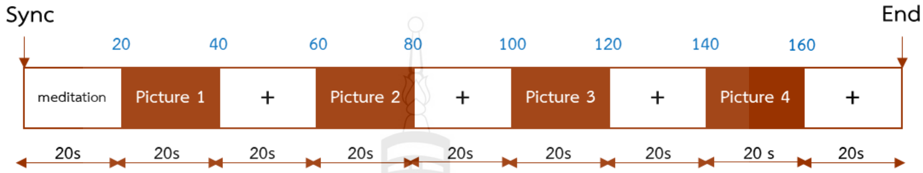


Figure 3.12 Timing diagram for experiment 2

3.6 The EEG Brain Signal Patterns for Touching Learning of Blinded People on Tactile Pictures with Several Positions by the Inexpensive Device

This experiment worked with EEG signals pattern of learning pictures for normal people and blinded people by touching on 4 geometry shape tactile pictures, such as square, triangle, circle and hexagon in the 9 positions, such as upper-left, upper-center, upper-right, center-left, center, center-right, lower-left, lower-center and lower-right, for each shape which show in figure 3.13. This experiment methodology was the same with topic 3.5 that show in figure 3.11 but different in stimulus position placements.

Figure 3.13 Example of stimulus in experiment 3

This experiment based on NeuroSky MindWave device EEG capturing with in OpenVIBE program. MATLAB will be integrated to analyze the dataset. Then, researcher analyze spectrum of the wave from raw EEG signal by fast fourier transform algorithm (FFT) same with experiment 3.5. The experiment result mentions in Chapter 4. The experiment result mentions in Chapter 4. The timeline of this method was showed in figure 3.14.

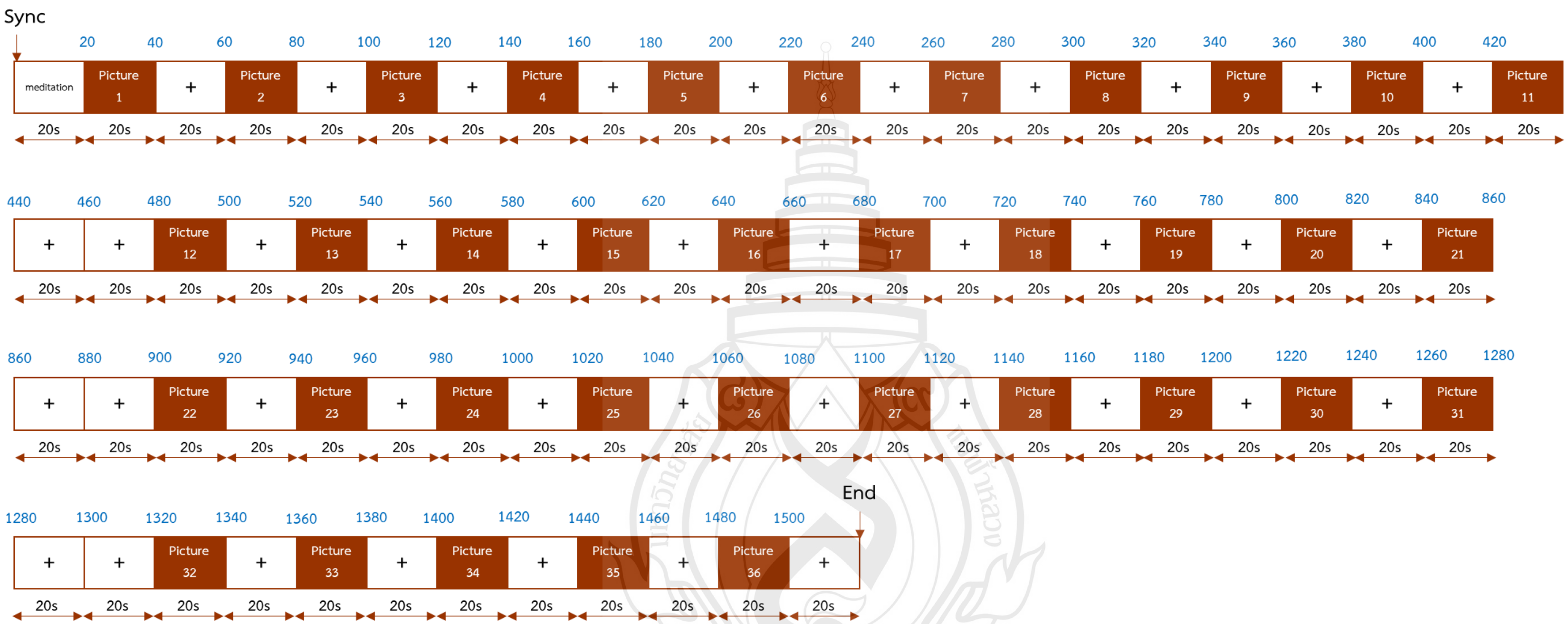


Figure 3.14 Timing diagram for experiment 3

3.7 Summary

According to the dissertation method, works separate to three parts of study which are 1) important waves of touching behaviors, 2) EEG wave patterns of touching behaviors on tactile pictures and 3) EEG wave patterns of touching behaviors on tactile pictures with several positions. Details of results will be explained in chapter 4.

CHAPTER 4

EXPERIMENTAL RESULTS

This chapter explained results from three experiments which explain the EEG of normal people and blinded people when they learn about the tactile pictures by touching. Experiments collected datasets from normal people and blinded people with the same stimulus.

4.1 The EEG Brain Signal Representation for Surfaces and Shapes Touching Behavior with an Inexpensive Device

With this experiment as mentioned in topic 3.4 of chapter 3, EEG dataset of four normal people that touch on three different types of smooth surface shapes, sphere, pyramid and cube were collected from participants like figure 4.1.

Figure 4.1 Touching experiment

NeuroSky MindWave device was set up via Bluetooth to connect to computer like figure 4.2. Thinkgear library was selected. The figure 4.3 shows the example dataset which be eight four-byte floating point numbers from device that communicate with library. The experiment timeline was run continuously by timeline diagram in topic 3.3.1 of Chapter 3. After data gathering method, datasets were record to excel CSV file.

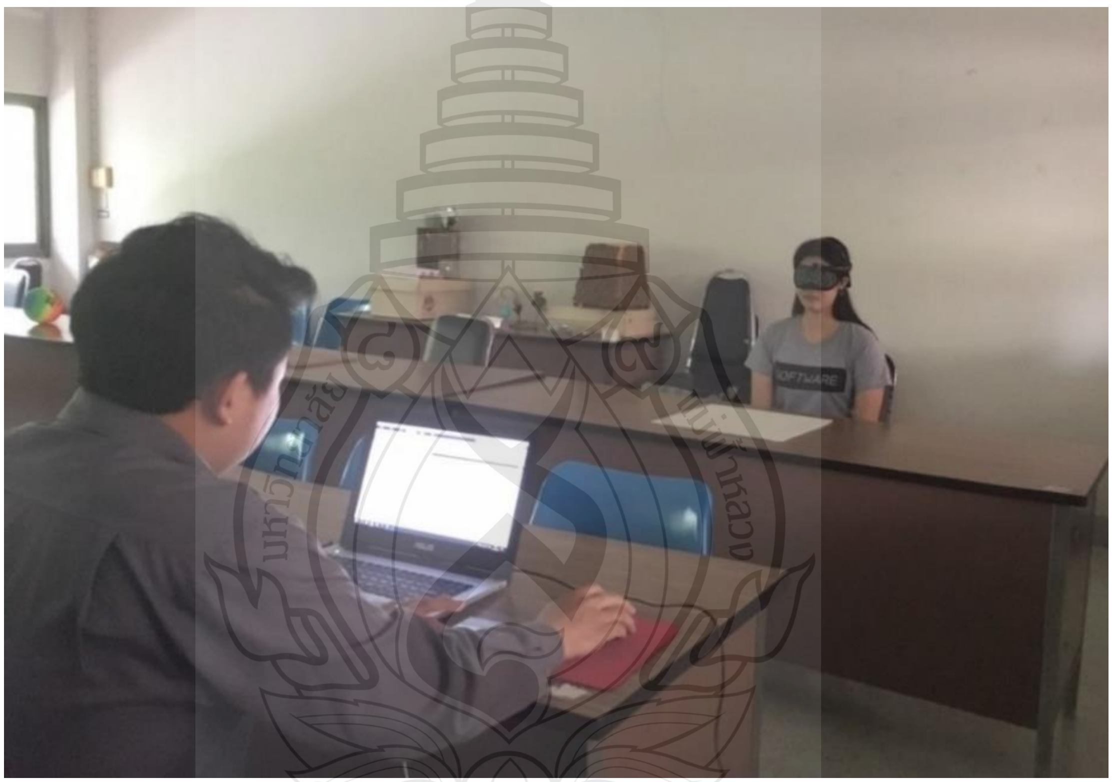


Figure 4.2 Data gathering method

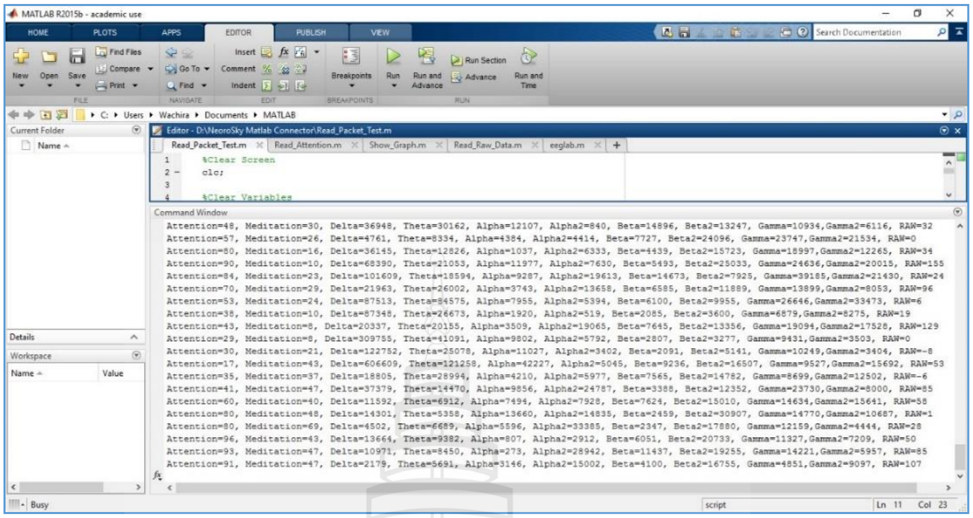


Figure 4.3 Data gathering via MATLAB and ThinkGear library

Then, researcher calculated dataset from excel CSV file and we used mean and standard deviation value calculation to analyze results. EEG calculation results show in several table, such as Table 4.1, Table 4.2, Table 4.3 and Table 4.4. Every value was converted to voltage.

Table 4.1 The touching of the smooth surface gypsum board stimulus of all subjects

EEG Band	Subject				$\bar{x}$	S.D.
	$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_3$	$\bar{x}_4$		
Delta	0.1728	0.1353	0.1306	0.0290	0.1169	0.0616
Theta	0.1000	0.0194	0.0262	0.0078	0.0384	0.0418
Low-Alpha	0.0302	0.0042	0.0056	0.0030	0.0107	0.0130
High-Alpha	0.0146	0.0039	0.0058	0.0032	0.0069	0.0053
Low-Beta	0.0018	0.0020	0.0037	0.0022	0.0024	0.0009
High-Beta	0.0289	0.0016	0.0047	0.0023	0.0094	0.0131
Low-Gamma	0.0008	0.0009	0.0047	0.0012	0.0019	0.0019

Table 4.1 (continued)

EEG Band	Subject				$\bar{x}$	S.D.
	$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_3$	$\bar{x}_4$		
Mid-Gamma	0.1523	0.0535	0.0033	0.0050	0.0536	0.0698

Table 4.2 The touching of the rough surface tile stimulus of all subjects

EEG Band	Subject				$\bar{x}$	S.D.
	$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_3$	$\bar{x}_4$		
Delta	0.1965	0.1811	0.0217	0.0496	0.1122	0.0894
Theta	0.0354	0.0381	0.0114	0.0073	0.0231	0.0160
Low-Alpha	0.0146	0.0080	0.0029	0.0023	0.0070	0.0057
High-Alpha	0.0056	0.0059	0.0041	0.0025	0.0045	0.0016
Low-Beta	0.0046	0.0028	0.0015	0.0021	0.0028	0.0014
High-Beta	0.0083	0.0029	0.0018	0.0027	0.0039	0.0030
Low-Gamma	0.0011	0.0003	0.0014	0.0015	0.0011	0.0005
Mid-Gamma	0.0787	0.0502	0.0011	0.0028	0.0332	0.0379

Table 4.3 The touching of the sphere rubber ball stimulus of all subjects

EEG Band	Subject				$\bar{x}$	S.D.
	$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_3$	$\bar{x}_4$		
Delta	0.0038	0.1199	0.0054	0.0174	0.0366	0.0558
Theta	0.0024	0.0193	0.0044	0.0061	0.0080	0.0076
Low-Alpha	0.0026	0.0049	0.0017	0.0022	0.0029	0.0014
High-Alpha	0.0266	0.0042	0.0049	0.0037	0.0098	0.0112
Low-Beta	0.0016	0.0029	0.0017	0.0026	0.0022	0.0007

Table 4.3 (continued)

EEG Band	Subject				$\bar{x}$	S.D.
	$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_3$	$\bar{x}_4$		
High-Beta	0.0018	0.0015	0.0020	0.0030	0.0021	0.0007
Low-Gamma	0.0013	0.0008	0.0017	0.0016	0.0013	0.0004
Mid-Gamma	0.0009	0.0081	0.0012	0.0014	0.0029	0.0035

Table 4.4 The touching of the cube wood piece with rough surface stimulus of all subjects

EEG Band	Subject				$\bar{x}$	S.D.
	$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_3$	$\bar{x}_4$		
Delta	0.0038	0.1199	0.0054	0.0174	0.0366	0.0558
Theta	0.0024	0.0193	0.0044	0.0061	0.0080	0.0076
Low-Alpha	0.0026	0.0049	0.0017	0.0022	0.0029	0.0014
High-Alpha	0.0266	0.0042	0.0049	0.0037	0.0098	0.0112
Low-Beta	0.0016	0.0029	0.0017	0.0026	0.0022	0.0007
High-Beta	0.0018	0.0015	0.0020	0.0030	0.0021	0.0007
Low-Gamma	0.0013	0.0008	0.0017	0.0016	0.0013	0.0004
Mid-Gamma	0.0009	0.0081	0.0012	0.0014	0.0029	0.0035

Table 4.1 showed the four subjects normal voltage EEG, Mean and Standard Deviation values of the touching of the smooth surface gypsum board brain signals. With the result of the table, there were show the Mean of the group of four subjects. They had the significant high values in Delta at 0.1169 in voltage with 0.0616 S.D. value, Mid-Gamma in 0.0536 with 0.0698 S.D. value and Theta in 0.0384 with 0.0418 S.D. value and slightly decreased in Low-Alpha, High-Beta, High-Alpha, Low-Beta and Low-Gamma by sequence like figure 4.4 with blue bar graphs. These results showed the subjects get high

value in Delta band that showed them more unconscious, Mid-Gamma showed them get higher mental activity and Theta showed them get more creative. Some people more use motor function and more creative than other people that showed by the high or low S.D. values of each waves. If S.D. values so high, it could show each subject use more brain when touching the stimulus.

Table 4.2 showed Mean and Standard Deviation values of the touching of the rough surface tile brain signals of four people that there were the significant high in Delta at 0.1122 voltage with 0.0894 of S.D, Mid-Gamma wave in 0.0332 by 0.0379 value of S.D and Theta in 0.0160 S.D value with 0.0231 voltage and slightly decreased in Low-Alpha, High-Alpha, High-Beta, Low-Beta and Low-Gamma by sequence like table 4.2. By each value showed the subjects get more unconscious, creative and higher mental activity. With this situation, the experimental showed the value of Delta, Theta, Low-Alpha, High-Alpha, High-Beta, Low-Gamma and Mid-Gamma lower than the Mean and Standard Deviation values of the touching of the smooth surface gypsum board. It has only Low-Beta value higher than the other like figure 4.4. This situation showed the people are alertness and agitation than the above touching. By the value of Delta, it showed the highest values in this experimental. People usually stayed on the mediation state and the next value is Mid-Gamma, it could show the people must use their muscle when touching.

Table 4.3 showed the Mean and Standard Deviation values of the touching of the sphere rubber ball brain signals. In the figure 4.5, there were the significant high in Delta, High-Alpha, Theta and slightly decreased in Mid-Gamma Low-Alpha, Low-Beta, High-Beta, and Low-Gamma by sequence like table 4.3. The voltage value of Delta was 0.0366 by 0.0558 S.D. The voltage value of High-Alpha was 0.0098 by 0.0112 S.D. The voltage value of Theta was 0.0080 by 0.0076 S.D. These results showed the subjects get more unconscious, tranquil but sometime get more conscious and they usually recall something from the brain. In this state, we knew that when people touching on the shape objects they must meditate and use the muscles. When we focus on the S.D. value of Delta wave, each people must stay in the state of meditation by different.

And the last one, Table 4.4 showed meaning full of the brain signal by the Mean and Standard Deviation values of the touching of the cube wood piece with rough surface brain signals. In the figure 4.5, there were the significant high values in Delta (0.0692 voltage with 0.0899 S.D.), Theta (0.0126 voltage with 0.0070 S.D.) and High-Alpha (0.0076 voltage with 0.0045 S.D.) and slightly decreased in Low-Alpha, Low-Beta, High-Beta, Low-Gamma and High-Gamma that showed in table 4.4. These results showed the subjects get more unconscious, higher mental activity and relaxed. But there was so very high value of S.D. in Delta wave which showed the different of the meditation state of each people. In the figure 4.5 the graph showed the comparison of the brain wave signals of the sphere object and cube object. The result showed values of cube object higher that sphere object in Delta, Theta, Low-Alpha, Low-Beta and Low-Gamma. But lower in High Alpha and Mid-Gamma. With this case, the result performed about the people usually use more brain when touching the edge objects than the smooth objects.

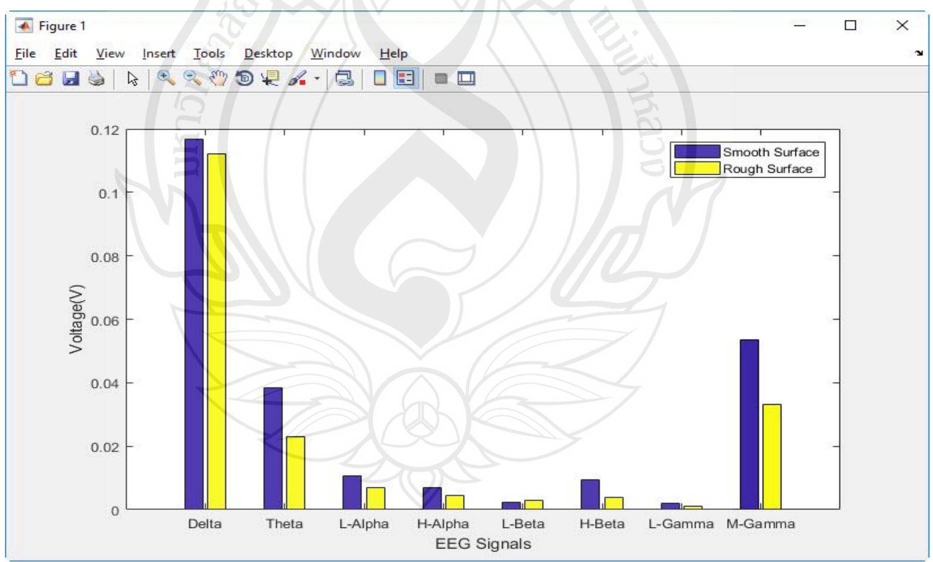


Figure 4.4 The different of graphs of Mean in the touching of the smooth surface gypsum board and the rough surface tile

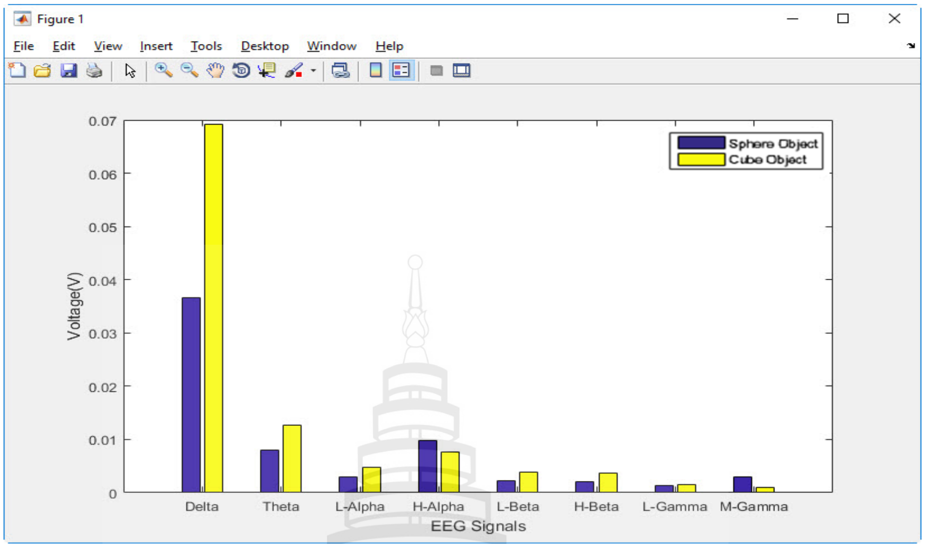
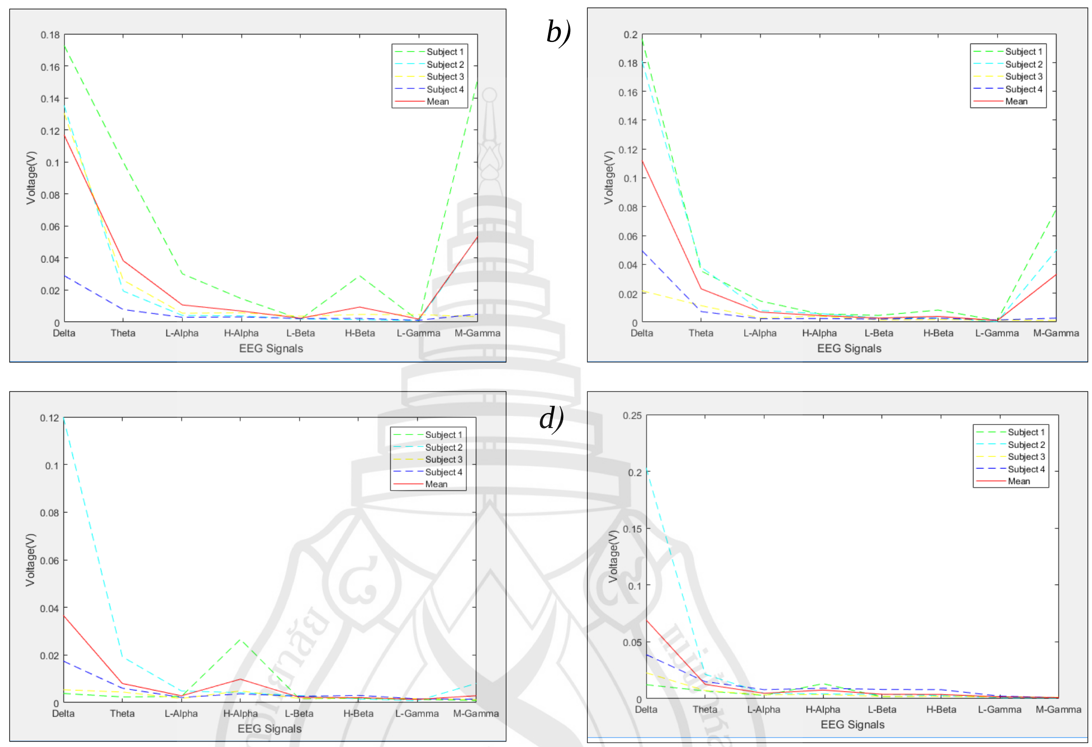


Figure 4.5 The different of graphs of Mean in the touching of the sphere rubber ball and the cube wood piece with rough surface

The next result, we showed the mean values of each wave, separate by people and represent by bar graph in figure.4.6 (a). The graph showed about the sample group get the highest values in Delta wave and slight down in Mid-Gamma and Theta. The next graph was the Mean values of several waves of touching on rough surface of each subject that represented by bar graph in figure.4.6 (b). This graph showed three highest brain waves of the subject are Delta, Theta and Mid-Gamma like figure.4.6 (a). With this simple analysis, the result showed the important brain wave that interact with the touching behavior on the surface are Delta, Theta and Mid-Gamma.

The next experiment, we showed the result of the brain signals analysis. We separate the wave type and people base on the sphere and cube shape stimulus that show in figure.4.6 (c) and figure.4.6 by sequence. The results of the figure.4.6 (c) showed the top 3 highest wave values that are Delta, Theta and High-Alpha. There were the important waves for the touching on the sphere object. In the same way, the result of the touching on the cube object effect to three waves with highest values are Delta, Theta and High-Alpha. With this analysis, the results showed the important brain waves which interact to the touching behavior on the shape are Delta, Theta and High-Alpha but some people got more serious or less down when touching on the objects.

a) b) c) d)



Note (a) The different of graphs of Mean in the touching of the smooth surface of each subject. (b) The different of graphs of Mean in the touching of the rough surface of each subject. (c) The different of graphs of Mean in the touching of the sphere shape of each subject. (d) The different of graphs of Mean in the touching of the cube shape of each subject

Figure 4.6 Experimental Results

The conclusion of this experiment was explained in chapter 5. This experiment discussed on the important wave for touching learning of normal people.

4.2 The EEG Brain Signal Patterns for Touching Learning of Blinded People on Tactile Pictures by the Inexpensive Device

This method was the most important. This method was collected and analyze the EEG dataset of the human behavior when touching tactile pictures and describe the type of them. Researcher recorded the EEG dataset via NeuroSky MindWave device that connect to the computer by Bluetooth port. The OpenVIBE program was select to support the data gathering method. Five normal volunteers who has aging between nineteen and twenty-four were selected and ten blinded volunteers with deference type blinded were selected by following table 4.5 and table 4.6.

Table 4.5 Normal people list

No.	Name	Sex	Age
1	Normal Volunteer 1	Female	20
2	Normal Volunteer 2	Female	21
3	Normal Volunteer 3	Female	24
4	Normal Volunteer 4	Female	24
5	Normal Volunteer 5	Male	19

Table 4.6 Blinded people list

No.	Name	Sex	Age	Blinded Type
1	Blinded Volunteer 1	Male	18	Low vision
2	Blinded Volunteer 2	Male	16	Low vision
3	Blinded Volunteer 3	Male	15	One-side blinded
4	Blinded Volunteer 4	Female	17	Low vision
5	Blinded Volunteer 5	Female	17	Low vision

Table 4.6 (continued)

No.	Name	Sex	Age	Blinded Type
6	Blinded Volunteer 6	Female	23	Two-side blinded
7	Blinded Volunteer 7	Female	22	Two-side blinded
8	Blinded Volunteer 8	Female	18	Two-side blinded
9	Blinded Volunteer 9	Male	16	Low vision
10	Blinded Volunteer 10	Female	16	Low vision

The data gathering method used OpenVIBE to collect the dataset from two types of people that mention in table 4.5 and 4.6. The dataset was recorded by five hundred and twelve sampling rates (five hundred and twelve wave cycle in one second) like figure 4.7.

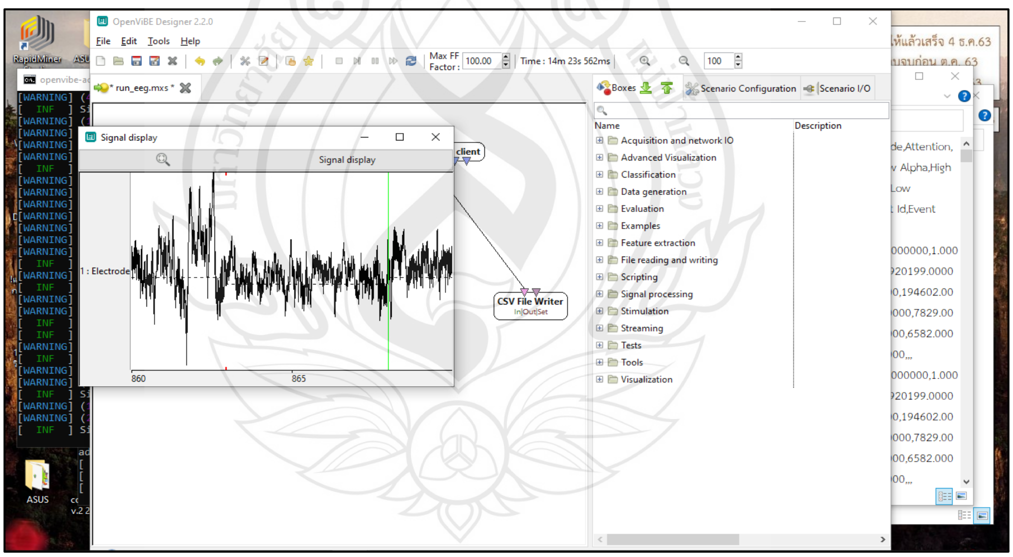


Figure 4.7 The example of EEG data recording via OpenVIBE software

The EEG data from OpenVIBE used Thinkgear library automatically record only RAW data from electrode. The data showed name of electrode in Excel CSV file. With the experiment 2, researcher recorded the important data for one hundred and eighty second and separated the data with forty second for each picture by MATLAB following the table 4.7. From figure 4.8, datasets were recorded by algorithm that showed in figure 4.9. Eight four-byte floating point values recorded by Thinkgear library of NeuroSky inc. are separate by the algorithm. Data from electrode were recorded that show in figure 4.8.

Table 4.7 Picture time list

No.	Pictures Name	Time (s)	Touching Time (s)
1	Pictures 1	0 – 40	20 – 40
2	Pictures 2	40 – 80	60 – 80
3	Pictures 3	80 – 120	100 – 120
4	Pictures 4	120 - 160	140 – 160

	A	B	C	D	E	F
1	Time:512Hz	Epoch	Electrode	Event Id	Event Date	Event Duration
2	0	0	68			
3	0.001953125	0	74			
4	0.00390625	0	72			
5	0.005859375	0	64			
6	0.0078125	0	58			
7	0.009765625	0	49			
8	0.01171875	0	37			
9	0.013671875	0	37			
10	0.015625	0	57			
11	0.017578125	0	68			
12	0.01953125	0	58			
13	0.021484375	0	44			
14	0.0234375	0	39			
15	0.025390625	0	52			
16	0.02734375	0	55			
17	0.029296875	0	50			
18	0.03125	0	41			
19	0.033203125	0	33			
20	0.03515625	0	29			
21	0.037109375	0	27			
22	0.0390625	0	35			
23	0.041015625	0	41			
24	0.04296875	0	38			
25	0.044921875	0	34			
26	0.046875	0	38			

	A	B	C	D	E
97254	189.9453	189	-28		
97255	189.9473	189	-107		
97256	189.9492	189	-226		
97257	189.9512	189	-225		
97258	189.9531	189	-91		
97259	189.9551	189	-2		
97260	189.957	189	37		
97261	189.959	189	92		
97262	189.9609	189	135		
97263	189.9629	189	91		
97264	189.9648	189	6		
97265	189.9668	189	-129		
97266	189.9688	189	-245		
97267	189.9707	189	-236		
97268	189.9727	189	-141		
97269	189.9746	189	-45		
97270	189.9766	189	37		
97271	189.9785	189	97		
97272	189.9805	189	145		
97273	189.9824	189	84		
97274	189.9844	189	-20		
97275	189.9863	189	-61		
97276	189.9883	189	-86		
97277	189.9902	189	-142		
97278	189.9922	189	-129		
97279	189.9941	189	-115		

Figure 4.8 Example of EEG data in Excel CSV File

After recorded the dataset from NeuroSky MindWave device via OpenVIBE, researcher import the dataset from CSV file in to MATLAB. Then, researcher created the matrix variable for analyze the data with Fast Fourier Transform (FFT) algorithm by the following figure 4.9. Researcher selected the Fast Fourier Transform because the result can show the amplitude of each wave which be important for find the touching pattern. Example of overall results showed in figure 4.10 to figure 4.25

```
x=transpose(dataset);        //matrix transpose
fs=512;                      //sampling rate
t=0:1/fs:1;                  //time vector of 1 second
nfft=length(dataset);        //length of FFT
X=fft(x,nfft);               //FFT function
X=X(1:nfft/2);               //FFT is symmetric, throw away second half
mx=abs(X);                   //Take the magnitude of FFT of x
f=(0:nfft/2-1)*fs/nfft;      //Evenly spaced frequency vector
```

Figure 4.9 Fast Fourier Transform (FFT) Algorithm in MATLAB

From figure 4.9, dataset is the EEG dataset. x is transpose dataset. fs is frequency sampling rate per second. t is time per one wave. nfft is length of FFT. X is FFT dataset. mx is even FFT dataset. F is evenly spaced frequency vector.

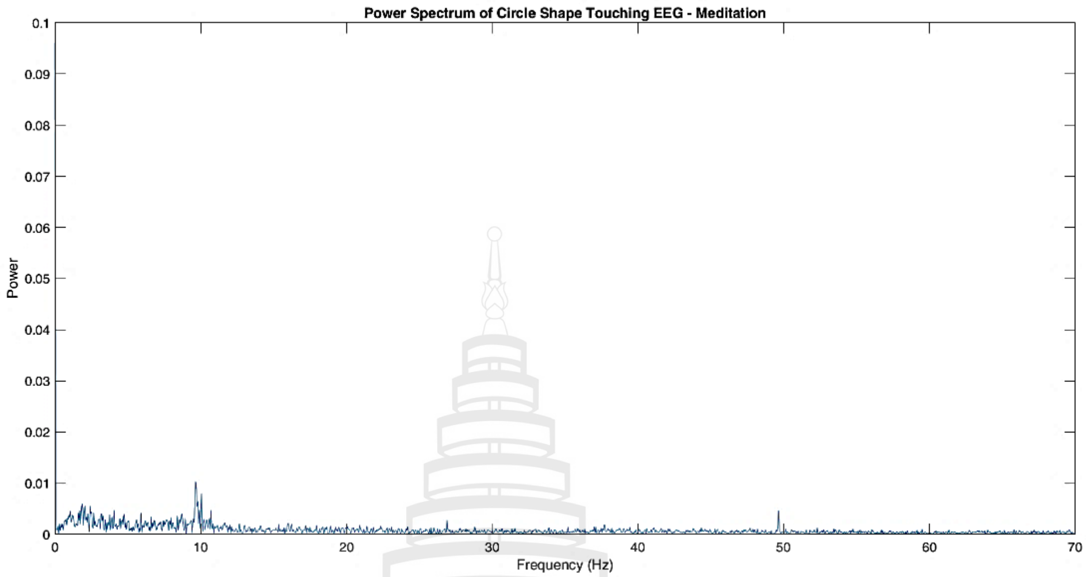


Figure 4.10 Circle shape meditation EEG signal of normal volunteer1

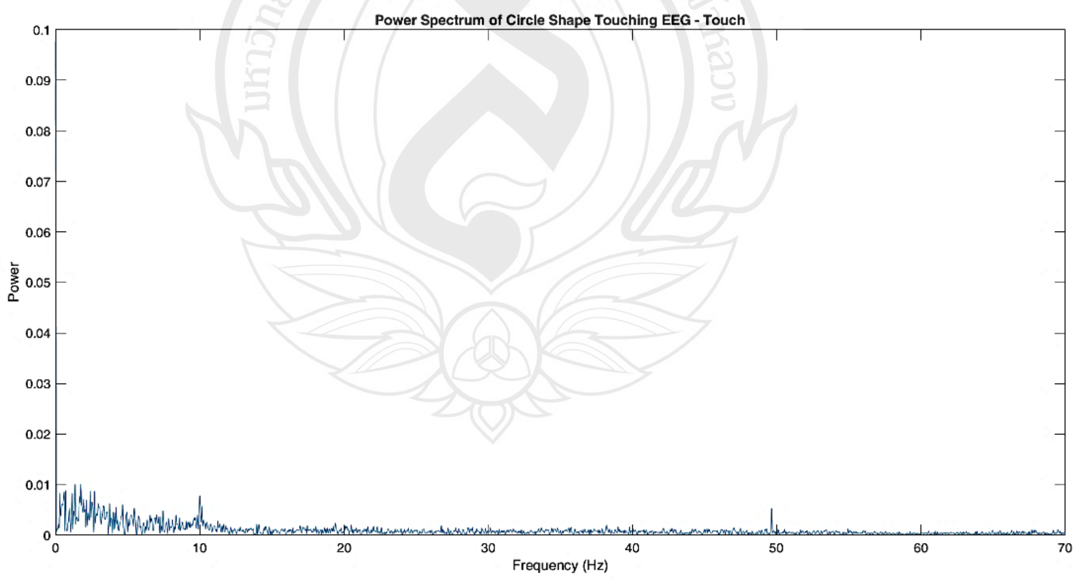


Figure 4.11 Circle shape touching EEG signal of normal volunteer1

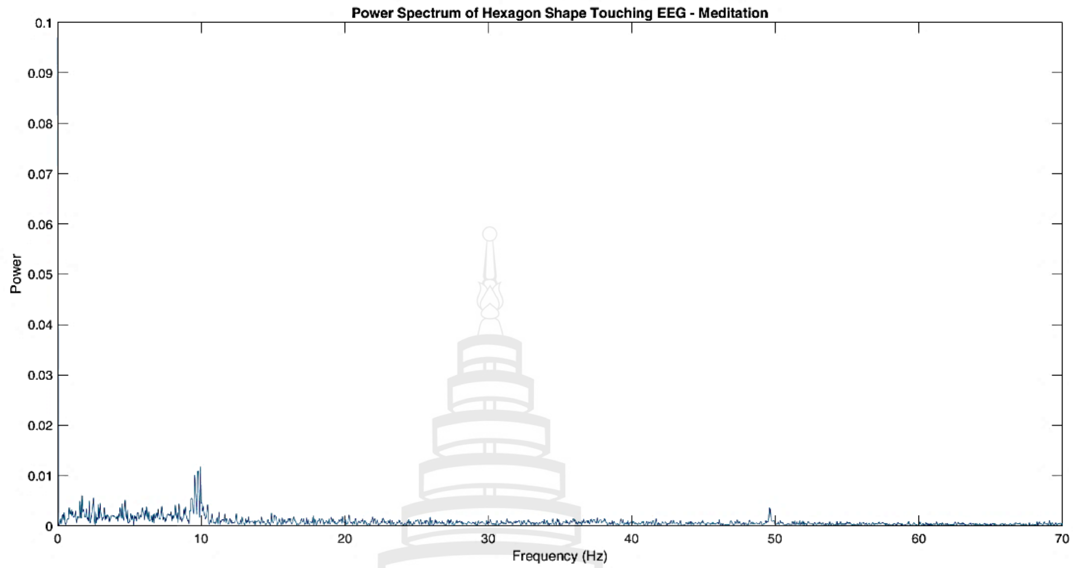


Figure 4.12 Hexagon shape meditation EEG signal of normal volunteer1

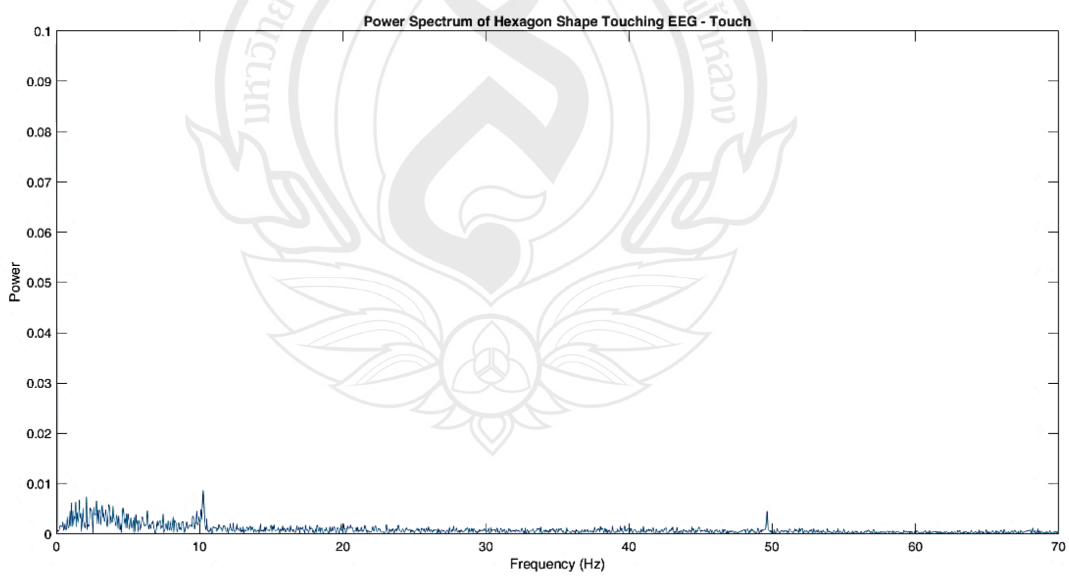


Figure 4.13 Hexagon shape touching EEG signal of normal volunteer1

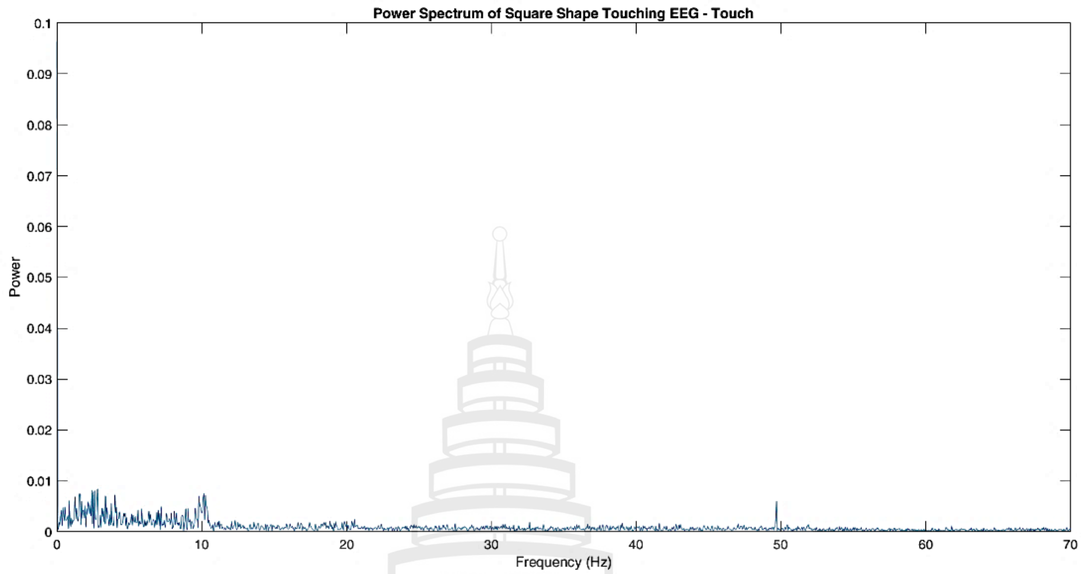


Figure 4.14 Square shape meditation EEG signal of normal volunteer1

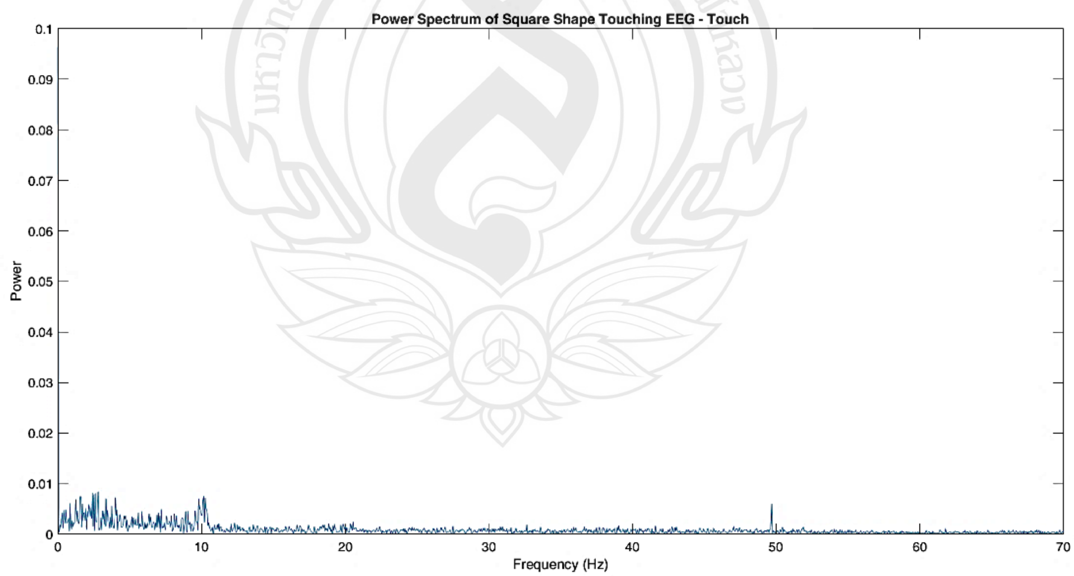


Figure 4.15 Square shape touching EEG signal of normal volunteer1

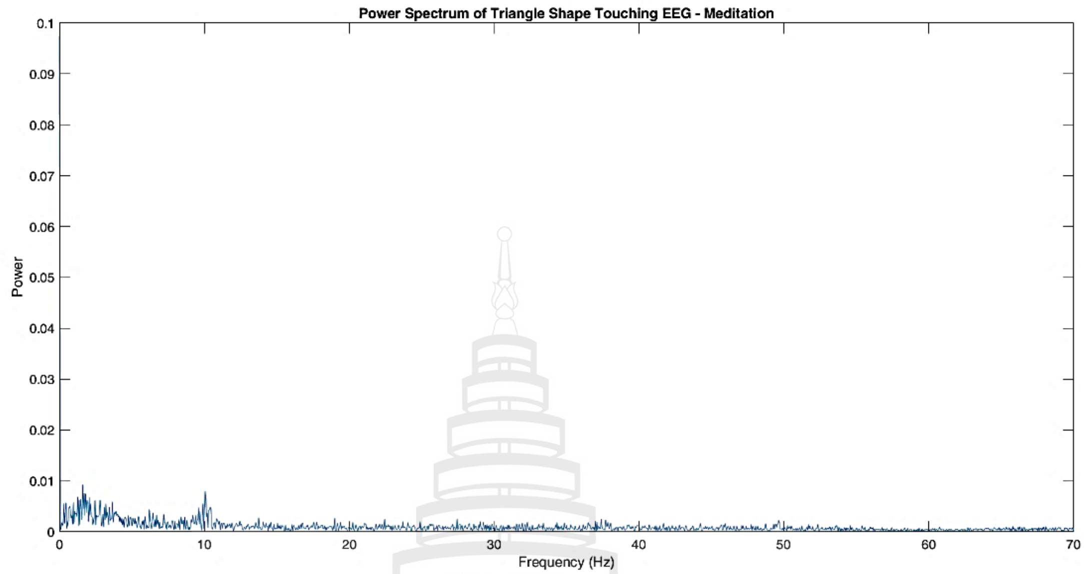


Figure 4.16 Triangle shape meditation EEG signal of normal volunteer1

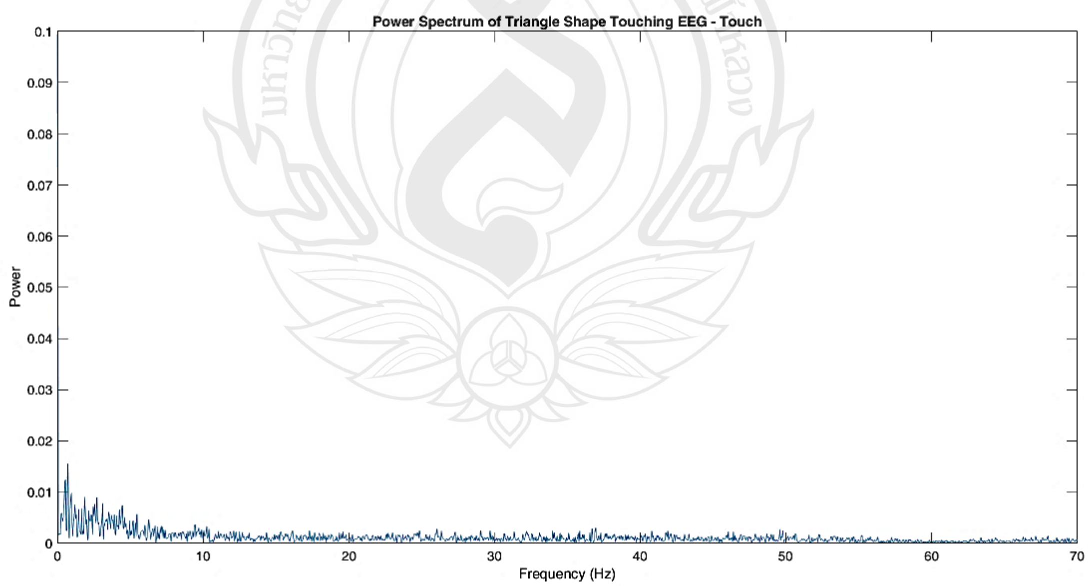


Figure 4.17 Triangle shape touching EEG signal of normal volunteer1

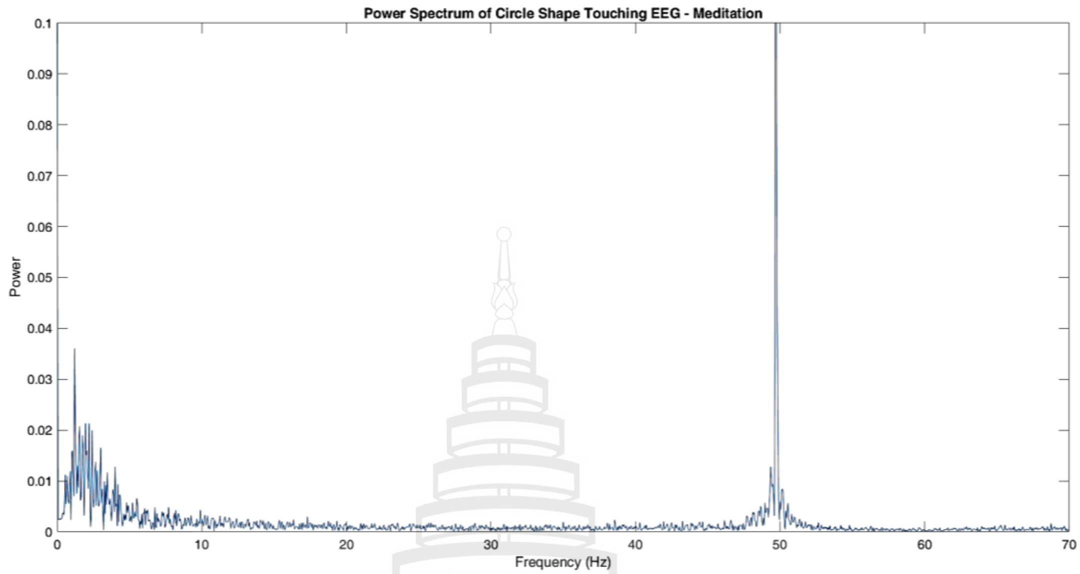


Figure 4.18 Circle shape meditation EEG signal of blinded volunteer5

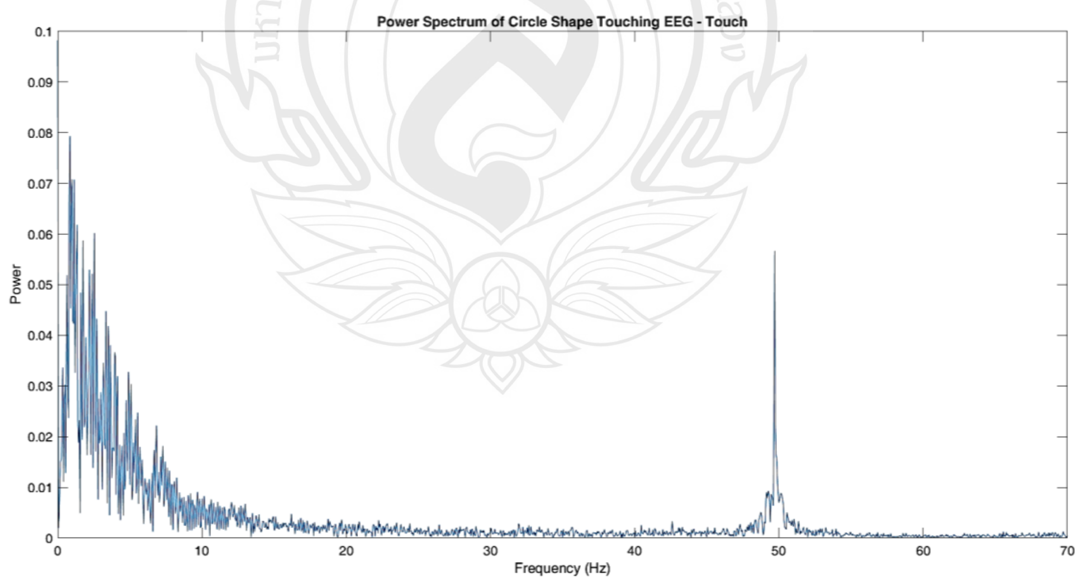


Figure 4.19 Circle shape touching EEG signal of blinded volunteer5

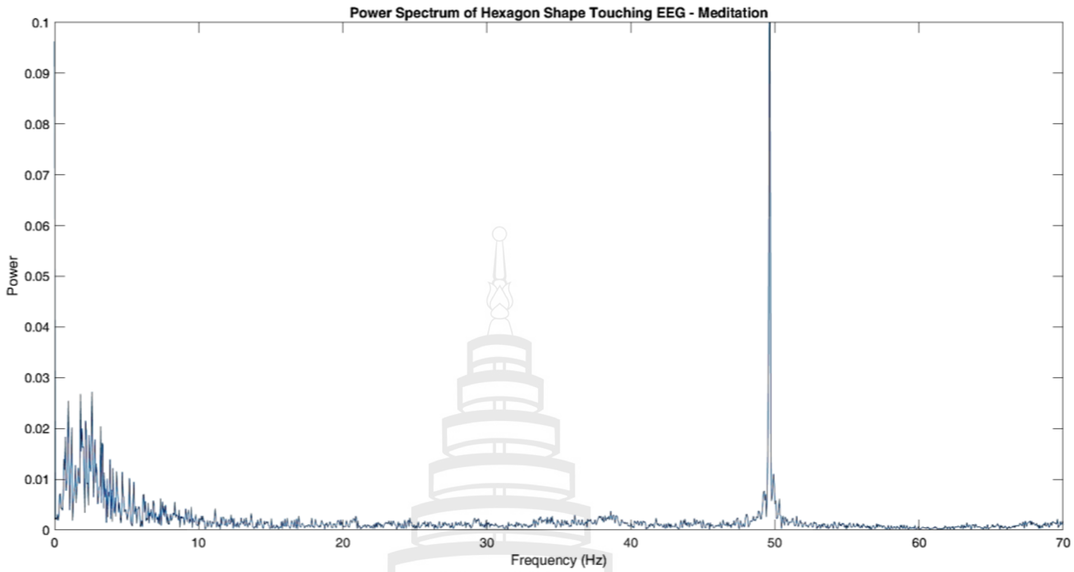


Figure 4.20 Hexagon shape meditation EEG signal of blinded volunteer5

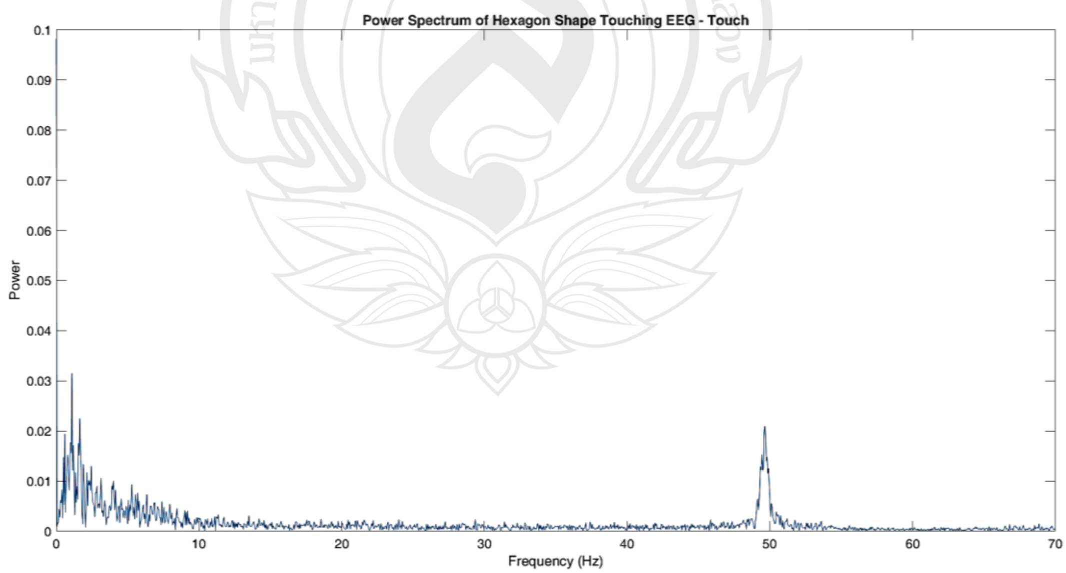


Figure 4.21 Hexagon shape touching EEG signal of blinded volunteer5

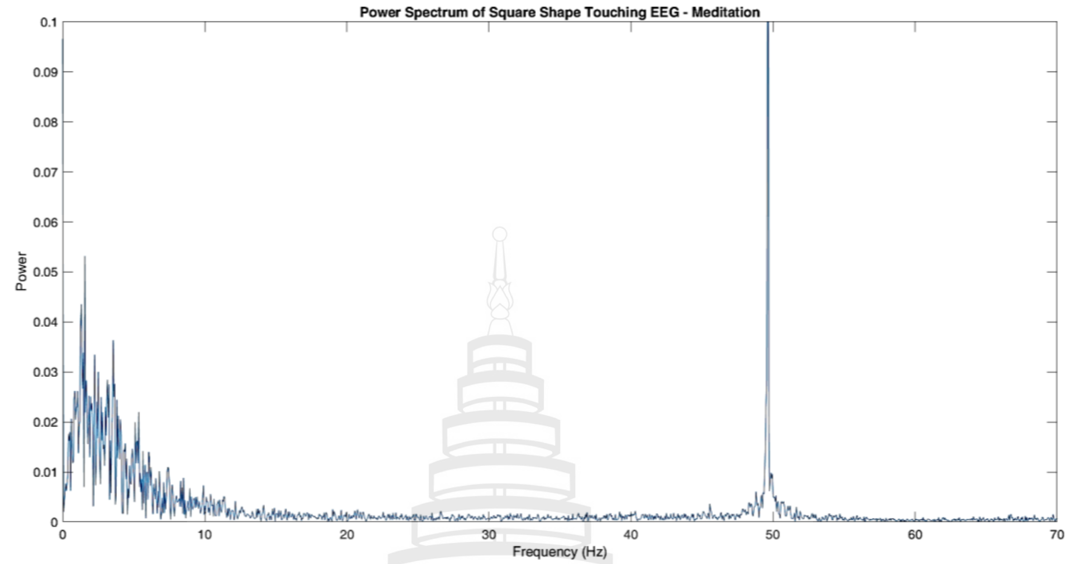


Figure 4.22 Square shape meditation EEG signal of blinded volunteer5

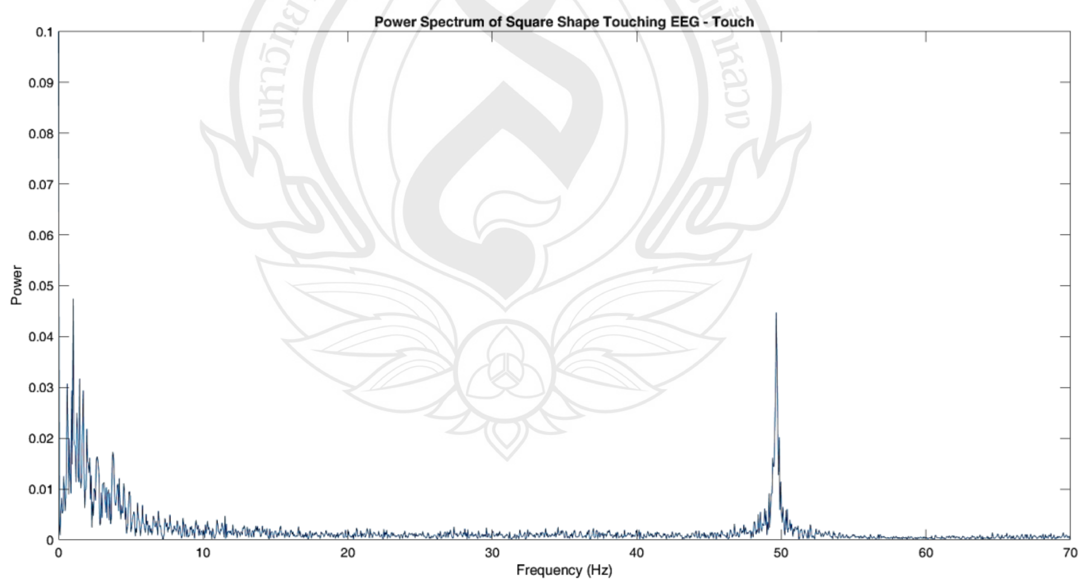


Figure 4.23 Square shape touching EEG signal of blinded volunteer5

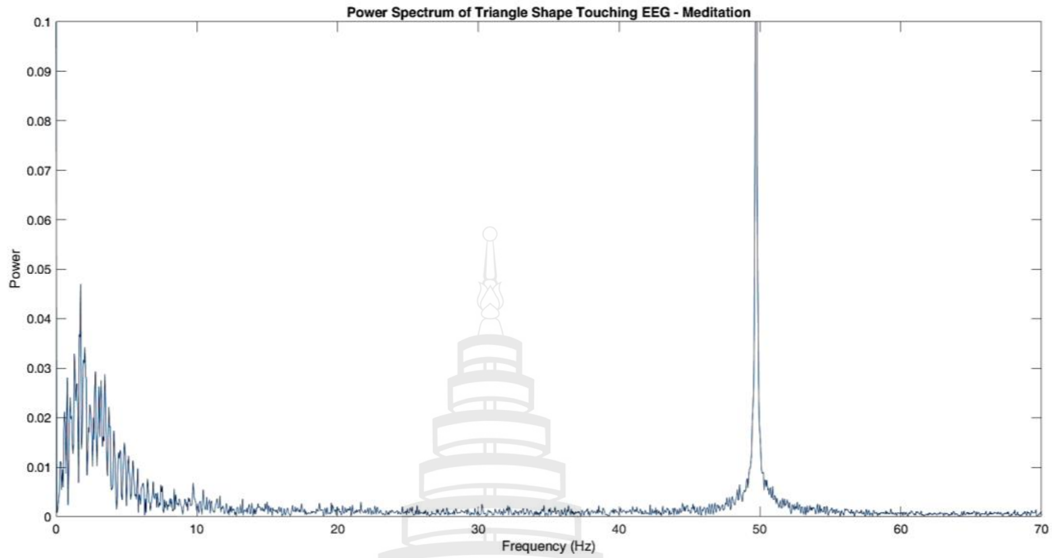


Figure 4.24 Triangle shape meditation EEG signal of blinded volunteer5

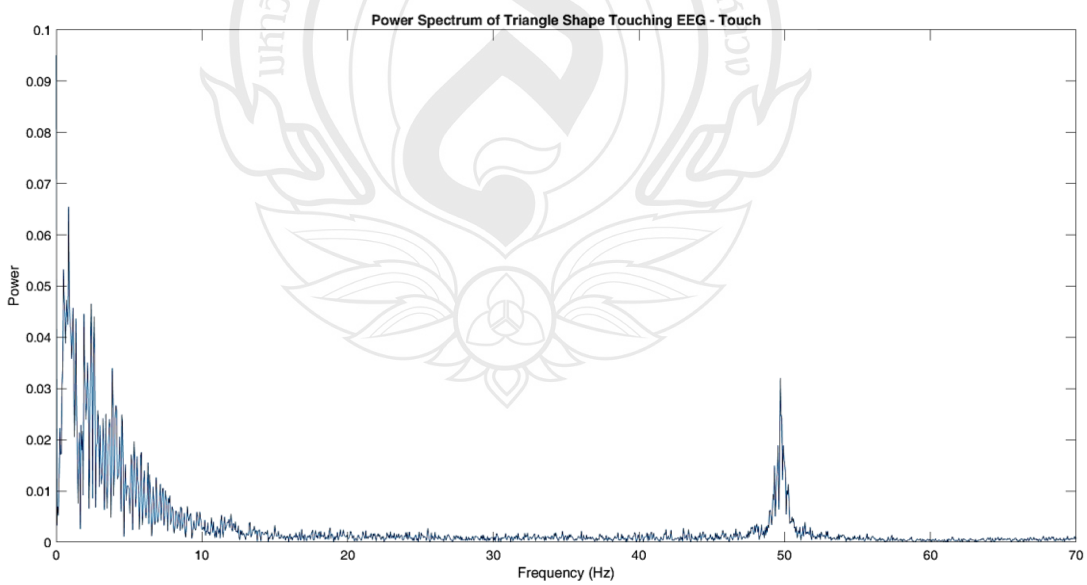


Figure 4.25 Triangle shape touching EEG signal of blinded volunteer5

After analyze the data, researcher calculated area under curve (AUC) by using TRAPZ command in MATLAB by figure 4.26.

```
s_range=0;                      //start frequency range (Hz)
e_range=3;                      //stop frequency range (Hz)
x=f(f>s_range&f<=e_range);      //ranged evenly spaced frequency vector dataset
y=mx(f>s_range&f<=e_range);     // ranged magnitude of FFT of x
area = trapz(x,y);              //Area Under Curve (AUC) of ranged dataset
```

Figure 4.26 Area Under Curve (AUC) Algorithm in MATLAB

Then, all Area Under Curve (AUC) values show the result in table 4.8. After the result, researcher compared AUC values to the other in several dimension, such as, normal people to normal people, blinded people to blinded people and normal people to blinded people. The result of comparing is separated by shape of tactile pictures.

4.2.1 EEG Power of Circle Shape Tactile Picture Touching Experiment

For this section, all results of circle shape tactile picture touching experiment showed in next table 4.8.

Table 4.8 Meditation and touching EEG power of circle shape tactile picture touching

Meditation								
Normal People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
N1	0.007884	0.007539	0.003980	0.007219	0.004335	0.009324	0.006112	0.005836
N2	0.004366	0.009342	0.008229	0.012632	0.008074	0.014862	0.008993	0.009133
N3	0.058283	0.025031	0.025031	0.008475	0.006425	0.012592	0.007490	0.023735

Table 4.8 (continued)

Meditation								
Normal People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
N4	0.011300	0.009085	0.003141	0.004061	0.005623	0.013605	0.009834	0.014390
N5	0.013258	0.009690	0.003192	0.003630	0.004941	0.011323	0.008955	0.018788
Blinded People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
B1	0.006832	0.006968	0.001922	0.003370	0.004152	0.010653	0.006923	0.008868
B2	0.042670	0.022793	0.004914	0.007420	0.009194	0.015888	0.008945	0.037527
B3	0.018434	0.021911	0.005763	0.009062	0.010001	0.022583	0.015261	0.016264
B4	0.016079	0.012776	0.003746	0.004384	0.006368	0.016390	0.012166	0.013700
B5	0.029274	0.015580	0.004221	0.005467	0.006166	0.011526	0.007299	0.033585
B6	0.003420	0.006143	0.004302	0.005611	0.006710	0.014530	0.008784	0.019362
B7	0.016127	0.009774	0.003064	0.003548	0.004221	0.010734	0.007295	0.007629
B8	0.004789	0.007100	0.003185	0.004086	0.006532	0.016391	0.012413	0.028105
B9	0.004301	0.004878	0.002782	0.003968	0.004005	0.009236	0.006492	0.037943
B10	0.007020	0.011022	0.005784	0.004980	0.006342	0.013612	0.007972	0.024920
Touching								
Normal People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
N1	0.013235	0.010621	0.003596	0.006148	0.004312	0.010292	0.007419	0.006418
N2	0.005182	0.007674	0.004125	0.009011	0.006470	0.013361	0.009138	0.009304
N3	0.049293	0.030280	0.030280	0.008251	0.007142	0.016207	0.010726	0.012744
N4	0.012933	0.009143	0.002757	0.003308	0.004957	0.011603	0.008034	0.013582
N5	0.012223	0.010193	0.003502	0.003720	0.005408	0.013698	0.010129	0.014850
Blinded People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
B1	0.052796	0.044610	0.005355	0.006867	0.007063	0.015025	0.011277	0.011919

Table 4.8 (continued)

Touching								
Blinded People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
B2	0.008826	0.011121	0.004372	0.004421	0.005612	0.013437	0.011197	0.031659
B3	0.021420	0.022579	0.006532	0.010851	0.011640	0.026166	0.018901	0.019075
B4	0.019216	0.012051	0.003543	0.004584	0.006804	0.018609	0.015818	0.015368
B5	0.099099	0.064930	0.015634	0.013884	0.014880	0.019330	0.009585	0.023560
B6	0.003562	0.006554	0.003521	0.004566	0.005481	0.013572	0.008222	0.013696
B7	0.011253	0.012522	0.003397	0.003402	0.004693	0.011920	0.009833	0.010483
B8	0.007130	0.008076	0.003508	0.004236	0.005880	0.016956	0.015818	0.033228
B9	0.003960	0.005180	0.002639	0.003989	0.004537	0.009569	0.006776	0.018262
B10	0.007516	0.011298	0.006973	0.004944	0.006383	0.013205	0.007264	0.026966

From table 4.8, this table showed eight waves power by EEG voltage calculation equation in chapter 3. The table compared the EEG wave powers of normal people and blinded people when touch on circle shape tactile picture that has the picture position in center point. The unit of the power is Volts-squared per Hz (V^2/Hz).

Next, the table 4.9 to 4.16 showed mean and standard deviation values of EEG brain signal power of normal and blinded people when touch on the circle shape tactile picture.

Table 4.9 Mean values of meditation EEG brain signal power of normal people when touching on circle shape tactile picture

Mean values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.019018	0.012137	0.008715	0.007203	0.005880	0.012341	0.008277	0.014376

Table 4.10 Standard deviation values of meditation EEG brain signal power of normal people when touching on circle shape tactile picture

Standard deviation values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.022210	0.007255	0.009360	0.003665	0.001453	0.002130	0.001475	0.007202

Table 4.11 Mean values of meditation EEG brain signal power of blinded people when touching on circle shape tactile picture

Mean values of EEG brain signal of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.019018	0.012137	0.008715	0.007203	0.005880	0.012341	0.008277	0.014376

Table 4.12 Standard deviation values of meditation EEG brain signal power of blinded people when touching on circle shape tactile picture

Standard deviation values of EEG brain signal of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.022210	0.007255	0.009360	0.003665	0.001453	0.002130	0.001475	0.007202

Table 4.13 Mean values of touching EEG brain signal power of normal people when touching on circle shape tactile picture

Mean values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.018573	0.013582	0.008852	0.006088	0.005658	0.013032	0.009089	0.011380

Table 4.14 Standard deviation values of touching EEG brain signal power of normal people when touching on circle shape tactile picture

Standard deviation values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.017490	0.009403	0.011989	0.002577	0.001143	0.002246	0.001384	0.003453

Table 4.15 Mean values of touching EEG brain signal power of blinded people when touching on circle shape tactile picture

Mean values of EEG brain signal of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.023478	0.019892	0.005547	0.006174	0.007297	0.015779	0.011469	0.020422

Table 4.16 Standard deviation values of touching EEG brain signal power of blinded people when touching on circle shape tactile picture

Standard deviation values of EEG brain signal of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.030303	0.019571	0.003823	0.003459	0.003334	0.004725	0.004078	0.008105

4.2.2 EEG Power of Hexagon Shape Tactile Picture Touching Experiment

In this section, all results of hexagon shape tactile picture touching experiment showed in next table.

Table 4.17 Meditation and touching EEG power of hexagon shape tactile picture touching

Meditation								
Normal People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
N1	0.006152	0.007625	0.004060	0.008014	0.004396	0.009366	0.006869	0.005796
N2	0.004548	0.008669	0.007459	0.012340	0.006749	0.013855	0.008159	0.008757
N3	0.011451	0.010859	0.010839	0.007428	0.004599	0.010198	0.007043	0.018553
N4	0.009044	0.010758	0.003223	0.003652	0.005512	0.013738	0.009890	0.017706
N5	0.011300	0.009085	0.003141	0.004061	0.005623	0.013605	0.009834	0.014390
Blinded People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
B1	0.006769	0.007101	0.002638	0.003112	0.004161	0.010819	0.006965	0.007741
B2	0.026836	0.027141	0.013119	0.014585	0.017245	0.029139	0.017330	0.048573
B3	0.008347	0.010634	0.005564	0.013873	0.008014	0.016078	0.009665	0.014730
B4	0.014286	0.010257	0.002867	0.003664	0.006400	0.014690	0.011741	0.013363
B5	0.032444	0.020801	0.005340	0.005079	0.005669	0.013367	0.013902	0.029866

Table 4.17 (continued)

Meditation								
Blinded People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
B6	0.004516	0.005777	0.003650	0.004701	0.005865	0.013899	0.008528	0.013728
B7	0.014077	0.010275	0.002299	0.003300	0.004487	0.010314	0.007094	0.008336
B8	0.004182	0.008547	0.003248	0.004735	0.006504	0.014767	0.011796	0.018814
B9	0.005692	0.005535	0.002215	0.003672	0.003968	0.008730	0.006558	0.033907
B10	0.004507	0.008184	0.004358	0.004745	0.006183	0.013131	0.007743	0.033396
Touching								
Normal People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
N1	0.008237	0.009947	0.003167	0.005642	0.004435	0.009940	0.006485	0.006337
N2	0.006762	0.009364	0.004579	0.007848	0.005886	0.013594	0.009364	0.008790
N3	0.040291	0.023300	0.023300	0.006352	0.005973	0.012528	0.008380	0.020947
N4	0.011334	0.007205	0.002416	0.002947	0.004237	0.010578	0.006967	0.015203
N5	0.012933	0.009143	0.002757	0.003308	0.004957	0.011603	0.008034	0.013582
Blinded People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
B1	0.066440	0.033691	0.007557	0.004267	0.006618	0.014223	0.008433	0.008530
B2	0.010280	0.011261	0.004095	0.004734	0.005415	0.014145	0.008522	0.022836
B3	0.015764	0.016894	0.005150	0.006712	0.009220	0.019501	0.014688	0.018289
B4	0.017081	0.012142	0.003446	0.003366	0.006064	0.013989	0.010967	0.011406
B5	0.027138	0.017452	0.005293	0.004975	0.005611	0.012588	0.007444	0.020066
B6	0.005993	0.007249	0.003649	0.004814	0.005418	0.013624	0.009007	0.013764
B7	0.012778	0.009996	0.003284	0.003851	0.004855	0.012257	0.010848	0.011892
B8	0.008656	0.010680	0.003484	0.003248	0.005233	0.013813	0.010398	0.017053
B9	0.005757	0.005908	0.002655	0.003799	0.004541	0.009716	0.007694	0.018887
B10	0.004277	0.008315	0.005292	0.004366	0.006264	0.013290	0.007634	0.025712

From table 4.17, this table showed eight waves power by EEG voltage calculation equation in chapter 3. The table compared the EEG wave powers of normal people and blinded people when touch on hexagon shape tactile picture that has the picture position in center point. The unit of the power is Volts-squared per Hz (V^2/Hz).

Next, the table 4.18 to 4.25 showed mean and standard deviation values of EEG brain signal power of normal and blinded people when touch on the hexagon shape tactile picture.

Table 4.18 Mean values of meditation EEG brain signal power of normal people when touching on hexagon shape tactile picture

Mean values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.008499	0.009399	0.005744	0.007099	0.005376	0.012152	0.008359	0.013040

Table 4.19 Standard deviation values of meditation EEG brain signal power of normal people when touching on hexagon shape tactile picture

Standard deviation values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.003081	0.001393	0.003349	0.003519	0.000939	0.002186	0.001459	0.005586

Table 4.20 Mean values of meditation EEG brain signal power of blinded people when touching on hexagon shape tactile picture

Mean values of EEG brain signal of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.012166	0.011425	0.004530	0.006147	0.006850	0.014493	0.010132	0.022245

Table 4.21 Standard deviation values of meditation EEG brain signal power of blinded people when touching on hexagon shape tactile picture

Standard deviation values of EEG brain signal of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.010006	0.007010	0.003243	0.004316	0.003854	0.005625	0.003526	0.013479

Table 4.22 Mean values of touching EEG brain signal power of normal people when touching on hexagon shape tactile picture

Mean values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.015911	0.011792	0.007244	0.005219	0.005098	0.011649	0.007846	0.012972

Table 4.23 Standard deviation values of touching EEG brain signal power of normal people when touching on hexagon shape tactile picture

Standard deviation values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.013846	0.006515	0.009013	0.002073	0.000804	0.001468	0.001146	0.005711

Table 4.24 Mean values of touching EEG brain signal power of blinded people when touching on hexagon shape tactile picture

Mean values of EEG brain signal of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.017416	0.013359	0.004391	0.004413	0.005924	0.013715	0.009564	0.016844

Table 4.25 Standard deviation values of touching EEG brain signal power of blinded people when touching on hexagon shape tactile picture

Standard deviation values of EEG brain signal of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.018526	0.008064	0.001446	0.001002	0.001318	0.002440	0.002235	0.005415

4.2.3 EEG Power of Square Shape Tactile Picture Touching Experiment

In this section, all results of square shape tactile picture touching experiment showed in next table.

Table 4.26 Meditation and touching EEG power of square shape tactile picture touching

Name	Delta	Theta	Low Alpha	High Alpha	Low Beta	High Beta	Low Gamma	High Gamma
Meditation								
Normal People								
N1	0.005173	0.008012	0.003687	0.007513	0.004443	0.009783	0.005974	0.005433
N2	0.008718	0.011957	0.009193	0.008928	0.006580	0.013243	0.006893	0.008051
N3	0.046901	0.036928	0.036928	0.013095	0.011857	0.021849	0.013315	0.021027
N4	0.013258	0.009690	0.003192	0.003630	0.004941	0.011323	0.008955	0.018788
N5	0.017650	0.012551	0.003479	0.004938	0.006525	0.015286	0.011533	0.016430
Blinded People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
B1	0.007888	0.007002	0.002320	0.003071	0.004622	0.009556	0.005498	0.006008
B2	0.011598	0.011157	0.003917	0.005390	0.006368	0.015231	0.012445	0.046822
B3	0.020483	0.018251	0.005927	0.011068	0.013086	0.026884	0.017238	0.021231
B4	0.017153	0.010254	0.002791	0.003872	0.005131	0.015321	0.011629	0.012951
B5	0.056401	0.044216	0.009135	0.009101	0.006880	0.012070	0.008469	0.033431
B6	0.007836	0.008171	0.003868	0.004844	0.006549	0.014329	0.007549	0.012634
B7	0.014846	0.012819	0.003219	0.003484	0.004794	0.010652	0.007715	0.007954
B8	0.003990	0.007391	0.003082	0.003462	0.006409	0.013468	0.010457	0.019446
B9	0.005773	0.006385	0.002046	0.004620	0.004536	0.010245	0.007103	0.031193
B10	0.008218	0.009765	0.008167	0.005280	0.007222	0.014667	0.008698	0.028369
Touching								
Normal People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
N1	0.010247	0.009702	0.003918	0.006441	0.004460	0.010015	0.006533	0.006519
N2	0.004089	0.007184	0.003923	0.008327	0.006550	0.013114	0.009407	0.008432
N3	0.095306	0.050881	0.050881	0.013588	0.013117	0.020459	0.011000	0.016790
N4	0.012223	0.010193	0.003502	0.003720	0.005408	0.013698	0.010129	0.014850
N5	0.008077	0.007164	0.002166	0.002952	0.004270	0.009717	0.006317	0.010428

Table 4.26 (continued)

Touching								
Blinded People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
B1	0.012043	0.010487	0.002937	0.003754	0.004656	0.011924	0.008790	0.008220
B2	0.007070	0.011577	0.004230	0.005084	0.005609	0.014014	0.008687	0.030351
B3	0.015928	0.017035	0.005287	0.008331	0.009449	0.020465	0.011675	0.011711
B4	0.020833	0.011464	0.003392	0.003640	0.006447	0.018245	0.014038	0.012826
B5	0.040549	0.021873	0.004022	0.005217	0.006625	0.012318	0.009461	0.025342
B6	0.004788	0.006241	0.003536	0.004664	0.005413	0.013259	0.007344	0.012194
B7	0.013155	0.012731	0.003822	0.003774	0.004905	0.011830	0.010465	0.011402
B8	0.006570	0.009465	0.003549	0.003535	0.005639	0.014137	0.011230	0.017204
B9	0.004753	0.005611	0.002204	0.003457	0.004376	0.009294	0.006901	0.024075
B10	0.006569	0.008459	0.006127	0.005622	0.006020	0.012563	0.007186	0.022657

From table 4.26, this table showed eight waves power by EEG voltage calculation equation in chapter 3. The table compared the EEG wave powers of normal people and blinded people when touch on square shape tactile picture that has the picture position in center point. The unit of the power is Volts-squared per Hz (V^2/Hz).

Next, the table 4.27 to 4.34 showed mean and standard deviation values of EEG brain signal power of normal and blinded people when touch on the square shape tactile picture.

Table 4.27 Mean values of meditation EEG brain signal power of normal people when touching on square shape tactile picture

Mean values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.018340	0.015828	0.011296	0.007621	0.006869	0.014297	0.009334	0.013946

Table 4.28 Standard deviation values of meditation EEG brain signal power of normal people when touching on square shape tactile picture

Standard deviation values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.016643	0.011934	0.014544	0.003702	0.002945	0.004700	0.003085	0.006837

Table 4.29 Mean values of meditation EEG brain signal power of blinded people when touching on square shape tactile picture

Mean values of EEG brain signals of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.015419	0.013541	0.004447	0.005419	0.006560	0.014242	0.009680	0.022004

Table 4.30 Standard deviation values of meditation EEG brain signal power of blinded people when touching on square shape tactile picture

Standard deviation values of EEG brain signal of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.015322	0.011329	0.002473	0.002623	0.002499	0.004925	0.003402	0.012917

Table 4.31 Mean values of touching EEG brain signal power of normal people when touching on square shape tactile picture

Mean values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.025988	0.017025	0.012878	0.007006	0.006761	0.013401	0.008677	0.011404

Table 4.32 Standard deviation values of touching EEG brain signal power of normal people when touching on square shape tactile picture

Standard deviation values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.038867	0.018978	0.021257	0.004261	0.003667	0.004331	0.002133	0.004317

Table 4.33 Mean values of touching EEG brain signal power of blinded people when touching on square shape tactile picture

Mean values of EEG brain signal of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.013226	0.011494	0.003911	0.004708	0.005914	0.013805	0.009578	0.017598

Table 4.34 Standard deviation values of touching EEG brain signal power of blinded people when touching on square shape tactile picture

Standard deviation values of EEG brain signal of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.010968	0.004905	0.001122	0.001499	0.001441	0.003267	0.002288	0.007478

4.2.4 EEG Power of Triangle Shape Tactile Picture Touching Experiment

In this section, all results of triangle shape tactile picture touching experiment showed in next table.

Table 4.35 Meditation and touching EEG power of triangle shape tactile picture touching

Meditation								
Normal People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
N1	0.010646	0.008831	0.002778	0.064300	0.004603	0.011229	0.007932	0.006907
N2	0.004132	0.009536	0.007424	0.011906	0.006597	0.014020	0.008101	0.008953

Table 4.35 (continued)

Name	Delta	Theta	Low Alpha	High Alpha	Low Beta	High Beta	Low Gamma	High Gamma
Meditation								
Normal People								
N3	0.057143	0.031618	0.031618	0.010530	0.007254	0.014361	0.008804	0.025224
N4	0.017650	0.012551	0.003479	0.004938	0.006525	0.015286	0.011533	0.016430
N5	0.009044	0.010758	0.003223	0.003652	0.005512	0.013738	0.009890	0.017706
Blinded People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
B1	0.039892	0.012500	0.003214	0.003700	0.006423	0.015347	0.013040	0.011051
B2	0.008246	0.009049	0.003771	0.006105	0.006206	0.013914	0.007692	0.049379
B3	0.019889	0.017315	0.004516	0.009097	0.009846	0.020515	0.012305	0.017501
B4	0.016925	0.011915	0.003287	0.004053	0.006015	0.017181	0.012208	0.013763
B5	0.054760	0.036438	0.005575	0.007225	0.006469	0.012809	0.068875	0.056889
B6	0.013986	0.014621	0.006471	0.005983	0.006192	0.014930	0.008890	0.018879
B7	0.012058	0.012358	0.003364	0.003353	0.004085	0.010233	0.007772	0.008078
B8	0.004320	0.007984	0.003128	0.003754	0.005465	0.015108	0.011955	0.024918
B9	0.008099	0.006476	0.002441	0.003700	0.003944	0.007957	0.005837	0.069885
B10	0.004540	0.007650	0.007241	0.004734	0.005671	0.013058	0.008557	0.034552
Touching								
Normal People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
N1	0.014309	0.012075	0.003286	0.004526	0.005450	0.013514	0.009829	0.009334
N2	0.005793	0.009799	0.004930	0.009733	0.005966	0.014216	0.008026	0.009183
N3	0.027091	0.034198	0.034198	0.010870	0.009949	0.017948	0.010208	0.014829
N4	0.008077	0.007164	0.002166	0.002952	0.004270	0.009717	0.006317	0.010428
N5	0.011334	0.007205	0.002416	0.002947	0.004237	0.010578	0.006967	0.015203

Table 4.35 (continued)

Touching								
Blinded People								
Name	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
B1	0.034470	0.020890	0.003375	0.003893	0.005418	0.013013	0.009549	0.008733
B2	0.006680	0.009266	0.003926	0.004054	0.005983	0.014528	0.011590	0.034429
B3	0.017064	0.019519	0.005573	0.009278	0.009111	0.016340	0.011397	0.012614
B4	0.019600	0.011704	0.003533	0.004323	0.005858	0.017420	0.014367	0.012577
B5	0.083955	0.049498	0.010821	0.009269	0.007621	0.013105	0.008682	0.024200
B6	0.005585	0.007663	0.004923	0.005563	0.006481	0.015166	0.009053	0.016551
B7	0.014633	0.011370	0.003460	0.004703	0.005501	0.014976	0.013990	0.015251
B8	0.007319	0.011244	0.003967	0.003858	0.005532	0.016075	0.014340	0.025373
B9	0.009296	0.006712	0.002555	0.003765	0.004047	0.009832	0.006834	0.019148
B10	0.005915	0.007623	0.004678	0.004823	0.005505	0.012833	0.008055	0.028846

From table 4.35, this table compared the EEG wave powers of normal people and blinded people when touch on triangle shape tactile picture that has the picture position in center point. The unit of the power is Volts-squared per Hz (V^2/Hz).

Next, the table 4.36 to 4.43 showed mean and standard deviation values of triangle shape tactile picture touching EEG brain signal power of normal and blinded people.

Table 4.36 Mean values of meditation EEG brain signal power of normal people when touching on triangle shape tactile picture

Mean values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.019723	0.014659	0.009704	0.019065	0.006098	0.013727	0.009252	0.015044

Table 4.37 Standard deviation values of meditation EEG brain signal power of normal people when touching on triangle shape tactile picture

Standard deviation values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.021471	0.009585	0.012391	0.025532	0.001042	0.001513	0.001490	0.007348

Table 4.38 Mean values of meditation EEG brain signal power of blinded people when touching on triangle shape tactile picture

Mean values of EEG brain signal of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.018272	0.013631	0.004301	0.005170	0.006032	0.014105	0.015713	0.030490

Table 4.39 Standard deviation values of meditation EEG brain signal power of blinded people when touching on triangle shape tactile picture

Standard deviation values of EEG brain signal of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.016491	0.008695	0.001606	0.001893	0.001618	0.003486	0.018839	0.021387

Table 4.40 Mean values of touching EEG brain signal power of normal people when touching on triangle shape tactile picture

Mean values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.013321	0.014088	0.009399	0.006206	0.005974	0.013195	0.008269	0.011795

Table 4.41 Standard deviation values of touching EEG brain signal power of normal people when touching on triangle shape tactile picture

Standard deviation values of EEG brain signal of normal people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.008347	0.011426	0.013905	0.003815	0.002345	0.003267	0.001714	0.002982

Table 4.42 Mean values of touching EEG brain signal power of blinded people when touching on triangle shape tactile picture

Mean values of EEG brain signal of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.020452	0.015549	0.004681	0.005353	0.006106	0.014329	0.010786	0.019772

Table 4.43 Standard deviation values of touching EEG brain signal power of blinded people when touching on triangle shape tactile picture

Standard deviation values of EEG brain signal of blinded people							
Delta	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**High Gamma**
0.024023	0.012868	0.002325	0.002138	0.001387	0.002198	0.002764	0.008194

From result tables 4.8 to 4.43, researcher described the meaning of only touching EEG data by using hypothesis testing with independent test to compare each wave between normal and blinded people touching signals. T-test score were used in this research with statistic significant at $p<0.1$ by 4-1 equation. Results were showed in table 4.44 to 4.47. The unit is Volts-squared per Hz (V^2/Hz).

$$t = \frac{\bar{x}-\mu}{s/\sqrt{n}} \qquad (4\text{-}1)$$

$\bar{x}$ is mean of each EEG signal value, μ is hypothesis, s is various of EEG signals and n is a number of EEG.

Table 4.44 Comparison of normal and blinded people EEG brain signal power when touching on circle shape tactile picture

EEG Band	**Normal People**		**Blinded People**		**T-score**	**P-value**
	Mean	**S.D.**	**Mean**	**S.D.**		
Delta	0.018573	0.017490	0.023478	0.030303	0.331459	0.745581
Theta	0.013582	0.009403	0.019892	0.019571	0.673741	0.512278
Low Alpha	0.008852	0.011989	0.005547	0.003823	-0.818458	0.427840
High Alpha	0.006088	0.002577	0.006174	0.003459	0.049310	0.961422

Table 4.44 (continued)

EEG Band	Normal People		Blinded People		T-score	P-value
	Mean	S.D.	Mean	S.D.		
Low Beta	0.005658	0.001143	0.007297	0.003334	1.051903	0.312005
High Beta	0.013032	0.002246	0.015779	0.004725	1.216035	0.245592
Low Gamma	0.009089	0.001384	0.011469	0.004078	1.249068	0.233664
High Gamma	0.011380	0.003453	0.020422	0.008105	2.354712	0.034918*

Note *p<0.1

Table 4.45 Comparison of normal and blinded people EEG brain signal power when touching on hexagon shape tactile picture

EEG Band	Normal People		Blinded People		T-score	P-value
	Mean	S.D.	Mean	S.D.		
Delta	0.015911	0.013846	0.017416	0.018526	0.159549	0.875689
Theta	0.011792	0.006515	0.013359	0.008064	0.375388	0.713426
Low Alpha	0.007244	0.009013	0.004391	0.001446	-1.013020	0.427840
High Alpha	0.005219	0.002073	0.004413	0.001002	-1.036364	0.318930
Low Beta	0.005098	0.000804	0.005924	0.001318	1.274525	0.224789
High Beta	0.011649	0.001468	0.013715	0.002440	1.724325	0.108329
Low Gamma	0.007846	0.001146	0.009564	0.002235	1.595572	0.134597
High Gamma	0.012972	0.005711	0.016844	0.005415	1.283351	0.221775

Note *p<0.1

Table 4.46 Comparison of normal and blinded people EEG brain signal power when touching on square shape tactile picture

EEG Band	Normal People		Blinded People		T-score	P-value
	Mean	S.D.	Mean	S.D.		
Delta	0.025988	0.038867	0.013226	0.010968	-0.995292	0.337760
Theta	0.017025	0.018978	0.011494	0.004905	-0.894330	0.387404
Low Alpha	0.012878	0.021257	0.003911	0.001122	-1.384199	0.189600
High Alpha	0.007006	0.004261	0.004708	0.001499	-1.569777	0.140479
Low Beta	0.006761	0.003667	0.005914	0.001441	-0.655100	0.523827
High Beta	0.013401	0.004331	0.013805	0.003267	0.203474	0.841915
Low Gamma	0.008677	0.002133	0.009578	0.002288	0.733474	0.476289
High Gamma	0.011404	0.004317	0.017598	0.007478	1.696358	0.113617

Note *p<0.1

Table 4.47 Comparison of normal and blinded people EEG brain signal power when touching on triangle shape tactile picture

EEG Band	Normal People		Blinded People		T-score	P-value
	Mean	S.D.	Mean	S.D.		
Delta	0.013321	0.008347	0.020452	0.024023	0.634524	0.536746
Theta	0.014088	0.011426	0.015549	0.012868	0.214348	0.833601
Low Alpha	0.009399	0.013905	0.004681	0.002325	-1.083233	0.298388
High Alpha	0.006206	0.003815	0.005353	0.002138	-0.563151	0.582915
Low Beta	0.005974	0.002345	0.006106	0.001387	0.137859	0.892464
High Beta	0.013195	0.003267	0.014329	0.002198	0.804275	0.435700
Low Gamma	0.008269	0.001714	0.010786	0.002764	1.845789	0.087814*
High Gamma	0.011795	0.002982	0.019772	0.008194	2.075988	0.058295*

Note *p<0.1

From table 4.44 to 4.47, every EEG bands were not different between normal and blinded people touching learning except gamma wave when touch on circle and triangle tactile pictures. These results showed blinded people can learn about pictures like normal people learn by touching but blinded people usually control muscle and move hands more than normal people.

4.3 The EEG Brain Signal Patterns for Touching Learning of Blinded People on Tactile Pictures with Several Positions by the Inexpensive Device

This experiment was record and analyze the EEG dataset of the human behavior when touching tactile pictures and describe the type of them but this experiment pay attention to the several position of tactile pictures with the same shape like topic 4.3 stimulus. Positions of picture were upper-left, upper-center, upper-right, center-left, center, center right, lower-left, lower-center and lower-right. Researcher recorded the EEG dataset via NeuroSky MindWave device that connect to the computer by Bluetooth. The OpenVIBE program was select to support the data gathering method. Five normal volunteers who has aging between nineteen and twenty-four were selected and ten blinded volunteers with deference type blinded were selected. The age of blinded people was between fifteen and twenty-three.

The analysis of this method all the same like experiment 2. Researcher focused on Fast Fourier Transform (FFT) algorithm, Area Under Curve (AUC) and power comparing. Example results of Fast Fourier Transform analysis showed in figure 4.27 to figure 4.41.

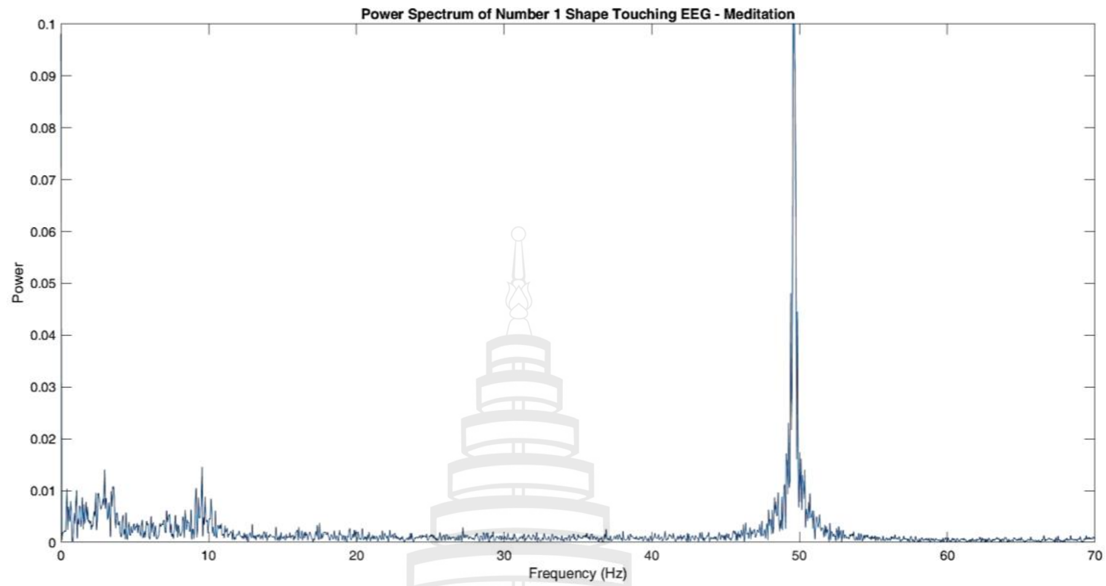


Figure 4.27 Shape1 meditation of normal volunteer2 amplitude graph

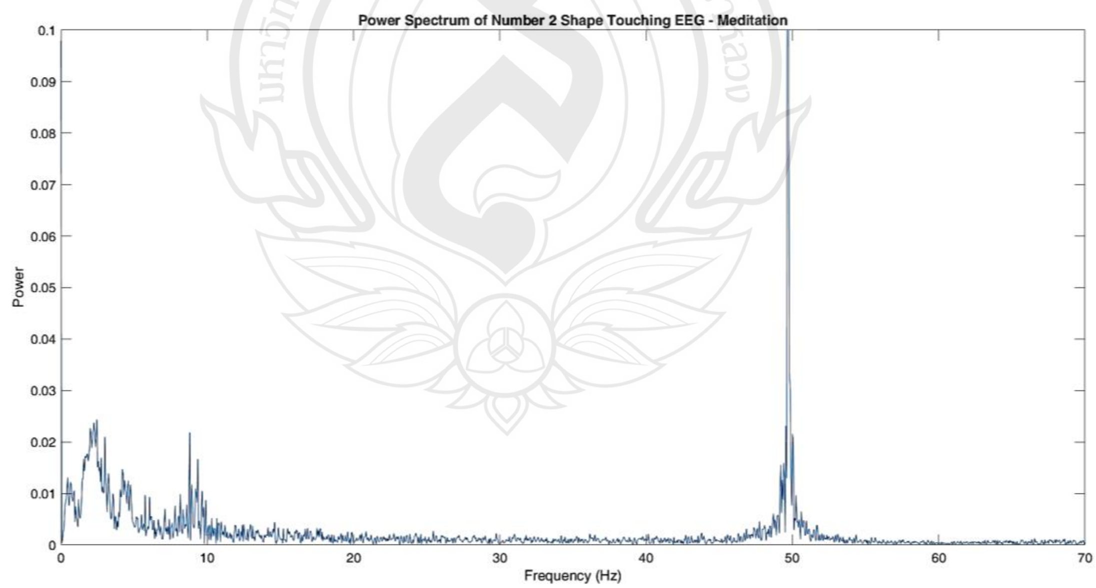


Figure 4.28 Shape2 meditation of normal volunteer2 amplitude graph

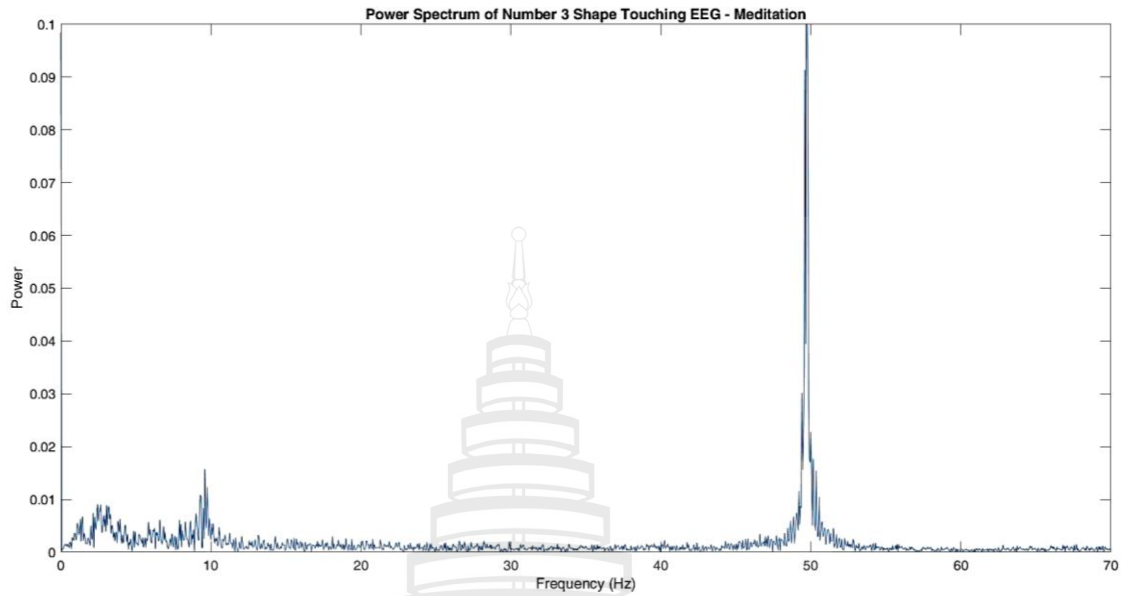


Figure 4.29 Shape3 meditation of normal volunteer2 amplitude graph

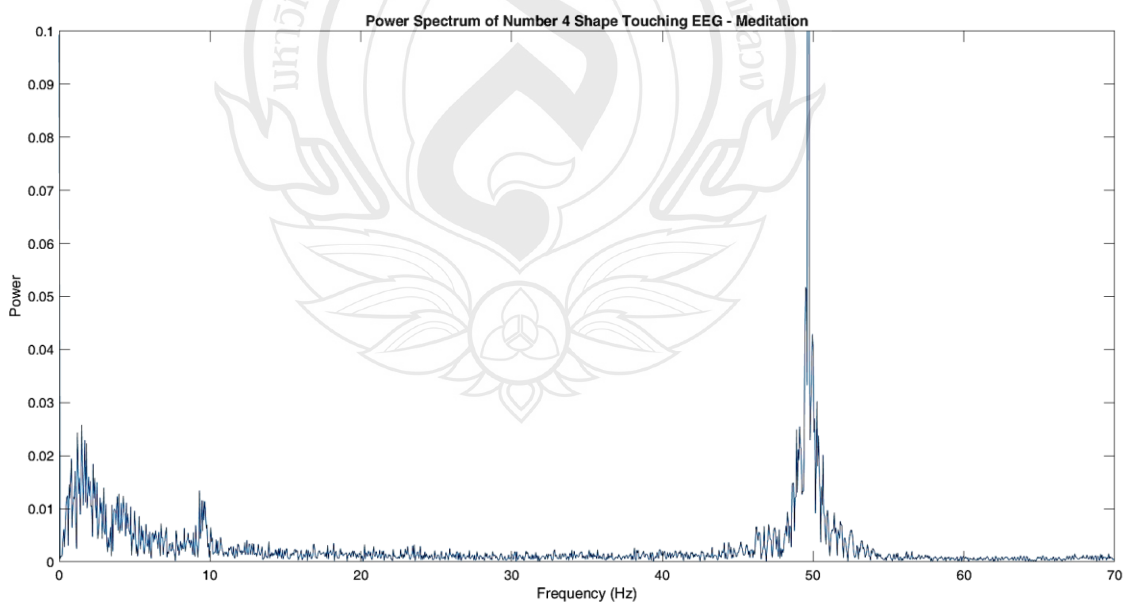


Figure 4.30 Shape4 meditation of normal volunteer2 amplitude graph

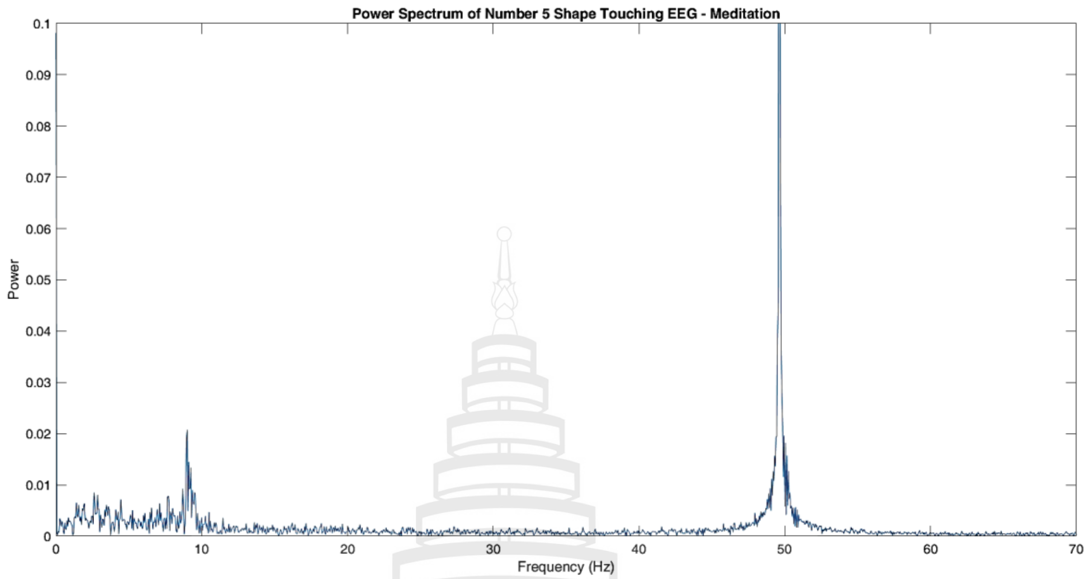


Figure 4.31 Shape5 meditation of normal volunteer2 amplitude graph

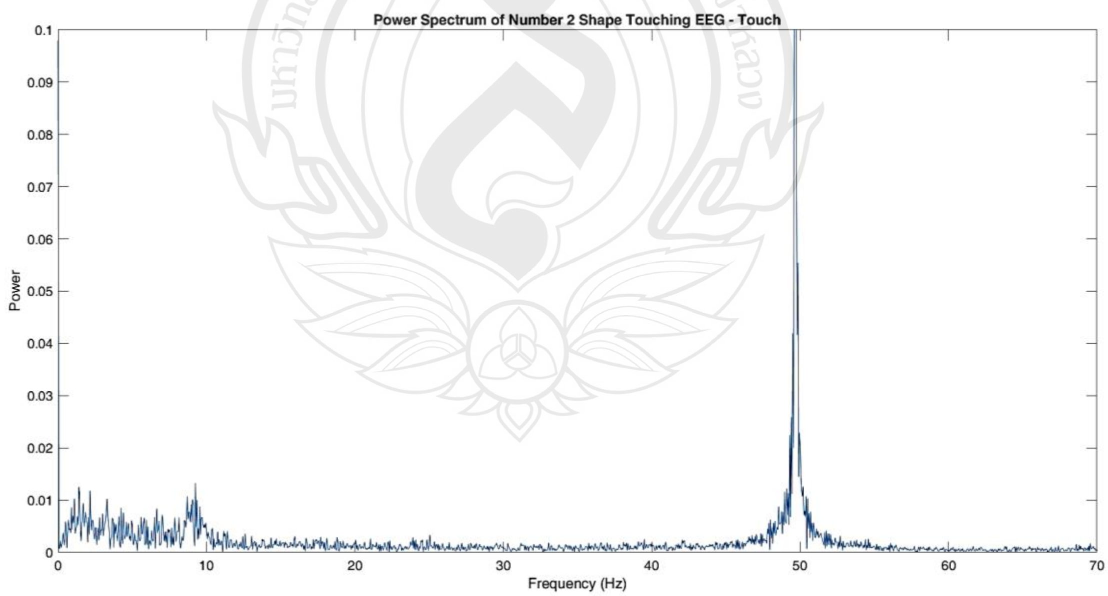


Figure 4.32 Shape2 touching of normal volunteer2 amplitude graph

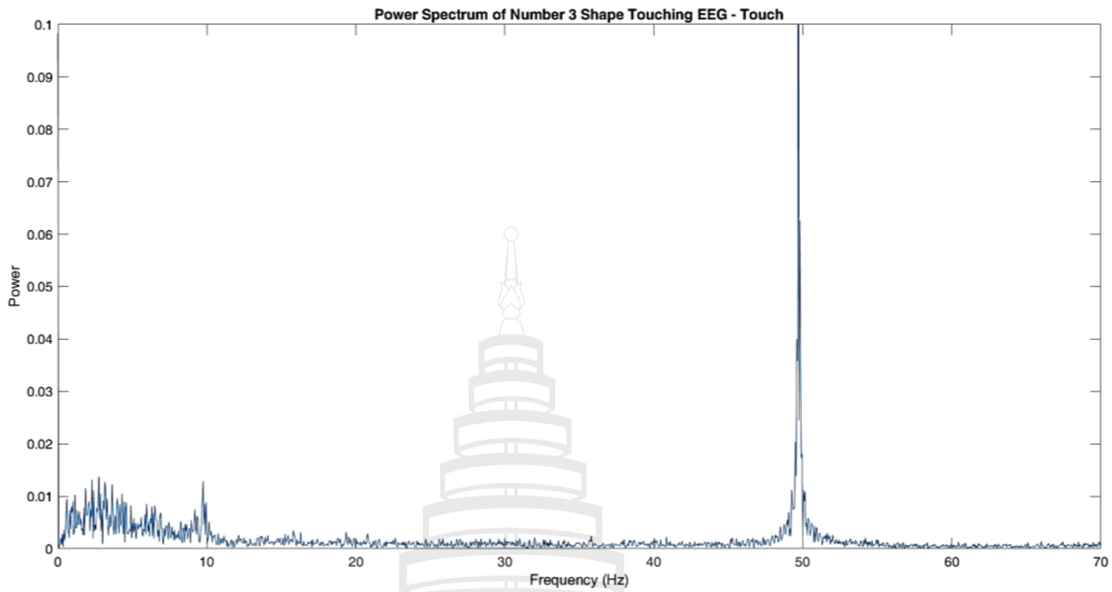


Figure 4.33 Shape3 touching of normal volunteer2 amplitude graph

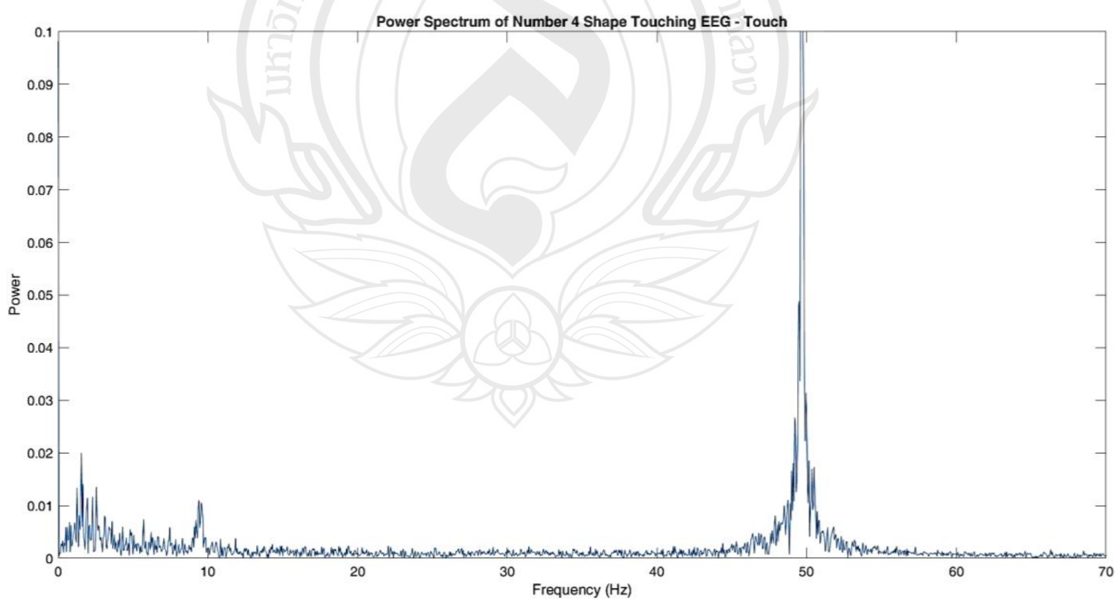


Figure 4.34 Shape4 touching of normal volunteer2 amplitude graph

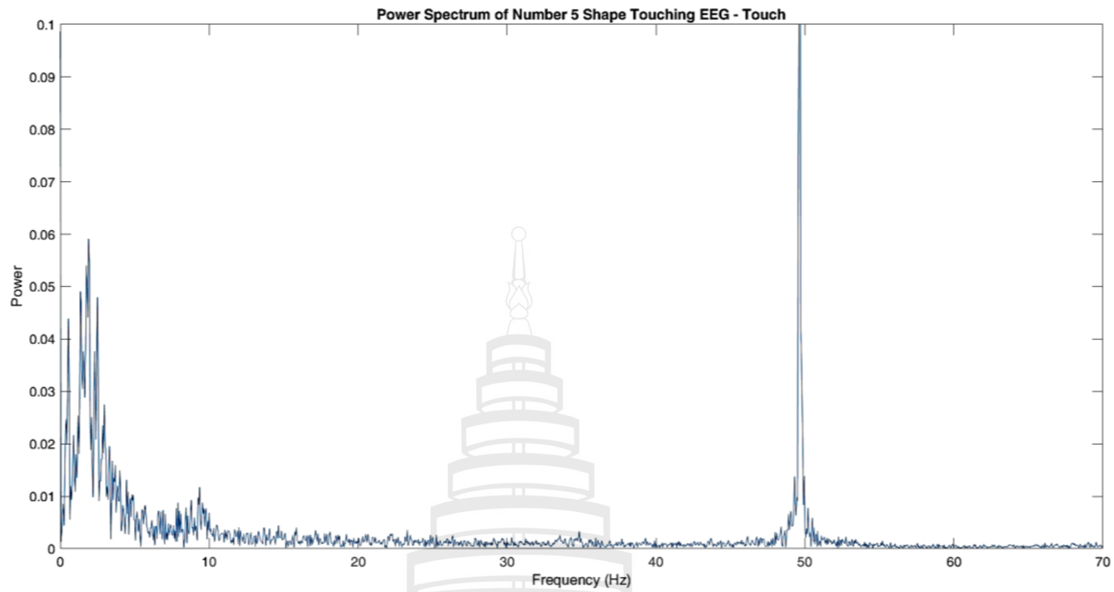


Figure 4.35 Shape5 touching of normal volunteer2 amplitude graph

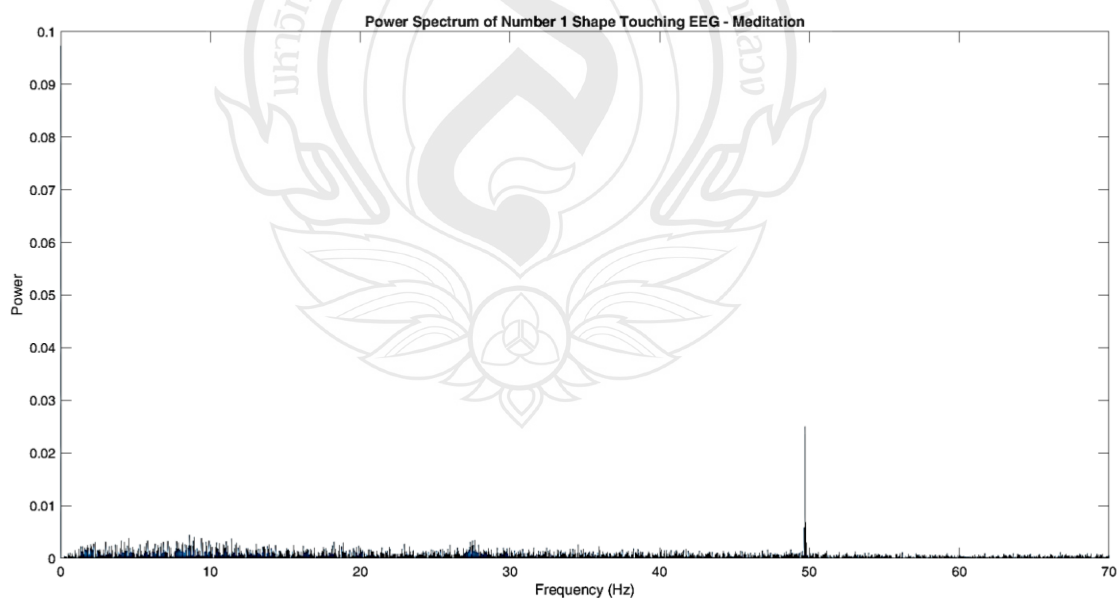


Figure 4.36 Shape1 meditation of blinded volunteer6 amplitude graph

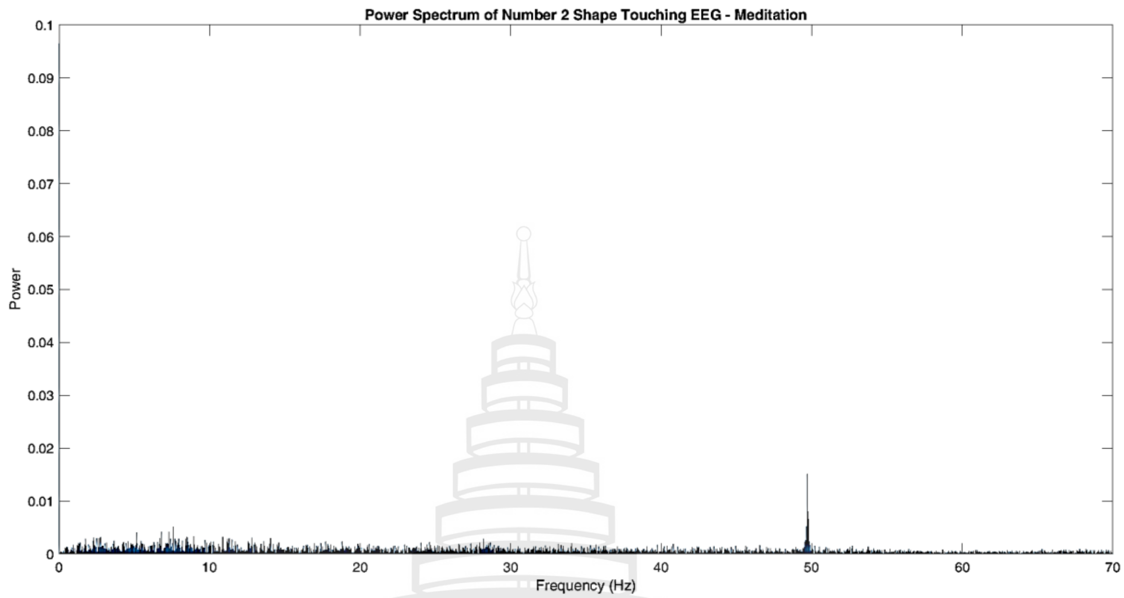


Figure 4.37 Shape2 meditation of blinded volunteer6 amplitude graph

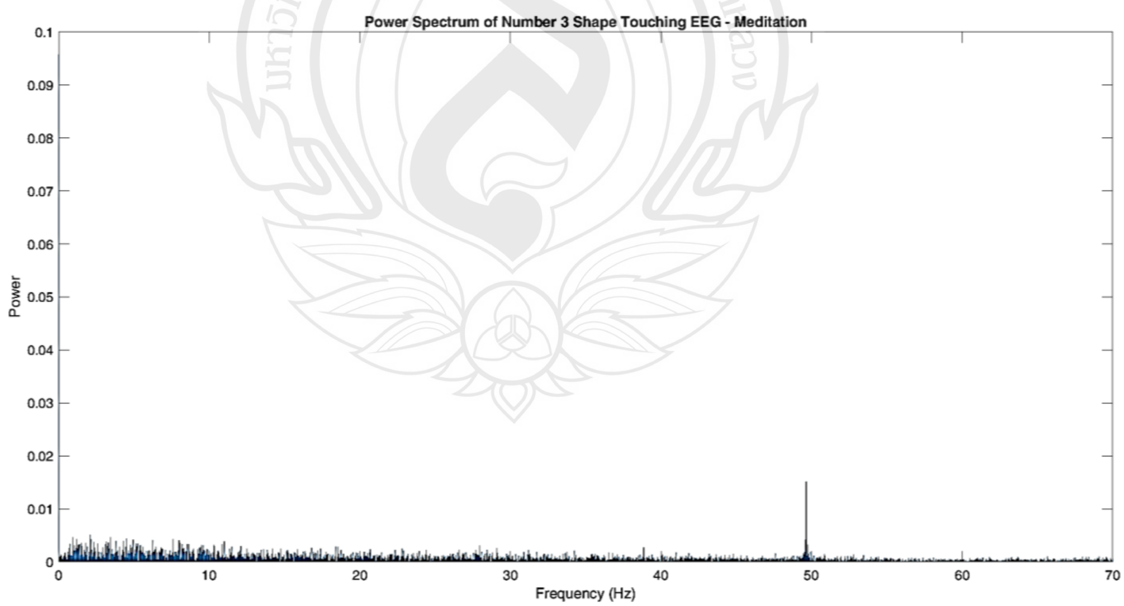


Figure 4.38 Shape3 meditation of blinded volunteer6 amplitude graph

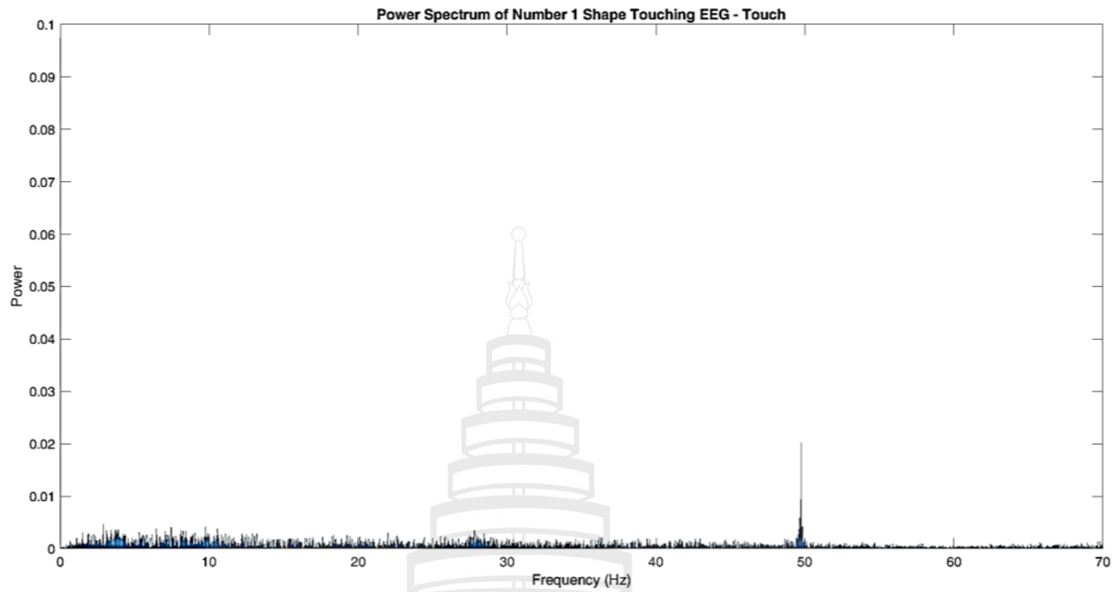


Figure 4.39 Shape1 touching of blinded volunteer6 amplitude graph

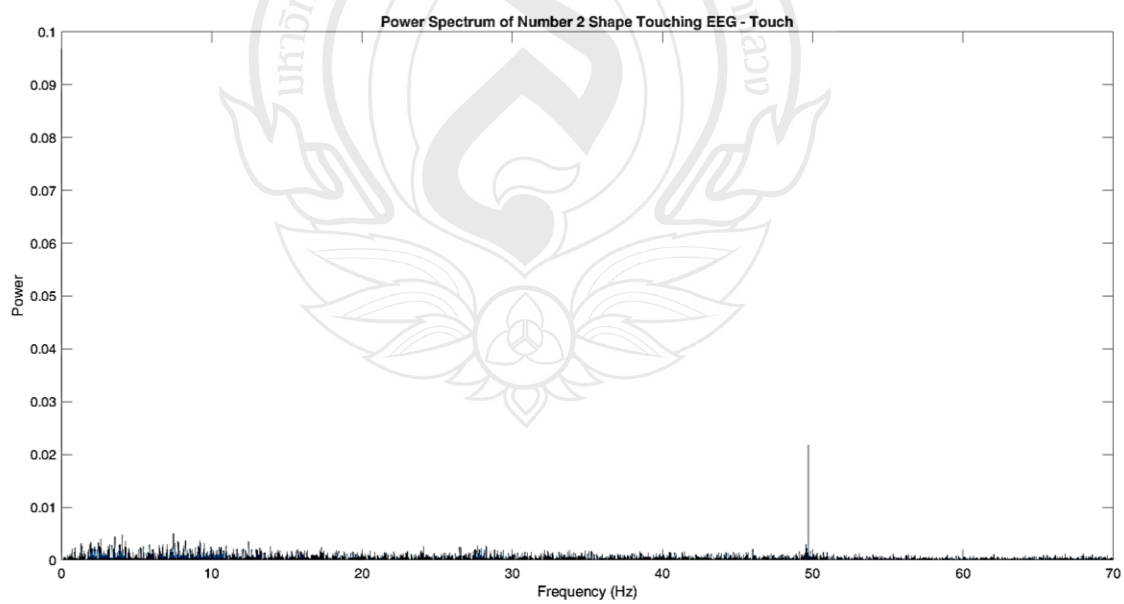


Figure 4.40 Shape2 touching of blinded volunteer6 amplitude graph

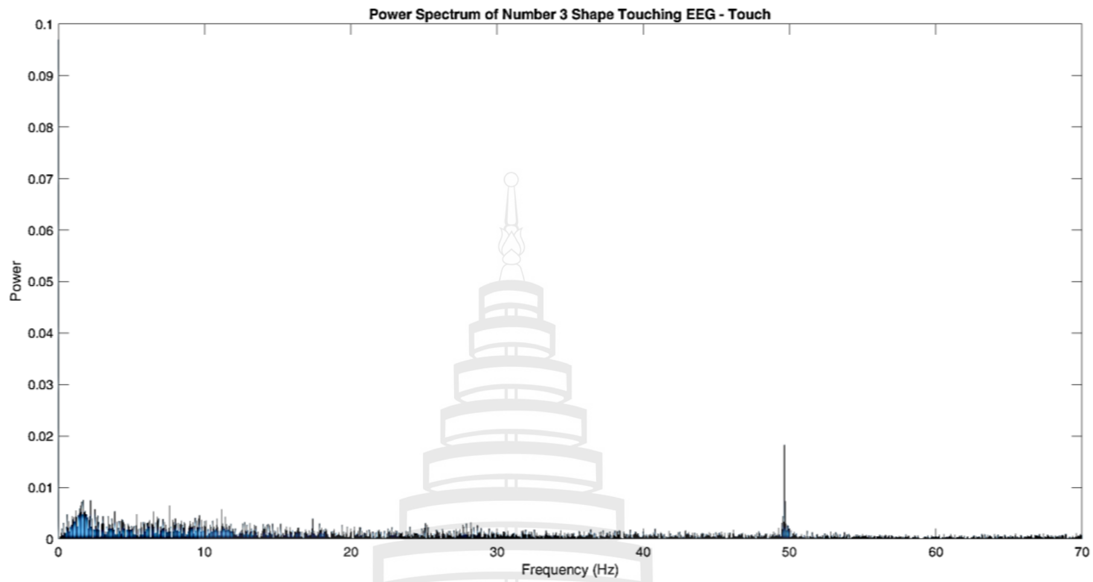


Figure 4.41 Shape3 touching of blinded volunteer6 amplitude graph

From figure 4.27 to figure 4.41, EEG power graphs of all figure were the same with experiment2. In other word, patterns of delta, theta and gamma got high values but alpha and beta got lower values. Because of patterns of all wave are the same like experiment2, results are the same.

CHAPTER 5

CONCLUSION AND FUTURE WORK

This chapter presents the conclusion and future work of two main objectives. The first objective mentions about the analysis and description of electroencephalography (EEG) brain wave patterns that blinded people use when they want to understand pictures. The second objective mentions about the comparison of electroencephalography (EEG) brain wave patterns between normal people and blinded people when they want to understand pictures. In the dissertation, researcher focus on the touching behavior on geometry shapes tactile pictures.

5.1 The EEG Brain Signal Representation for Surfaces and Shapes Touching Behavior with an Inexpensive Device

From experiment results that mentioned in chapter 4, datasets of each brain wave band were recorded for sixty seconds, but researcher was analyzed the wave between twenty-one to forty seconds because this timeline is time for touching experimental. This experiment results show volunteers use the creative, higher mental activity and motor function for the touching behavior. In addition, results performed on the high values in Delta, Theta, High-Alpha and Mid-Gamma but values were not the same numbers. These results show some people use more brain for thinking but some people use brain less than others.

5.2 The EEG Brain Signal Patterns for Touching Learning of Blinded People on Tactile Pictures by the Inexpensive Device

This method results show the power of each EEG wave signal. The unit of this experiment is Volts-squared per Hz (V^2/Hz). For analysis method, Fast Fourier Transform algorithm was selected to analyze the amplitude of each wave before calculate the power density. Then, researcher calculated area under curve (AUC) values to compare the wave. After power analysis, researcher found patterns of the touching learning of normal and blinded people by following results. From result table 4.8 to 4.16 in chapter 4, the normal people's circle picture touching EEG signal result summary shows in table 5.1. The blinded people's circle picture touching EEG signal result summary shows in table 5.2. Results in tables mean normal people use delta, theta, high beta and low gamma signals to find the circle shape touching. Blinded people use all wave to find the circle shape touching.

Table 5.1 Ratio of normal volunteer number that EEG touching power higher than meditation for circle touching learning picture

Wave Type	Frequency (Hz)	Ratio of Volunteer Number (%)
Delta *	0.1-3	60%
Theta *	4-7	80%
Low Alpha	8-9	40%
High Alpha *	10-12	0%
Low Beta	13-17	40%
High Beta	18-30	60%
Low Gamma	31-40	80%
High Gamma *	41-50	40%

Note *The important wave types related to experiment 1

Table 5.2 Ratio of blinded volunteer number that EEG touching power higher than meditation for circle touching learning picture

Wave Type	Frequency (Hz)	Ratio of Volunteer Number (%)
Delta *	0.1-3	70%
Theta *	4-7	80%
Low Alpha	8-9	60%
High Alpha *	10-12	50%
Low Beta	13-17	60%
High Beta	18-30	70%
Low Gamma	31-40	80%
High Gamma *	41-50	60%

Note *The important wave types related to experiment 1

From table 5.1 and table 5.2, results show more normal people get higher in delta, theta, high beta and low gamma when touching on circle shape tactile pictures. However, blinded people get higher in every wave when touching on circle shape tactile pictures. These results show blinded people use the brain more than normal people when touching learning.

From result table 4.17 to 4.25 in chapter 4, the normal people's hexagon picture touching EEG signal result summary shows in table 5.3. The blinded people's circle picture touching EEG signal result summary shows in table 5.4.

Table 5.3 Ratio of normal volunteer number that EEG touching power higher than meditation for hexagon touching learning picture

Wave Type	Frequency (Hz)	Ratio of Volunteer Number (%)
Delta *	0.1-3	100%
Theta *	4-7	80%
Low Alpha	8-9	20%
High Alpha *	10-12	0%
Low Beta	13-17	40%
High Beta	18-30	40%
Low Gamma	31-40	40%
High Gamma *	41-50	60%

Note *The important wave types related to experiment 1

Table 5.4 Ratio of blinded volunteer number that EEG touching power higher than meditation for hexagon touching learning picture

Wave Type	Frequency (Hz)	Ratio of Volunteer Number (%)
Delta *	0.1-3	60%
Theta *	4-7	60%
Low Alpha	8-9	60%
High Alpha *	10-12	40%
Low Beta	13-17	50%
High Beta	18-30	50%
Low Gamma	31-40	50%
High Gamma *	41-50	40%

Note *The important wave types related to experiment 1

From table 5.3 and table 5.4, results show more normal people get higher in delta, theta and high gamma when touching on hexagon shape tactile pictures. However, blinded people get higher in delta, theta and low alpha when touching on hexagon shape tactile pictures. These results show blinded people use the brain more about the imagination when touching on more angle picture learning.

From result table 4.26 to 4.34 in chapter 4, the normal people's square picture touching EEG signal result summary shows in table 5.5. The blinded people's square picture touching EEG signal result summary shows in table 5.6.

Table 5.5 Ratio of normal volunteer number that EEG touching power higher than meditation for square touching learning picture

Wave Type	Frequency (Hz)	Ratio of Volunteer Number (%)
Delta *	0.1-3	40%
Theta *	4-7	40%
Low Alpha	8-9	60%
High Alpha *	10-12	20%
Low Beta	13-17	40%
High Beta	18-30	40%
Low Gamma	31-40	60%
High Gamma *	41-50	40%

Note * The important wave types related to experiment 1

Table 5.6 Ratio of blinded volunteer number that EEG touching power higher than meditation for square touching learning picture

Wave Type	**Frequency (Hz)**	**Ratio of Volunteer Number (%)**
Delta *	0.1-3	30%
Theta *	4-7	40%
Low Alpha	8-9	60%
High Alpha *	10-12	40%
Low Beta	13-17	30%
High Beta	18-30	50%
Low Gamma	31-40	50%
High Gamma *	41-50	20%

Note * The important wave types related to experiment 1

From table 5.5 and table 5.6, results show more normal people get higher in low alpha and high gamma when touching on square shape tactile pictures. However, blinded people get higher in low alpha when touching on square shape tactile pictures. These results show blinded people use the brain more about the conscious when touching on angle picture learning like normal people.

The normal people's triangle picture touching EEG signal result summary shows in table 5.7. The blinded people's triangle picture touching EEG signal result summary shows in table 5.8.

Table 5.7 Ratio of normal volunteer number that EEG touching power higher than meditation for triangle touching learning picture

Wave Type	Frequency (Hz)	Ratio of Volunteer Number (%)
Delta *	0.1-3	60%
Theta *	4-7	60%
Low Alpha	8-9	40%
High Alpha *	10-12	20%
Low Beta	13-17	40%
High Beta	18-30	60%
Low Gamma	31-40	60%
High Gamma *	41-50	40%

Note * The important wave types related to experiment 1

Table 5.8 Ratio of blinded volunteer number that EEG touching power higher than meditation for triangle touching learning picture

Wave Type	Frequency (Hz)	Ratio of Volunteer Number (%)
Delta *	0.1-3	60%
Theta *	4-7	60%
Low Alpha	8-9	80%
High Alpha *	10-12	80%
Low Beta	13-17	50%
High Beta	18-30	70%
Low Gamma	31-40	60%
High Gamma *	41-50	20%

Note * The important wave types related to experiment 1

From table 5.7 and table 5.8, results show more normal people get higher in delta, theta, high beta and low gamma when touching on triangle shape tactile pictures. However, blinded people get higher in delta, theta, alpha, high beta and low gamma when touching on triangle shape tactile pictures. These results show blinded people use the brain more about the imagination, conscious and thinking when touching on picture learning more than normal people.

From chapter 4 between table 4.54 and table 4.57, the hypothesis testing was used to analyze the differentiation of each EEG wave band. P-Values showed in table 5.9 were related to statistic significant at 0.1

Table 5.9 Related P-Value of Each EEG band to statistic significant at 0.1

Tactile Picture	EEG Band	T-Score	P-Value
Circle	High Gamma	2.354712	0.034918
Triangle	Low Gamma	1.845789	0.087814
Triangle	High Gamma	2.075988	0.058295

From table 5.9, only low and high gamma were accepted to statistic significant at 0.1. This result mean that blinded people control their arms and hands to touching tactile picture more than normal people do. Both blinded and normal people think and recognize the meaning of pictures the same. If scientists try to develop tools for learning of blinded people, they must design tools that comfortable to touch by hands.

5.3 The EEG Brain Signal Patterns for Touching Learning of Blinded People on Tactile Pictures with Several Positions by the Inexpensive device

From the experiment results, researcher focus on difference EEG patterns when touch on difference position, but each wave and patterns were the same with the center position in experiment 2. Delta, theta, alpha, beta and gamma were not difference amplitude pattern from the experiment 2. Researcher concludes the result that several positions not affected to the EEG brain signal patterns when touching learning.

5.4 Summary

From research, important waves for touching behavior are Delta, Theta, Alpha and Gamma. Algorithms for analysis are Fast Fourier Transform (FFT), Area Under Curve (AUC), mean, S.D., T-score and P-value by sequence. First, FFT used for separated raw signal to each wave band. Second, AUC used for calculate area of wave between lowest and highest frequency of each EEG wave band. Next, mean and S.D. used for calculate average AUC value of each participant group. Last, T-score and P-value used to analyze differential of EEG waves between normal and blinded people.

In conclusion, Hypothesis testing with T-score and P-values results illustrated that normal and blinded people EEG wave patterns are high in Delta, Theta, Alpha and Gamma wave. Especially, gamma wave of blinded people got higher than normal people on some touching activities, circle and triangle shape tactile pictures. In additional, gamma wave showed that blinded people use muscle and movement activities more than normal people on touching learning. In addition, they learned about picture in several position by activities that be same with center picture position touching. The EEG values get high in Delta, Theta, Alpha and Gamma. EEG wave patterns were not different.

5.5 Suggestion

From experiments of this research, researcher found important suggestions for future works. First, guidance of experimental field shows by following descriptions:

1. Because of NeuroSky Mindwave has two version model, 50 and 60 Hz electric reduction, other researchers should select the device that relate to electric frequency in your country. In Thailand, researchers can use 50 Hz electrical reduction model.
2. When working on data recording method, researchers should manage data recording room with quiet environment, away from electrical equipment and find no crowd place to avoid with other undesirable stimulus.
3. The timeline of experiment should be precision. When recording dataset, assistants should be usable. They should give a signal for participants when time is up.

Second, suggestion of future work field shows by following directions:

1. Researchers should select a greater number of electrodes, such as Emotive EPOC headset which include sixteen electrodes EEG device for more accuracy when record dataset from blinded people for observe synapse activities in other region of brain.
2. With blinded people case, researchers should design experiment for analyze blinded people EEG brain wave when touching on more complex tactile pictures, such as forest, sea or city. This experiment should show more activities of brain.

5.6 List of Publications

5.6.1 International Conferences

Lawpradit, W. & Yooyativong, T. (2018). The EEG brain signal representation for surfaces and shapes touching behavior with an inexpensive device. In *The International ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunications Engineering 2018 (ECTI-NCON 2018),* (pp. 115-120). Chiang Rai : School of Information Technology, University of Phayao Chiang Rai Campus.

Lawpradit, W. & Yooyativong, T. (2021). Analysing Blinded People EEG Signals while Touching using Lightweight Device. In *The 6th International Conference on Digital Arts, Media and Technology (DAMT) and 4th ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunications Engineering (NCON)*, (pp. 407-411). Online Conference.

5.6.2 International Journals

Lawpradit, W. & Yooyativong, T. (2021). A Comparison of Blinded and Normal People Touching Learning EEG Brain Signal. *Journal of Mobile Multimedia*. (in process)

REFERENCES

REFERENCES

Blausen Medical. (2014). *Medical gallery of blausen medical 2014*. Retrieved March 29, 2017, from https://upload.wikimedia.org/wikiversity/en/7/72/Blausen_gallery_2014.pdf

Compound Interest. (2015). *A simple guide to neurotransmitters*. Retrieved April 13, 2017, from http://www.compoundchem.com/2015/07/30/neurotransmitters

Dougherty, P. (2017). *Somatosensory pathways*. Retrieved May 12, 2017, from http://neuroscience.uth.tmc.edu/s2/chapter04.html

Emotiv. (n.d.). *EMOTIV Epoc*. Retrieved January 9, 2017, from https://www.emotiv.com/epoc/

Freedom Scientific, Inc. (2012). *JAWS for windows quick start guide*. Florida, USA: Freedom Scientific, Inc.

Gierach, J. (2009). *Assessing Students' Needs for Assistive Technology (ASNAT)*. Milton, USA: Wati.

Heckbert, P. (1995). Fourier Transforms and the Fast Fourier Transform (FFT) Algorithm [Lecture Notes]. Retrieved January 11, 2019, from http://www.cs.cmu.edu/afs/andrew/scs/cs/15-463/2001/pub/www/notes/fourier/fourier.pdf

Huang, W. (n.d). Fast fourier transform and MATLAB implementation [PowerPoint Slides]. Retrieved January 12, 2019, from https://personal.utdallas.edu/~dlm/3350%20comm%20sys/FFTandMatLab-wanjun%20huang.pdf

Ilyas, M. Z., Saad, P., & Ahmad, M. I. (2015). A Survey of analysis and classification of EEG signals for brain-computer interfaces, *2nd International Conference on Biomedical Engineering (ICoBE),* Penang, Malasia: IEEE.

Lachs, L., (n.d.). *Multi-modal perception*. Retrieved May 13, 2017, from http://nobaproject.com/modules/multi-modal-perception

Larsen, E. A. (2011). *Classification of EEG signals in a brain-computer interface system*. Master's Thesis. Norwegian University of Science and Technology, Trondheim, Norway.

NeuroSky, Inc. (2009). *Brain wave signal (EEG) of neuroSky, Inc.* Los Angeles, CA: NeuroSky, Inc.

NeuroSky, Inc. (2015). *MindWave mobile: user guide*. Los Angeles, CA: NeuroSky, Inc.

NeuroSky, Inc. (n.d.). *NeuroSky mindWave mobile*. Retrieved January 9, 2017, from https://store.neurosky.com/pages/mindwave

OECD. (2007). *Understanding the brain: The birth of a learning science*. Massachusetts, USA: OECD.

Pujol, R. (2017). *Auditory brain*. Retrieved May 12, 2017, from http://www.cochlea.eu/en/auditory-brain

Schalk, G., & Mellinger, J. (2010). *A practical guide to brain–computer interfacing with BCI2000*. London, UK: Springer.

Squire, L., Berg, D., Bloom, F., Lac, S. D., . . . Spitzer, N. (2008). *Fundamental Neuroscience 3rd* Ed. North Carolina, USA: Academic Press.

WebMD, LLC. (2014). *Picture of the brain*. Retrieved April 30, 2017, from http://www.webmd.com/brain/picture-of-the-brain#1

APPENDICES

APPENDIX A

STATEMENTS

This statement was used to gather dataset for EEG recording method. It consists of the statement on ethical statement. Researcher was obtained certificate of online research ethics training from National Research Council of Thailand (NRCT) and Forum for Ethical Review Committee in Thailand (FERCIT).

Certificate of Completion

National Research Council of Thailand (NRCT) and Forum for Ethical Review Committee in Thailand (FERCIT)

Certify that

Wachira Lawpradit

Has completed the ON-LINE RESEARCH ETHICS TRAINING

Course หลักสูตรหลักจริยธรรมการวิจัยในมนุษย์ สำหรับนักศึกษา/นักวิจัย

Date approved (10/11/2563)

Date expired (10/11/2566)

(Professor Dr.Sirirurg Songsivilai)
Secretary-General
National Research Council of Thailand

Figure A1 Ethical certificate

CURRICULUM VITAE

CURRICULUM VITAE

NAME	Mr. Wachira Lawpradit
DATE OF BIRTH	9 November 1981
ADDRESS	156/2 Anusuowaree Road, Prabat, Muang Lampang, Lampang 52000 Thailand

EDUCATIONAL BACKGROUND

2009	Master of Science Internet and Information Technology Naresuan University
2005	Bachelor of Science Computer Science Mae Fah Luang University

WORK EXPERIENCE

2009 - Present	Lecturer in Computer Information System program Rajamangala Univerisity of Technology Lanna Lampang Lampang, Thailand
2006 - 2009	Computer Technical Officer Mae Tha hospital Lampang, Thailand
2004 - 2006	Owner GT Computer Chiang Rai, Thailand