T.C.
FATIH UNIVERSITY
INSTITUTE OF BIOMEDICAL ENGINEERING

INVESTIGATION OF ELECTROENCEPHALOGRAPHY SIGNALS BASED ON HAND MOVEMENTS

İrem HASPOLAT

MSc THESIS
BIOMEDICAL ENGINEERING PROGRAMME

İSTANBUL, JANUARY / 2016

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THESIS ADVISOR
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T.C.
FATİH ÜNİVESİTESİ
BİYOMEDİKAL MÜHENDİSLİK ENSTİTÜSÜ

EL HAREKETLERİNE BAĞLI EEG SİNYALLERİNİN ARAŞTIRILMASI

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YÜKSEK LİSANS TEZİ
BİYOMEDİKAL MÜHENDİSLİĞİ PROGRAMI

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İSTANBUL, OCAK / 2016

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İrem HASPOLAT, a **MSc** student of Fatih University **Institute of Biomedical Engineering** student ID 520112034, successfully defended the **thesis/dissertation** entitled **"INVESTIGATION OF ELECTROENCEPHALOGRAPHY (EEG) SIGNALS BASED ON HAND MOVEMENTS"** which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Prof. Dr. Sadık KARA

Director

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To my lovely family and my friends,

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January 2016 İrem HASPOLAT

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ABBREVIATIONS

ALS	: Amyotrophic Lateral Sclerosis
ANN	: Artificial Neural Network
BCI	: Brain Computer Interface
BMI	: Brain Machine Interface
DWT	: Discrete Wavelet Transform
EEG	: Electroencephalography
EMG	: Electromyography
FMRI	: Functional Magnetic Resonance Imaging
MEG	: Magnetoencephalography
MD	: Minimum Distance
PET	: Positron Emission Tomography
PSD	: Power Spectral Density
SEMG	: Surface Electromyography
SNR	: Signal to Noise Ratio
WT	: Wavelet Transform

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SUMMARY

INVESTIGATION OF ELECTROENCEPHALOGRAPHY SIGNALS BASED ON HAND MOVEMENTS

İrem HASPOLAT

Biomedical Engineering Program
MSc Thesis
Advisor: Assist. Prof. Dr. Saime AKDEMİR AKAR

EEG based on BCI systems has been increasing in recent years. Many different disorders (Brainstem stroke, Amyotrophic lateral sclerosis (ALS), brain or spinal cord injury etc.) can prevent the neuromuscular channels to communicate with brain and controls its external environment. The aim of our thesis is to investigate the EEG signals of healthy subjects during 4 different hand movements using advanced engineering methods for BCI applications. Therefore, EEG data of subjects in a quiet environment during real, imaginary, and random situations were recorded. The recorded signals were analysed using the discrete wavelet transform by dividing them into the sub-bands such as alpha, beta, delta, gamma, and theta and power spectral density values of each band. Moreover, in the experiments of righthand-left hand movements, the relationship between real, random and imaginary situations were examined using statistical approaches.

A significant result obtained from different EEG signals bands demonstrated that four different movements are distinguished from each other to characterize them with respect to statistical analysis.

Keywords: BCI, hand movement, EEG, wavelet transform, power spectral density, statistical analysis.

FATIH UNIVERSITY - INSTITUTE OF BIOMEDICAL ENGINEERING

ÖZET

EL HAREKETLERİNE BAĞLI EEG SİNYALLERİNİN ARAŞTIRILMASI

İrem HASPOLAT

Biyomedikal Mühendisliği Programı
Yüksek Lisans Tezi
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EEG tabanlı BCI sistemlerine yönelik çalışmalar son yıllarda artış göstermektedir. Birçok farklı hastalıklar (Amyotrofik lateral skleroz (ALS), beyin sapı inme, beyin ya da omurilik yaralanması gibi) beynin dış ortamla iletişimini sağlayan nöromüsküler kanalları bozabilirdiği yapılan birçok araştırma da görülmüştür. Tezin amacı BCI uygulamalar için ileri mühendislik yöntemleri kullanılarak 4 farklı el hareketleri sırasında sağlıklı deneklerin EEG sinyallerini araştırmaktır. Bu nedenle sessiz bir ortamda gerçek, hayali ve rasgele durumlar için deneklerin EEG verileri kaydedildi. Kaydedilen sinyaller alfa, beta, delta, gama, teta gibi alt bantlara ayrılarak ve her bandın spektral güç yoğunluğu değerleri üzerinden ayrık dalgacık dönüşümü kullanılarak incelendi. Ayrıca, deneylerde sağ-sol el hareketlerinin gerçek, rastgele ve hayali durumlar arasındaki ilişki istatistiksel yaklaşımlar kullanılarak incelenmiştir.

Farklı EEG sinyal bantlarında istatistiki olarak elde edilen anlamlı sonuçlar göstermiştir ki 4 farklı el hareketi ayrıştırılabilmiştir.

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Anahtar kelimeler: Beyin Bilgisayar Arayüzü, El hareketleri, EEG, Dalga analizi, Güç Spektral Yoğunluğu, İstatistik Analiz,

FATİH ÜNİVERSİTESİ -BİYOMEDİKAL MÜHENDİSLİK ENSTİTÜSÜ

CHAPTER 1

INTRODUCTION

1.1 Purpose of the Thesis

Various disorders can prevent the neuromuscular channels to communicate with brain and controls its external surroundings. Many diseases like brainstem stroke, Amyotrophic lateral sclerosis (ALS), brain or spinal cord damage, muscular dystrophies, cerebral palsy and multiple sclerosis destroy the neural pathways controling muscles or destroy the muscles itselves [1].

Many of patients contracted these disorders could lose every voluntary muscle control which include respiration and eye movements. They can not be able to communicate in any way which means that they become paralyzed from their whole bodies. Especially, stroke has been leading to reason of important long lasting disability in the world. In general, the following sequence of recovery is seen in individuals after stroke: neurophysiological, motor, activities of daily living (ADLs), language, and cognition. Contemporary technology developed to support people who have disability is the significant assistant for most individuals to make their life easier so that this technology can help them to lighten severe life conditions.

The importance of communicating with and controlling external environment on human life, especially for patients with serious motor disabilities, is so obvious. Therefore, these people need alternative methods. Over the last ten years, a many of studies have analyised the likelihood that scalp-recorded electroencephalographam (EEG) activity could be the essence of a new possible way of communication. Latest studies prove that patients could communicate and control specific components of their EEG. System enabling this is called a brain–computer interface (BCI). Brain Computer Interfaces allows a non-muscular communication between the people brain and the outside environment. Signals coming from brain could be obtained using invasive or non-invasive techniques and EEG is a technique considered to be a superior non-invasive one. EEG is a high temporal resolution; however low spatial resolution and poor signal-to-noise ratio (SNR). The high non-stationarity and poor SNR nature of EEG information demand very effective pre-processing and feature extraction possibilities to extract the necessary data in BCI. The extracted characteristics are mainly used to improve a classifier to convert into control signals for an effector such as a prosthetic limb or a robot.

These type of patients could have had their arm amputated or have experienced a stroke or spinal cord damages. The lost hand of an amputee can be replaced by a robotic prosthetic hand, when the non-functional limb of a victim of a stroke or spinal cord injury can be supported by a robotic exoskeletal orthotic limb. BCI redirects the signals from the brain that decoded with EEG signal analysis to external devices which means that external apparatus can be controlled using the patient's thoughts [2].

In this thesis, individuals performing essential hand movements that facilitate the performance of daily activities were observed. The movements that patients learn, over the course of motor rehabilitation, four basic hand movements are considered i.e. thump-up, index-up, little-ring-middle-up together and half-opened hand is called the most essential hand movements. Efficient BCI solution requiring that the neural data related to the necessary hand movements be collected and translated from EEG signal will be applied. During EEG implementation, people are asked to only imagine the action in their brain with no actual action. As a result of this, imaginary movement can be observed in the sensorimotor parts of the brain and create the same EEG pattern as though the action were taken. For that reason, motor imagery is an important model of BCI in spontaneous EEG. In this thesis, signals detected from EEG were analyzed by implementing discrete wavelet transform (DWT). Feature extraction and pattern estimation algorithms based on power spectral methods were investigated to find discriminative features between different hand movements during different situations (real, imaginary, and random).

Figure 1 shows the general schematic diagram of the thesis. First, the experimental procedure was determined It was examined in three situations (real, random and imaginary). In the second, the data were recorded after that third, preprocessing of data. In forth feature extraction of data and last one is statistical analysis of the results.

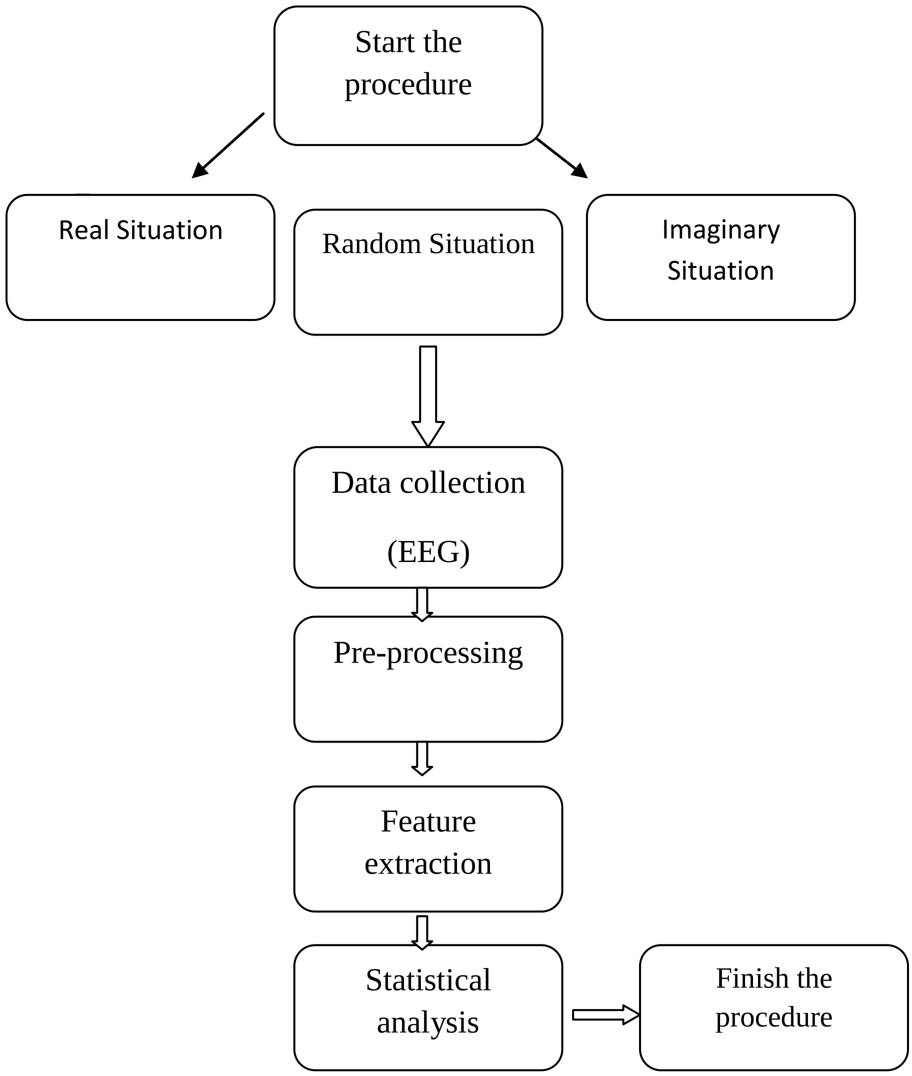

Figure 1.1 General schematic diagram of the thesis

1.2 Thesis Overview

In Chapter 1 some brief information about panic disorder, purpose of the thesis and what chapters include are summarized. It is described what brain computer interface, some information about EEG and literature studies in BCI Systems using EEG in Chapter 2.

Chapter 3 includes the methodology study of this study. How signals were collected from subjects, procedure of data collecting, measurement system, information about EEG, signal processing, transformation, and analysis methods were explained with details. The results part are included in Chapter 4. Analysis and statistical results of the study were explained briefly. Graphs and tables were used to give detailed information. The discussion part, some recommendations were given and the thesis were concluded in Chapter 5.

CHAPTER 2

2.1 Brain Computer Interface (BCI)

BCI is a communication system that establishes a connection between the brain and the external device. In this system, the individual sends messages and commands to outside world but does not go from muscles and nerves. Brain signals taken to the computer using EEG, electromyography (EMG), functional magnetic resonance imaging (fMRI), positron emission tomography (PET), etc. the technique, processed, according to the command sent to features extracted and will be transferred to external devices (e.g. a basic word processing program, a wheelchair, or a neuroprosthesis)[3].

BCI can be used to make easier the lives of people who suffer from these diseases. For example, for patients developed partial paralysis wheelchair with joystick the help of equipment as directed by patients to need muscle movements. However, BCI eliminate the need for fully paralyzed patients could allow using a wheelchair not only for half paralyzed patients [4].

A surface electromyogram is an electrical signal used for controlling of external devices like a power-assist robot or an electric artificial arm.sEMG provides users with operating these devices by analyzing user’s motion intention [5].

In addition to functionality of sEMG, it is based on a lot simpler technology and needs smaller time constants when in comparison with other non-invasive approaches like MEG, PET and fMRI. Since it is possible to process digitized EEG signals on a computer, the urge to use EEG was great as a direct communication way from the brain to the actual world. As result, it has been several intense developments in the wide area of BCI research in last decade [6].

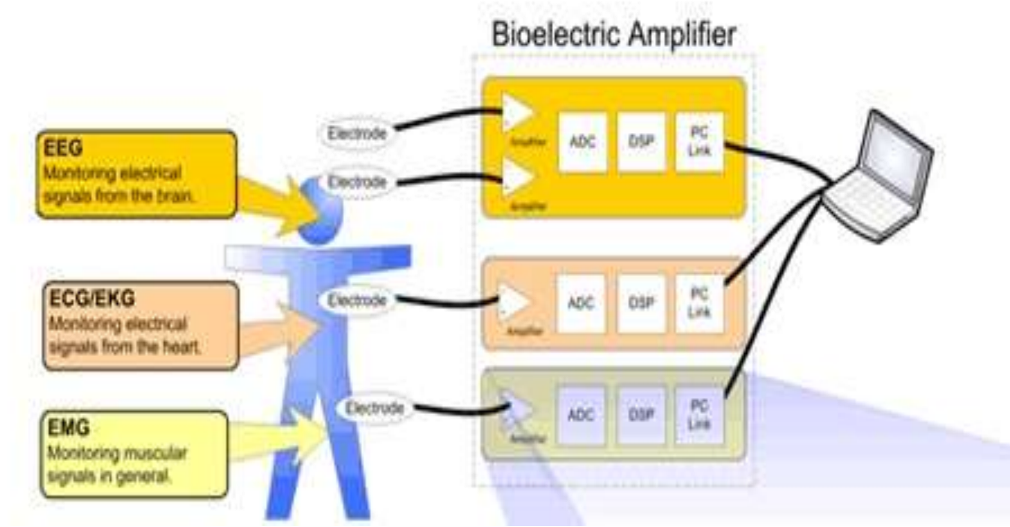

Figure 2.1 An illusturation EEG, EMG and ECG signals based BCI studies [7]

The basis of an efficient BCI solution needs that the neural data related with the necessary hand movements be collected and transferred from neural signals, like EEG, in real-time. The combination of these four important hand movements has not been discoverd in EEG-based BCI literature [2].

As a measurement technique of EEG signal, method of getting signal from electrodes on the scalp is developed and used in order to be employed by BCI systems [8].

The interface between a robot and EEG signals is named as BCI. Compared to EMG signals, when measuring EEG signal, you don't need to make an action. Hence, EGG signal plays a signicant role to implement into wearable robots because it is possible to measure EEG signals even when amputees and paralyzed people who are not able to create EMG signals. If the intention of user's motion can be predicted from the measured EEG signals, it makes a huge contributation on research with respect to enhancing patient's condition [9].

A modern BCI system can be divided into five parts such as, pre-processing, feature classification, data acquisition, feature extraction and output.

Figure 2.2 shows operation and basic design of any BCI system. Signals coming from the brain are collected by electrodes on the scalp, the cortical surface, or from the brain and are processed to gather certain signal features which channels the user's features are translated into commands that operate a device (e.g., a wheelchair, or a neuroprosthesis).

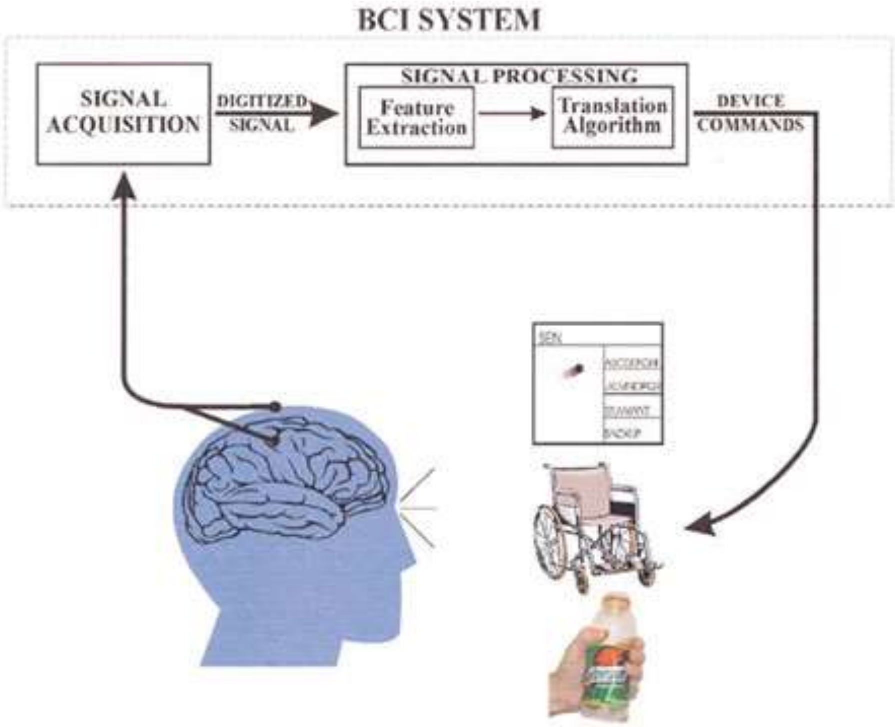

Figure 2.2 Basic design and operation of any BCI system [10]

2.2 EEG based BCI Studies

2.2.1 EEG

Any action or commands when it is produced the ions exchange begins between nerve cells in the brain. This exchange, lobe of the brain that performs the associated action in the form of a wave spread along.During the propagation, some of the ions transferred from the skulls gets far the away. Pasted to the scalp with a conductive gel of the electrode electrically charged ions attracts and repels the charged particles throughout the skul.This movement of charged particles creates a potential difference between the electrodes. The potential difference can be measured with the help of a simple voltmeter. The EEG signals collected from electrodes that connect tomany devices and pass the pre-process and transfers it to a system. This system can be monitor for displaying signals. It can be computer for signal processing purposes [11].

Properties of EEG signals: From electrodes on the scalp or the surface of the brain EEG signals measured with low amplitude (μV peak-to-peak 1-400) bioelectric signals.Low-amplitude makes it difficult to get this information.Therefore the collected signal pre-processed for aimed at strengthening.EEG has a wide frequency band (0.5-100 Hz). But clinical and physiological interest is concentrated between 0.5 and 30 Hz. This frequency range is divided into 4 Frequency bands. These are:

- **Alpha Waves (8 to 12 hz)**

The term is used to determine the frequency range of human brain activity between 8 and 12 Hz. Alpha band is defined as wave of comfort, relax, reflective awareness, calm and peaceful understanding. Most significant results from alpha band can be obtained when brain is calm and peaceful, but never experienced numbness. It has the most appropriate frequency when perceiving the realities in the world. This wave is not observed when sleepind deeply or having anxiety and fear [12].

- **Delta Waves (0.5 to 3 hz)**

The term is used to determine the frequency range of human brain activity between 12 and 38 Hz. Delta band is a low-frequency wave that are irregular which can be observed in the depths of the unconscious mind and also in the deepest stages of sleep . These waves are generated during the deepest meditation [12].

- **Beta Waves (12 to 38 hz)**

The term is used to determine the frequency range of human brain activity between 12 and 38 Hz. Beta defines fast activities in human life such as the logically thinking, judgment, engaging in problem solving and focusing mental activity when the mind is awake [13].

- **Theta Waves (3 to 8 hz)**

The term is used to determine the frequency range of human brain activity between 3 and 8 Hz. These waves occur most often in sleep but are also dominant in deep meditation. It plays a role as our gateway to learning and memory. In addition, these waves play an significant role in establishing the necessary connections for the revealing of suppressed emotions and creativity. [13].

- **Gamma Waves (38 to 42 hz)**

The term is used to determine the frequency range of human brain activity between 38 and 42 Hz. Gama waves have high frequency and low amplitude which are the fastest of brain waves. These waves occur during rapid motion that transmits information fast. Gamma rhythms above the frequency of neuronal firing which modulate perception and consciousness disappear under anaesthesia. [13].

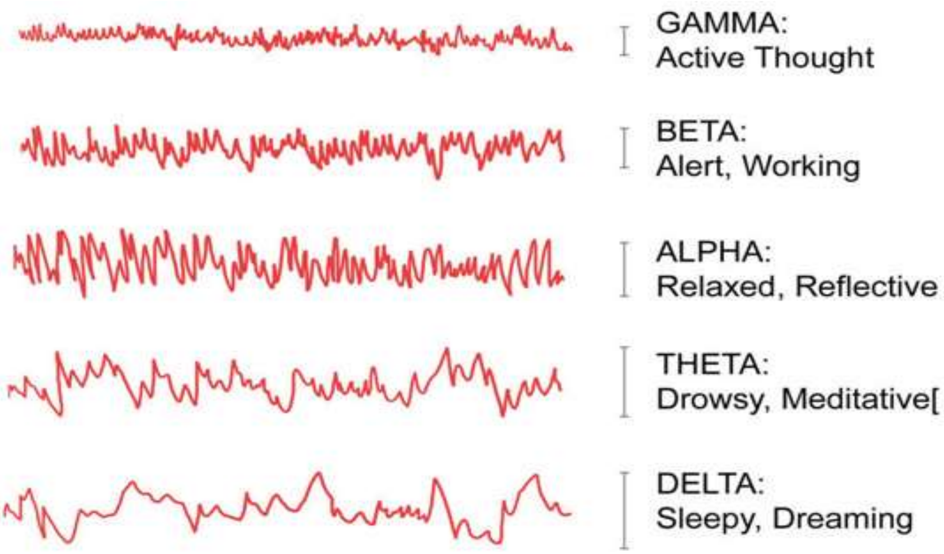

Figure 2.3 Brain Waves [14]

Figure 2.4 displays that the electrode locations used in the 10-20 system are indicated with a letter followed by a number. The letters that are used include F, T, C, P, and O, which correspond with the order of frontal, temporal, central, parietal, and occipital.

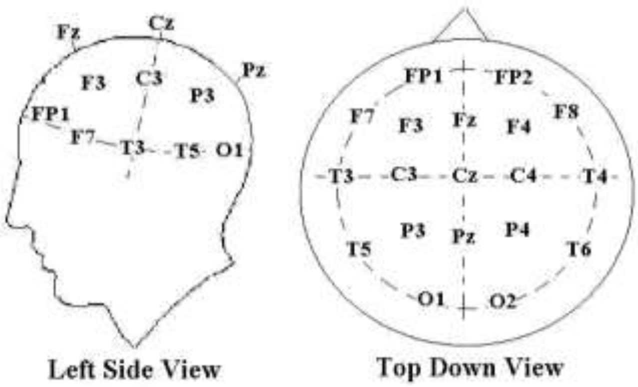

Figure 2.4 The International 10-20 electrode placement systems [15]

2.2.2. Literature studies in BCI Systems using EEG

Brain computer interface systems has been implementing in various growing areas. Because it serves the world as creating a mutual understanding between users and their surrounding, it contributes in several different fields. Mind reading, remote controlling or neuronal rehabilitation in medical field is each one of the instances shows where it can be used. In this section, major application fields based on BCI systems benefiting from brain waves which were chosen from prestigious papers will be discussed.

The recent studies have been conducted on EEG demonstrate that controlling certain components of EEG as shown in figure 2.5 can make people communicate. This communication is build up by using a system called a BCI. Contrary to ECG, which is a procedure to detect muscles and the nerve cells that control motor neurons, BCI communication doesn't need any muscle control to find out the reflection on people's intent [16].

When using rhythmic EEG components or slow negative potential shifts as an input signal for a BCI, internally paced control is possible, whereas evoked potentials need external stimulation of a specific modality and are therefore dependent on sensory input. A BCI can be useful for many different patients. A brand new communication channel is required for patients in a late stage of amyotrophic lateral sclerosis, or any other patients with severe motor handicap [6].

Figure 2.5 EEG Device [17]

Figure 2.6 shows that basic buildings block of brain computer interface systems including Signal Acquisition (EEG), Signal Processing: Feature Extraction and Classification, Output [6].

In patients with spinal cord lesions and paralysed limbs, different types of motor behaviour can be restored with the help of functional electrical stimulation (FES). The FES has to be switched on and off and the stimulation sequence should be set to being modify. A BCI might also be useful for such switching procedures [18].

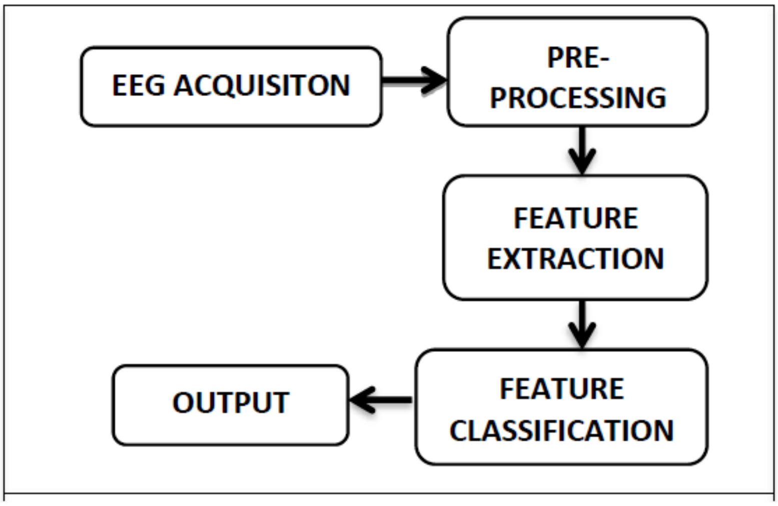

Figure 2.6 Block Diagram of BCI [6]

While breathtaking studies related to EEG based BCI has been carrying out extensively by scientist, latest studies made by Bin He and his team at the University of Minnesota report the potential of an EEG based brain-computer interface to complete tasks successufully corresponding to invasive brain-computer interface. Using advanced functional neuroimaging including bold functional MRI and EEG source imaging, Bin He and collegues were able to identify the co-variation and co-localization of electrophysiological and hemodynamic signals induced by motor imagination [19].

In literature, there are several stimulating studies that have been proposed on different application with EEG based on BCI. One of these inspiring works was done by A.K. Mohamed, et.al. that figured out discrimination between unilateral wrist and finger movements. They used this discrimination factor to interpret EEG signal features employed by BCI in order to control a prosthetic/orthotic hand. In the experiment, the data reflecting characteristics of five right-handed, healthy, male, untrained volunteers in their early twenties was used. A trial were repeated with 20th times for 5 for real movements and 5 for imagined movements which means that patient only imagines the movement. To understand difference and make discrimination between two different movements, some classification techniques were used such as Minimum Distance (MD) and Artificial Neural Network (ANN) classifiers. According to average results obtained from these algorithms are 65 % and 71 % respectively which indicate that offline discrimination between wrist and finger movement when real and imagined movements are on. This is a significant beginning for us to cover essential hand movements based on EEG [2].

The other work related EEG based on BCI systems focused on open and close of right and left hand finger movement of EEG signal as indicated in Figure 2.7. It is important to take account of the fact that eyes of the subjects must be closed when recording EEG signal. Because blinking eyes causes an undesirable artifact during signal. The aim of this study was to analyze the EEG signals for different finger movements. Since Alpha and Beta band of EEG signal are essential band to analyze meaning of finger movement, these two bands were extracted from the orginal signal using Discrete Wavelet Transform. Feature extraction is critical part for understanding discrimination between various movements. Therefore, some features in Time domain and Frequency domain were tested by using feature extraction methods such as Root Mean Square, Simple Square Integral, waveform Length, Modified Mean absolute Value in the time and, Zero Crossing and Slope Sign Change, respectively. The results from obtained feature extraction demonstrated that these six features are the best features in terms of reliability of EEG features. Moreover, authors stated that they can be good candidates for further classification of different finger movements as a promising idea of the study [6].

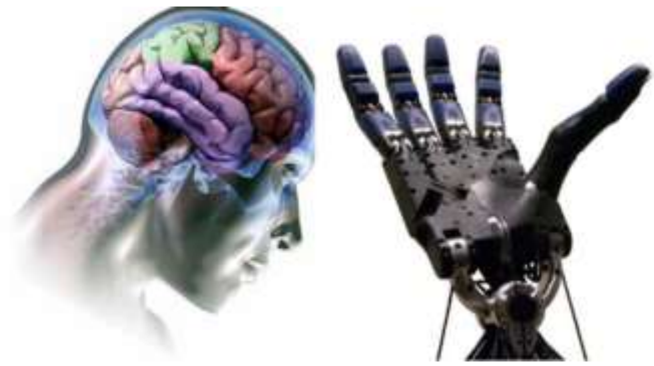

Figure 2.7 An illustration of BCI systems for hand movements [20]

Compared to EEG signals based on BCI systems, there are several studies based on electromyography (EMG) signals using Brain Machine Interface (BMI). A BMI provides the control of machines with specific signal features translated directly from human brain that allows commands to operate the device such as a simple word processing program, a wheelchair, or a neuroprosthesis. The real application based on using BMI was proposed that a 14-electrode EPOC headset and emotiv programme were combined to analyze and classify brain signals to be employed by BMI. Control signals from BMI were used to operate a 7-degree-of-freedom robotic arm. Data collected from EMG indicates the real movement of the facial muscles. Because of each control signal requiring only a couple of minutes to train, each individual trains with a personal set of EEG configuration. Since accuracy on control is crucial for the robotic arm, a generic threshold is applied for all users by measuring EMG signal detections. As a result of this, the training time was proportional with EEG based commands. This study demonstrated that EMG based control has a immediate response and is the best candidate for fMRI, for instance, can directly display areas of the brain that are active compared to EEG predicting what areas are activated by a specific response that uses interpretations [21]. This part of discussion will be discussed through the next chapter as a research topic of this thesis.

Since it is important to comprehend the deep knowledge behind BMI systems, work of S. Vernon et. al. can be a favorable example to take a look at realistic applications of EMG based on BMI. They offered an idea of a mobile-phone-based brain-muscle-computer interface for severely paralyzed persons. The project used a single surface electromyography (sEMG) signal which can be separated in two different frequency bands with specified power levels from human muscles. This analog electrical signal was converted to digital signal to transfer to Android-based mobile phone via an internal A/D converter. The commands are sent to external devices via a bluetooth interface users by the android phone. Users can control the operant condition with simple cursor indicating target activities on phone. Development of this design can be guidance for future applications based on interface monitoring by analyzing sEMG signals [22].

There are two phenomena accepted as playing an important role in BCI systems which are neurological and asynchronous controls. Neurological phenomena are the specific features of the brain activity related with to cognitive response and used to translate into command to control device. Asynchronous control leads patients to operate device when it is active meaning that user intends to control and it is inactivated that they have no desire to control it. In literature, there is a study reporting a new mouse control system used two different methods together that are EEG and EMG to combine these two phenomena. Four commands for the mouse control as an indicator of neurological control was defined and stop command indicating the intention of users like having no desire to control device was implemented which defines asynchronous control. EEG signals were used for the discrimination between left and right or up and down depending on EMG signal making command reverse. According to paper, experimental result had a feasible accuracy to realize the project [23].

CHAPTER 3

EXPERIMENTAL METHOD AND CONFIGURATION

3.1 Material &Methods

In this section, information about subjects, the experimental protocol, EEG recordings and signal processing methods were explained. MATLAB® was chosen for signal analysis and SPSS® package programme was used for paired sample t test and one-way ANOVA tests.

3.1.1 Subjects

The EEG signals were recorded from eight subjects (Table 3.1). The average age of eight subjects was 38. The gender of all subjects was female that were right-handed. Informed consent forms were collected from healthy subjects for voluntarily participation. The study protocol was supported by the ethics committee of the University. Subjects were seated in a comfortable chair and they were asked to perform four types of identified gestures comprising of finger movements. These gestures are classified three different tasks which consist of real, imaginary and random movement. In addition, they were trained before beginning experiment in order to learn movements properly that helps them to imagine and remember these movements during the experiment.

In the beginning of the experiment, subjects were asked to try to not blink their eyes. This is because blinking-eye movement causes an artifact that affects EEG signal. Experiments were made on the right hand and left hand. 3 repetitions were made in all methods for the hands (Table 3.2). Each movement lasted for 3 sec. Before and after each movement there were 2 seconds for preparation time. Test period was adjusted as 29 seconds for each repetition as can be seen in Figure 3.1.

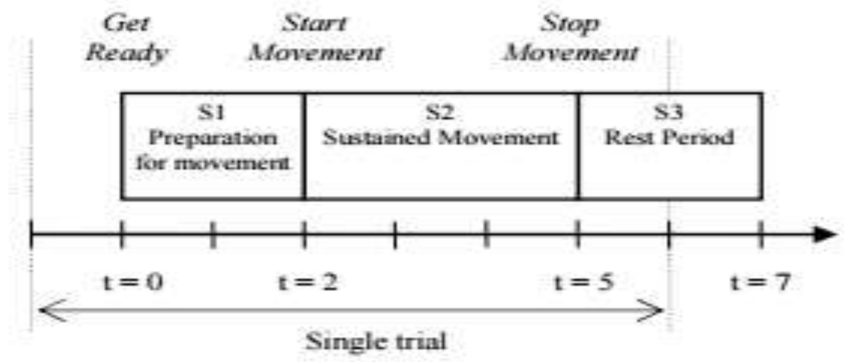

Figure 3.1 Time order and instructions for a single trial [24]

Table 3.1 Characteristics of participants

1.subject	Female	42 age	Healthy
2.subject	Female	41 age	Healthy
3.subject	Female	52 age	Healthy
4.subject	Female	17 age	Healthy
5.subject	Female	45 age	Healthy
6.subject	Female	42 age	Healthy
7.subject	Female	35 age	Healthy
8.subject	Female	36 age	Healthy

Experiments consist of three section called real, random and imaginary parts. In the session of random movements, one of the four different finger movements (thump-up, index-up, little-ring-middle-up together and half-opened hand) was randomly chosen and presented by trainer. According to these random movements, subjects perform repetitive movements of corresponding fingers. It can be said that part of real movements was the easiest session for subjects. They performed finger movements ordered in a sequence with three repetitions. In the last part of the experiment, subjects were asked to imagine the movement represented by trainer but not to make a movement corresponding fingers.

Table 3.2 Experimental procedure

	Random	***Real***	***Imaginary***
Right hand	3 repetition	3 repetition	3 repetition
Left hand	3 repetition	3 repetition	3 repetition

3.1.2 Experimental Task and Procedure

8 healthy people made gestures that have identified which are shown Figure 3.2. The assembled EEG information is classified into 1 of 4 control signals as first movement is thumb up, second movement is index-up, third movement is little-ring-middle-up together and last movement half-opened hand.

Figure 3.2 Experiment setup

Headset (easycap) with fourteen electrodes were situated over 10-20 international system locations. BrainAmp recording program is used for EEG recording Electrodes are attached on frontal lobe (FP1,FP2,F3,F4,F7,F8), central lobe (FC3,FC4), temporal lobe (T7,T8), parietal lobe (P7,P8) and occipital lobe (O1,O2) regions of brain but using 2 reference electrodes (FC3,FC4). Figure 3.3 shows regions of electrodes in regard to the International 10-20 system of BrainAmp.

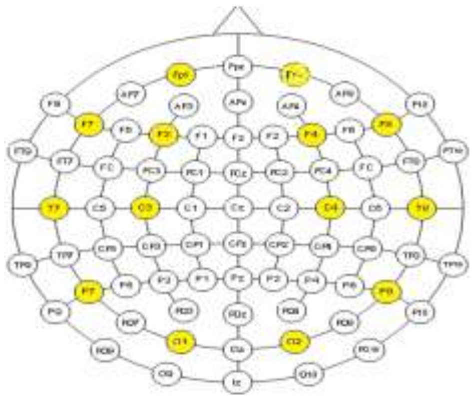

Figure 3.3 The location of regions of electrodes

Figure 3.4 shows process of experiment. First of all is resting period which takes 2 seconds. Then comes 1st movement, it takes 3 seconds. After that third period that is resting 2 comes for 4 seconds. 2nd movement is four periods that takes 3 seconds. Fifth period is resting 3 comes for 4 seconds. 3th movement is sixth period that takes 3 seconds. Seventh period is resting 4 comes for 4 seconds. 4th movement is eighth period that takes 3 seconds. Last one is resting period; it takes 2 seconds like the others.

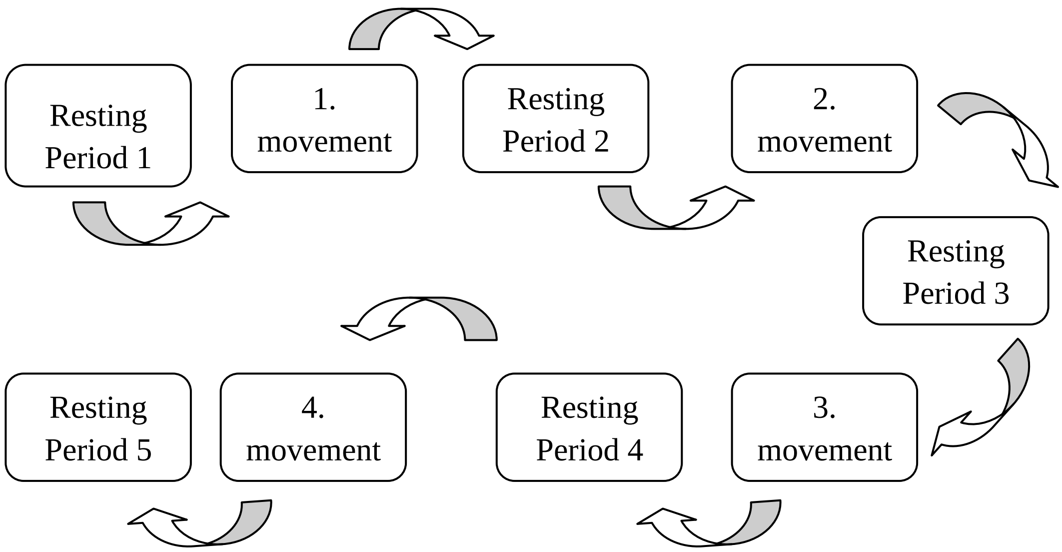

Figure 3.4 Process of experiment

Data were collected from all electrodes; however, a previous study [25] has shown that channels C3 and C4 comprise much important information for this application. Therefore, datasets of channel C3 and C4 were investigated in this thesis study [26]. Moreover, the finger movements are illustrated in the Figure 3.5.

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

Figure 3.5 (a) 1^{st} movement, (b) 2^{nd} movement, (c) 3^{th} movement, (d) 4^{th} movement

3.1.3 Data Acquisition System

V-Amp DC model of Brain Vision Product is used electroencephalogram measurements in Figure 3.6. It can be used also for acqusition of EOG, ECG, EMG, EEG signals. The auxiliary ports consist of sensors for peripheral signals like GSR, blood flow, temperature interface.

Figure 3.6 V-Amp DC model of Brain Vision Product [27]

3.2 Signal Processing

Analyses were made of the data in MATLAB®. Sampling frequency was 250 Hz. 8th order low-pass Butterworth filter (40 Hz) and 8th order Butterworth high-pass filter (0.5Hz) were used for noise elimination with Signal Processing Toolbox in MATLAB® for data preprocessing. Moreover, eye blink and other sources of artifacts were visually eliminated. Signal decomposition using DWT using Daubechies family (db3) and 5th level were preformed to obtain EEG sub-bands. According to the reports in the literature [28], the alpha and beta sub-bands of EEG signals were investigated during different hand movements in real, imaginary and random situations in this thesis.

3.2.1 Wavelet Transform

An entire signal is defined as the sum is multiplied by a shifted (time was changed) and scaled (frequency modulated) samples of a mother wavelet function. The output of continuous wavelet transform, the wavelet coefficients of many of the scale and location functions.

The result is multiplied the appropriate scaled and shifted wavelet by each coefficients that wavelet component of the original data signal. While processing at equal intervals in the Fourier transformation, wavelet transformation processes that at low frequencies in a wide time interval and at high frequencies in small time interval.

Wavelet analysis is widely used in BCI systems. Wavelet transforms to extract the discriminative features from time frequency plots [29], Brain waves (Theta, alpha, beta etc.) can be extracted by this transformation [30]. Wavelet components are decomposed wavelet transform.These are time-domain signals. More detailed information are supplied these signals [31].

The signal f(x) is decomposed onto an orthonorma1 basis, as mentioned previously. Given an original sequence f(n), n E Z, where f(n) is the discrete version of f(x), we derive the difference of information between the approximations of the signal at the resolutions 2j and 2i+. In order to compute this difference, we build an orthonormal basis by dilating and translating a particular function $(x), called a ***mother wavelet,*** where

$$\varphi_2(x) = \sqrt{2^j}\varphi(2^j x) \tag{3.1}$$

Eq.(3.1) is the central equation in the wavelet transform theory. It is observed that if the mother wavelet Ii/(x) is given, then the other wavelet functions can be computed from by dilation and translation [30].

Classic Fourier transform has succeeded in stationary signals processing. But, EEG signal consists of transitory or non-stationary features. Such signals are not appropriate being directly applied by Fourier transform.

The wavelet transform disintegrates a signal into a set of functions obtained by shifting and dilating one single function called mother wavelet [32].

3.2.2 Discrete Wavelet Transform

DWT analysis filters are obtained by repeated application of a discrete signal.The for yielding a fast calculation of WF, Discrete Wavelet Transform which is hinged on sub-band coding is found. The time bandwidth product of the wavelet transform output can be reduced the use of the DWT [33].

- **One level of the transform**

Signal's Discrete Wavelet Transform the x is obtained by sending it through series of filters. At first, examples are passed in low pass filter with impulse respose g which concluded in convolution of x and g:

$$y[n] = (x * g)[n] = \sum_{k=-\infty}^{\infty} x[k]g[n-k] \tag{3.2}$$

At the same time high pass filter divides the signal in level 1. Results give the spesification (obtained from high pass), approximation indices (obtained from low pass). Yet, because half the frequencies of signal have been casted out, half patterns could be got rid of in accordance to Nyquist theory. The filter outcomes can sub-sample by 2. In the formula given below, g stands for high pass while h represents low pass like in Mallat's and common equation:

$$y_{low}[n] = \sum_{k=-\infty}^{\infty} x[k]h[2n-k] \tag{3.3}$$

$$y_{high}[n] = \sum_{k=-\infty}^{\infty} x[k]g[2n-k] \tag{3.4}$$

This division has reduced the time resolution in half since filter outcome characterises the signal. Yet, since each outcome has half frequency band of input, frequency resolution is doubled.

As $\downarrow$ used for subsampling

$$(y\downarrow k)[n] = y[kn] \tag{3.5}$$

This equation is able to written.

$$y_{low} = (x * g) \downarrow 2 \tag{3.6}$$

$$y_{high} = (x * h) \downarrow 2 \tag{3.7}$$

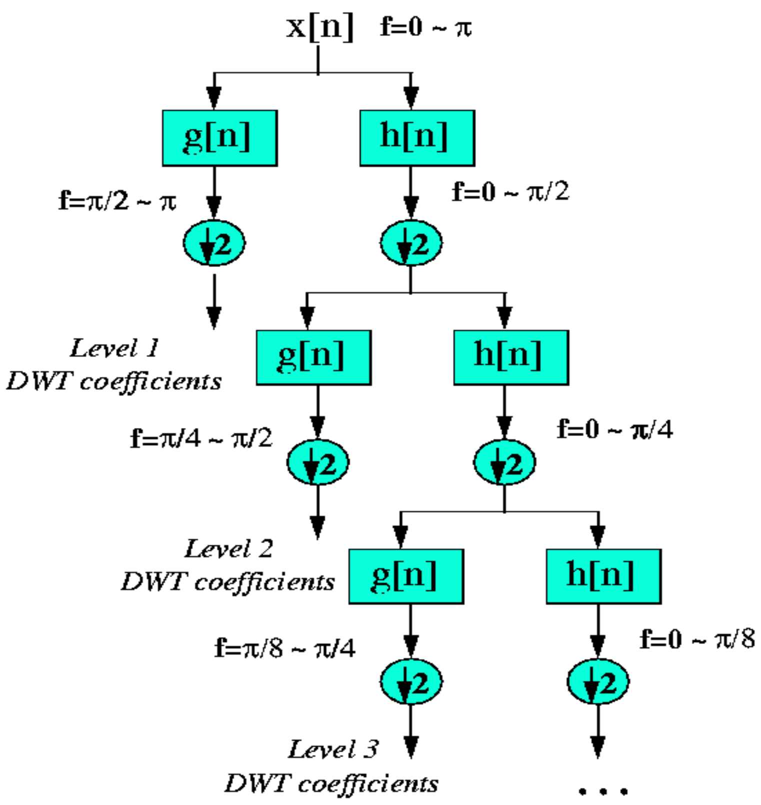

Figure 3.7 The subband coding algorithm [34]

However calculating a calculate convolution $x * g$ with forward down sampling takes much time.The Lifting schema is an optimization which puts above two computations to blank page.This division is used repeteadly to increase the frequency resolution and the approximation coefficients divided with high and low pass filters and then down-sampled. This is illustrated as a binary tree with points (nodes) which represent a sub-space with a different time-frequency localisation. The tree is known as a filter bank [35].

The above method is also named as the sub-band coding, is able to use for further division. In each stage, the filtering and sub-sampling will conclude half the number of samples (and therefore half the time resolution) and half the frequency band spanned (and therefore doublehe frequency resolution). Figure 3.7 shows that method, where x[n] is the original signal to be divided (decomposed), and h[n] and g[n] are lowpass and highpass filters, respectively. The bandwidth of the signal in each stage is signed on the figure as "f" [34].

3.3 Feature Extraction

In literature there are lots of feature extractions which we examined. In those papers power spectral density values were found as statistically significant. Therefore, in this thesis power spectral density values of the EEG signals (sub-bands of EEG signals) were extracted and evaluated.

3.3.1 Power Spectral Density

It is easy to find the rate or the energy value of the signals that are defined numerically according to different frequencies but we have to use different method if we have a random signal.To define the change of the signal based on time, autocorrelation function can be used. This can be functional if the Fourier transform of a random time signal is itself random, and because of that little use calculating transfer relationships. [36].

Let {Xn} show a weakly constant random process with an autocovariance function that comes to an end "sufficiently quickly" in the sense.

$$\sum_{k=-\infty}^{\infty}|\gamma(k)| < \infty \qquad (3.8)$$

If (3.8) is satisfied,

$$H(\omega)= \frac{1}{2\pi}\sum_{k=-\infty}^{\infty}\gamma(k)e^{-j\omega k} \qquad -\pi < \omega < \pi \qquad (3.9)$$

Exists and is called the "power spectral density". It is straightforward to illustrate (Multiply (3.6) by eiωl, and integrate from −π to π, to give)

$$\int_{-\pi}^{\pi}h(\omega)e^{j\omega l}d\omega = \sum_{k=-\infty}^{\infty}\gamma(k)\frac{1}{2\pi}\int_{-\pi}^{\pi}e^{-j\omega(k-l)}d\omega = \sum_{k=-\infty}^{\infty}\gamma(k)\delta_{kl} =\gamma(l) \qquad (3.10)$$

$$\gamma(k) = \int_{-\pi}^{\pi}h(\omega)\, e^{-j\omega k}d\omega \qquad k=0, \pm1, \pm2 \ldots \qquad (3.11)$$

γ(k) and h(ω) are a "Fourier Transform pair". If you have one,you can get the other. They confirm complementary, but equivalent, information on {Xn} in the lag (k) and frequency (ω) domains.

Setting k = 0 in (3.11) grants the sequent statement to the variance of a process with regards to its PSD:

$$\sigma_X^2 = \int_{-\pi}^{\pi} h(\omega)d\omega \tag{3.12}$$

Figure 3.8 shows that PSD of an AR (1) process in Gaussian Distribition with a = 0.7. Frequency ω ranges from $-\pi$ to π. (Note that a frequency of π corresponds to a period of 2Δ.) if 0 ≤ ω1 < ω2 ≤ π then 2 $ ω2 ω1 h(ω)dω is the contribution to the variance from variations with frequencies between ω1 and ω2.

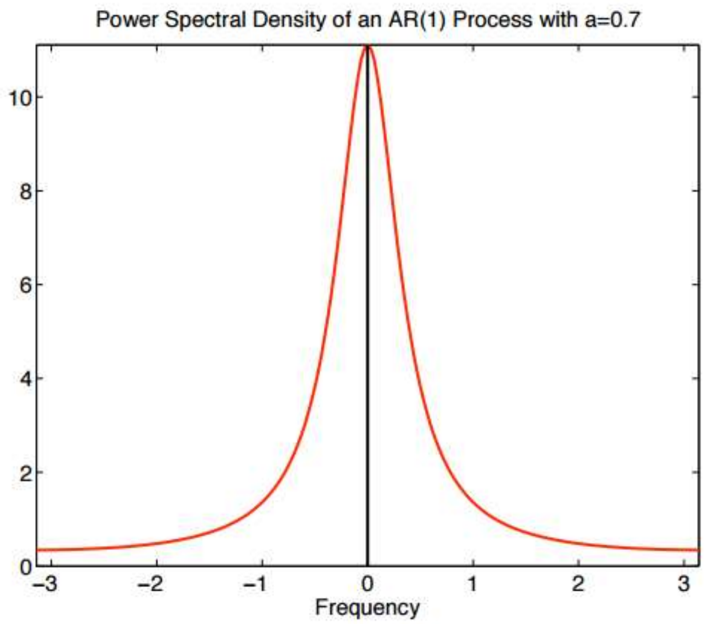

Figure 3.8 PSD of an AR (1) process in Gaussian Distribition with a = 0.7 [37]

3.4 Statistical Analysis

In this study, four different movements were applied in three sessions which are random, real and imaginary situations. For the analysing data we used paired sample t test and one-way ANOVA in which a significant level of 5% was used. SPSS® (v.20) was used for statistical analysis. We chose them to be suitable for a normal distribution. For the pair sample t test, pairs are chosen in the order of hand movements between 1-2, 1-3,1-4, 2-3, 2-4, 3-4. On the other hand, we investigated each of the extracted features in four hand movements using one-way ANOVA.

3.4.1 Independent Paired Sample T Test

The assumption is accepted that independent two groups are in independent universes. But, examination may be needed that in different circumstances, how the same experimental object behaves in experimental study [38]. The main target is to research that results which are obtained from different circumstances is different or not [38].

$$t=\frac{\frac{\sum d}{N}}{\sqrt{\frac{\sum d^2-\frac{(\sum d)^2}{N}}{N(N-1)}}} \qquad (3.13)$$

In formula, d is the difference between matched samples and N is number of samples [39].

3.4.2 One-Way ANOVA Test

Anova test or analyze is used to compare between averages or expected values of two independent groups or more independent groups. Two fundamental assumptions are in this test. One of assumption is that every group has Gaussian (normal) distribution. Second of assumption is that variances of groups are homogenous relatively.

$$H_O: \mu_1 = \mu_2 = \mu_3 = \cdots = \mu_K \qquad (3.14)$$

Where μ= expected value and k= number of expected values. If, however, the one-way ANOVA returns a significant result, alternative hypothesis (H_A) is accepted, which is that there are at least 2 group expected values that are significantly different from each other [40].

CHAPTER 4

RESULTS AND ANALYSIS

In this chapter, results of analyzed EEG signals were explained. Recorded EEG signals from 8 healthy subjects were decomposed into their sub-bands using DWT approach then the total area under the PSD curve of alpha and beta sub-bands were extracted and investigated statistically.

Table 4.1 compares the p values of sequential left hand movements in alpha sub-band in regard to paired sample t-test in FC3 and FC4 brain regions between imaginary (img), real and random (rndm) situations. For example, the first row in the table compares these situations between Movement 1 and movement 2.

Table 4.1 Four movements in all situations with left-hand, in alpha band from frontocentral 3 and 4 zones of the brain

	ALPHA BAND, LEFT HAND					
	FC3			FC4		
P	İMG	REAL	RNDM	İMG	REAL	RNDM
MOV1-MOV2	0,436	0,549	0,321	0,333	0,225	0,662
MOV1-MOV3	0,906	0,014	0,318	0,994	0,024	0,515
MOV1-MOV4	0,272	0,218	0,79	0,373	0,663	0,682
MOV2-MOV3	0,461	0,163	0,851	0,595	0,406	0,898
MOV2-MOV4	0,711	0,112	0,678	0,866	0,282	0,789
MOV3-MOV4	0,417	0,049	0,725	0,589	0,164	0,929

Figure 4.1 shows the total area of PSD during left hand - imaginary situation from FC3 electrode, in alpha band. In the case of imaginary situation according to this figure of PSD comparison, it has been found that the 4^{th}movement has higher PSD values than the other movements' PSD and it has been found that the 1^{st} movement has lower PSD values than the other movements' PSD.

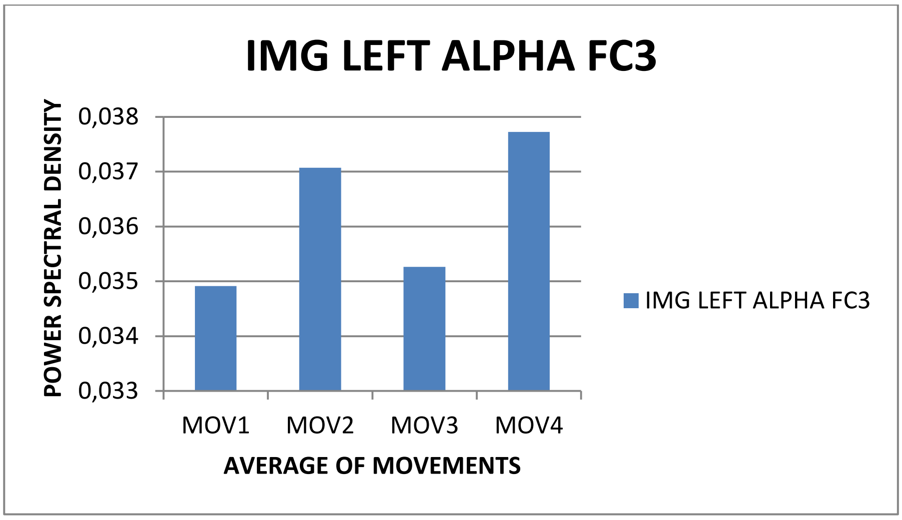

Figure 4.1 Four movements in imaginary situation with left-hand, in alpha band from frontocentral 3 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test.Figure 4.2 shows that the p-values of sequential left hand movements in alpha sub-band in regard to paired sample t-test in imaginary (img) situation from the FC3 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

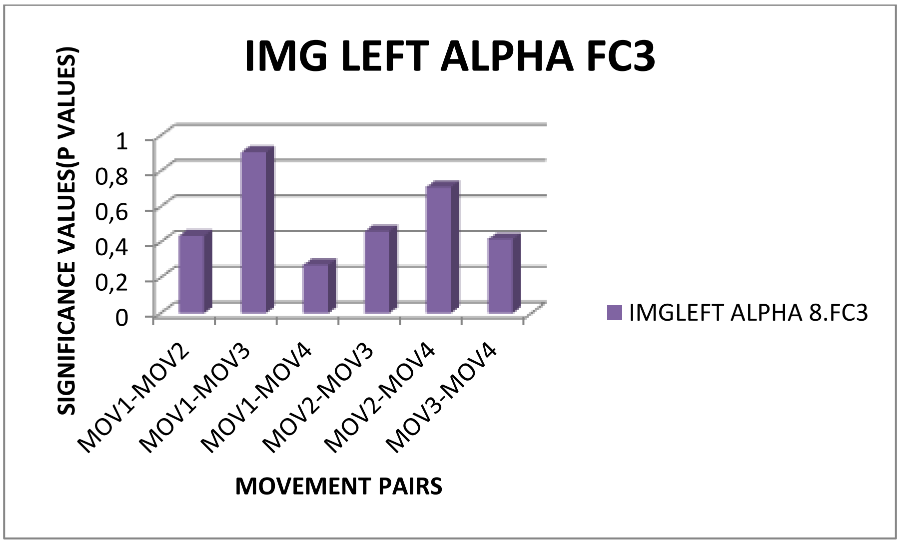

Figure 4.2 Four movements in imaginary situation with p-values of sequential left-hand, in alpha band from frontocentral 3 zone of the brain

Figure 4.3 shows the total area of PSD during left hand - imaginary situation from FC4 electrode, in alpha band. In the case of imaginary situation according to this figure of PSD comparison, it has been found that the 4th movement has higher PSD values than the other movements' PSD. and it has been found that the 2nd movement has lower PSD values than the other movements' PSD and it has been found that the 3th movement has lower PSD values than the other movements' PSD.

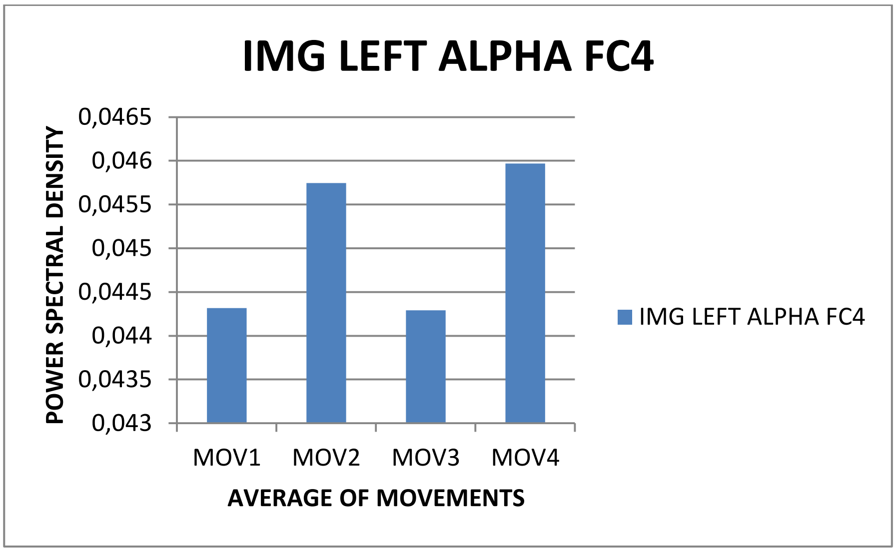

Figure 4.3 Four movements in imaginary situation with left-hand, in alpha band from frontocentral 4 zone of the brain

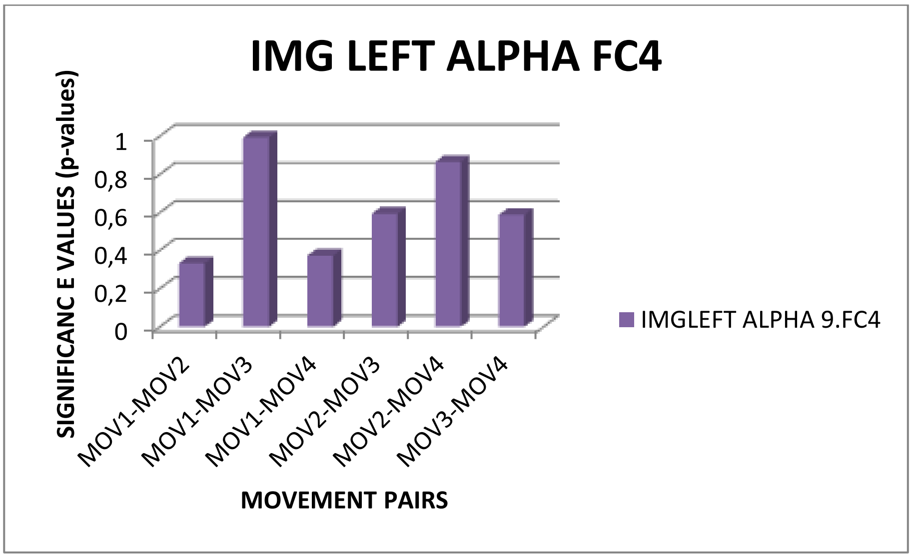

Figure 4.4 Four movements in imaginary situation with p-values of sequential left-hand, in alpha band from frontocentral 4 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.4 shows that the p-values of sequential left hand movements in alpha sub-band in regard to paired sample t-test in imaginary (img) situation from the FC3 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

Figure 4.5 shows the total area of PSD during left hand - real situation from FC3 electrode, in alpha band. In the case of real situation according to this figure of PSD comparison, it has been found that the 3thmovement has higher PSD values than the other movements' PSD and it has been found that the 4th movement has lower PSD values than the other movements' PSD.

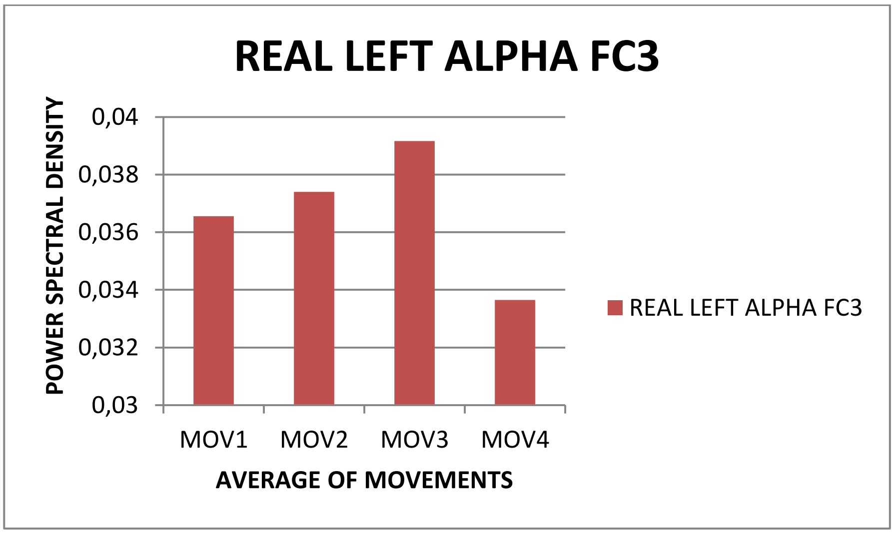

Figure 4.5 Four movements in real situation with left-hand, in alpha band from frontocentral 3 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.6 shows that the p values of sequential left hand movements in alpha sub-band in regard to paired sample t-test in real situation from the FC3 of brain regions.

When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant. However, the reason of power spectral density values were less than P value, mov1-

mov3 and mov3-mov4 values were meaningful statistically. These movements were meaningful statistically which was show that movements can be separated.

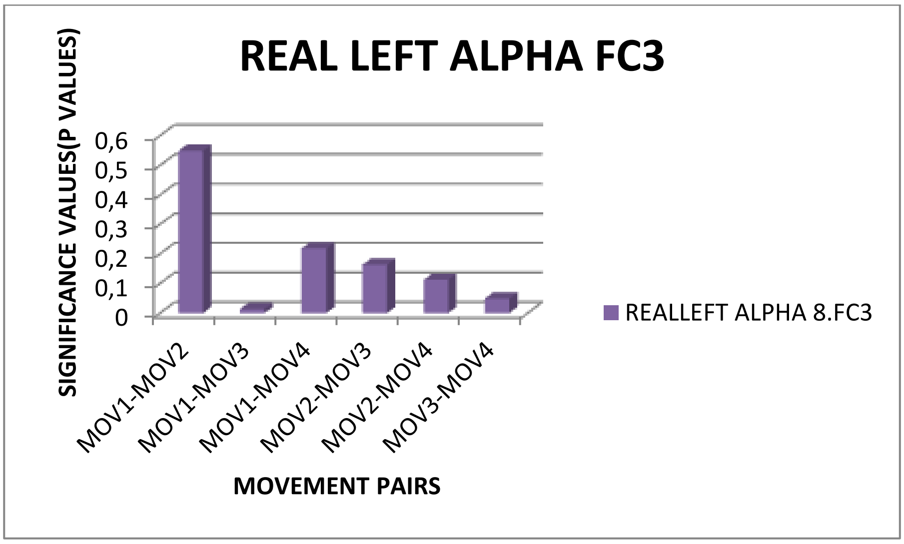

Figure 4.6 Four movements in real situation with p-values of sequential left-hand, in alpha band from frontocentral 3 zone of the brain

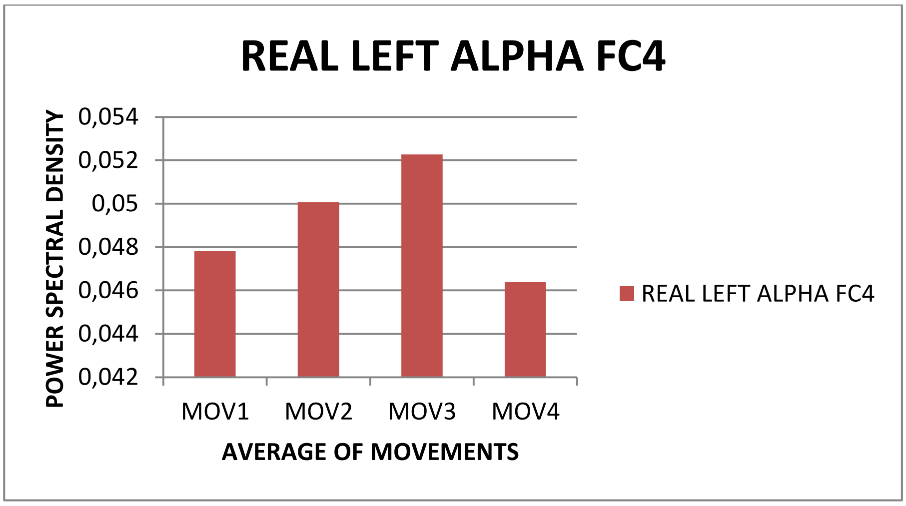

Figure 4.7 Four movements in real situation with left-hand, in alpha band from frontocentral 4 zone of the brain

Figure 4.7 shows the total area of PSD during left hand - real situation from FC4 electrode, in alpha band. In the case of real situation according to this figure of PSD comparison, it has been found that the 3thmovement has higher PSD values than the other movements' PSD and it has been found that the 4th movement has lower PSD values than the other movements' PSD.

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.8 shows that the p values of sequential left hand movements in alpha sub-band in regard to paired sample t-test in real situation from the FC4 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant. However, the reason of power spectral density values were less than P value, mov1-mov3 is meaningful statistically .These movements were meaningful statistically which were show that movements can be seperated.

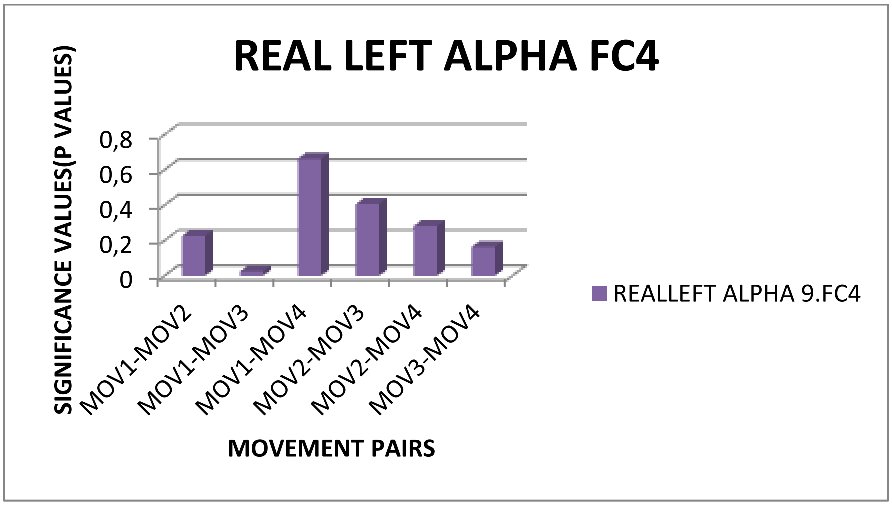

Figure 4.8 Four movements in real situation with p-values of sequential left-hand, in alpha band from frontocentral 4 zone of the brain

Figure 4.9 shows the total area of PSD during left hand - random situation from FC3 electrode, in alpha band. In the case of random situation according to this figure of PSD comparison, it has been found that the 2ndmovement has higher PSD values than the other movements' PSD and it has been found that the 1st movement has lower PSD values than the other movements' PSD.

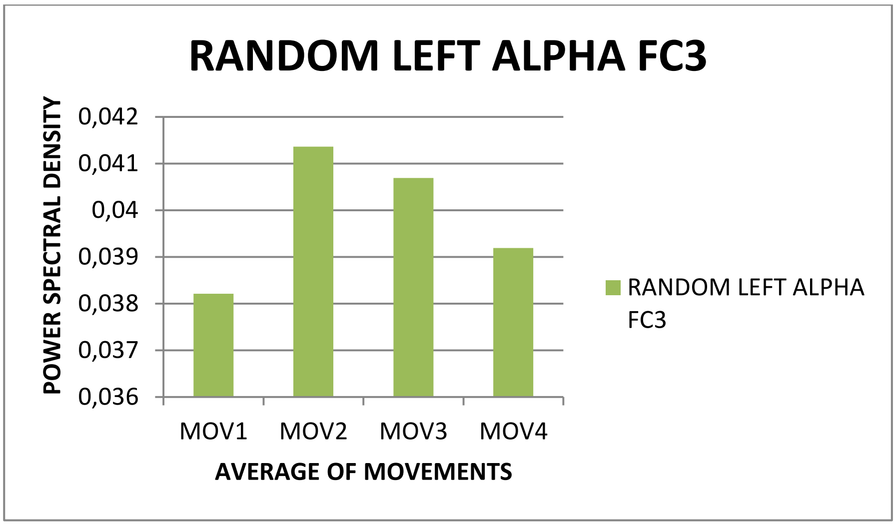

Figure 4.9 Four movements in random situation with left-hand, in alpha band from frontocentral 3 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.10 shows that the p-values of sequential left hand movements in alpha sub-band in regard to paired sample t-test in random situation from the FC3 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

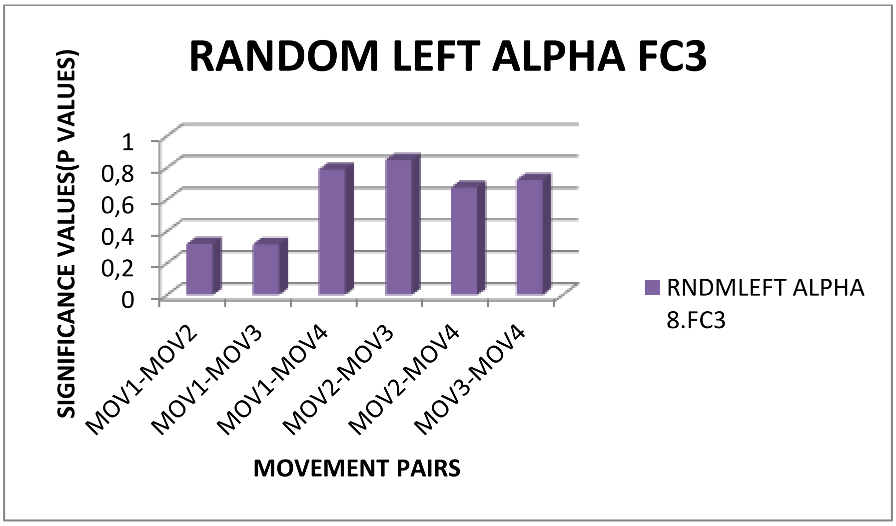

Figure 4.10 Four movements in random situation with p-values of sequential left-hand, in alpha band from frontocentral 3 zone of the brain

Figure 4.11 shows the total area of PSD during left hand - random situation from FC4 electrode, in alpha band. In the case of random situation according to this figure of PSD comparison, it has been found that the 4thmovement has higher PSD values than the other movements' PSD and it has been found that the 1st movement has lower PSD values than the other movements' PSD.

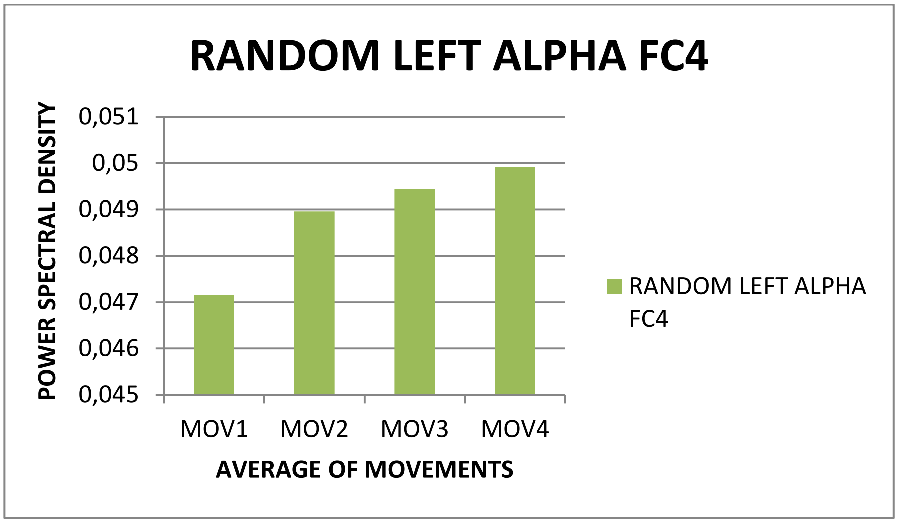

Figure 4.11 Four movements in random situation with left-hand, in alpha band from frontocentral 4 zone of the brain

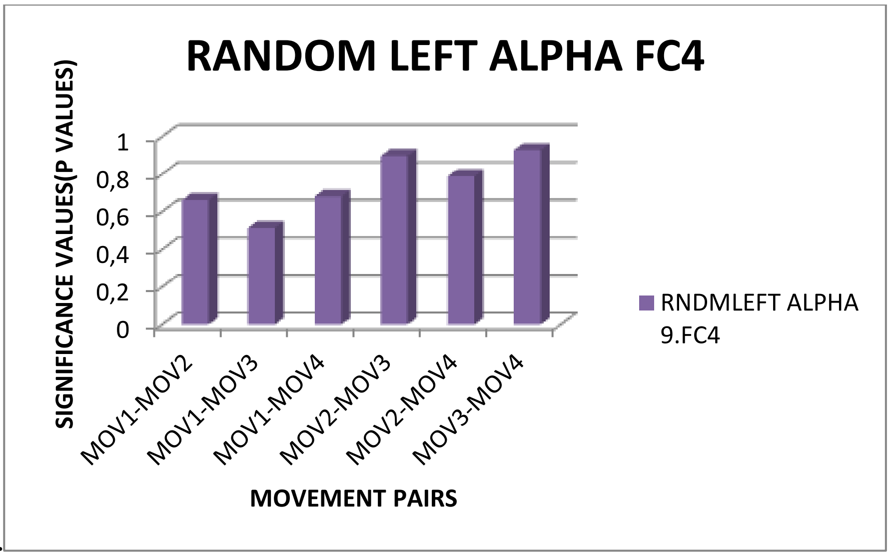

Figure 4.12 Four movements in random situation with p-values of sequential left-hand, in alpha band from frontocentral 4 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.12 shows that the p-values of sequential left hand movements in alpha sub-band in regard to paired sample t-test in random situation from the FC4 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

Table 4.2 compares the p values of sequential right hand movements in alpha sub-band in regard to paired sample t-test in FC3 and FC4 brain regions between imaginary (img), real and random (rndm) situations. For example, the first row in the table compares these situations between Movement 1 and movement 2.

Table 4.2 Four movements in all situation with right-hand, in alpha band from frontocentral 3 and 4 zones of the brain

	ALPHA BAND, RIGHT HAND					
	FC3			FC4		
P	İMG	REAL	RNDM	İMG	REAL	RNDM
MOV1-MOV2	0,526	0,248	0,852	0,925	0,54	0,809
MOV1-MOV3	0,702	0,678	0,825	0,425	0,92	0,198
MOV1-MOV4	0,701	0,647	0,774	0,265	0,781	0,34
MOV2-MOV3	0,514	0,065	0,934	0,492	0,208	0,174
MOV2-MOV4	0,402	0,05	0,485	0,555	0,494	0,239
MOV3-MOV4	0,465	0,72	0,584	0,234	0,665	0,591

Figure 4.13 shows the total area of PSD during right hand - imaginary situation from FC4 electrode, in alpha band. In the case of imaginary situation according to this figure of PSD comparison, it has been found that the 2^{nd}movement has higher PSD values than the other movements' PSD and it has been found that the 4^{th} movement has lower PSD values than the other movements' PSD.

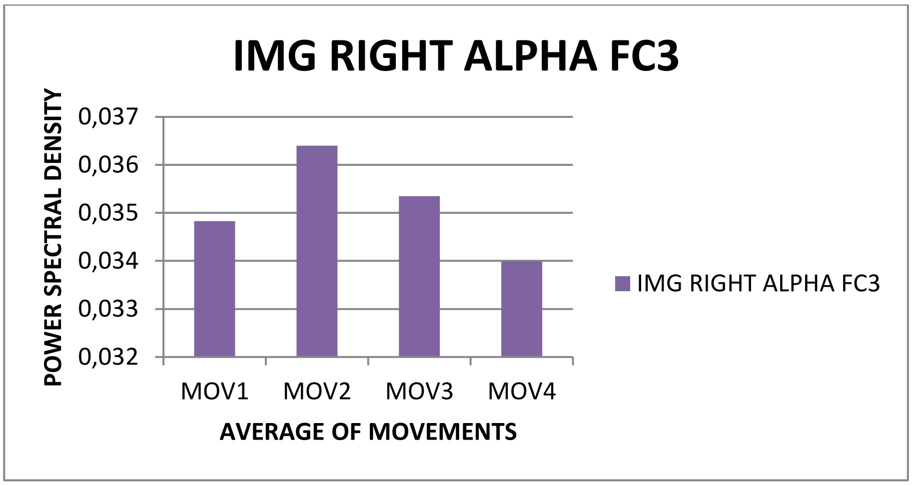

Figure 4.13 Four movements in imaginary situation with right-hand, in alpha band from frontocentral 3 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.14 shows that the p-values of sequential right hand movements in alpha sub-band in regard to paired sample t-test in imaginary situation from the FC3 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

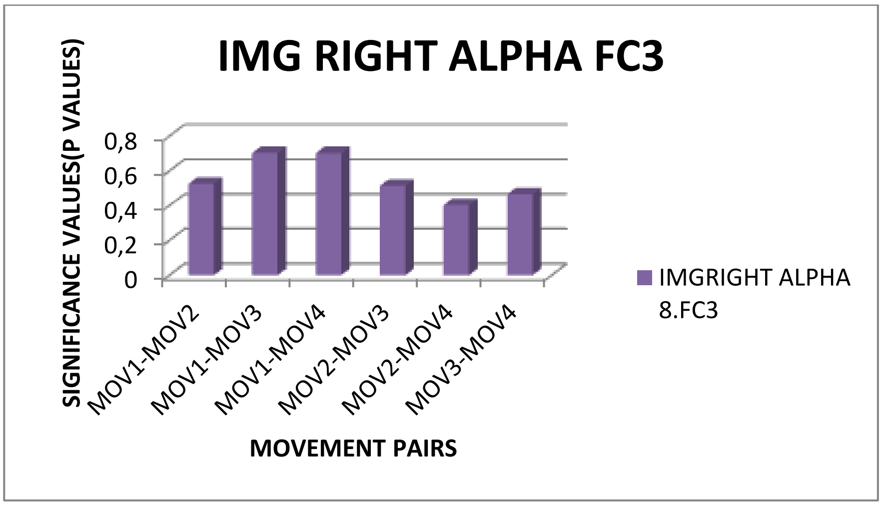

Figure 4.14 Four movements in imaginary situation with p-values of sequential right-hand, in alpha band from frontocentral 3 zone of the brain

Figure 4.15 shows the total area of PSD during left hand - random situation from FC3 electrode, in alpha band. In the case of random situation according to this figure of PSD comparison, it has been found that the 3th movement has higher PSD values than the other movements' PSD and it has been found that the 4th movement has lower PSD values than the other movements' PSD.

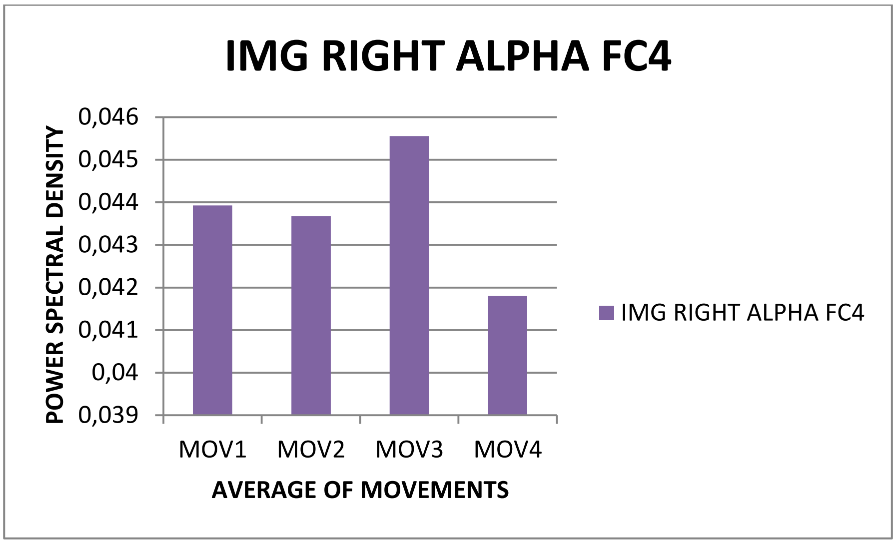

Figure 4.15 Four movements in imaginary situation with right-hand, in alpha band from frontocentral 4 zone of the brain

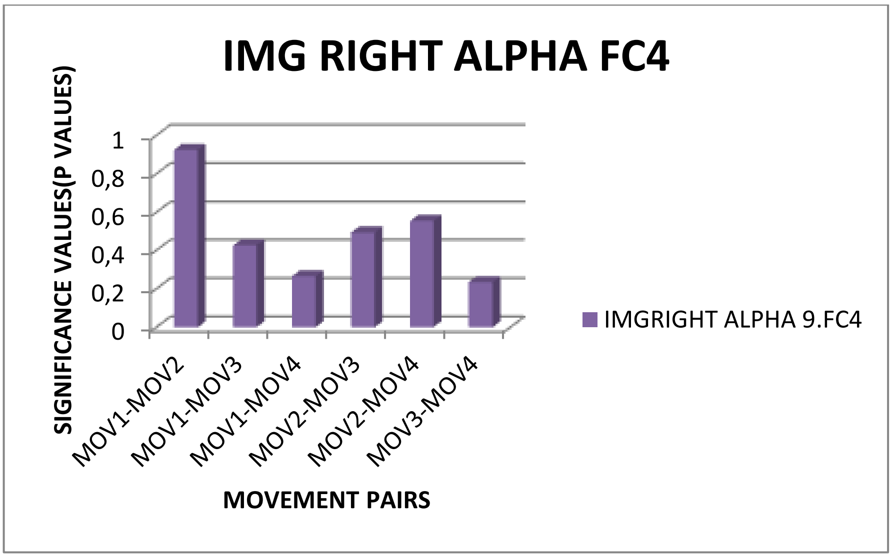

Figure 4.16 Four movements in imaginary situation with p-values of sequential right-hand, in alpha band from frontocentral 4 zone of the brain

Figure 4.17 shows the total area of PSD during right hand - real situation from FC3 electrode, in alpha band. In the case of real situation according to this figure of PSD comparison, it has been found that the 2nd movement has higher PSD values than the other movements' PSD and it has been found that the 1st movement has lower PSD values than the other movements' PSD.

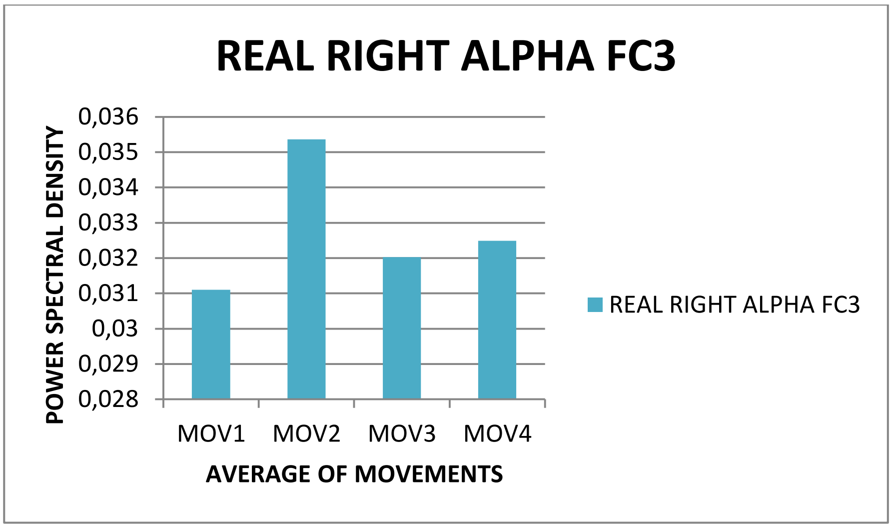

Figure 4.17 Four movements in real situation with right-hand, in alpha band from frontocentral 3 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.18 shows that the p values of sequential right hand movements in alpha sub-band in regard to paired sample t-test in real situation from the FC3 of brain regions.

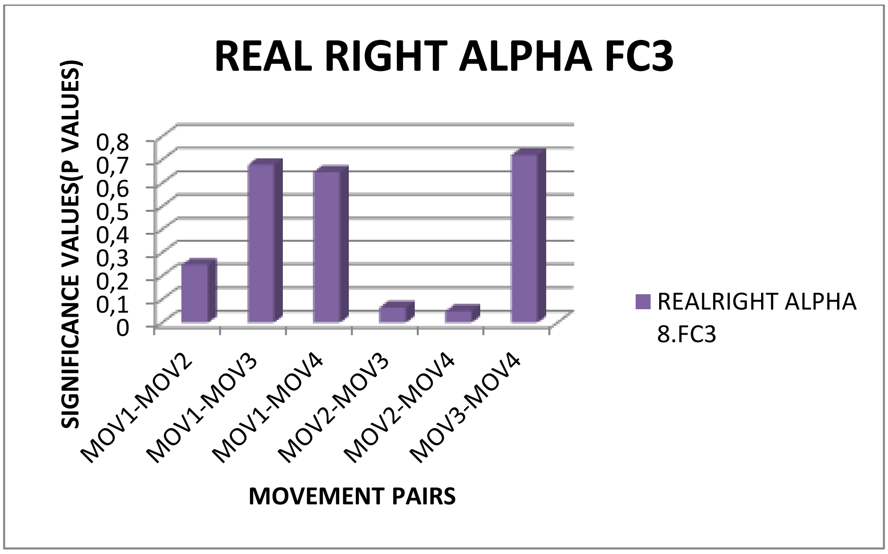

Figure 4.18 Four movements in real situation with p-values of sequential right-hand, in alpha band from frontocentral 3 zone of the brain

When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant. However, the reason of power spectral density values were less than P value, mov2-mov4 value was meaningful statistically. These movements were meaningful statistically which was show that movements can be seperated.

Figure 4.19 shows the total area of PSD during right hand - real situation from FC4 electrode, in alpha band. In the case of real situation according to this figure of PSD comparison, it has been found that the 2nd movement has higher PSD values than the other movements' PSD and it has been found that the 3th movement has lower PSD values than the other movements' PSD.

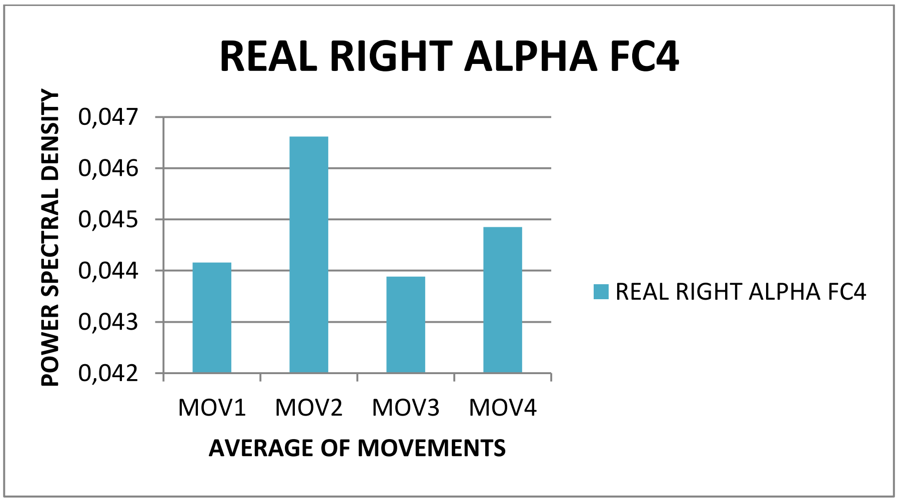

Figure 4.19 Four movements in real situation with right-hand, in alpha band from frontocentral 4 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.20 shows that the p-values of sequential right hand movements in alpha sub-band in regard to paired sample t-test in real situation from the FC4 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

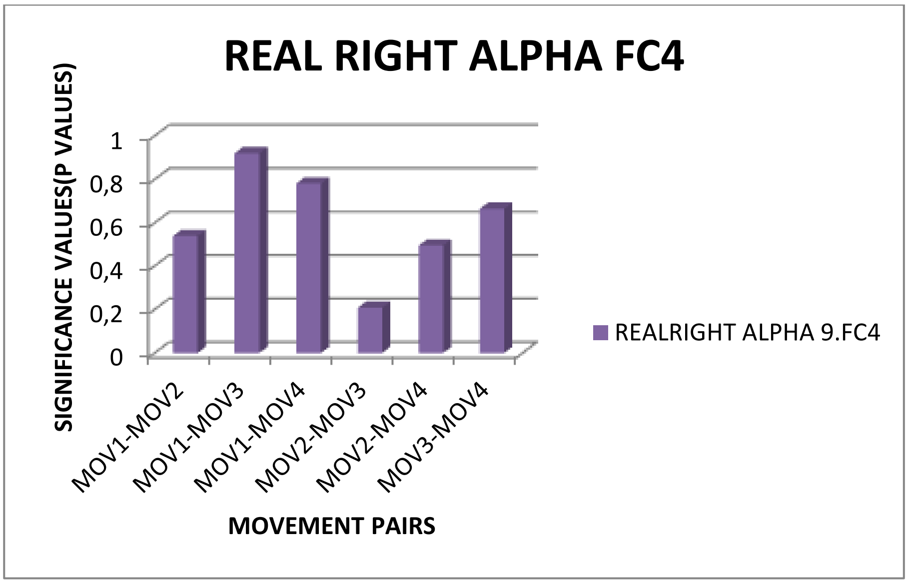

Figure 4.20 Four movements in real situation with p-values of sequential right-hand, in alpha band from frontocentral 4 zone of the brain

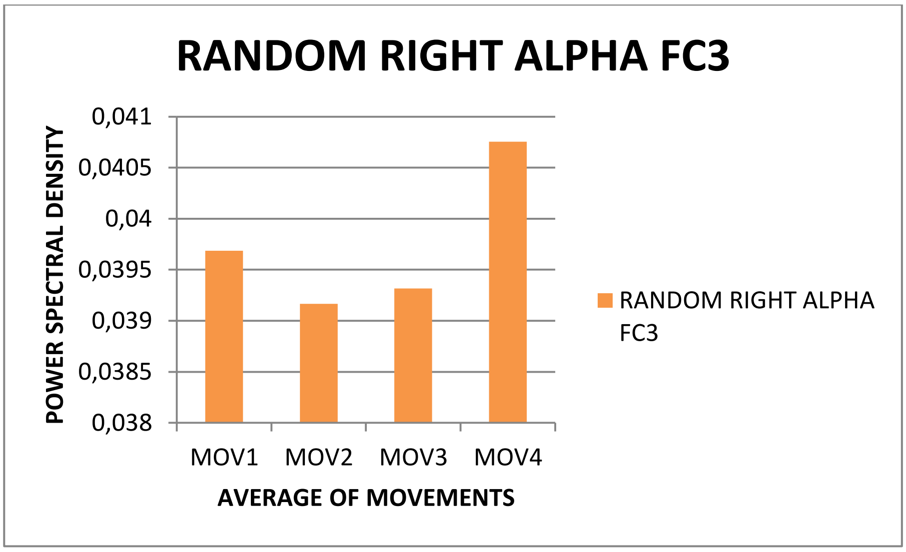

Figure 4.21 Four movements in random situation with right-hand, in alpha band from frontocentral 3 zone of the brain

Figure 4.21 shows the total area of PSD during right hand -random situation from FC3 electrode, in alpha band. In the case of random situation according to this figure of PSD comparison, it has been found that the 4th movement has higher PSD values than the other movements' PSD and it has been found that the 2nd movement has lower PSD values than the other movements' PSD.

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.22 shows that the p-values of sequential right hand movements in alpha sub-band in regard to paired sample t-test in random situation from the FC3 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

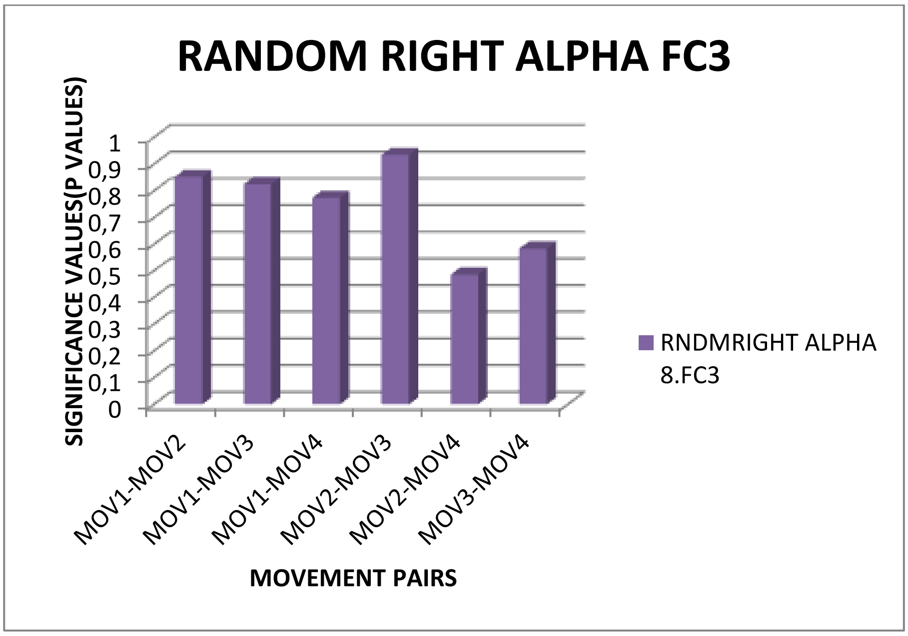

Figure 4.22 Four movements in random situation with p-values of sequential right-hand, in alpha band from frontocentral 3 zone of the brain

Figure 4.23 shows the total area of PSD during right hand -random situation from FC4 electrode, in alpha band. In the case of random situation according to this figure of PSD comparison, it has been found that the 4^{th}movement has higher PSD values than the other movements' PSD and it has been found that the 2^{nd} movement has lower PSD values than the other movements' PSD.

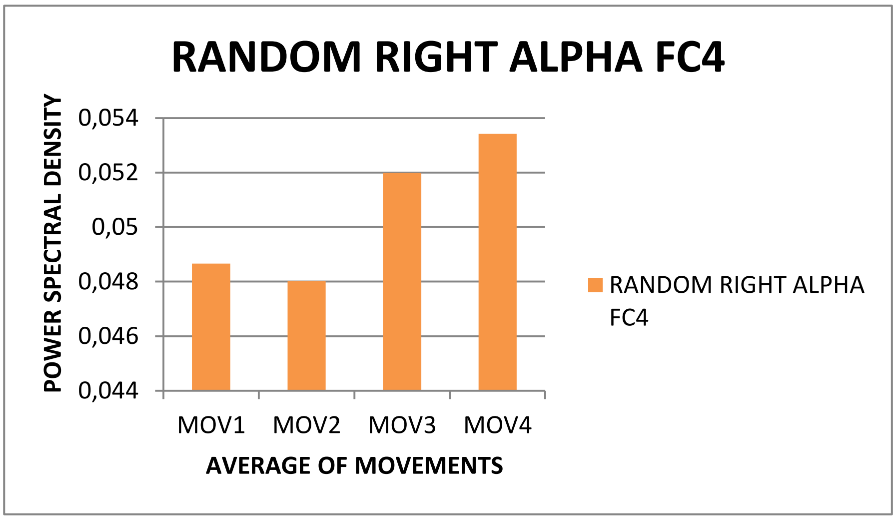

Figure 4.23 Four movements in random situation with right-hand, in alpha band from frontocentral 4 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.24 shows that the p-values of sequential right hand movements in alpha sub-band in regard to paired sample t-test in random situation from the FC4 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

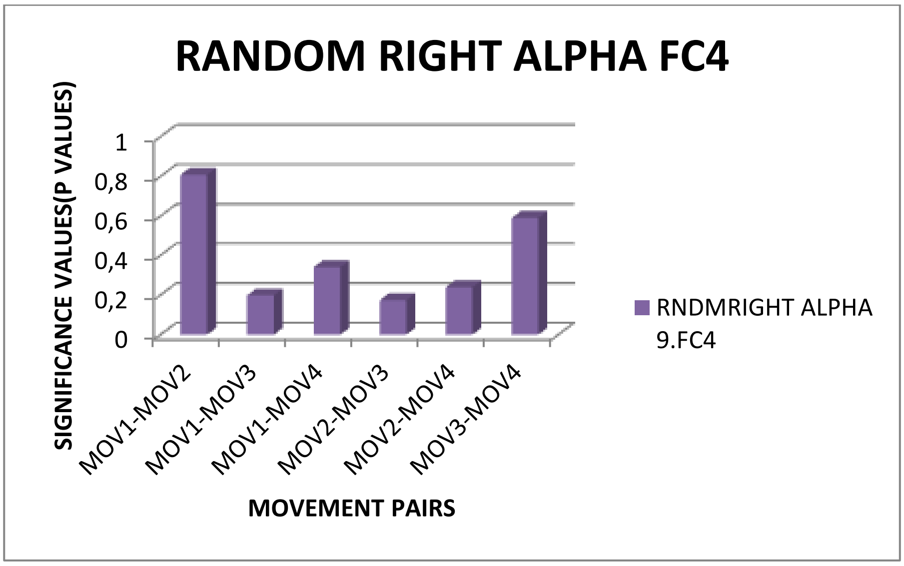

Figure 4.24 Four movements in random situation with p-values of sequential right-hand, in alpha band from frontocentral 4 zone of the brain

Table 4.3 compares the p values of sequential left hand movements in beta sub-band in regard to paired sample t-test in FC3 and FC4 brain regions between imaginary (img), real and random (rndm) situations. For example, the first row in the table compares these situations between Movement 1 and movement 2.

Table 4.3 Four movements in all situations with left-hand, in beta band from frontocentral 3 and 4 zones of the brain

	BETA BAND, LEFT HAND					
	FC3			FC4		
P	İMG	REAL	RNDM	İMG	REAL	RNDM
MOV1-MOV2	0,517	0,263	0,517	0,713	0,586	0,258
MOV1-MOV3	0,685	0,176	0,778	0,688	0,664	0,21
MOV1-MOV4	0,772	0,67	0,524	0,862	0,666	0,771
MOV2-MOV3	0,362	0,756	0,368	0,537	0,915	0,776
MOV2-MOV4	0,33	0,422	0,954	0,667	0,831	0,426
MOV3-MOV4	0,935	0,053	0,463	0,802	0,93	0,456

Figure 4.25 shows the total area of PSD during left hand -imaginary situation from FC3 electrode, in beta band. In the case of imaginary situation according to this figure of PSD comparison, it has been found that the 3rd movement has higher PSD values than the other movements' PSD and it has been found that the 2nd movement has lower PSD values than the other movements' PSD.

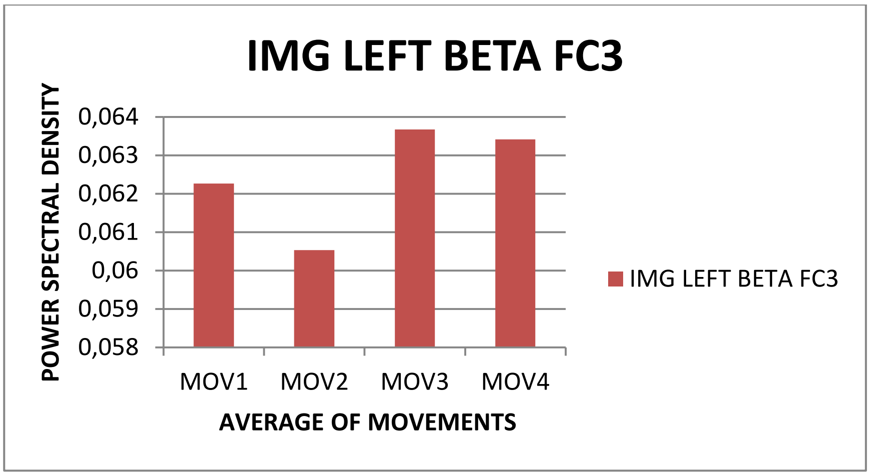

Figure 4.25 Four movements in imaginary situation with right-hand, in alpha band from frontocentral 3 zone of the brain

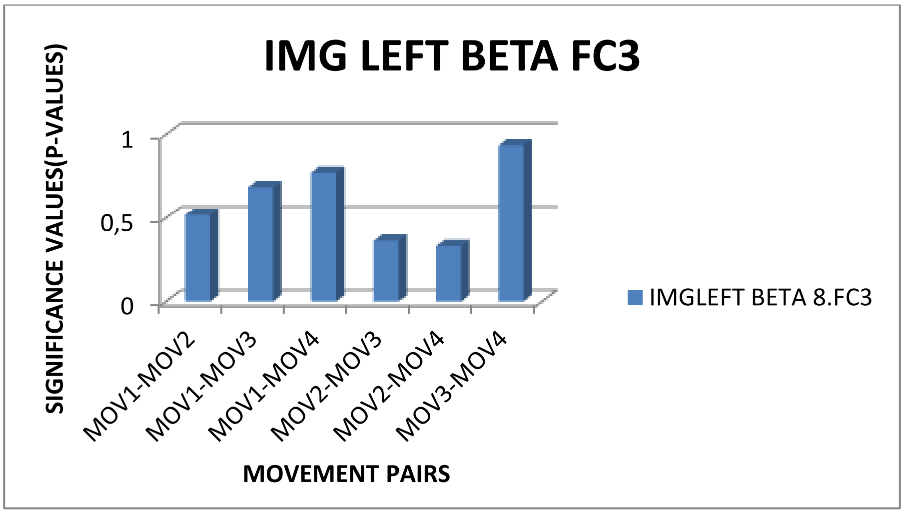

Figure 4.26 Four movements in imaginary situation with p-values of sequential left-hand, in beta band from frontocentral 3 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.26 shows that the p-values of sequential left and movements in beta sub-band in regard to paired sample t-test in imaginary situation from the FC3 of brain regions.When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

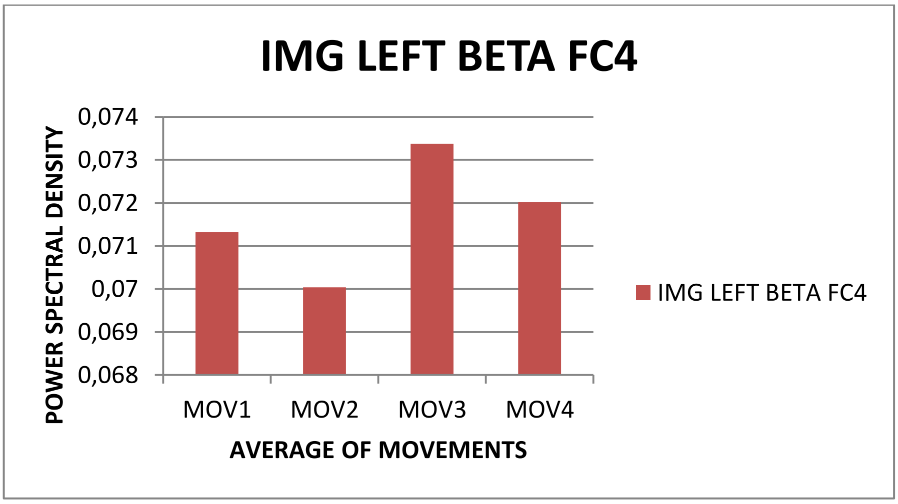

Figure 4.27 Four movements in imaginary situation with left-hand, in beta band from frontocentral 4 zone of the brain

Figure 4.27 shows the total area of PSD during left hand -imaginary situation from FC3 electrode, in beta band. In the case of imaginary situation according to this figure of PSD comparison, it has been found that the 3th movement has higher PSD values than the other movements' PSD and it has been found that the 2nd movement has lower PSD values than the other movements' PSD.

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.28 shows that the p-values of sequential left and movements in beta sub-band in regard to paired sample t-test in imaginary situation from the FC4 of brain regions.

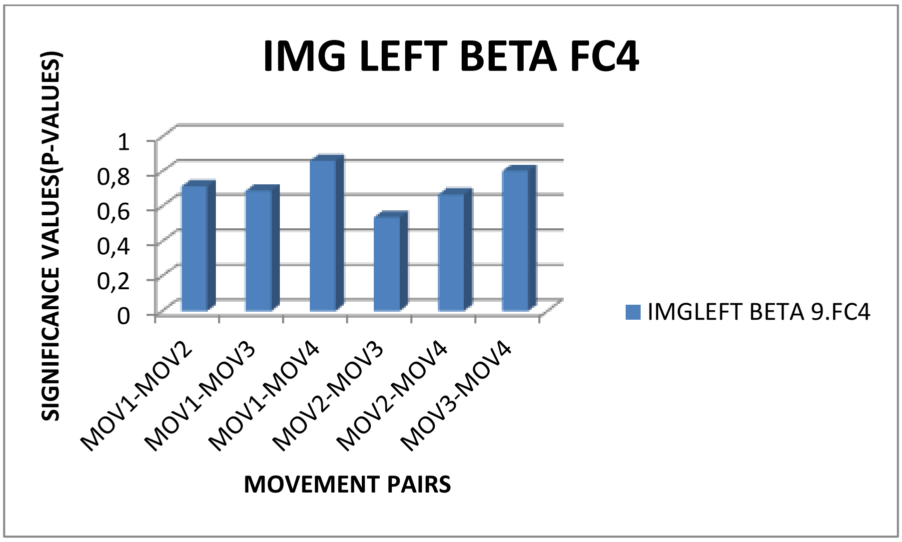

Figure 4.28 Four movements in imaginary situation with p-values of sequential left-hand, in beta band from frontocentral 4 zone of the brain

When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

Figure 4.29 shows the total area of PSD during left hand -real situation from FC3 electrode, in beta band. In the case of real situation according to this figure of PSD comparison, it has been found that the 1stmovement has higher PSD values than the other movements' PSD and it has been found that the 3th movement has lower PSD values than the other movements' PSD.

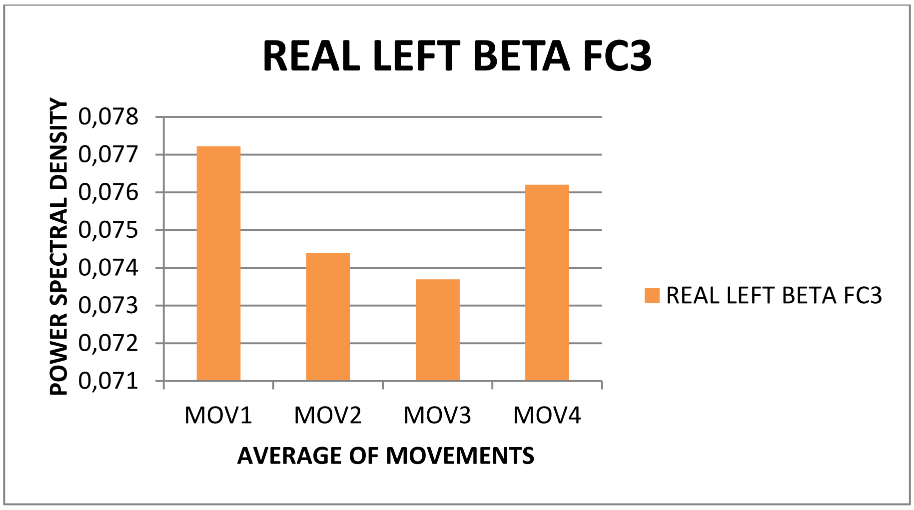

Figure 4.29 Four movements in real situation with left-hand, in beta band from frontocentral 3 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.30 shows that the p-values of sequential left and movements in beta sub-band in regard to paired sample t-test in real situation from the FC3 of brain regions.

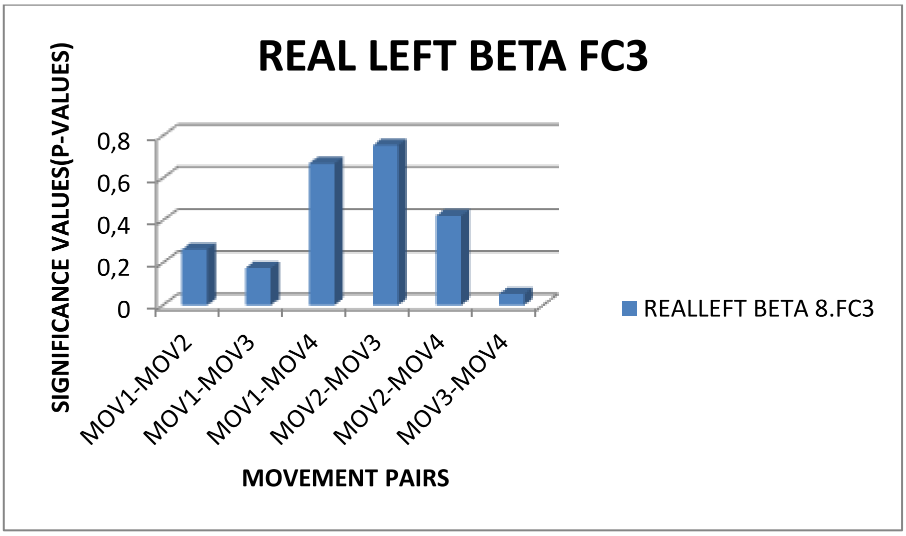

Figure 4.30 Four movements in real situation with p-values of sequential left-hand, in beta band from frontocentral 3 zone of the brain

When calculated values were evaluated, it was seen that these values were larger than the value of 0.05.As a result, the values were not found as statistically significant. However, the reason of power spectral density values were less than P value, mov3-

mov4 value was meaningful statistically. These movements were meaningful statistically which was show that movements can be seperated.

Figure 4.31 shows the total area of PSD during left hand -real situation from FC4 electrode, in beta band. In the case of real situation according to this figure of PSD comparison, it has been found that the 1st movement has higher PSD values than the other movements' PSD and it has been found that the 2nd movement has lower PSD values than the other movements' PSD.

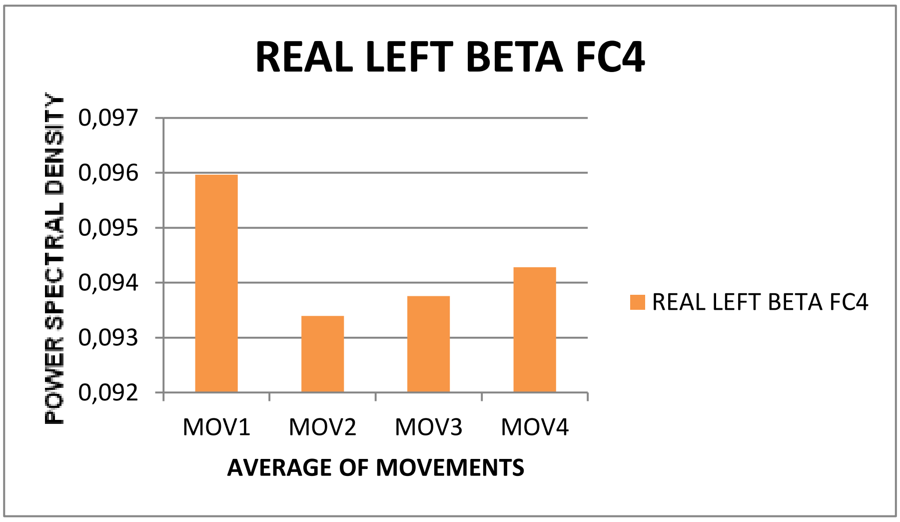

Figure 4.31 Four movements in real situation with left-hand, in beta band from frontocentral 4 zone of the brain

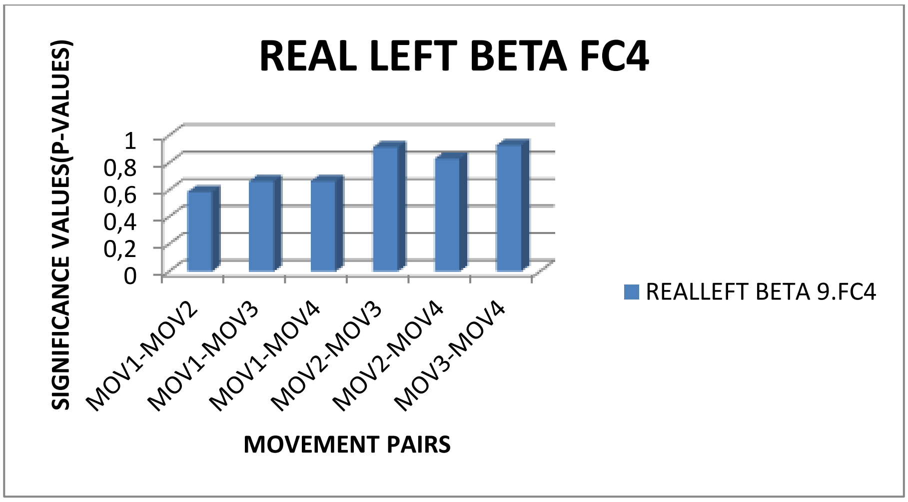

Figure 4.32 Four movements in real situation with p-values of sequential left-hand, in beta band from frontocentral 4 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.32 shows that the p-values of sequential left and movements in beta sub-band in regard to paired sample t-test in real situation from the FC4 of brain regions.When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

Figure 4.33 shows the total area of PSD during left hand -random situation from FC3 electrode, in beta band. In the case of random situation according to this figure of PSD comparison, it has been found that the 4thmovement has higher PSD values than the other movements' PSD and it has been found that the 1st movement has lower PSD values than the other movements' PSD.

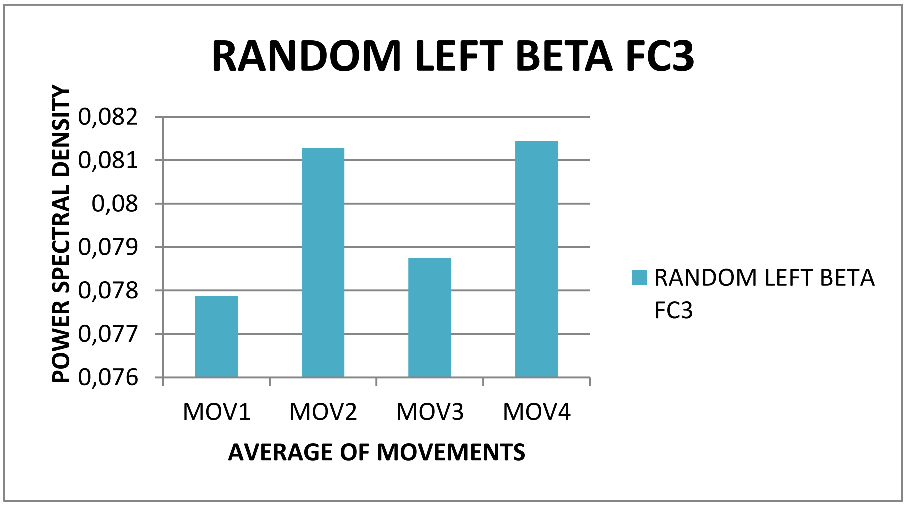

Figure 4.33 Four movements in random situation with left-hand, in beta band from frontocentral 3 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.34 shows that the p-values of sequential left and movements in beta sub-band in regard to paired sample t-test in random situation from the FC3 of brain regions.

When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

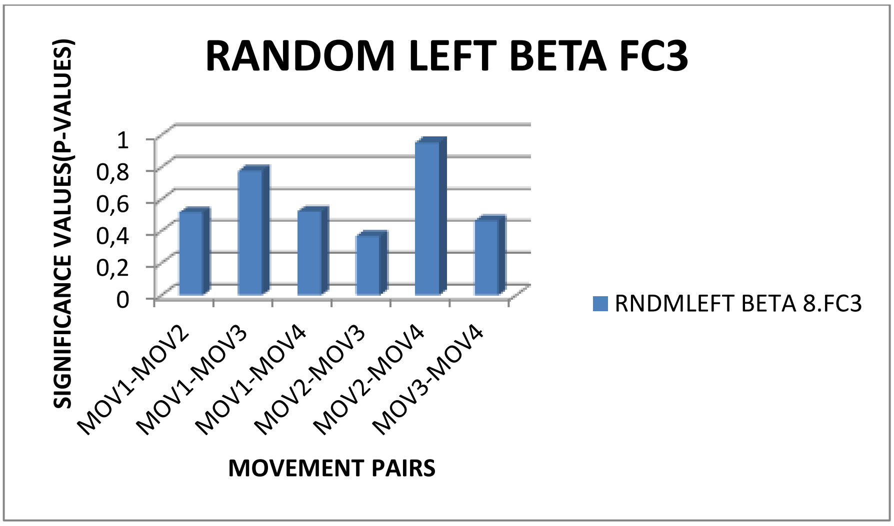

Figure 4.34 Four movements in random situation with p-values of sequential left-hand, in beta band from frontocentral 3 zone of the brain

Figure 4.35 shows the total area of PSD during left hand -random situation from FC4 electrode, in beta band. In the case of random situation according to this figure of PSD comparison, it has been found that the 1stmovement has higher PSD values than the other movements' PSD and it has been found that the 3th movement has lower PSD values than the other movements' PSD.

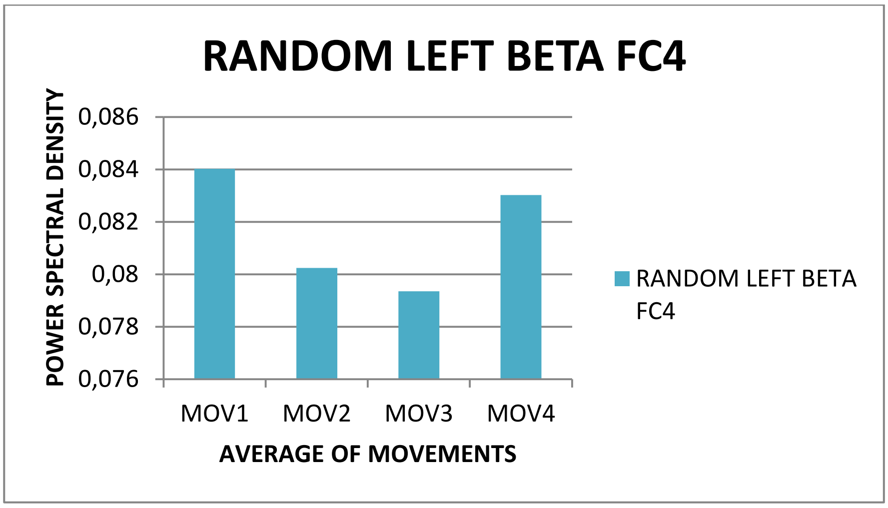

Figure 4.35 Four movements in random situation with left-hand, in beta band from frontocentral 4 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.36 shows that the p-values of sequential left and movements in beta sub-band in regard to paired sample t-test in random situation from the FC4 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

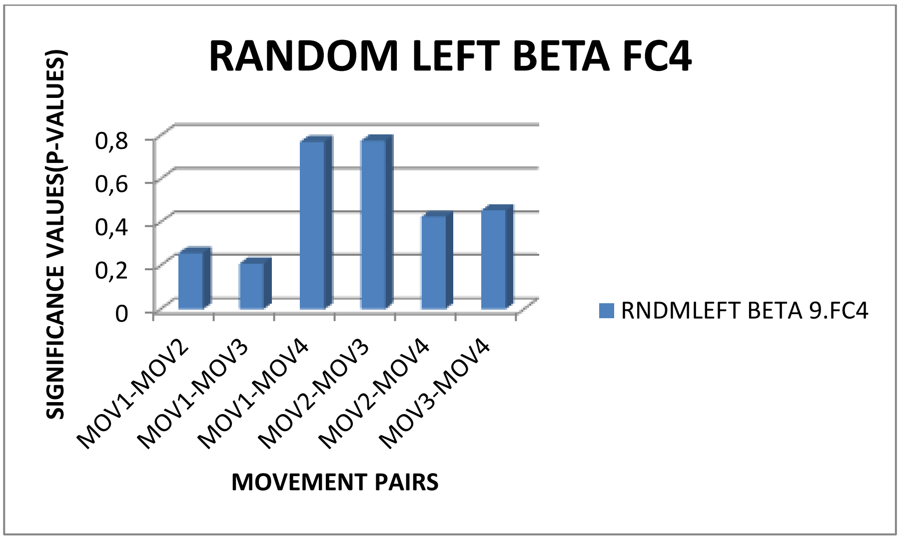

Figure 4.36 Four movements in random situation with p-values of sequential left-hand, in beta band from frontocentral 4 zone of the brain

Table 4.4 compares the p values of sequential right hand movements in beta sub-band in regard to paired sample t-test in FC3 and FC4 brain regions between imaginary (img), real and random (rndm) situations. For example, the first row in the table compares these situations between Movement 1 and movement 2.

Table 4.4 Four movements in all situations with right-hand, in beta band from frontocentral 3 and 4 zones of the brain

	BETA BAND, RIGHT HAND					
	8.FC3			9.FC4		
P	İMG	REAL	RNDM	İMG	REAL	RNDM
MOV1-MOV2	0,431	0,631	0,535	0,755	0,705	0,759
MOV1-MOV3	0,42	0,513	0,614	0,398	0,979	0,903
MOV1-MOV4	0,151	0,695	0,684	0,161	0,806	0,495
MOV2-MOV3	0,825	0,852	0,426	0,418	0,429	0,869
MOV2-MOV4	0,562	0,783	0,998	0,152	0,242	0,846
MOV3-MOV4	0,535	0,64	0,505	0,281	0,514	0,815

Figure 4.37 shows the total area of PSD during right hand-imaginary situation from FC3 electrode, in beta band. In the case of imaginary situation according to this figure of PSD comparison, it has been found that the 1stmovement has higher PSD values than the other movements' PSD and it has been found that the 4th movement has lower PSD values than the other movements' PSD.

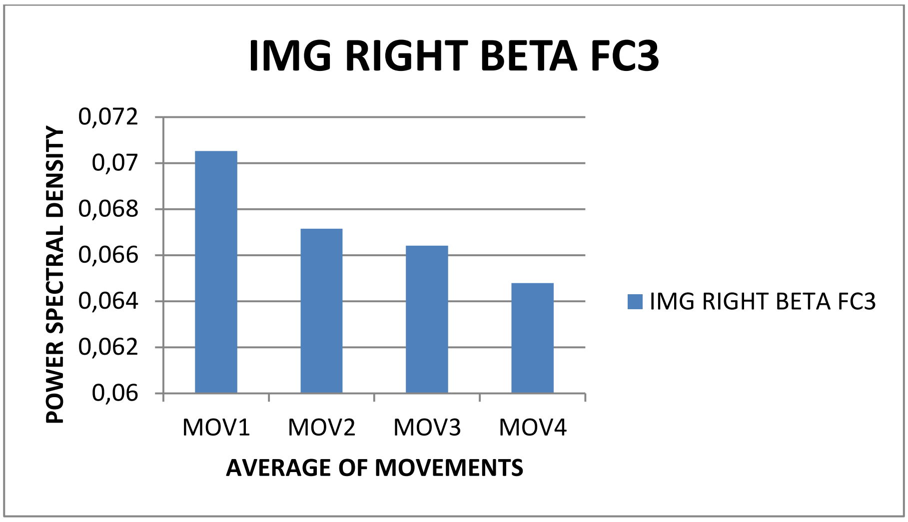

Figure 4.37 Four movements in imaginary situation with right-hand, in beta band from frontocentral 3 zone of the brain

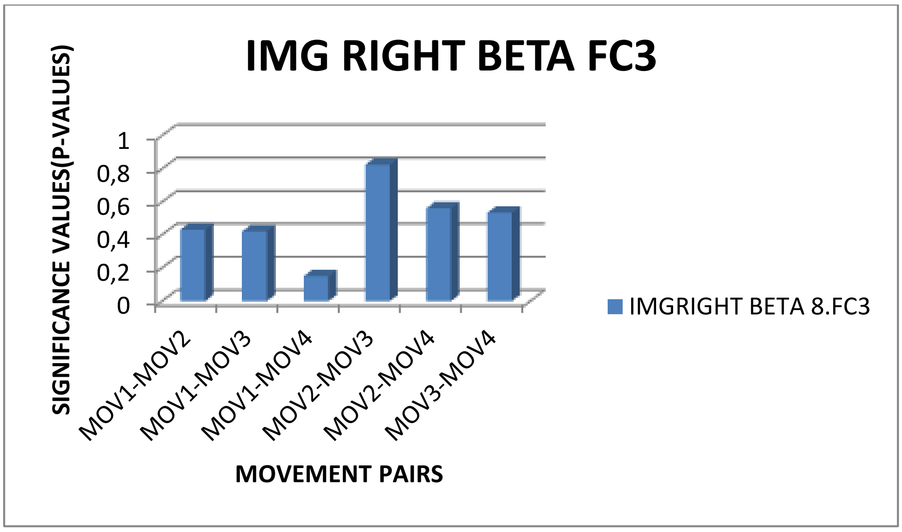

Figure 4.38 Four movements in imaginary situation with p-values of sequential right-hand, in beta band from frontocentral 3 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.38 shows that the p-values of sequential right and movements in beta sub-band in regard to paired sample t-test in imaginary situation from the FC3 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

Figure 4.39 shows the total area of PSD during right hand-imaginary situation from FC4 electrode, in beta band. In the case of imaginary situation according to this figure of PSD comparison, it has been found that the 1stmovement has higher PSD values than the other movements' PSD and it has been found that the 4th movement has lower PSD values than the other movements' PSD.

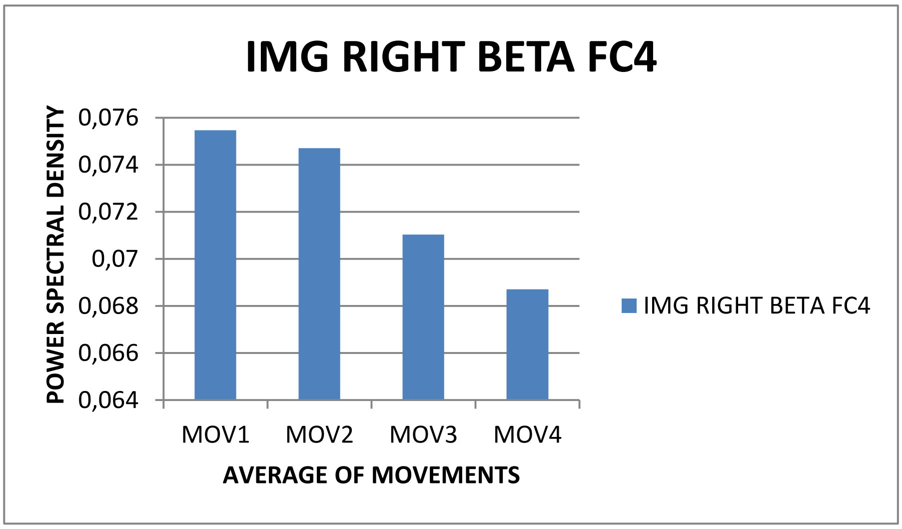

Figure 4.39 Four movements in imaginary situation with right-hand, in beta band from frontocentral 4 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.40 shows that the p-values of sequential right and movements in beta sub-band in regard to paired sample t-test in imaginary situation from the FC4 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

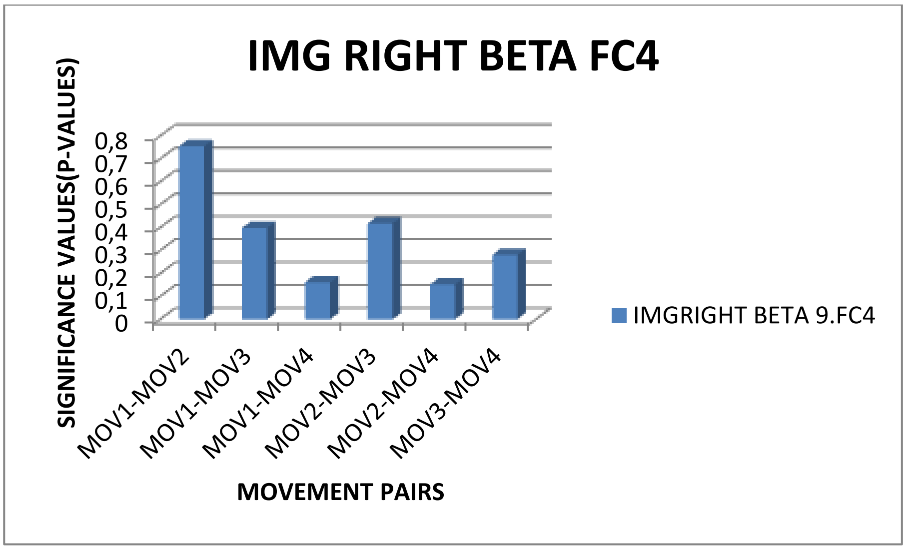

Figure 4.40 Four movements in imaginary situation with p-values of sequential right-hand, in beta band from frontocentral 4 zone of the brain

Figure 4.41 shows the total area of PSD during right hand-real situation from FC3 electrode, in beta band. In the case of real situation according to this figure of PSD comparison, it has been found that the 3thmovement has higher PSD values than the other movements' PSD and it has been found that the 1st movement has lower PSD values than the other movements' PSD.

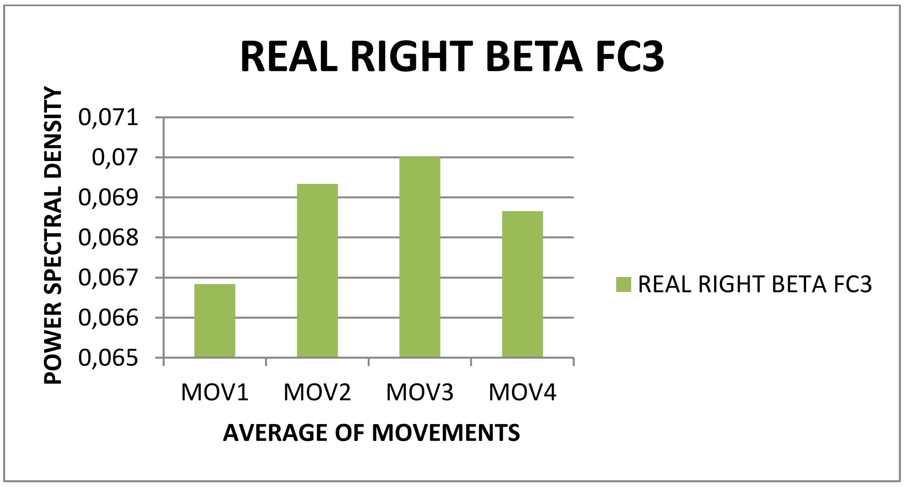

Figure 4.41 Four movements in real situation with right-hand, in beta band from frontocentral 3 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.42 shows that the p-values of sequential right and movements in beta sub-band in regard to paired sample t-test in imaginary situation from the FC4 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

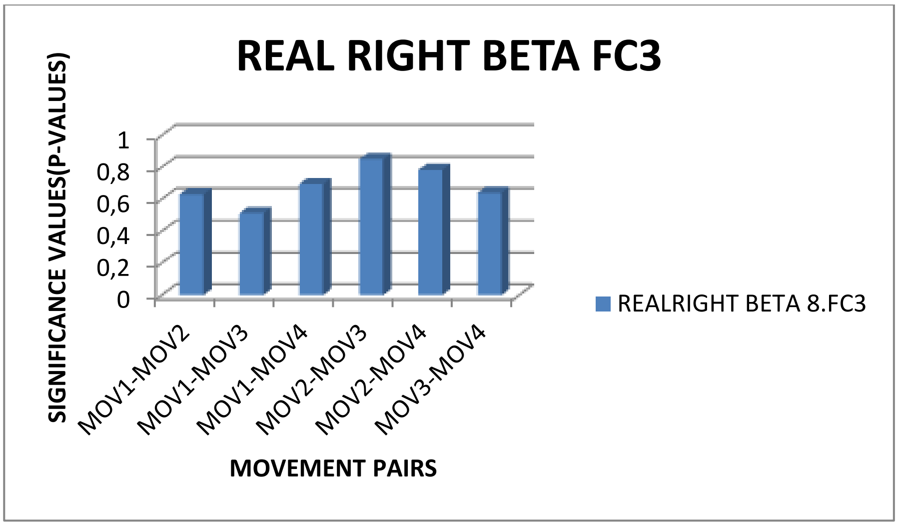

Figure 4.42 Four movements in real situation with p-values of sequential right-hand, in beta band from frontocentral 3 zone of the brain

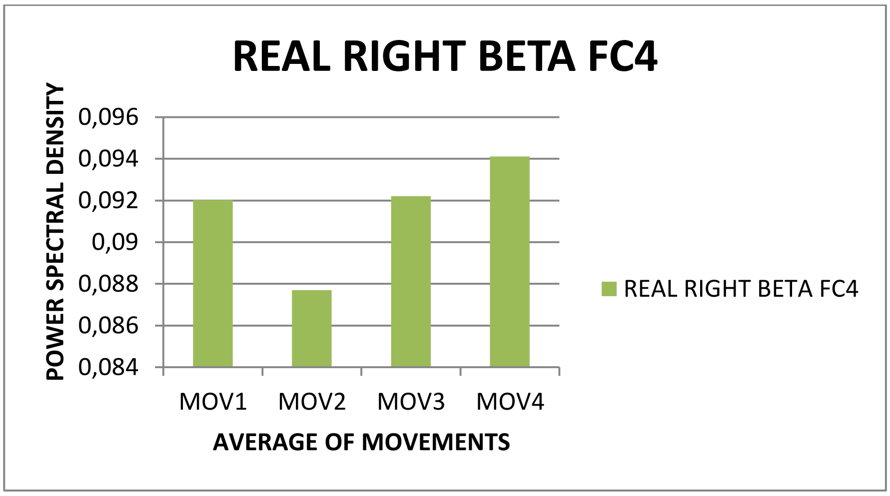

Figure 4.43 Four movements in real situation with right-hand, in beta band from frontocentral 4 zone of the brain

Figure 4.43 shows the total area of PSD during right hand-real situation from FC4 electrode, in beta band. In the case of real situation according to this figure of PSD comparison, it has been found that the 4^{th}movement has higher PSD values than the other movements' PSD. 1st and 3th movements have approximately same PSD values and and it has been found that the 2nd movement has lower PSD values than the other movements' PSD.

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.44 graph shows that the p-values of sequential right and movements in beta sub-band in regard to paired sample t-test in imaginary situation from the FC4 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

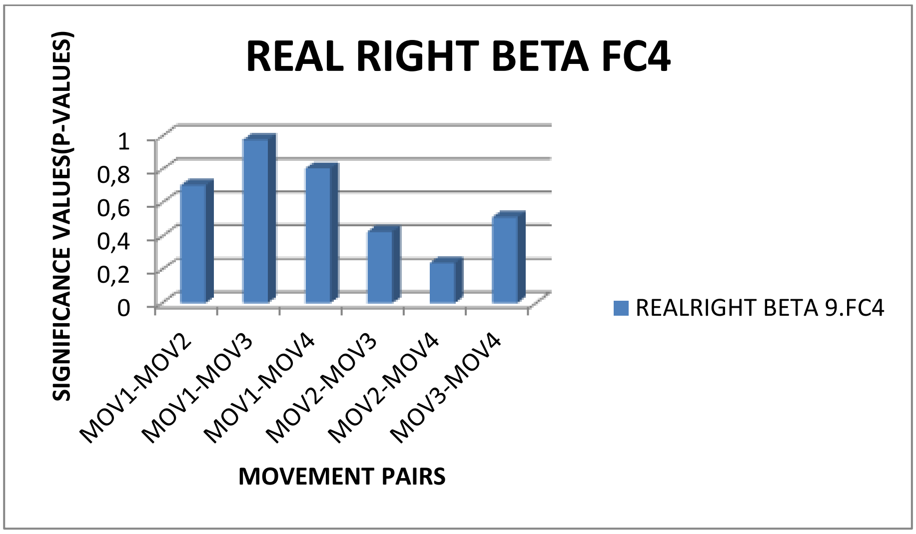

Figure 4.44 Four movements in real situation with p-values of sequential right-hand, in beta band from frontocentral 4 zone of the brain

Figure 4.45 shows the total area of PSD during right hand-random situation from FC3 electrode, in beta band. In the case of random situation according to this figure of PSD comparison, it has been found that the 4th movement has higher PSD values than the other movements' PSD and it has been found that the 3th movement has lower PSD values than the other movements' PSD.

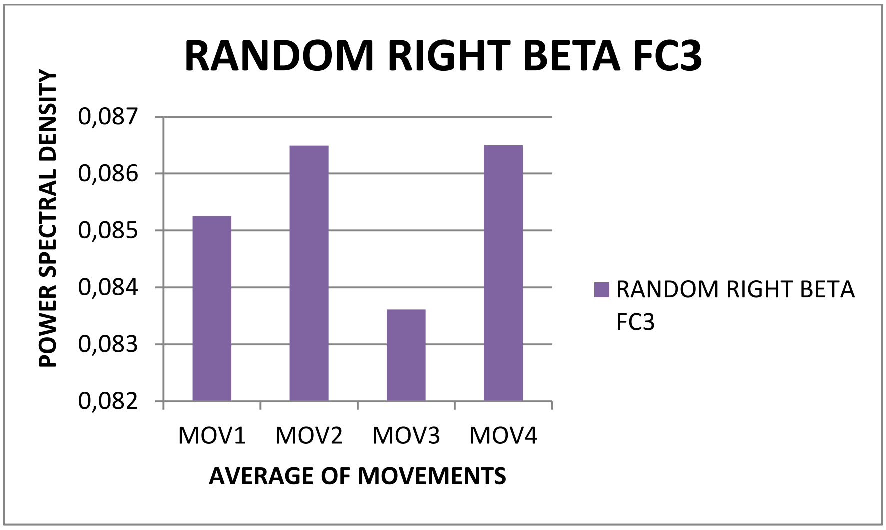

Figure 4.45 Four movements in random situation with right-hand, in beta band from frontocentral 3 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test. Figure 4.46 shows that the p-values of sequential right and movements in beta sub-band according to the paired sample t-test in random situation from the FC3 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

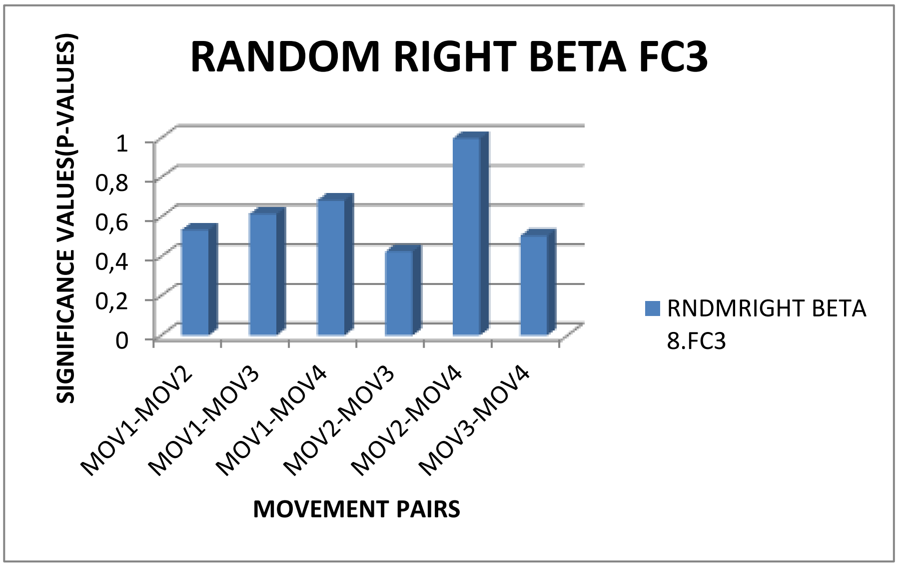

Figure 4.46 Four movements in random situation with p-values of sequential p-values of sequential right-hand, in beta band from frontocentral 3 zone of the brain

Figure 4.47 shows the total area of PSD during right hand-random situation from FC4 electrode, in beta band. In the case of random situation according to this figure of PSD comparison, it has been found that the 1st movement has higher PSD values than the other movements' PSD and it has been found that the 4th movement has lower PSD values than the other movements' PSD.

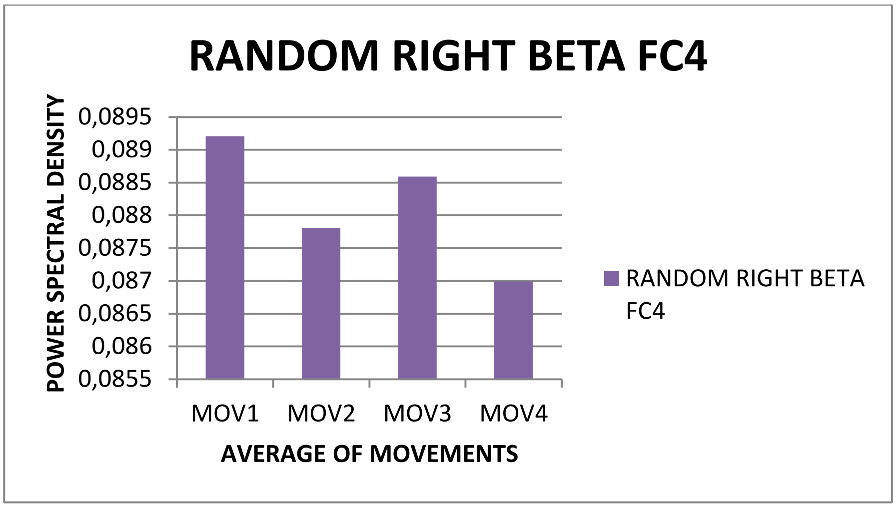

Figure 4.47 Four movements in random situation with right-hand, in beta band from frontocentral 4 zone of the brain

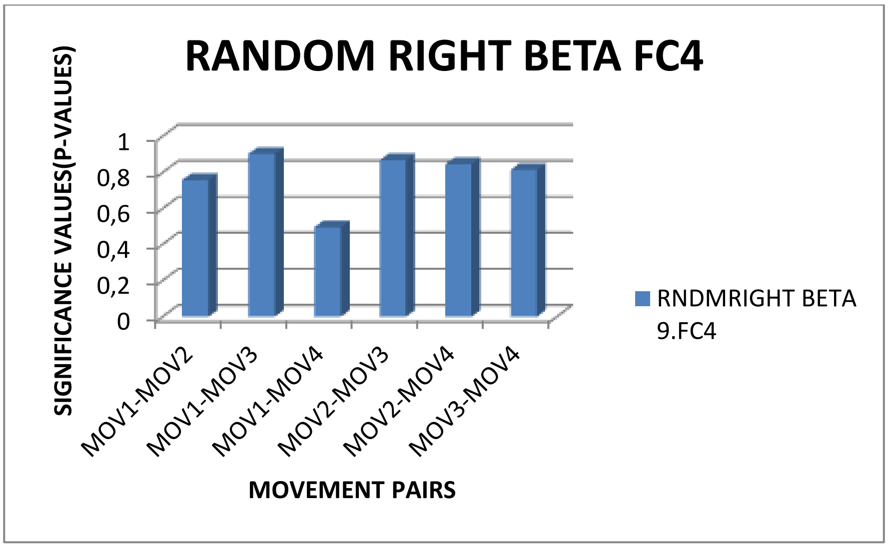

Figure 4.48 Four movements in random situation with p-values of sequential right-hand, in beta band from frontocentral 4 zone of the brain

In order to clearify significance level, we obtain a graph than includes paired sample T test.Figure 4.48 shows that the p-values of sequential right and movements in beta sub-band according to the paired sample t-test in random situation from the FC4 of brain regions. When calculated values were evaluated, it was seen that these values were larger than the value of 0.05. As a result, the values were not found as statistically significant.

In order to test if there was a significant difference in the PSD values of four different hand movements, one-way ANOVA was performed in SPSS. Table 4.5 lists the significance levels of this test. The p-values of tables and graphs are higher than the value of P.(%5). As a result, the values were not found as statistically significant.

Table 4.5 Difference between 4 movements using One-Way ANOVA

SIG.		IMGRIGHT	IMGLEFT	REALRIGHT	REALLEFT	RNDMRIGHT	RNDMLEFT
ALPHA	8.FC3	0,969	0,926	0,771	0,764	0,991	0,957
	9.FC4	0,971	0,994	0,975	0,873	0,853	0,99
BETA	8.FC3	0,979	0,991	0,999	0,999	0,999	0,997
	9.FC4	0,962	0,995	0,964	0,999	0,999	0,988

In this table, visual comparison of p-values were shown in Fig. 4.49, Fig 4.50, Fig. 4.51, Fig. 4.52 for the alpha and beta bands.

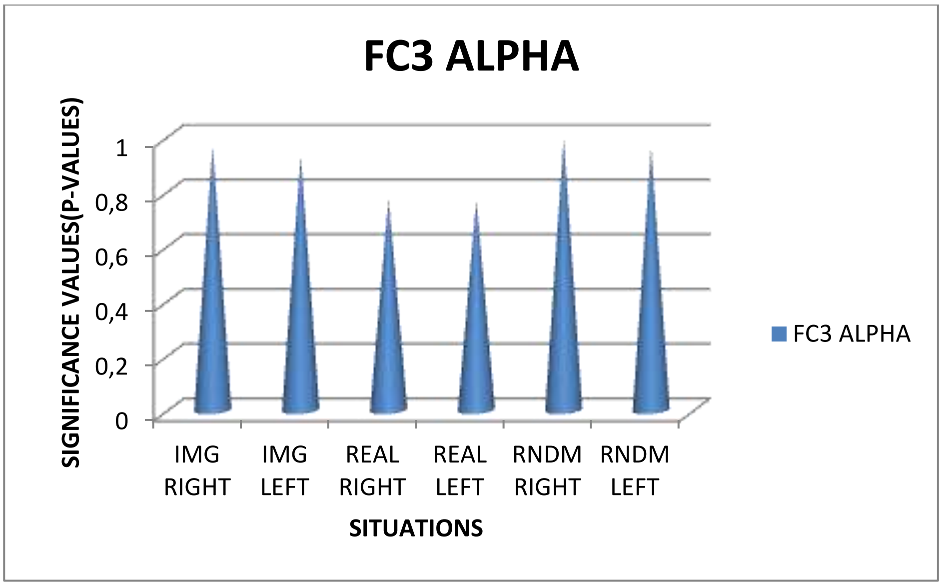

Figure 4.49 Difference between 4 movements in all situation for left-right hand in alpha band from FC3 zone of brain

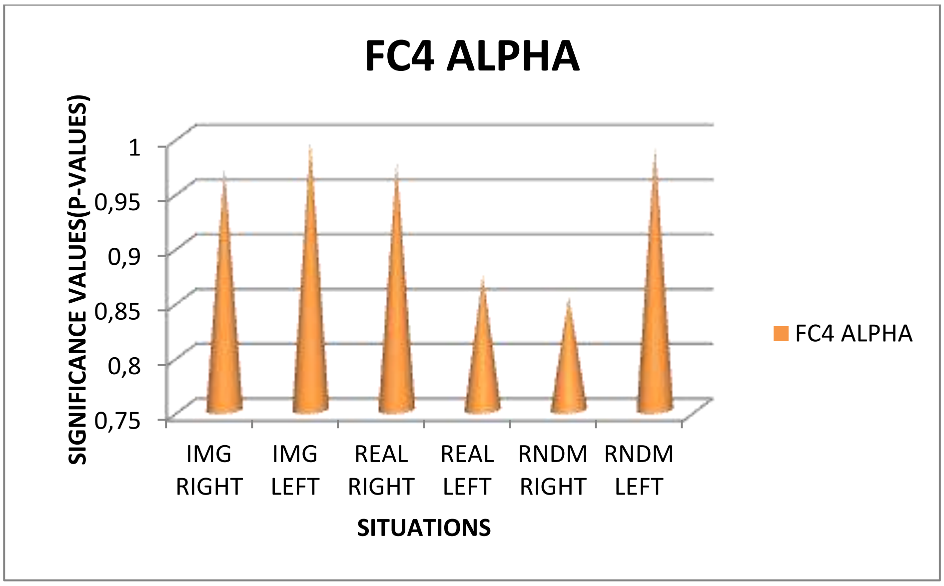

Figure 4.50 Difference between 4 movements in all situation for left-right hand in alpha band from FC4 zone of brain

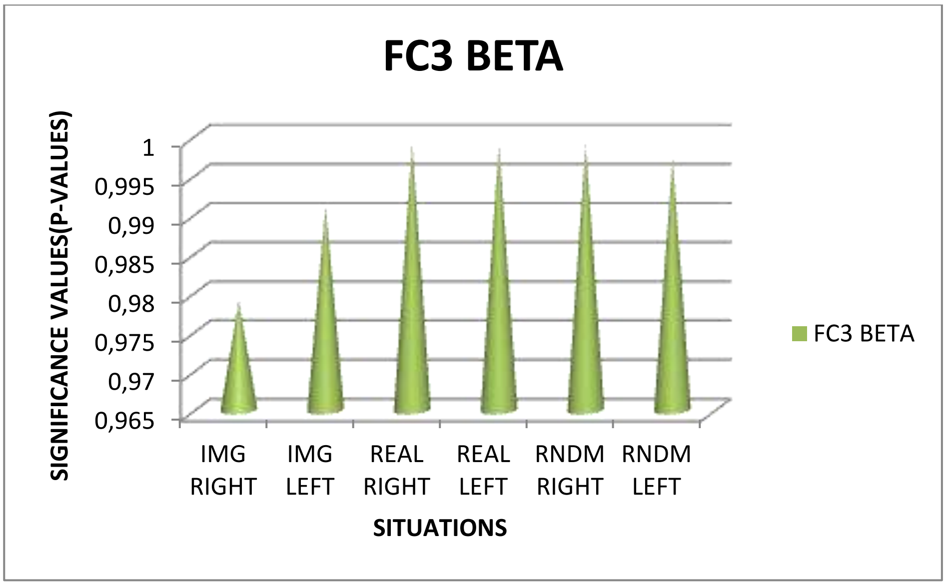

Figure 4.51 Difference between 4 movements in all situation for left-right hand in beta band from FC3 zone of brain

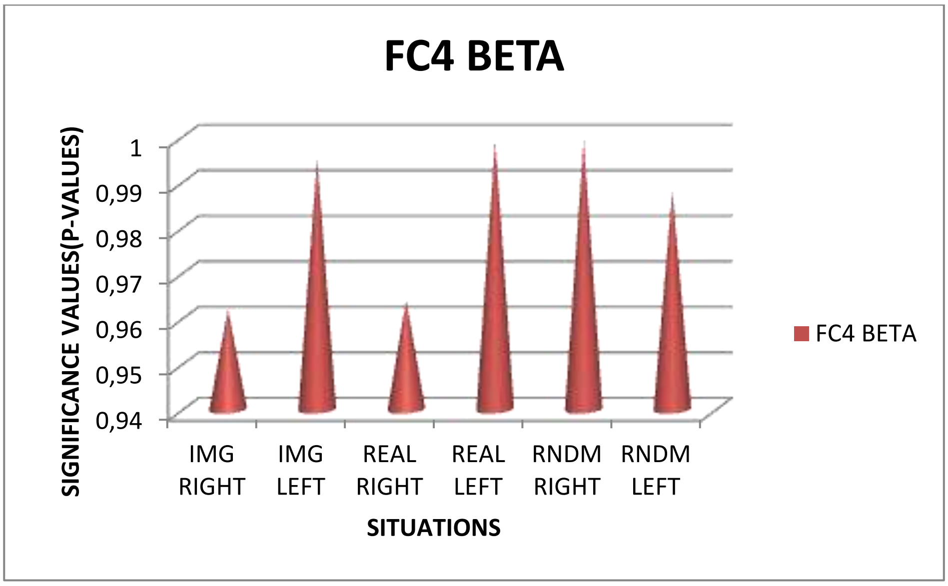

Figure 4.52 Difference between 4 movements in all situation for left-right hand in beta band from FC4 zone of brain

CHAPTER 5

DISCUSSION

EEG based on BCI systems has been increasing in recent years. Many different disorders(Amyotrophic lateral sclerosis (ALS), brainstem stroke, brain or spinal cord injury etc.) can disrupt the neuromuscular channels through which the brain communicates with and controls its external environment. The lost hand of an amputee can be replaced by a robotic prosthetic hand, whilst the non-functional hand of a victim of a stroke or spinal cord injury able to be supported by a robotic exoskeletal orthotic hand.The target of our survey was to research the discriminative features of four different hand movements in the EEG signals using advanced engineering methods (discrete wavelet transform and PSD) in healthy subjects for BCI applications. The data recording began with resting state, after 2^{nd},4^{th},6^{th} 8^{th} periods four different movement applied and 3^{th},5^{th},7^{th}, 9^{th} resting state periods began. Bearing in mind the movements that patients learn, during motor rehabilitation, four basic hand movements were considered i.e. thump-up, index-up, little-ring-middle-up together and half-opened hand are called the most essential hand movements. Effective BCI solution requiring that the neural data associated with the essential hand movements be extracted and interpreted from EEG signal will be applied. During the recording subjects sat up chair and they did not move. Their eyes opened during EEG data recording. Recorded EEG signals were analysed in MATLAB® using discreate wavelet decomposition. It decomposed data to sub bands (alpha, beta).Than paired sample t-test and one-way ANOVA were used to clarify the differences between hand movements. After signal processing, we observed that the bands showed some differences between periods, however, statistically significant results only obtained in certain bands in healthy subject' EEG data.

In terms of PSD, there was no similarity between right and left hand movements which is show that it can be discriminated only in imaginary situation such as in imaginary situation for left-right hand in beta band from FC3, FC4 brain regions. In generally a movement which has highest value in FC3 has also highest value in FC4 by using same situation. For example 4th movement as highest value by using real sitiation for right hand in beta band in from FC3 and FC4, too. In generally a movement which has lowest value in FC3 has also lowest value in FC4 by using same situation. For example 1st movement as lowest value by using real sitiation for right hand in beta band in from FC3 and FC4 too.

Mostly p-values of 1-3 and 3-4 movements were statistically significant in real situation. In terms of PSD, in imaginary situation right hand PSD values were found as higher than the left hand values by using all variables only in beta band. In terms of PSD, in random situation right hand values were higher than left hand values by using all variables only in beta band. In contrast, in terms of PSD values, in real situation left hand values found as higher than right hand values by using all variables only in beta band.

Limitations of the this study were that small sample size of the participants. For future studies, the data recording procedure can be repeated with larger number of participants to find more statistically significant differences in extracted features between different hand movements. Moreover, the study can be further developed for obtain discriminative features for patients with amputation for control of prothesis hands.

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