Deanship of Graduate Studies

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Analysis of significant EEG frequency Bands for Epilepsy Disease using the Self-Organizing map

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Thesis Approval

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Dedication

I dedicate this thesis to my family and many friends who have meant and continue to mean so much to me.

I also dedicate this thesis to my teachers, and I appreciate every word have been said to me by my teachers.

Declaration

I hereby certify that this thesis is the result of my own research, except where the otherwise acknowledged, and that this study has not been submitted for a higher degree or institution.

Signed :

Mukhammad Ziyad Khalel Abdelkader

Date: 20 / 7 /2022

Acknowledgement

Thank God The Merciful and Graceful.

I would like to express my profound gratitude to my research supervisor, Dr. Hazem Doufesh for his encouragement and continuous support through all stages of this work.

Special thanks to my family, friends, who encourage me constantly.

ملخص بالعربية

عنوان الرسالة: تحليل نطاقات ترددات إشارات الدماغ الهامة لمرض الصرع باستخدام خرائط التنظيم الذاتي.

إعداد: محمد زياد خليل عبد القادر

إشراف: د.حازم دوفش

الملخص:

تهدف هذه الرسالة إلى إيجاد أثر مرض الصرع على نطاقات التردد الخمسة لموجات الدماغ عند الانسان. و لقد شملت هذه الرسالة على عينة من 28 شخصا مصابون بمرض الصرع , حيث تم تسجيل و رصد إشارات الدماغ لهم عبر جهاز تخطيط إشارات الدماغ و حفظها في قاعدة بيانات باستخدام جهاز الحاسوب.

تم إجراء تحليل لإشارات الدماغ, باستخدام تحويلات فورييه السريعة و ذلك من أجل الحصول على طاقة النطاقات الخمسة ثم إدخال هذه البيانات كمدخلات في خريطة التنظيم الذاتي, و قد تبين من هذه الدراسة وجود تباين واضح بين بيانات المرضى و السليمين , حيث ظهر أنه يوجد ارتفاع كبير في طاقة موجة ثيتا للمصابين بمرض الصرع.

توضح هذه الدراسة أهمية استخدام الذكاء الاصطناعي و تحديد الشبكات العصبية الاصطناعية وهنا نركز على تقنية خرائط التنظيم الذاتي, لأن لها القدرة على عرض معلومات كبيرة و ذات أبعاد عالية, على شكل شبكة في بعدين يسهل فهمها , وهذا ما قمنا به على مرض الصرع.

Abstract

This thesis aims to find the effect of epilepsy on the five frequency bands of human brain waves. And this thesis included a sample of 28 people with epilepsy, where their brain signals were recorded and monitored through an EEG device and saved in a database using a computer.

An analysis of brain signals was carried out, using fast Fourier transforms, in order to obtain the energy of the five bands and then enter these data as inputs in the self-organizing map, and it was found from this study that there is a clear discrepancy between the data of patients and healthy ones, where it appeared that there is a large increase in the energy of theta wave for people with epilepsy.

This study demonstrates the importance of using artificial intelligence and identifying artificial neural networks, and here we focus on the technique of self-organizing maps, because it has the ability to provide large and high-dimensional information in the form of a network in two dimensions that is easy to understand, and this is what we have done on epilepsy.

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List of abbreviations

Abbreviation	Abbreviation representation
EEG	Electroencephalography
PSD	Power Spectral Density
SVM	Support Vector Machine
HRV	Heart Rate Variability
FFT	Fast Fourier Transform
SOM	Self-Organizing Map
BMU	Best Matching Unit
TE	Topographic Error
QE	Quantization Error
ECG	Electrocardiogram
DFT	Discrete Fourier transform
CT	Computerized Tomography
MRI	Magnetic Resonance Imaging

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Chapter One: Introduction

1.1Overview:

This study aims to find the correlation between the five frequency bands and epilepsy disease, so the best introduction for it in this chapter is about the brain and general highlights about the disease.

1.1.1 The brain:

The brain is the control community for the body. It has a huge number of cells called neurons. Neurons fire chemical messages to make our bodies work appropriately. Now and again neurons might fizzle and the chemical message is stirred up. This can cause a seizure. What sort of seizure happens relies upon where in the mind the failure to discharge occurred. To comprehend, it assists with knowing the pieces of the cerebrum and what they do. Our brains, mean human brain have two parts called halves of the globe, a left and a right one. Both hemispheres are divided into lobes: temporal, frontal, parietal & occipital.

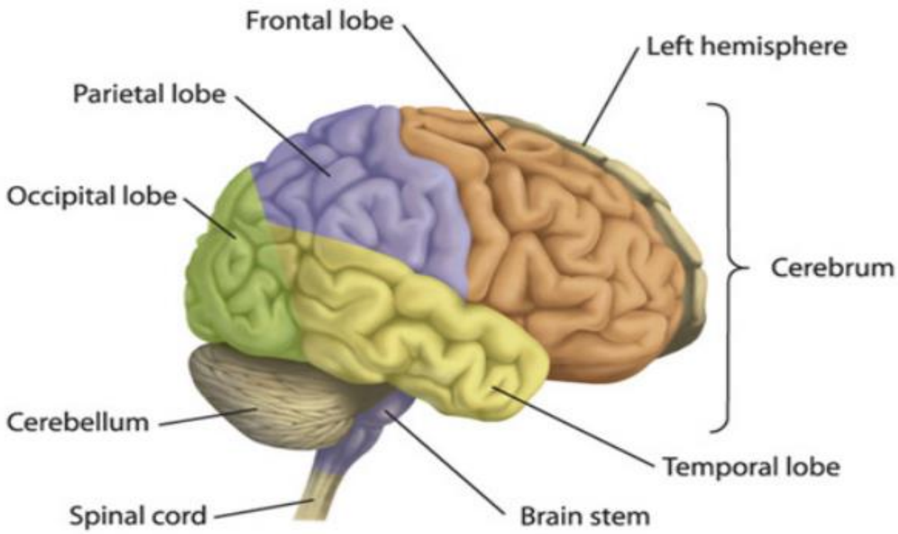

Fig1. 1: Regions and parts of the human brain.(D. Purves 2001)

Table 1 : Brain lobe's controls and affects.

Lobe of the brain	What it controls and affects
Temporal lobe	Memory and emotions Reading and writing Non verbal processing
Frontal lobe	Language, speech, visual and auditory skills Planning and organization Judgement and problem solving Making decision
Occipital lobe	Visual perception and attention Reading and writing
Parietal lobe	Hand-eye co-ordination Spatial and direction awareness Body awareness and touch

1.1.2 Epilepsy (General Highlights) :

Epilepsy as characterized by the International League Against Epilepsy (ILAE) is an illness of the mind that outcomes in no less than two unjustifiable seizures no less than 24 hours separated. An individual may likewise be determined to have epilepsy assuming that they have one unmerited seizure and have a high opportunity (more than 60%) of including one more seizure inside the following 10 years or on the other hand assuming that they have an epilepsy disorder(Christian M Kaculini 2021.03).

Epilepsy is a disease generally connected with evil spirits and mystery, nevertheless right up 'til now frequently conveys social marks of disgrace(Christian M Kaculini 2021.03) . Its long history, alongside its social ramifications, makes epilepsy a special problem.

Humans have lived with epilepsy over our time. Nonetheless, the main point by point depiction of the illness is in a 3,000-year old clinical text called the Sakikku. Composed at some point around 1,050 BC by the Babylonians (an old civilization in advanced Iraq)(https://www.epsyhealth.com/seizure-epilepsy-blog/the-history-of-epilepsy-the-ancient-world February 4, 2022).

Studying epilepsy is beset with difficulties accurate diagnosis and case ascertainments stay serious issues, since epilepsy is just a side effect of numerous dissimilar causative elements. Certain determination or rejection in all instances of seizures is troublesome on the grounds that seizure types fluctuate, strange way of behaving and clear spells may not be perceived as seizures, there might be no going with neurological signs and in the event that an onlooker account is inadequate, the analysis may not be made by any stretch of the imagination. Different circumstances are promptly mistaken for epilepticseizures(directory , D Smith 1999 Jan).

EEG is a strategy for recording electrical action of the brain cues that can be utilized to analyze the neurological problems like epilepsy, Alzheimer and Parkinson diseases. Epilepsy happens sporadically and capriciously because of impermanent electrical aggravation of the brain. Data content of EEG signals is fundamental for location of numerous issues in the brain (Sharkey May 27, 2019).

This study will extract the five sub-signals from EEG signals involving fast fourier transform procedure to compute the power spectral density (PSD), which might give backing to clinical specialists in direction and work on the diagnosis of epilepsy.

1.2 Objectives:

The main objective of this study is to find the correlation between the five frequency bands and the epilepsy disease using self-organizing map.

In addition we have also sub objectives:

1- Use the Electroencephalography (EEG) for diagnosing Epilepsy in human brain

2- Use the statistical analysis (SPSS software) to find the correlation between the five frequency bands and the epilepsy disease.

1.3 Scope of work:

Two groups of subjects were recruited in this study: group one (Epilepsy group) which contains subjects from both males and females of different ages who suffer from epilepsy disease while group two (Normal group) have healthy subjects who are free from epilepsy or any neurological disorders. The EEG data of two groups have been recorded and analyzed using self-organizing map technique.

1.4 Thesis organization:

This thesis is divided into five chapters including: introduction, literature review, methodology, results and discussion, and conclusion.

Chapter one contains the general overview, objectives, and the scope of work

Chapter Two contains the deep meaning of epilepsy, seizures, power spectral density and Fast Fourier transform, self-organizing map, and medical applications of self-organizing maps.

Chapter Three introduces, subjects, EEG recording, EEG signal processing, and EEG power spectral density analysis.

Chapter Four talk about the results of power spectral analysis and self-organizing map technique results and comparison between normal and epilepsy groups.

Chapter Five presents the conclusions and suggestions for future work for developing.

Chapter Two: Literature review

This chapter describes the background studies basically, then we will discuss deeply the meaning of epilepsy and seizures in terms of it’s definition, characteristics and how we can diagnosing of the epilepsy. Regarding to frequency bands, this chapter will show the classification of five frequency bands and it’s main properties and of course the EEG data acquisition. Finally an introduction to self-organizing map technique as an our method to find the correlation between the epilepsy and frequency bands.

2.1 Previous studies:

1. Frequency Analysis of Healthy & Epileptic Seizure in EEG using Fast Fourier Transform(Meenakshi June-July, 2014).

   The purpose of this research is to early detect of range of frequency for epileptic seizure k-nearest neighbors and linear discriminate analysis are used for detection of emotions via EEG signals recording, then it has been separated in to five frequency band and finally compare the signals between epileptic and healthy subjects.

2. Epileptic Seizure Prediction using Power Spectrum and Amplitude Analysis of Beta Band of EEG Signals(Raj Sadaye December 2016).

   This research gives a seizure prediction technique via frequency and amplitude analysis of beta band. this done by calculation of power spectrum and combined with the amplitude of the EEG signal and classified using support vector machine and the results with an accuracy of 70%.

3. EEG Waves Classifier using Wavelet Transform and Fourier Transform(Shaker 3 2007).

   In this research the researcher has been achieve the classification of the EEG frequency bands via Discrete Wavelet Transform and Fast Fourier Transform, the results improve the ability of the proposed technique.

4. A New Approach For Diagnosing Epilepsy By Using Wavelet Transform And Neural Networks (M.Akin 2001 , October 25-28).

   In this study classification of the EEG signals and diagnose the epileptic seizures directly by using wavelet transform and an artificial neural network model. Using wavelet transform EEG signals has been separated into delta, theta, alpha and beta spectral components . These frequency bands are used as an input data to the of the neural network. Then neural network is trained to give three outputs to signify the health situation of the patients.

5. Application of Self Organizing Map to identify Nocturnal Epileptic Seizures(Barbara Pisano 2017).

   The purpose of this research is patient-specific seizure detection system, especially Nocturnal Frontal Lobe Epilepsy, the EEG signals has been recorded and used as an input data vector in to Som. describing the dynamic of the brain state via EEG signals through the obtaining a trajectory by the SOM, mean the SOM can be used as seizure early detector.

The analysis of the trajectory can provide information on an eventual impending seizure event.

6. EEG Power Spectrum Analysis to the Human Impact of Epilepsy Disease by using Fast Fourier Transform(Aleian 2018).

   The purpose of this research is to determine the influence of the epilepsy via EEG signals, via power spectral density analysis and Fast Fourier Transform, and the result is that the higher average power is theta band for patients with epilepsy.

7. Subdural EEG Classification Into Seizure and Non-seizure Files Using Neural Networks in the Gamma Frequency Band(Melvin Ayala February 2011).

   This research, basically based on two stages: first stage is through evaluation of tentative and frequency-based features, it was established a decisional space on the basis of the interelectrode mean of the spectral power in the gamma frequencies. And the second stage, is building the neural networks that processedon this decitional space to determine the epileptic group from healthy group. The purposed technique based onto gather the power in the specific frequency range and analyzing its attitude with time progress, searching for patterns indicative of seizures evolution.

8. Comparison of Frequency Bands Using Spectral Entropy for Epileptic Seizure Prediction(Susana Blanco 8 May 2013).

   The purpose of this research is to predict an epileptic seizure via frequency bands, so to determine the best band of EEG signals, the comparative process between the results of spectral entropies calculated in several EEG bands. The researchers have been measure the Fourier spectrum to achieve the results.

9. Classification of Epileptic EEG by Using Self-Organizing Maps(P. Elo 1992).

In this paper the application of the Kohonen's self-organizing map for classification of epileptic EEG signals in order to reduce the time needed for analysis. The results of this experiment show the capability of self-organizing map for classification of various normal and epileptic signals.

10. Automatic Epileptic Seizure Detection in EEG Signals Using Multi-Domain Feature Extraction and Nonlinear Analysis(Lina Wang 27 May 2017).

    the aim of this research is to provide an automatic epilepsy disease diagnosis based on two steps, firstly, remove the artifacts from EEG signal using the wavelet threshold method. Secondly, extract representative features in time-frequency, time and frequency domains and nonlinear analysis features based on the information theory, which extracted in five frequency bands. Ultimately the results demonstrate that the proposed d epileptic seizure detection method can achieve a high average accuracy of 99.25%.

11. Classification of EEG Signals for Detection of Epileptic seizures based on wavelets and statistical pattern recognition (D. Gajic 2014).

    This research gives a self-acting sorting of EEG waves which aims to detection of epileptic seizures using wavelet transform and statistical pattern recognition. There are three stages in this research: extraction based on wavelet transform, dimension reducing through scatter matrices and finally sorting by quadratic classifiers

    Also in this research three groups of sample has been used: healthy subjects, epileptic subjects during a seizure-free interval, and epileptic subjects during a seizure. The results shows that the presented technique has a possibility in the sorting of EEG signals and detection of epileptic seizures.

12. Self-organizing Map in Recognition of Topographic Patterns of EEG Spectra(Sirkka-Liisa Joutsiniemi NOVEMBER 1995).

    In this paper, the SOM an artificial neural network algorithm was used to the recognition of topographic patterns in clinical 22-chanel EEG, each location of SOM contains a model for a cluster of similar input patterns the best matching model determines the location of the map, the clustering and comprehensible conception of topographic EEG are acquiredon a SOM in current time.

13. Autosomal dominant nocturnal frontal lobe epilepsy seizure characterization through wavelet transform of EEG Records and Self Organizing maps(B. Pisano SEPT. 13–16, 2016).

    In this paper, the author's purpose a seizure's detection system for nocturnal frontal lobe epilepsy, with the purpose to support the neurologists in the labelling efforts, in this research polysomnographic signals are used in order to detect and differentiate seizure epochs, and this task has been performed by recording the EEG signal in different regions of the features space. the result is a SOM which allows to detect the relations in the complex input space for the description of seizures.

14. Spectral information of EEG signals with respect to epilepsy classification (Tsipouras 2019).

    in this research the author was defined a number of spectral thresholds and generate the respective frequency bands combinations, after this the EEG signal is analyzed and vector of spectral characteristics is defined for each of these frequency band combination, the results shows that the additional frequency band analysis is beneficial toward epilepsy detection. This work includes the first systematic assessment of the effect of the EEG frequency bands to the epileptic EEG frequency bands, and have never been reported in the literature before this paper.

2.2 Epilepsy:

Epilepsy is a brain sickness characterized by intermittent (iterative), ridiculous seizures which are frequently erratic. Epilepsy is a range condition with a wide scope of seizure types and control shifting from individual to-individual.(Valeta 2017).

Epilepsy is certainly not a solitary illness or a solitary strange condition however side effects of various and frequently various problems sharing for all intents and purpose the event of epileptic seizures. At the end of the day, epilepsy is an assortment of issues with tremendous contrasts in their seriousness, types and signs of seizures and causes, coinciding ailments, and shifting psychosocial, instructive and business impacts on people and their families. The utilization of plural "epilepsies" is to stress their enormous varieties in appearances, cause, the management and prognosis.(Valeta 2017).

The conceptual ILAE definition is (Epilepsy , Valeta 2017): “Epilepsy is a disorder of the brain characterised by an enduring predisposition to generate epileptic seizures and by the neurobiological, cognitive, psychological and social consequences of this condition.” This definition of epilepsy - requires the occurrence of at least one epileptic seizure- with the precondition that this is ‘in association with an enduring disturbance of the brain capable of giving rise to other seizures’ (Epilepsy , Valeta 2017).

The operational (practical) ILAE definition of epilepsy is: (Fisher RS 2014 , Valeta 2017)

Epilepsy is a disease of the brain defined by any of the following conditions:

1. At least two unprovoked (or reflex) seizures occurring >24 hours apart.

2. One unprovoked (or reflex) seizure and a probability of further seizures similar to the general recurrence risk (at least 60%) after two unprovoked seizures, occurring over the next 10 years.

3. Diagnosis of an epilepsy syndrome.

2.3 Epileptic seizures:

A seizure is an abrupt, uncontrolled electrical disturbance influence in the brain. It can cause changes in your way of behaving, movements or sentiments, and in degrees of consciousness.

Seizures are the consequence of a transient and unexpected electrical unsettling influence of the brain and inordinate neuronal release of the electrical action of the mind(D. Gajic 2014) .Epileptic seizures and side effects change among brief and imperceptible side effects to significant stretches of lively shaking of human nerve framework (Md. Kamrul Hasan Published August 2017). Chang and Lowenstein (2003) referenced that seizures will quite often repeat, and have no prompt basic causes (Chang BS 2003). Fisher (2014) and his associates reasoned that seizures that happen because of a particular reason are not considered to address epilepsy (Fisher RS 2014).Others, similar to Fisher and his partners (2005) proposed that epileptic seizures are the aftereffect of unnecessary and strange cortical nerve cell movement in the brain(Fisher RS 2005).

There are many sorts of seizures, which range in side effects and seriousness. Seizure types shift by where in the brain they start and how far they spread. Most seizures last from 30 seconds to two minutes. A seizure that lasts longer than five minutes is a medical emergency. Seizures can occur after a stroke, , a contamination like meningitis or another sickness a shut head injury. Ordinarily, however, the reason for a seizure is obscure. Most seizure issues can be controlled with medicine, yet the board of seizures can in any case fundamentally affect your day to day existence.(https://www.mayoclinic.org/diseases-conditions/seizure/symptoms-causes/syc-20365711#:~:text=A%20seizure%20is%20a%20sudden).

In general we can categorize seizures as either focal (partial) or generalized(https://epilepsyontario.org/about-epilepsy/types-of-seizures/) :

1. Focal seizures happen when seizure action is restricted to a piece of one brain side . There is a site, or a concentration, in the brain where the seizure starts, by other word electrical impulses that generate from a relatively small part of the brain, and it is may be with retained awareness or loss awareness.
2. Generalized seizures happen when there is boundless seizure movement in the left and right halves of the brain by other word seizures produced by widespread abnormal electrical impulses.

2.4 Epilepsy diagnosis:

There are a few clinical problems that cause side effects like epilepsy, this can make epilepsy challenging to analyze. An epilepsy expert will make a finding dependent fundamentally upon the seemed signs and side effects. They might request that patients have a few tests at emergency clinic or government medical care labs. These incorporate EEG tests and electronic tomography(CT) ormagnetic reverberation imaging(MRI) examines. None of these tests can demonstrate that the individual do or don't have epilepsy, however they might give helpful data. This incorporates the conceivable reason for epilepsy and the sort of seizures that the patient might experience the ill effects of.(https://www.nationwidechildrens.org/headache-testing).

Diagnosing epilepsy can be troublesome: except if somebody is having a seizure, there is much of the time no undeniable sign that they have epilepsy Many individuals will have an oddball seizure sooner or later in their lives, however a determination of epilepsy is normally made after an individual has had more than one seizure. The individual who has the seizure may not recall what occurred. So it tends to be exceptionally useful to have a depiction of what occurred, from somebody who saw the seizure, to give to the trained professional(society January 2019).

Various examinations might give more definite data that can assist with a determination. These incorporate blood tests, an Electroencephalogram (EEG) and mind sweeps like Computerized Tomography (CT) and Magnetic Resonance Imaging (MRI). In any case, these tests alone can't affirm or preclude a determination of epilepsy. Frequently it is a mix of experimental outcomes, an individual's clinical history and data from the people who saw the seizure, that is utilized to arrive at a conclusion.(society January 2019).

2.5 Electroencephalography(EEG):

EEG is "an electroencephalogram test that measures and records the electrical activity of the human brain" where, unique sensors (electrodes) are appended to patient's head and snared by wires to a PC framework. The PC records mind's electrical action on a screen or on a paper as wavy lines. Certain circumstances, like seizures, should be visible to the progressions in the typical example of the brain electrical activity(https://www.emedicinehealth.com/electroencephalogram_eeg-health/article_em.htm).

An EEG can determine changes in brain action that may be helpful in diagnosing brain problems, particularly epilepsy or another seizure issue. An EEG could likewise be useful for diagnosing or treating the accompanying issues: 1. brain tumor 2. brain damage from head injury 3. Sleep disorders 4. Inflammation of the brain 5. Stroke (https://www.mayoclinic.org/tests-procedures/eeg/about/pac-20393875).

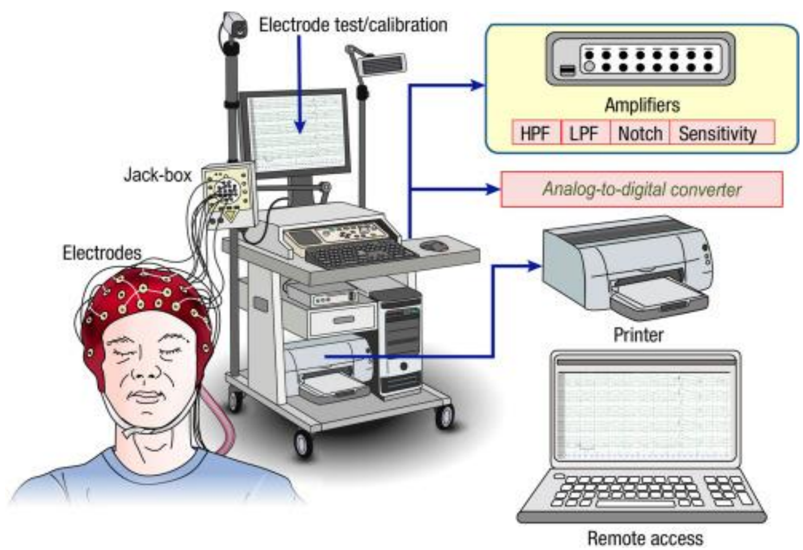

Fig. 2: EEG machine (Anteneh M.Feyissa 2019)

And EEG signals record result like be

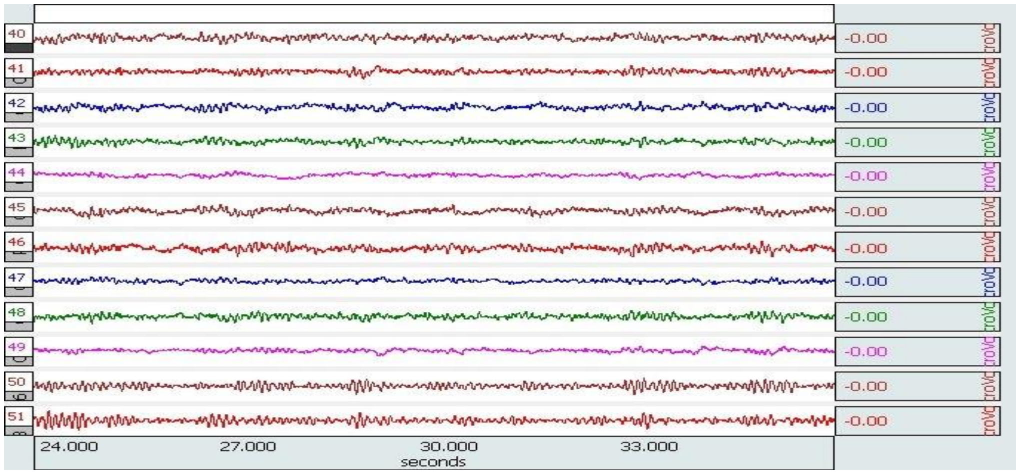

Fig. 3: EEG signal(https://www.biopac.com/application/eeg-electroencephalography/)

The EEG recording shows five frequency bands that are clinically significant. Specifically: delta , theta, alpha, beta and gamma.

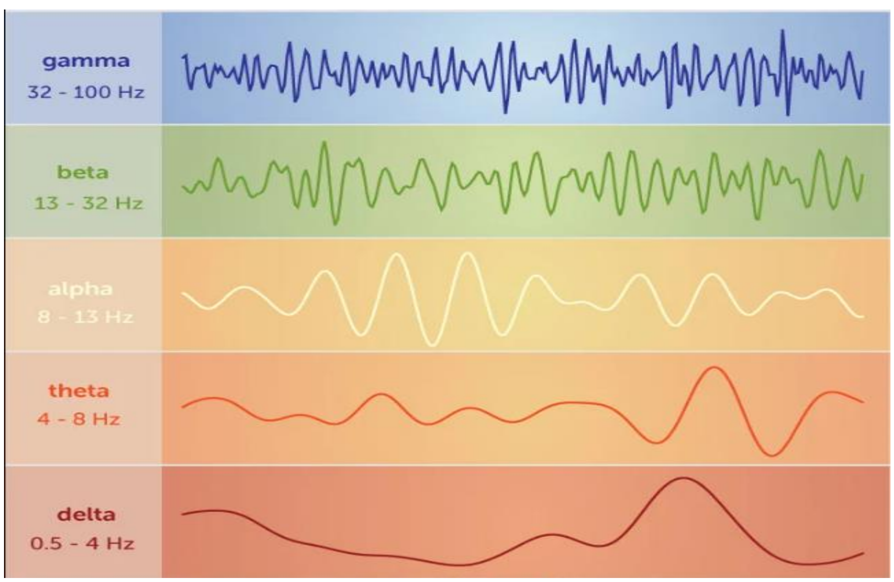

Fig. 4: Five frequency bands of EEG(https://neurogrow.com/can-neurofeedback-effectively-treat-adhd/)

The 5 main types of brainwave frequencies(https://choosemuse.com/blog/a-deep-dive-into-brainwaves-brainwave-frequencies-explained-2/ June 25, 2018):

Gamma brainwaves: frequency (32 – 100 Hz) associated with heightened perception, problem solving and learning.

Beta brainwaves: frequency (13 – 32 Hz) associated with active thinking, alert, making decisions and learning a new concept.

Alpha brainwaves: frequency (8 – 13 Hz) associated with physically and mentally relaxed like just before falling asleep.

Theta brainwaves: frequency (4 – 8 Hz) associated with dreams, reduced consciousness and daydreaming.

Delta brainwaves: frequency (0.5 – 4 Hz) associated with sleep and dreaming.

2.6 Power spectral density and Fast Fourier Transform:

A Power Spectral Density (PSD) is the measure of signal's power content versus frequency and it is a method for evaluating the distribution of power in a signal over a range of frequencies. PSD is usually used to decide levels of brain activity.

The Fourier Transform (FFT) can, in fact, speed up the training process of convolutional neural networks and it is an algorithm that calculates the Discrete Fourier transform (DFT) of some sequence – the discrete Fourier transform is a tool to convert specific types of sequences of functions into other types of representations. It is especially utilized in region like signal handling, where its purposes range from separating and frequency analysis to power spectrum estimation. To determine the FFT algorithm the following equation is used

$$X_k^{(n)} = \sum_{n=0}^{n-1} x(n) e^{\frac{-j2\pi kn}{N}} \qquad (1)$$

K = 0,1,….. , N – 1

Superscript (N) is to show the length of DFT for each value of k, computation of X(k) requires N= Complex multiplications, N-1= Complex additions.

2.7 Self organizing map (SOM) :

The guideline objective of the SOM is to change the high-layered input into a basic low-layered topological request output. The info designs in SOM bunched such that comparable examples are addressed by similar result neurons.(Back B 1998).

The original data components in SOM are put away while a significant topological connections inside the it are protected to prepare set. This shows that the SOM deciphers the factual conditions between the information into mathematical connections while keeping up with the main topological and metric information contained in the essential data(R 2009). Self-sorting out map comprises of two completely interconnected layers of neurons: The multi-dimensional input layer and the result layers (additionally called Kohonen layer), as represented in Figure below, the input layer gets the information as addressed by

$$x_o = (x_1^o, x_2^o, \dots\ x_m^o)\ o = 1, \dots, q \qquad (2)$$

Where is the input sample vector, o is the input pattern number, q is the number of the input pattern and m is the dimension of the input sample vector. The output layer is a neuron's grid, which is usually two dimensional. The most important difference is that the neurons of the output layer are connected with each other, and each neuron has synaptic weight w_j given by

$$w_j = (w_{j1}, w_{j2}, \dots, w_{jm}), \quad j = 1, \dots, N \qquad (3)$$

Where N is the total number of neurons(T 1990, Faisal T 2010).

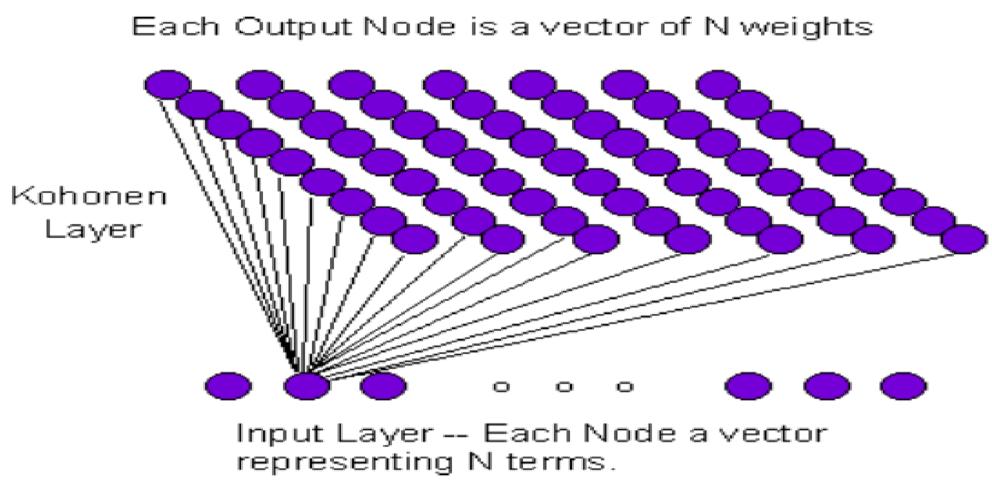

Fig. 5 : The Self-organizing map structure

(https://repository.arizona.edu/bitstream/handle/10150/106141/A_Scalable-98.htm;jsessionid=206728C5B8C6DCA034F5325F80DB59D5)

The topology or the construction of the network set is decided by the quantity of result neurons introduced in the artificial neural network, and by the manner by which they are interconnected. Typically, the neurons on the result layer are associated with one another by means of either a rectangular or hexagonal cross section. Every neuron in a rectangular grid is associated with four neighbors, and every neuron in a hexagonal cross section is associated with six neighbors, with the exception of the ones at the edges of the grid.(Back B 1998).

The quantity of neurons in the result layer decides the map size of the SOM. The map size M might differ from a couple dozen up to a few thousands. It influences the exactness and speculation ability of the SOM If the map size is extremely enormous, the data will be appropriated on the map, while, too little map size won't give clear view on the information. There is no immediate strategy to decide the size of the map(Faisal T 2010).

The self organizing map is like any other artificial neural network. The executed algorithm is dependable for training and the map starts with initializing the synaptic weights in the network. After this, there are three fundamental stages included in the training of the artificial neural network, to be specific Competition, Cooperation and Synaptic adaptation stages.(SS 1999).

In the competition stage (also called vector quantization), a random sample from the input is introduced to the map, for each input pattern, the neurons compute their respective values of a Euclidean distance between the input vector and each output neurons, which gives the basis for competition, and all the neurons in the network compete with each other to determine the winning neuron or the best matching unit (BMU). In another meaning, the node which has the closest weight vector to the input vector, will be the winner. The BMU is determined according to minimum Euclidean distance between the input vector and each output node (the neurons), based on the following equation:

$$k(x) = argmin_j \left\| x_o(n) - w_j(n) \right\| \qquad (4)$$

In the cooperation process, a neighborhood relation, among the winning neuron and the other neurons is determined to find the spatial location of a topological neighborhood of the excited neurons, where winning neuron is centralized, thereby providing the basis for cooperation among neighboring neurons.

The Gaussian function $h_{jk(x)}$ is used to determine the topological neighborhood function:

$$h_{jk(x)} = e^{(-\frac{d_{j.k}^2}{2\delta^2(n)})} \quad (5)$$

$$\delta(n) = \delta_o e^{(-\frac{n}{\tau_1})} \quad (6)$$

Where $d_{j,k}$ is the lateral distance between the winning neuron, $k(x)$ and the excited neuron j, δ is the radius of the topological neighborhood, τ_1 is the time constant. And there is many features of topological neighborhood: it is symmetrical about that node, have a miximum value at the winning node and it is goes to zero monotonically as the distance goes to infinity, also it is independent of the position of the winning node.(SS 1999, Faisal T 2010).

In the adaptive process , all the synaptic weight vectors of the nodes are updated and its neighbours will have their weights updated as well, in the relation to the patterns presented at the input x_o, repetitively. The impact of each learning weight update is to mobilization the weight vector wj of the BMU node and its vicinity towards the input vector x. The equation is applied to the whole map of nodes inside the neighborhood region using the following equation:

$$w_j(n+1) = w_j(n) + \mu(n)h_{j,k(x)}(n)\left(x_o(n) - w_j(n)\right) \quad (7)$$

$$\mu(n) = \mu_o e^{(-\frac{n}{\tau_2})} \quad (8)$$

Where $w_j(n)$ is the current weights, $\mu(n)$ is current learning rate, $h_{j,k(x)}(n)$ is the degree of neighborhood with respect to winner, $\left(x_o(n) - w_j(n)\right)$ is the difference between current weights and input vector and τ_2 is the time constant.

After adaptation stage is completed, the three stages will be applied again for another random sample until all the samples are given to the grid, the discrete time n is increased by n + 1, and this process continue until there are no remarkable variations.

There are two types of errors which paly main roll of the quality of the map: quantization error and topographical error(Uriarte A 2005).

The quantization (QE) error concerningon the quality of the grid, on the other word map resolution. The calculation of quantization error based on basically measuring the mean distance between the each data vector and it's BMU using this formula:

$$QE = \frac{1}{N}\sum \left\| x_j - k_{xj} \right\| \qquad (9)$$

Where N is the number of data vectors and k_{xj} is the best matching prototype of the corresponding data vector x_j .

Topographical error (TE) reflects the proportion of all data vectors for which firrst and second best-matching units (BMU) are not adjacent vectors. It can be calculated using the following equation:

$$TE = \frac{1}{N}\sum_{I=1}^{N} u(\vec{x}_i) \qquad (10)$$

Where N is the number of samples, the function $u(\vec{x}_i)$ is equal to 1 if $(\vec{x}_i)$ data vectors first and second best matching units of the map are adjacent and 0 otherwise(Uriarte A 2005).

The quantity of map units characterizes the precision and generalization capability of the SOM. The larger map size gives lower quantization error and higher topographic error. Since the larger map size means to increase the computational cost, the purpose is to compromise between increases of the topographic error and minimize of the quantization error with preserved a lower map size.

This can be accomplished by changing the map size during the training of the network, and selecting the optimum map size, where the QE and TE resulted with minimum values(Uriarte A 2005).

2.8 Medical Self-organizing map applications:

There are many medical applications of self-organizing map, many scholars used SOM to determine epilepsy disorders, various results had been seen. I will start with B. Pisano et al. (2016) in "autosomal dominant nocturnal frontal lobe epilepsy seizure characterization through wavelet transform of eeg records and self organizing maps" where the author's have been offered an approach for the automatic detection of Autosomal Dominant Nocturnal Frontal Lobe Epilepsy seizures. The research has been addressed by recording the EEG signals then using the self-organizing map for mapping the electroencephalographic signals. The results shows that the self-organizing maps are suitable to detect brain electrical activities. In other word, the purpose to support the neurologists in the labelling efforts, in this research polysomnographic signals are used in order to detect and differentiate seizure epochs, and this task has been performed by recording the EEG signal in different regions of the features space. the result is a SOM which allows to detect the relations in the complex input space for the description of seizures. (B. Pisano SEPT. 13–16, 2016).

Also B. Pisano et al. (2017) in " Application of self-organizing map to identify noturnal epileptic seizures " In this paper, the author's prupose a seizure's detection system for nocturnal frontal lobe epilepsy, in another word, the purpose of this research is patient-specific seizure detection system, especially Nocturnal Frontal Lobe Epilepsy, the EEG signals has been recorded and used as an input data vector in to Som. describing the dynamic of the brain state via EEG signals through the obtaining a trajectory by the SOM, mean the SOM can be used as seizure early detector. The analysis of the trajectory can provide information on an eventual impending seizure event.(Barbara Pisano 2017).

Sirkka-Liisa et al. (1995) ”Self-organizing map in recognition of topographic patterns of EEG spectra” Over here the self-organizing map was applied for recognition of topographic patterns in EEG. In this paper, the SOM an artificial neural network algorithm was used to the recognition of topographic patterns in clinical 22-chanel EEG, each location of SOM contains a model for a cluster of similar input patterns the best matching model determines the location of the map, the clustering and comprehensible conception of topographic EEG are acquiredon a SOM in current time (Sirkka-Liisa Joutsiniemi NOVEMBER 1995).

Pekka Elo et al. (1992) ” Classification of epileptic EEG by using Self-Organizing Maps ”In this paper the application of the Kohonen’s self-organizing map for classification of epileptic EEG signals in order to reduce the time needed for analysis. The results of this experiment show the capability of self-organizing map for classification of various normal and epileptic signals.(P. Elo 1992).

Manel Zribi (2012) ” The self-organizing maps of Kohonen in the medical classifications ” in this paper, the author’s were used a neural approach, Kohonen self-organizing maps to perform a clasification of tumors, the results are show the importance of self-organizing maps for cancer tissue presence detection and classification.(Manel ZRIBI 2012).

Chapter Three: Methodology

In this chapter we will discuss the procedure used to find the correlation between the five frequency bands and the epilepsy disease. For that firstly we will describe the subjects information, EEG data acquisition and EEG signals processing using self-organizing map.

3.1 Subjects:

Two groups of subjects were participated in this study:

1. First group (Epilepsy group) which contains subjects from both males and females of different ages who suffer from epilepsy disease and were patients of the mental hospital in Bethlehem, who live in various areas of Palestine.
2. Second group (Normal group) have healthy subjects without epilepsy or any neurological disorders.

3.2 EEG Recording:

During the experiment, EEG signals were recorded with (Nicolet NicVue) data acquisition system. EEG signals was recorded with electrodes positioned on the participants head. According to the international 10-20 system of electrode placement, EEG data gathered from the eight electrode positions on the scalp occipital region which is O1 and O2 electrodes, the parietal region which is P3 and P4 electrodes, the frontal region which is F3 and F4 electrodes and the central region which is C3 and C4 electrodes. This method had been taken upon previous studies that used EEG.

The EEG signals were sampled at a rate of 1024 and all signals were filtered between 1.0 and 100 Hz , then a Matlab software was used to determine the the power spectral density of the EEG signals. And the mean power (MP) was calculated according to:

$$MP = \int_{fI}^{fh} Sx(f)df \qquad (11)$$

Where: fh and fI are its starting and ending frequencies, respectively from 1 to 100 Hz with $Sx(f)$ defining fast fourier transform coefficient at frequency f.

3.3 EEG signal processing:

In this study we used self-organizing map analysis to determine the correlation between frequency bands and epilepsy disease. This technique was implemented using MATLAB R2020a (Math Works, 2020) and SOM Toolbox.

As we said before the SOM is similar to any other neural network, in which the implemented algorithm responsible for training the map starts by initializing the synaptic weights in the network. Once the map is initialized, three essential stages are applied in the training of the network, namely, competition, cooperation, and synaptic adaptation.

Figure 6 illustrates the training procedures for constructing the SOM.The figure shows how the neighborhood of the BMU (node 13) moved toward the BMU with every iteration.

According to the above algorithm, three initial parameters were selected for training the SOM: learning rate, topology of the map, and neighborhood.

The network topology was selected as hexagonal, whereas the neighborhood was chosen as Gaussian. The resolution of the map was measured using quantization error (QE) and topographic error (TE). TE and QE were considered to facilitate the selection of the map size.

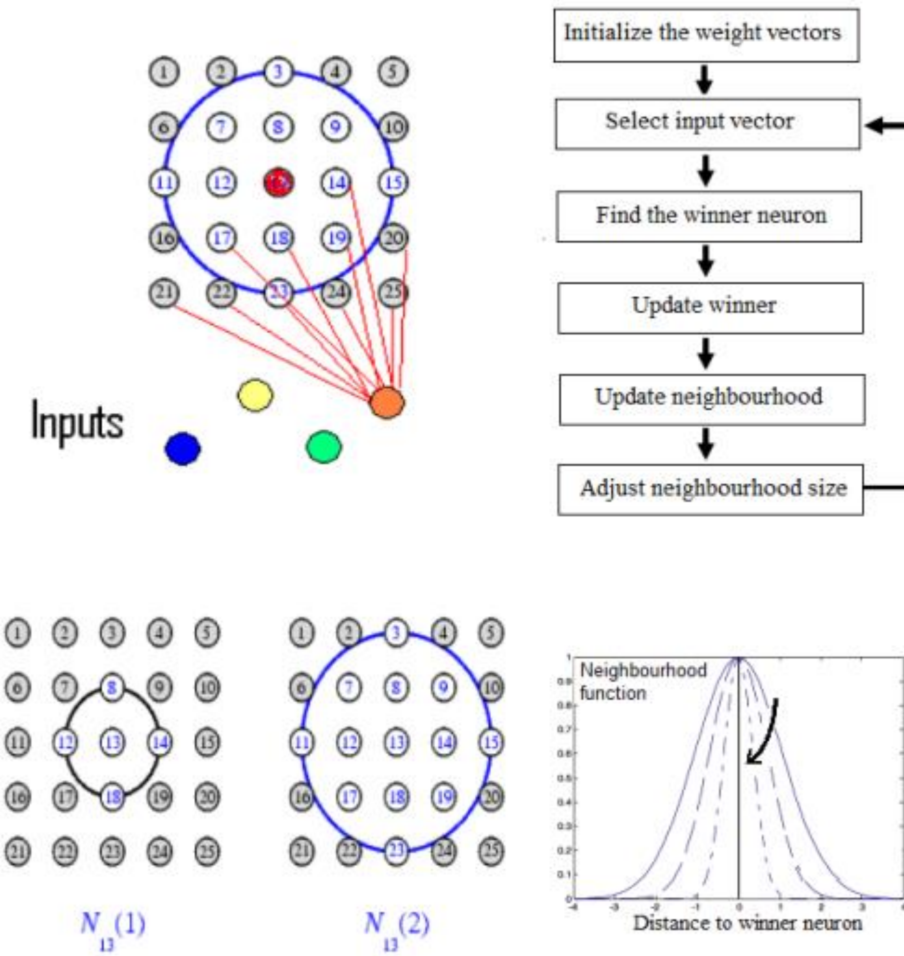

Fig. 6 : Training procedure of the self-organizing map (Tang YY 2009)

Figure 7 shows the Block diagram for performing the self-organizing map analysis to determine the relation between the five frequency bands and epilepsy disease. The data were normalized to zero and one because self-organizing map processing involves the measurements of distances from one vector to another.

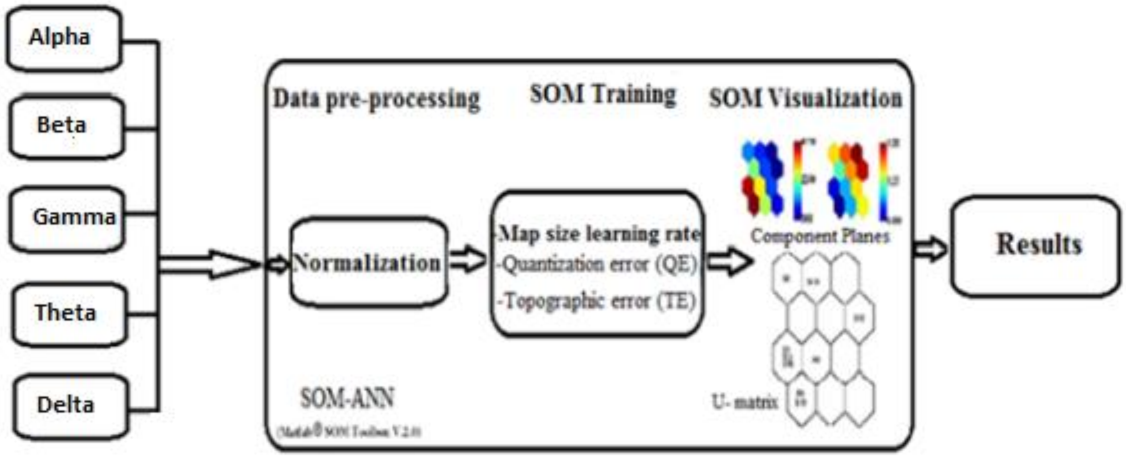

Fig. 7: Block diagram for the methodology used to perform SOM analysis in this study.

Chapter Four: Results and discussion

In this chapter we will demonstrate the results of the spectral power analysis for the five frequency bands and the results based on the self-organizing map technique. As a sample we will discuss the electrode O1 consequences, and other electrodes likewise (see Appendix). We will compare between a epilepsy group and normal group results on the one hand of self-organizing map analysis of the five frequency bands.

4.1 Results:

This section is divided into sub sections:

1. results of spectral power analysis for epilepsy group
2. results of spectral power analysis for normal group
3. results of self-organizing map technique

4.1.1 Epilepsy group:

Figures 8, 9, 10, 11, 12, 13, 14, and 15 represents the averages and the standard deviations of power spectral density within the people with epilepsy. It's clear from the charts that theta band has the highest power and the chart shows that the delta power is the lowest one furthermore, the charts shows that after theta comes beta band then alpha band.

It's obvious from the figures that the theta band power is the highest between the peoples with epilepsy disease. These values are found in table's page 40 and in chart's page 48.

It is noteworthy that the theta band has the highest power at P3, P4, and O1 electrode positions, also notice that the lowest delta power at F3, C3, and C4 electrode positions. These values are found in table's page 40 and in chart's page 48.

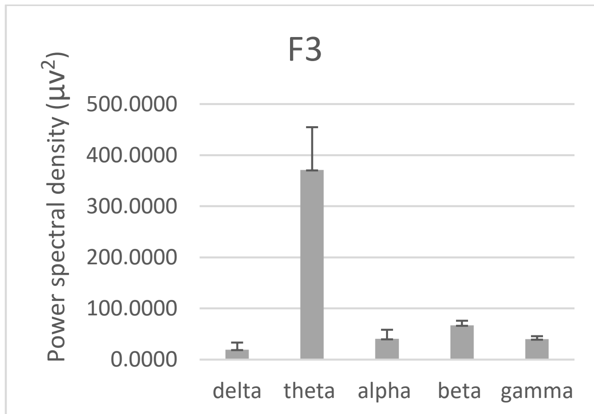

Fig. 8: The power spectral density of the five frequency bands at the electrode position F3 for epilepsy group

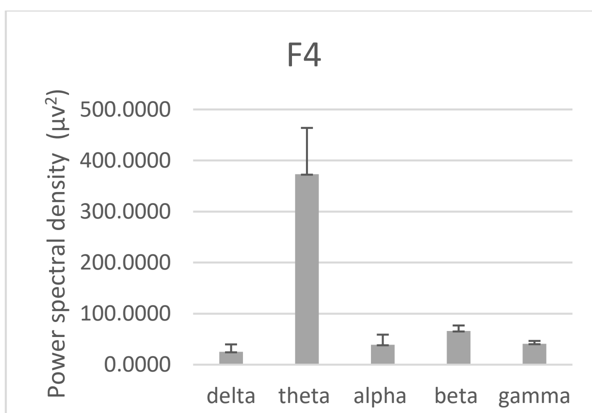

Fig. 9: The power spectral density of the five frequency bands at the electrode position F4 for epilepsy group

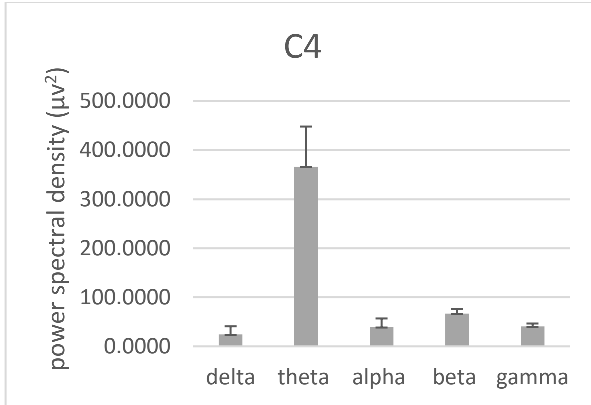

Fig. 10: The power spectral density of the five frequency bands at the electrode position C4 for epilepsy group

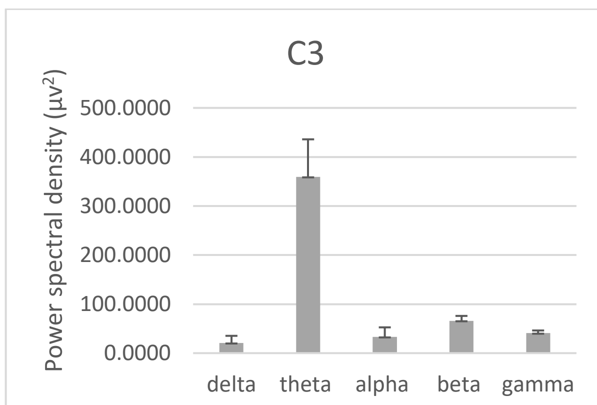

Fig. 11: The power spectral density of the five frequency bands at the electrode position C3 for epilepsy group

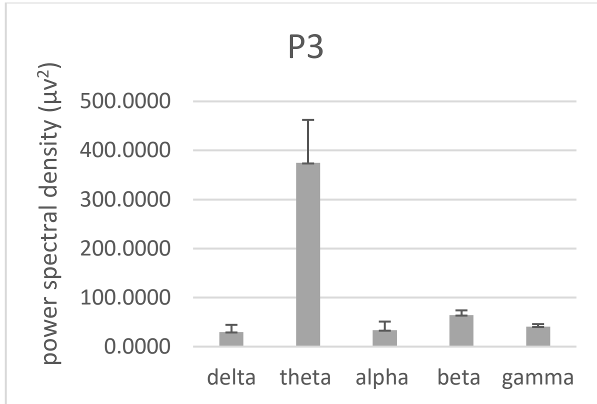

Fig. 12: The power spectral density of the five frequency bands at the electrode position P3 for epilepsy group

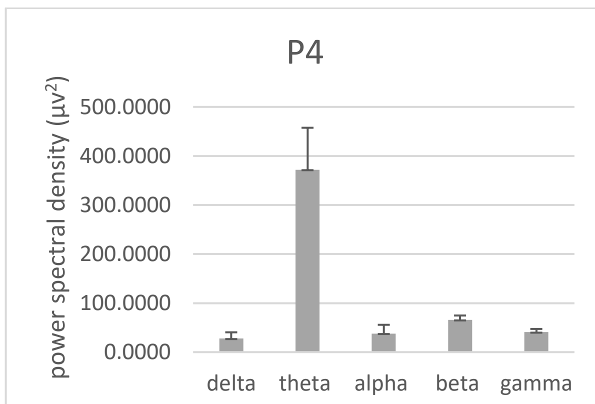

Fig. 13: The power spectral density of the five frequency bands at the electrode position P4 for epilepsy group

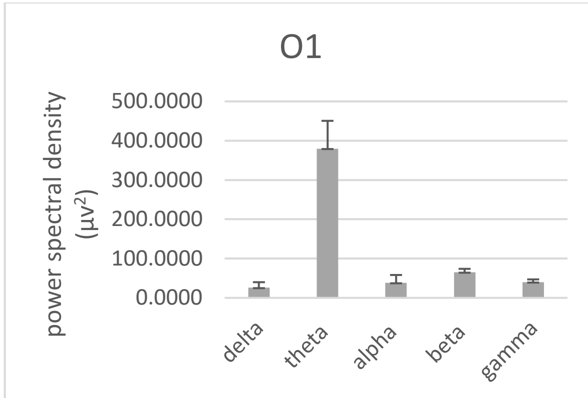

Fig. 14 : The power spectral density of the five frequency bands at the electrode position O1 for epilepsy group

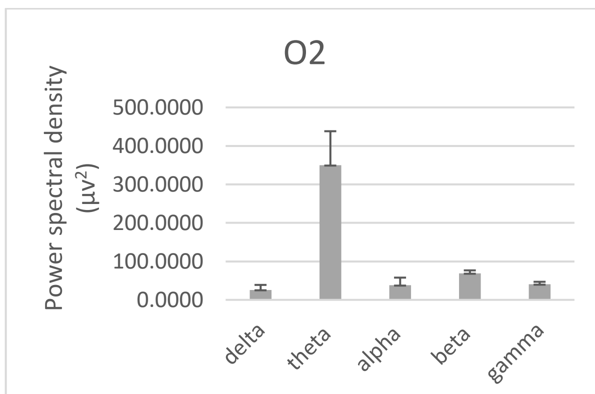

Fig. 15: The power spectral density of the five frequency bands at the electrode position O2 for epilepsy group

4.1.2 Normal group:

The figures 16, 17, 18, 19, 20, 21, 22, and 23 represents the averages and the standard deviations of power spectral density within the normal people (People who do not have Epilepsy. It's obvious from the figures that delta band power is the highest one, and clearly that the theta band is much lower than the value of the delta band power, followed by gamma and alpha power respectively.

It's obvious from the figures that the delta band power is the highest between the peoples without epilepsy disease (normal group) and the theta band is the much lower than delta band power. These values are found in table's page 44 and in chart's page 50.

Notice that the electrodes P4, O1, and O2 provides the highest power of delta band among electrodes. And the results provide that the delta power is the lowest at electrode positions O1, F4, and F3. These values are found in tables, page 44 and in chart's page 50.

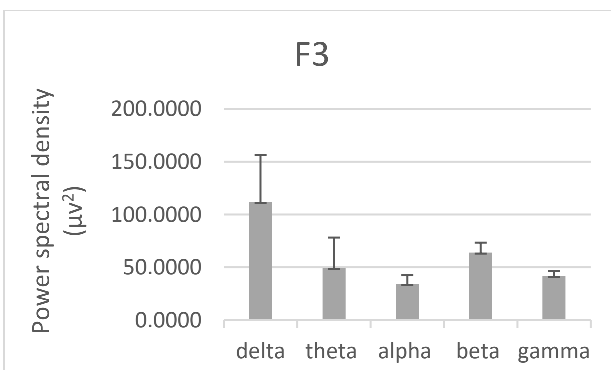

Fig. 16 : The power spectral density of the five frequency bands at the electrode position F3 for normal group

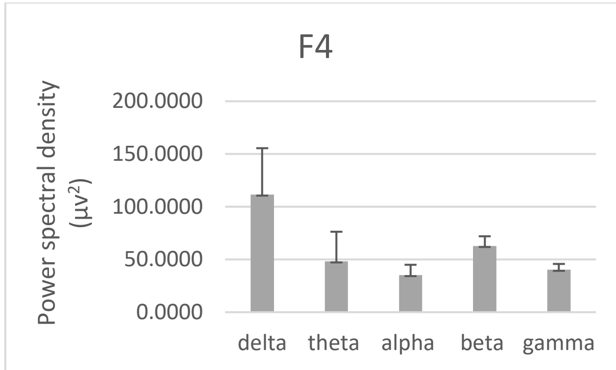

Fig. 17 : The power spectral density of the five frequency bands at the electrode position F4 for normal group

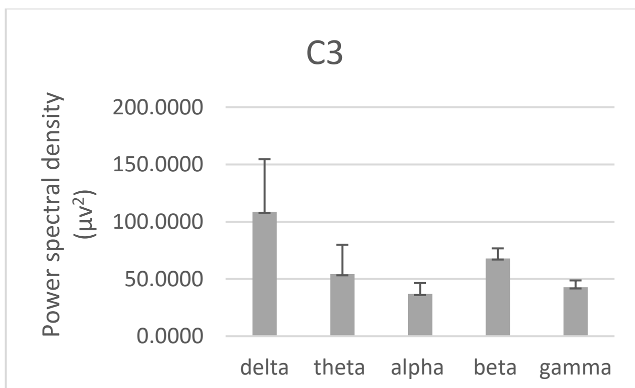

Fig. 18 : The power spectral density of the five frequency bands at the electrode position C3 for normal group

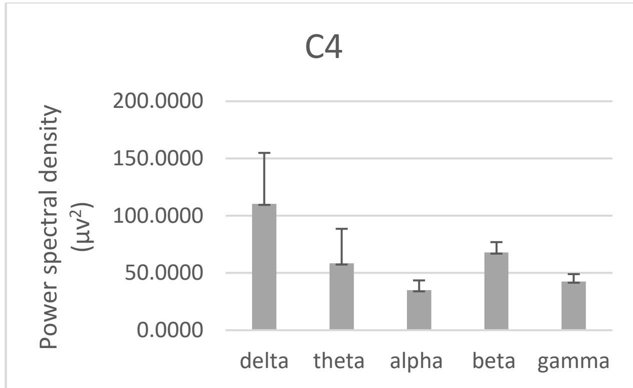

Fig. 19 : The power spectral density of the five frequency bands at the electrode position C4 for normal group

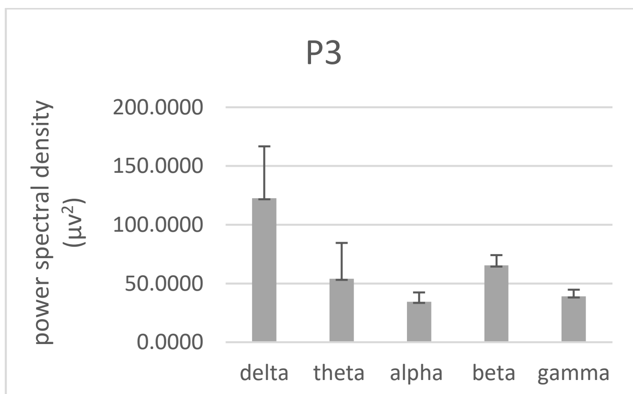

Fig. 20 : The power spectral density of the five frequency bands at the electrode position P3 for normal group

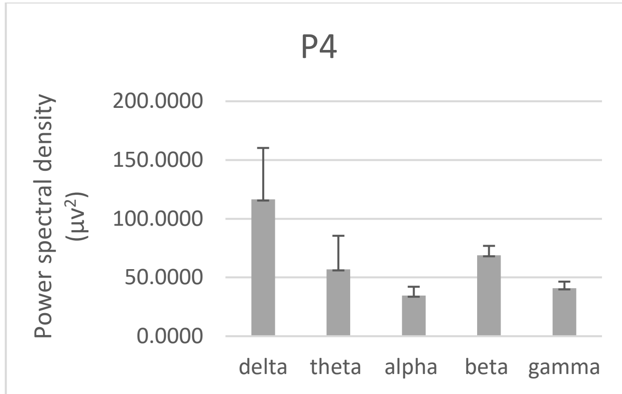

Fig. 21 : The power spectral density of the five frequency bands at the electrode position P4 for normal group

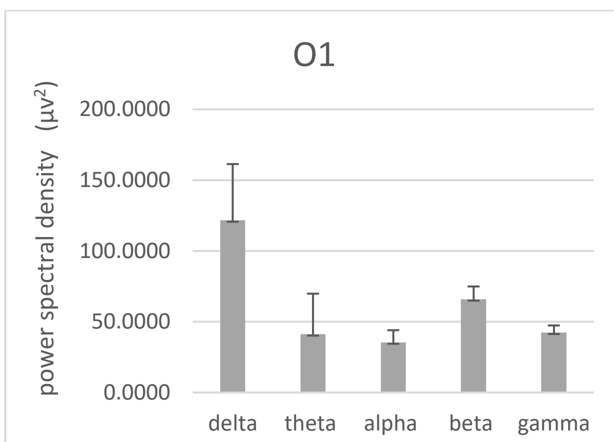

Fig. 22 : The power spectral density of the five frequency bands at the electrode position O1 for normal group

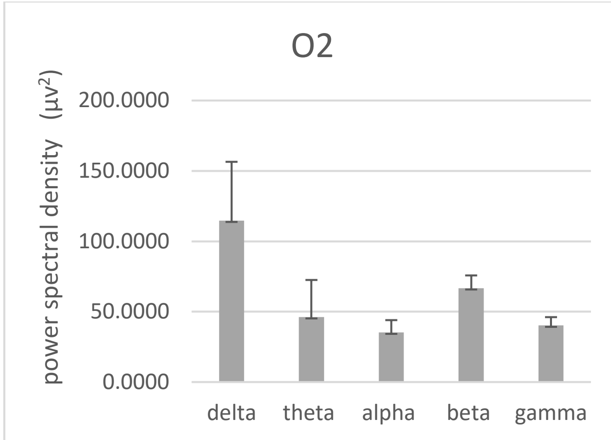

Fig. 23 : the power spectral density of the five frequency bands at the electrode position O2 for normal group

4.1.3 Self-organizing map technique results:

As shown in the figure, after training, the self-organizing map provided results that clearly visualized and explicated utilize unified distance matrix method (U-matrix), label matrix, and component planes (CPs).

After several trainings was performed to detect the better map size for each 8 electrode, over here we take O1 electrode as an example, and other 7 electrodes was placed in the appendix (see Appendix).

In figure 24 , the U-matrix shows 2 main clusters. The first cluster is in the upper side of the map and the second cluster appears in the lower side of the map. During the label matrix of electrode, we can clearly see that theta band is more correlated (red color) and delta band is less correlated (blue color).

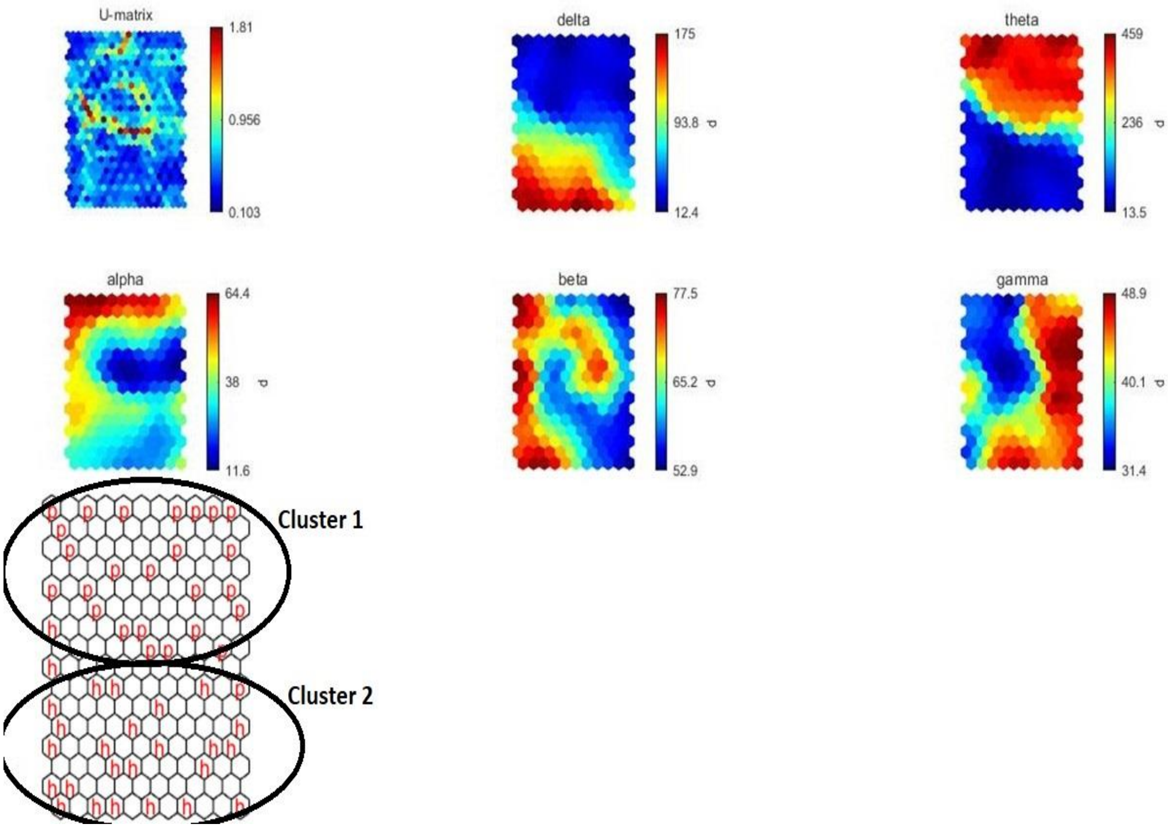

Fig. 24: Visualization of the U-matrix, CP, and label map of SOM for electrode O1

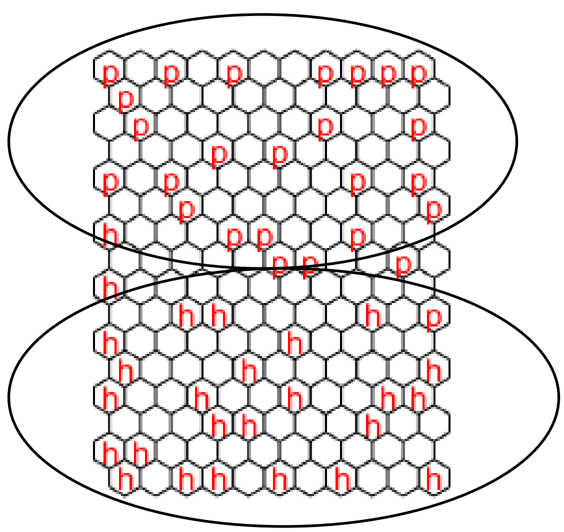

Fig. 25: Label map of the SOM for O1 electrode

4.2 Discussion:

This study is aimed to find a correlation between the epilepsy disease and five frequency bands using the self-organizing map technique also this five frequency bands are under clinical interest. Higher power are most related to abnormal brain position such as epilepsy. The influence of the epilepsy of the brain signals was studied using the power spectrum density the self-organizing map technique was performed, which shows that theta band has highest correlation in epilepsy group.

The results of our research is completely different than the results of the other related researches, in this research I tried to introduce the artificial intelligence neural networks techniques, and specially self-organizing map. The results of this research proves the suitable application of self-organizing map technique for correlation hunting same as statistical analysis and other methods.

The influence of epilepsy disease on EEG frequency bands in the occipital region which is O1 and O2 electrodes, the parietal region which is P3 and P4 electrodes, the central region which is C3 and C4 electrodes and the frontal region which is F3 and F4 electrodes was studied using the power spectrum density and self-organizing map technique. The analysis shows the correspondence with previous studies of which it revealed that theta frequency band is the highest among all other frequency bands. In contrast the analysis shows the the influence on the sample of people who do not have epilepsy was higher on delta frequency band than other frequency bands.

Eight maps were build to determine the correlations between the five frequency bands and epilepsy disease, each electrode has it's own map, and the best map size was decided by the least possible values of Topographic error and quantization error.

Analysis of the relations between frequency bands and epilepsy disease was built on the seeking of the similarity between clusters in U-matrix and labels with component planes. The rate of each part are represented using different colors, notice that the scale on the right of each component map.

The results in figures 24 and 25 shows clearly two clusters in label matrix, cluster 1 (upper cluster) which high correlated with patients (epilepsy group) and cluster 2 (lower cluster) which low correlated with patients but high correlated with healthy peoples (normal group).

Through matching the each component map with label matrix , we can clearly see that theta band is high correlated with patient group (red color) and in contrast theta band is low correlated with normal group (blue color), also delta band is high correlated with normal group (red color) and low correlated with patients group (blue color).

These results agree with statistical results mentioned above in sections 4.2.1 and 4.2.2 which reads that theta is high correlated with patient group and low correlated with normal group.

Other frequency bands, which is alpha, beta and gamma have no correlations with epilepsy disease, that obvious from component maps, and it’s agree with statistical analysis, mean the average values and statistical charts of each electrode position, which are mentioned and explained above in sections 4.2.1 and 4.2.2 . Thus, no significant correlations were observed between five frequency bands and epilepsy disease in all the eight electrode positions.

Chapter Five: Conclusion and future work

The purpose of this study is to detect the effects of epilepsy disease on the five EEG frequency bands (delta, theta, alpha, beta and gamma). We used the (EEG) data, after extract the power spectrum density of the five frequency bands, as a input data for self-organizing map technique, and the results are the colored map which will be used for diagnosing epilepsy in human brain.

The unnatural and strange changes in EEG spectrum is happening with epileptic patients, which leads to increasing in the power spectrum also which leads to negative effects of brain functional connection.

The experimental results gives that, there are contrast between the normal people and people with epilepsy in power spectrum values . This experimental results provide evidence that there are the obvious difference between normal group and people with epilepsy especially in theta band, which will be used for epilepsy disease determination.

In this study, 28 persons with epilepsy, and 30 healthy ones were diagnosed. We analyzed the EEG spectrum and classified them by waves to recognize the average value of the power and the standard deviation of the five frequency bands, then used it as an input data vectors in self-organizing map code in MATLAB R2020a.

This research basically based on the Fast Fourier Transform, which used as a classifier of the EEG five frequency bands, this technique is highly professional technique as it's known.

The main purpose of the self-organizing map is reduction the number of dimensions, in other word reduce the high dimensional input data into a low dimensional map output, so self-organizing map technique was used to correlation hunting between the five frequency bands and epilepsy disease, which gave the result that theta band was most correlated with epilepsy disease.

5.1 Future work:

After the results of this research, it is recommended for any researcher who is interested in studying the epilepsy disease, to research about how epilepsy disease influence on the heart rate variability (HRV) in the ECG signal, on two sides, high frequency and low frequency as well, this will be provide us a more valuable informations about epilepsy.

On the other hand, there are many other disease, can be studied by the same way, for example Alzheimer and Parkinson diseases, however this two disease also have an effects on brain waves, so it will be a very good field of research, about how the Alzheimer and Parkinson diseases affects on the EEG frequency bands.

On the one hand of artificial intelligence neural networks, there are many other techniques that researcher can use for studying the effects of disease on the EEG frequency bands.

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Appendix 1

Epilepsy group

(note that each row represent a patient case)

F3					F4					
delta	theta	alpha	beta	gamma	delta	theta	alpha	beta	gamma	
3.592555	313.7658	51.76355	71.04582	32.73434	40.03594	451.8169	69.93051	53.04067	49.37072	
35.62043	234.6176	37.0403	80.65525	42.56622	10.31145	344.8225	11.45313	80.20027	34.86957	
24.4406	273.2296	44.81121	59.25328	41.48398	2.926052	413.6708	49.87173	50.68505	35.62913	
50.02379	206.0346	42.92184	66.43062	38.58392	3.337818	245.3513	24.46318	52.99139	45.34222	
5.7612	465.9393	8.827197	76.72788	30.64292	27.00912	441.9663	69.96208	71.58721	40.89337	
32.92403	482.7291	47.29808	73.02086	48.30117	34.31801	475.2712	35.06582	67.22337	49.01913	
37.51645	320.8921	47.16501	53.00768	38.99525	50.8127	436.2782	36.54849	66.26719	40.99106	
17.78519	223.2385	26.14129	60.53415	40.75513	36.15292	303.3867	45.34711	79.42755	34.78978	
16.37186	276.3453	49.73411	78.05954	43.89253	24.98837	476.4808	33.16631	78.15584	32.29272	
3.451447	378.3817	17.82254	77.80208	36.27885	11.03835	479.4899	43.81079	78.88898	34.48219	
10.17199	495.1216	39.13955	63.65481	32.92061	32.1544	346.9741	25.15409	53.3753	49.49938	
13.13468	280.9489	70.94073	67.22081	34.02248	6.149753	425.4171	12.96628	79.47241	48.5116	
6.839903	423.8226	66.67676	72.29146	46.58775	43.15752	499.4693	20.78609	72.64584	44.01246	
2.847862	326.1972	40.32146	76.73173	46.00279	38.49802	277.3257	54.4399	72.38489	49.00342	
6.787764	460.8672	30.60038	50.90235	41.2761	31.24824	487.2184	68.78052	76.15364	41.9576	
37.10752	449.7211	68.27388	58.61311	39.35007	14.93523	407.0481	4.622488	51.04066	43.46179	
6.608274	414.2558	36.4324	52.13743	49.27653	45.84524	286.5132	55.62784	72.81201	31.60868	
30.00557	369.0543	50.7331	57.96964	31.01573	9.855923	217.4602	44.15927	60.17665	37.76791	
42.89935	406.0437	65.34323	61.92977	40.4842	41.17057	394.6121	7.503387	56.52324	37.50329	
7.544052	369.3266	13.00431	58.84479	47.92157	46.84754	288.6955	52.23241	55.09173	37.71293	
34.59601	433.0444	54.14915	76.90392	45.46834	4.186765	217.8106	64.418	70.25708	37.79208	
25.30866	419.7432	38.6977	77.57132	31.50635	27.11621	411.9199	9.437283	71.37927	46.04986	
8.248274	376.3328	32.4768	73.05137	37.72978	10.69597	216.434	46.9736	53.07379	39.80065	
15.14371	316.493	5.915239	72.71983	39.52202	30.53906	444.8984	65.62307	80.78828	37.61318	
31.19685	432.8274	35.54115	70.95224	49.85746	15.18312	428.6256	19.46061	59.09676	47.7859	
9.829866	481.9278	18.25498	67.64513	34.55399	32.39588	274.5279	47.20998	78.37789	44.87709	
25.96907	455.1355	30.26907	53.27373	44.6378	12.33853	311.9391	30.66201	54.39468	40.68645	
7.727442	306.6846	67.84258	71.56458	33.72933	23.36552	445.0606	44.23956	54.25437	38.00851	
13.69851	83.61526	17.78997	8.929188	5.802708	14.54265	90.64945	19.76613	10.77098	5.42946	Standard deviation
19.6234	371.1686	40.6478	67.1613	40.0035	25.2362	373.2316	39.0684	66.0631	41.1190	Mean value

C3					C4					
delta	theta	alpha	beta	gamma	delta	theta	alpha	beta	gamma	
2.839097	388.4514	22.83467	67.74278	44.91945	12.01556	411.6579	35.86744	66.95188	37.77357	
13.61559	432.2635	22.43474	52.59088	36.13505	49.42406	477.7944	33.97857	57.0755	36.96402	
21.64136	276.1154	28.9553	72.73554	35.1179	12.9608	439.1916	13.48468	74.92817	42.33616	
12.57327	354.8501	4.506985	68.66958	43.56866	29.88246	237.7683	44.0111	54.14057	34.0114	
10.82775	330.9759	54.49355	79.59517	44.94325	50.85295	217.8778	46.21675	75.30408	48.444	
46.70592	437.9286	25.95846	50.76553	37.46935	50.49216	296.4057	40.28249	50.83877	36.09265	
31.75083	469.7345	12.39671	77.26673	37.79507	2.656586	474.3548	42.95752	69.60283	48.47419	
48.88405	357.7081	18.30068	51.40735	45.98429	40.94049	360.7914	51.70279	75.28101	40.83778	
7.304364	461.2055	46.31294	60.23141	48.6691	9.84686	468.5044	18.09254	77.92893	48.41677	
21.44685	338.4116	24.12292	69.54589	41.6212	50.8068	373.9657	68.35777	50.8017	49.90279	
8.387006	287.4654	39.63896	57.45104	46.59159	33.02986	413.0203	12.3102	71.77423	37.45776	
43.73001	444.6425	33.64605	73.29275	47.33346	45.23398	315.0208	42.94311	72.90075	41.48354	
17.82598	247.5285	51.22681	68.33575	34.45825	8.850214	241.7042	70.74532	51.48921	48.11583	
3.216495	370.9704	4.34433	61.15233	35.47431	17.30067	326.8679	52.46423	65.04657	44.24946	
6.339792	272.3634	4.441137	80.55583	32.97474	2.376361	441.3281	32.47835	68.6137	45.32472	
50.76985	231.238	60.1392	51.36152	50.17962	13.99285	405.0433	37.72356	78.17951	35.32824	
12.471	290.7368	20.30102	63.36295	37.05799	24.16034	259.694	10.43746	67.14736	36.19161	
13.08275	331.7734	23.45613	59.41246	40.09346	4.394541	418.1221	19.94663	52.3487	30.36729	
5.684953	439.7021	70.80234	69.98794	33.97211	7.548194	359.7058	52.26387	80.77425	43.47682	
4.523829	478.4382	30.56697	79.30794	37.892	25.77035	271.3559	24.0012	59.16024	49.06574	
37.83481	473.135	24.28765	79.84306	47.59494	38.93424	389.8059	45.43509	61.06946	31.04918	
35.64596	468.8352	29.18694	51.32442	31.82623	44.83398	447.0376	58.07648	59.17323	36.80738	
28.16548	369.9591	10.01663	54.06891	41.77675	33.257	426.4688	42.4587	78.54021	40.71631	
21.67393	320.5376	68.02634	69.06323	33.35457	17.66657	420.3421	68.52998	69.779	32.27047	
12.24933	334.7036	46.80417	79.19375	43.59863	19.70192	391.4196	67.4358	75.39063	37.5145	
5.835793	262.152	66.10093	69.65039	42.74564	2.764355	461.0539	23.8327	74.23167	32.93859	
29.59288	271.2886	57.13735	56.04716	36.502	26.66549	297.306	22.2158	51.53754	49.85561	
24.3903	320.7405	25.9091	73.31871	49.43814	5.11902	220.8277	25.77935	77.04915	42.00297	
14.6193	76.55815	19.50555	9.930951	5.5306	16.55755	81.66089	17.48575	9.832085	6.049427	Standard deviation
20.6789	359.4234	33.0839	65.9743	40.6817	24.3385	366.5870	39.4296	66.6807	40.6239	Mean value

P3					P4					
delta	theta	alpha	beta	gamma	delta	theta	alpha	beta	gamma	
29.25752	410.8723	43.1082	76.77335	39.36313	20.34081	436.4034	12.25324	65.85028	46.04308	
32.38434	471.3619	32.1087	71.67617	46.19557	50.69409	213.0635	48.52646	72.29166	43.6114	
16.79063	449.3472	17.15087	67.78612	39.0931	18.94162	336.4859	29.24913	58.85759	38.36332	
2.33723	327.3315	17.93784	75.65787	38.54202	21.65931	375.0619	28.4087	56.59968	47.26563	
50.36776	432.3786	12.084	56.36732	32.62461	16.6672	417.0614	13.14716	52.86171	47.83637	
48.4849	385.2309	41.81314	79.29804	39.12043	39.22124	369.5439	48.31771	63.21095	34.13978	
39.77046	461.6929	32.31675	69.02247	35.76163	30.53583	447.0617	61.87176	50.33461	49.54997	
36.56022	453.1864	9.731852	54.35553	30.15593	45.40101	382.0279	57.23833	55.39226	44.07524	
3.162292	221.9038	63.77779	60.15865	39.75338	23.402	455.9459	44.19896	52.96586	40.30895	
18.15427	417.5872	11.03461	74.08333	46.77627	21.79856	352.2421	38.85384	77.18572	46.46509	
28.54036	416.924	66.00757	57.44583	50.15361	35.41692	225.4639	62.88604	65.33244	30.44762	
48.69275	455.9142	41.4501	55.9982	41.39657	38.89212	485.5799	18.91252	78.89254	32.02845	
24.01787	230.5161	45.62384	77.64652	41.23749	37.34993	486.8813	41.38875	78.64653	35.57755	
39.36138	366.0688	21.82228	53.71538	42.16904	46.77461	438.6798	62.2194	54.91539	33.45708	
26.81259	417.7236	60.7955	51.82259	40.63157	4.149562	439.9672	19.95603	66.96272	49.00695	
9.206881	494.8794	24.24542	52.90675	36.15378	5.480334	468.6547	47.76981	61.24687	34.49462	
38.26349	354.3722	37.60562	77.55205	46.0801	21.84302	389.4384	30.96397	64.10425	41.62224	
43.81026	488.2019	11.21052	65.30323	45.58952	46.63701	201.2547	44.00528	76.53972	48.87188	
46.33706	254.3035	61.57956	71.65739	39.85823	21.46277	419.886	33.05742	68.86156	38.65985	
35.51659	258.8742	50.92844	50.60392	34.49508	14.39742	308.0891	60.60157	65.89613	50.81673	
48.13274	435.348	8.966497	70.08925	35.75463	15.97832	318.1813	12.16419	63.65436	39.06169	
13.25781	296.7415	23.99106	68.55045	41.87169	31.6436	200.0562	17.30567	75.82405	46.74916	
17.94439	214.4973	39.34564	71.08534	48.99348	23.82965	388.2299	39.49646	70.15659	30.41871	
24.38386	387.4958	39.52437	50.66126	43.071	40.69889	452.7304	40.31847	76.15819	38.10855	
47.43821	346.8929	25.60386	71.72037	42.38222	22.48251	279.851	59.87943	74.20042	32.46789	
4.827772	322.3831	15.29606	50.15713	34.72829	44.20904	350.7948	63.10346	78.78029	49.32993	
34.02212	237.4903	55.10229	55.2409	48.57105	8.527844	452.7508	4.289116	51.73167	39.32295	
29.51441	476.4583	28.4686	63.11885	44.75003	24.03457	324.6857	19.82104	62.91812	31.89188	
14.53477	87.79794	17.53323	9.645778	5.004589	12.87499	85.49119	17.87629	9.008431	6.592021	Standard deviation
29.9054	374.4992	33.5225	64.3019	40.9026	27.5882	372.0026	37.8644	65.7276	40.7140	Mean value

O1					O2					
delta	theta	alpha	beta	gamma	delta	theta	alpha	beta	gamma	
3.157689	378.9033	5.332278	55.62196	50.2252	3.232877	426.7081	36.05309	58.14769	38.55965	
6.418543	347.5936	12.50949	51.24227	30.26401	13.73994	313.0804	37.46262	61.55158	30.29954	
47.18874	479.0137	65.39268	54.63296	40.62584	38.48811	362.5949	23.75807	73.13194	50.44988	
10.11469	390.5437	61.50249	56.35334	30.14102	39.90254	412.4692	22.9394	77.80534	31.58699	
27.75998	219.3217	57.555	67.61899	33.82105	13.81779	292.4519	5.715703	55.73454	38.69693	
48.16192	303.7617	7.583788	63.92552	46.01052	37.3892	468.8573	70.81697	74.30448	32.67715	
26.46322	374.0748	43.64819	66.7512	45.87065	34.04507	363.8207	36.05112	64.99919	39.36364	
26.83025	425.2285	31.62863	67.90918	48.41339	15.78049	220.711	58.99918	63.27772	35.85149	
25.62429	439.5547	39.01604	74.5203	41.54021	33.28633	201.365	61.81071	56.67778	32.3267	
31.31764	330.9481	35.10186	67.16714	33.9995	30.81793	249.9999	68.87174	61.24477	48.89722	
44.34446	374.5217	13.70015	71.83052	36.0641	23.00379	256.3817	41.39725	75.19029	49.40667	
12.97066	439.327	41.38068	50.49598	38.95056	37.38108	427.9817	40.55787	68.78915	44.29323	
20.76773	379.8731	31.21087	63.99639	32.1838	41.79676	301.3565	38.07202	64.83299	44.37219	
26.45304	485.918	65.61683	73.24891	31.87288	12.61094	323.5209	51.53712	64.01908	45.57282	
39.02307	364.9589	13.05985	63.2259	33.19718	41.27286	481.5602	37.46647	78.21479	44.48454	
5.173661	330.236	70.88887	77.90233	36.13705	44.26266	396.7667	19.56548	80.33948	49.87866	
49.38206	451.6568	53.02067	75.91674	34.59552	38.38291	459.4225	46.67321	79.29783	34.34509	
34.96589	343.8954	18.2338	78.80169	50.24507	26.06875	232.3386	5.533902	72.82714	36.83871	
42.3783	332.7162	9.702544	69.47643	32.11125	2.07479	202.1551	70.89751	69.96523	35.18365	
22.51141	379.6125	61.64586	60.70005	48.85386	8.639852	387.5673	32.50608	78.14149	35.13323	
37.21663	303.4544	42.44006	56.14723	49.28719	30.05344	333.7832	37.30262	75.13009	44.0521	
37.68583	420.0328	19.3764	57.87244	48.67022	8.318042	406.4949	20.27964	76.83382	45.22064	
30.63639	223.884	46.05316	53.33256	48.16207	28.67913	358.4981	42.61907	63.70653	33.10329	
20.88606	378.1886	32.59525	69.2375	33.13958	29.23053	430.6167	13.15241	70.1452	30.5412	
15.36517	458.7518	50.23655	55.02344	44.95546	17.80789	491.013	4.708833	74.4458	39.85927	
1.817292	461.9622	19.43665	59.295	47.47356	41.27734	247.7798	65.1357	71.8444	41.43406	
21.0391	500.1591	56.35898	78.53185	38.09504	26.30701	295.1838	18.06221	67.14459	50.91323	
4.468156	313.4267	61.93466	78.70849	32.47986	6.390031	452.4723	57.86496	52.53356	48.3902	
14.22868	70.81147	20.14627	8.873281	7.096417	13.00273	88.25808	19.722	7.728498	6.595819	Standard deviation
25.7186	379.6971	38.0772	64.9817	39.9066	25.8592	349.8911	38.0647	68.9384	40.4190	Mean value

Appendix 2

Normal group

(note that each row represent a normal case)

F3					F4					
delta	theta	alpha	beta	gamma	delta	theta	alpha	beta	gamma	
88.6500967	18.40808	30.52047	80.75065	47.78721	108.4319	98.40689	47.89044	59.59725	43.00812	
167.561489	81.74442	41.75799	56.89375	34.13554	60.19674	35.66275	43.86067	63.86846	38.1685	
174.750251	75.81932	26.49782	50.76707	46.6597	92.65862	20.98441	31.57274	51.57746	30.39267	
56.5676845	48.65383	39.24396	57.8161	41.77894	200.0832	62.12388	43.87432	53.6922	43.04978	
107.392058	10.89306	49.51191	68.9425	34.13464	196.6827	82.88877	24.68867	61.04376	42.3715	
186.99689	1.641063	41.45229	76.24528	47.15134	111.6195	14.29441	20.41446	55.12938	40.95839	
182.247124	89.20482	25.07237	66.40964	49.34239	104.4389	28.70369	39.17755	54.48538	49.40159	
152.626573	7.377222	25.88312	65.04336	44.33179	162.1893	20.35983	39.79588	60.68277	34.02614	
97.1524353	50.94063	24.46278	64.56845	37.61601	75.77265	85.27462	23.99602	78.0515	32.3927	
86.16424	24.90805	32.46702	58.32473	45.44536	65.89071	84.06165	30.68669	54.69232	38.77908	
83.1749575	72.59825	40.12154	73.60402	42.87504	98.62846	17.4731	29.93264	77.76506	46.53463	
52.6652913	71.52257	42.97828	57.86192	44.54393	194.1734	8.177712	21.34397	79.6815	35.19918	
74.7481356	28.01726	37.79454	73.77655	35.50945	90.62474	77.75091	26.36513	53.08362	41.76244	
81.4726019	62.48141	49.07559	79.67437	40.41889	81.41926	82.18511	48.56793	69.61406	43.78759	
196.759872	46.03539	23.71531	75.8817	48.6911	58.7815	58.19732	50.30758	54.6921	36.08955	
71.0392659	86.44402	28.93519	51.1955	45.79249	92.07642	8.926203	32.0985	70.7828	48.498	
76.7480849	10.53217	40.60509	66.12554	34.83319	60.63313	55.338	40.72462	63.87979	34.90673	
68.8286185	17.34899	24.24192	52.47665	37.67552	138.838	26.40915	31.87458	61.65081	41.04802	
67.8094986	79.21462	31.19868	53.57577	42.34363	118.4068	10.82353	40.54194	50.73654	42.51811	
167.471266	71.69299	34.8545	73.3878	45.44949	73.94371	44.74748	50.00543	69.57643	49.03391	
106.979407	94.26997	39.50896	72.26979	41.26645	139.9042	51.98127	21.42058	66.40893	31.67154	
115.333195	37.53724	29.86218	70.93307	34.17763	122.2853	8.395356	23.25757	52.35192	34.2422	
53.7924488	10.95943	34.70937	65.88659	43.38562	60.51305	31.19797	31.95286	69.09213	43.24065	
168.876485	45.81467	46.92613	61.64694	40.36313	83.78933	78.10102	22.91157	56.53376	39.64979	
128.795236	43.07117	43.87539	52.14706	46.79548	149.7731	68.03931	46.92402	53.90043	36.49259	
133.144606	80.16852	24.26002	50.6698	42.00782	158.5498	61.45544	47.44073	63.98806	50.6082	
83.7769208	42.82245	22.81917	64.49824	37.47281	165.1483	50.82099	34.48113	80.25922	43.42175	
99.1833734	79.00731	23.27149	51.50591	44.20358	57.6432	76.75093	40.66877	73.52254	34.83512	
44.6331574	28.61989	8.402433	9.389791	4.643406	43.96182	28.09778	9.731706	9.119587	5.557246	Standard deviation
111.8110	49.6117	34.1294	64.0314	42.0067	111.5391	48.1976	35.2420	62.8693	40.2174	Mean value

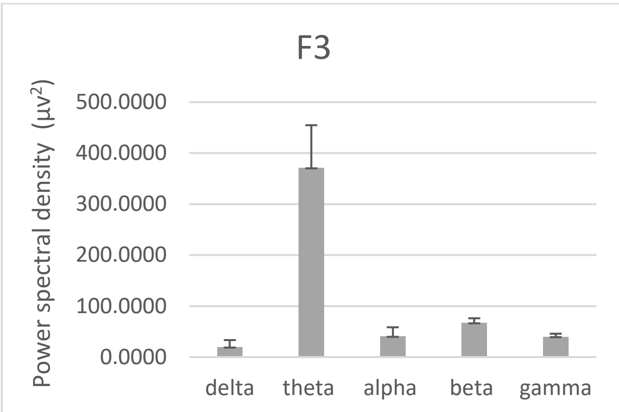
C3					C4					
delta	theta	alpha	beta	gamma	delta	theta	alpha	beta	gamma	
166.824	27.63632	44.84755	65.87506	38.94429	142.1831	38.2866	45.58778	73.56643	50.31495	
147.5182	95.19266	42.76556	70.24453	46.2709	58.87861	18.39629	31.59857	56.34265	45.4223	
67.28117	1.725341	49.07809	79.12378	50.87264	66.12971	99.6281	40.32459	70.018	38.5547	
100.0628	35.25871	20.27302	79.05375	50.03937	65.33522	51.72372	25.72379	80.72632	32.64444	
187.1382	75.04962	50.44983	77.84084	43.0986	64.22949	68.59244	30.1887	50.68309	45.50735	
71.28519	81.1648	31.37283	51.10587	33.02301	116.8393	59.00769	34.7978	80.54406	43.66689	
59.10315	54.43072	37.26688	56.28619	43.92463	60.44492	42.48891	42.18781	50.92471	32.29398	
50.32938	27.30235	25.81795	52.67101	49.66048	186.922	80.62887	35.08329	69.798	50.58574	
69.78419	44.57011	28.22668	62.90223	32.50228	157.8807	36.33938	20.42046	60.97918	33.90692	
181.147	77.75776	23.79652	66.28248	42.61032	185.0062	85.65587	39.74307	68.07646	49.88586	
193.469	52.84456	42.01872	52.24807	46.97436	90.31479	97.11056	48.28786	62.52566	50.0638	
53.3904	45.85942	41.76684	65.0118	40.85454	60.49692	83.2072	22.4463	74.84349	43.57506	
88.61333	49.65959	22.70092	76.55454	43.6809	144.9573	5.888749	27.2155	62.36947	45.37184	
96.7883	81.99687	33.51754	65.31294	42.9974	59.9224	43.95631	28.18063	71.0715	50.43987	
143.6836	91.64347	47.46946	68.50097	35.23726	126.066	80.84963	24.37449	58.93164	39.55664	
54.31822	51.67953	36.04436	71.26388	41.57504	102.2765	56.15445	28.68188	79.90152	40.5282	
86.03604	22.01088	20.21184	73.00184	45.85487	115.0747	96.66563	20.04559	78.65076	33.29988	
96.52973	71.06127	40.22827	63.13789	34.31781	138.6372	71.22887	41.58726	72.30684	42.69176	
80.91765	90.87311	43.61279	74.6576	49.76647	100.4232	26.48274	42.12073	78.82834	31.90253	
176.5456	79.42259	39.77312	73.34741	50.90073	51.0359	37.38203	49.30783	62.20713	33.16162	
103.6903	71.09104	48.59284	68.65997	43.85825	132.1667	64.51167	42.1283	59.8714	50.08149	
72.07175	65.56563	24.90241	58.49894	49.26581	174.1173	15.3468	29.57118	69.87276	44.186	
177.3254	10.66338	48.83536	79.26858	44.94236	72.25858	33.7637	31.76419	58.16914	46.62348	
83.92175	31.65432	27.79582	62.88861	33.05054	111.2123	38.79011	39.59853	78.75592	32.58533	
91.29002	49.48489	46.52092	80.71479	44.01637	81.94024	100.2525	46.58845	56.6876	50.22499	
116.4611	21.36605	45.58382	75.35918	48.4824	169.829	100.142	39.86827	78.90291	44.6914	
71.73916	78.34176	38.66718	57.6306	39.22779	187.969	3.477168	27.47399	70.64142	40.17225	
157.823	31.89817	33.22362	76.171	30.38304	70.89939	98.65264	43.42697	64.73807	47.5519	
45.7862	25.77703	9.477559	8.747885	6.017412	44.44026	30.19093	8.581477	9.072911	6.513947	Standard deviation
108.7531	54.1859	36.9772	67.9862	42.7262	110.4802	58.3790	34.9401	67.8905	42.4818	Mean value

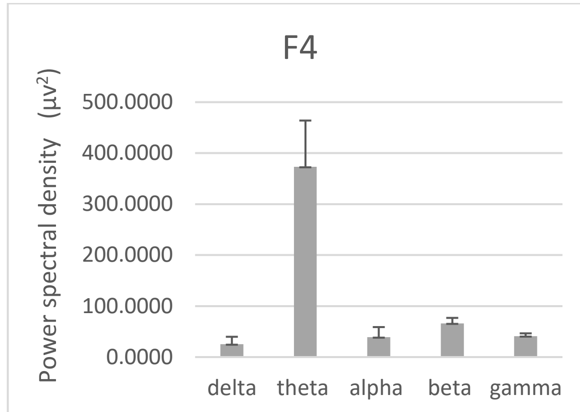
P3					P4					
delta	theta	alpha	beta	gamma	delta	theta	alpha	beta	gamma	
145.9876	72.03631	24.93945	65.68884	40.74387	99.74866	31.38735	40.99235	64.17735	44.17553	
58.21713	26.82658	40.12049	56.61207	33.5553	93.51095	83.59811	23.19968	77.83069	36.26002	
160.8593	11.35767	23.18336	74.7573	44.62685	89.85486	100.9609	23.21821	75.86537	50.9859	
94.36743	100.5267	27.6175	71.30419	32.77662	180.5317	18.80361	31.52327	56.63138	35.64899	
83.35102	94.85333	46.15999	52.77848	33.86308	85.67903	67.76007	30.61537	79.15651	30.29906	
199.4807	52.86828	29.24846	50.8461	36.86723	165.5464	80.82323	41.97459	69.39692	47.34151	
138.0273	11.63663	33.85011	71.734	35.26588	98.76048	43.74669	38.8843	74.90214	40.54268	
103.8291	1.500644	38.21015	58.59889	35.65017	74.83627	28.90843	48.7981	77.39736	47.87061	
95.35579	47.62724	46.78661	67.36437	50.70679	182.9438	81.0657	23.99435	65.55915	37.49577	
134.5138	94.68034	37.19621	78.25837	39.07633	172.8864	57.18609	37.6374	65.03988	33.97072	
99.38565	76.99925	29.31663	68.74559	47.9417	114.029	95.64473	41.5907	75.12126	41.17173	
124.4308	55.35117	28.09892	78.36543	39.09308	110.5868	14.49938	32.7517	71.06004	35.16855	
154.5832	64.17457	37.07464	72.05851	32.76921	60.17673	70.94894	27.26827	66.19436	35.05667	
187.4545	16.63018	41.74163	63.48179	41.60803	137.8671	4.575587	28.16056	68.51676	37.89982	
60.92402	79.4414	29.43508	52.37623	48.20656	132.6443	80.17213	38.17616	54.77792	42.47303	
153.6317	79.26167	24.7559	60.46932	46.40701	70.56643	91.01644	37.78988	71.69402	36.44408	
124.9147	30.47248	43.42449	51.97523	46.37588	105.9808	69.82018	34.08783	75.60078	42.63502	
98.51032	47.75438	41.29009	59.31978	38.74582	162.646	58.55248	26.01429	65.37628	50.90089	
169.8816	39.47704	29.03268	76.04493	43.2957	197.6851	69.10879	35.14498	66.98721	40.90048	
50.3868	60.35829	28.61262	71.25192	34.80576	57.9826	63.42505	34.17668	67.2461	40.63887	
200.7577	92.57964	43.03306	77.23542	45.8835	170.7601	95.59675	39.26114	77.85423	40.77258	
75.84859	1.436716	27.72098	53.88291	30.51261	179.7845	7.453377	42.81558	76.20714	30.87985	
145.9995	83.5615	25.11222	78.65326	34.94146	100.9084	49.34952	32.31276	72.87149	37.84709	
152.579	19.05302	42.07631	67.41767	35.76528	106.3773	84.52984	42.98629	61.07458	45.32894	
125.486	94.08008	21.20668	69.46172	40.14525	57.42575	29.6504	47.17109	79.63412	41.85121	
61.13881	70.78155	48.95551	60.16469	39.48202	68.94974	16.16306	22.05306	50.29615	49.04347	
173.6574	29.48534	36.6468	60.22779	30.62565	57.24672	61.2615	25.19553	54.66329	47.81283	
61.33203	58.94652	40.19098	61.79274	34.12301	126.3497	40.07311	41.14133	71.35767	42.91232	
44.0534	30.46272	7.9263	8.759729	5.649423	43.73976	28.5075	7.50749	7.88956	5.585797	Standard deviation
122.6747	54.0628	34.4656	65.3881	39.0664	116.5095	57.0029	34.6048	69.0175	40.8689	Mean value

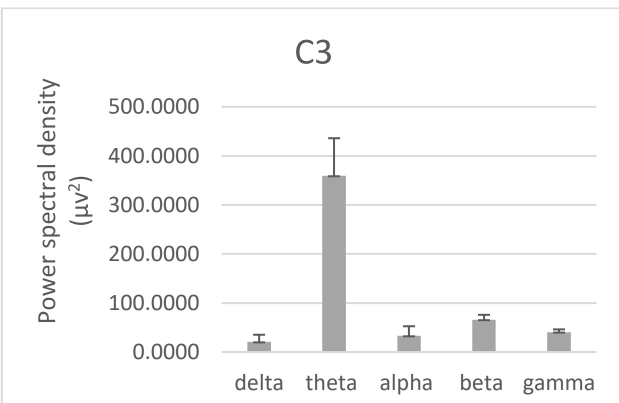
O1					O2					
delta	theta	alpha	beta	gamma	delta	theta	alpha	beta	gamma	
185.3935	22.76189	31.65711	79.95446	44.38884	96.58974	43.48296	36.35073	70.78365	43.49387	
132.5735	97.47551	50.84697	71.23545	37.65506	65.72407	50.58405	27.94659	55.43415	45.23432	
79.44994	61.11097	40.15569	76.48585	43.08545	79.63158	35.31404	46.07025	58.3242	49.30573	
75.25717	4.313265	26.42007	57.99156	44.12137	156.0079	56.73349	38.18523	56.49152	47.1337	
113.3453	34.89953	41.55768	52.89061	47.75706	160.0112	40.29046	44.64622	78.48194	31.19758	
60.91602	48.77153	25.03944	55.78632	47.3075	123.2736	36.24978	36.70652	50.26494	44.66285	
52.19814	57.0102	44.9056	53.06022	46.01662	100.6586	27.64635	32.20507	64.37285	30.42075	
91.18614	66.68577	22.29089	55.18374	43.56498	51.82033	23.87361	35.65791	75.20327	46.74566	
164.2093	46.54494	22.02396	57.55785	43.78606	88.05834	48.27182	36.8812	60.90701	47.53555	
101.5132	14.22732	44.68242	55.42923	42.08345	151.8707	30.39827	40.90556	78.26662	40.43519	
69.15694	53.3093	30.78014	65.41533	49.89673	167.8724	26.78687	49.18014	54.81104	49.78595	
106.4581	2.24512	41.79956	56.3224	32.74603	107.4662	84.56536	27.38563	54.29158	38.41104	
172.0949	15.6241	32.28701	77.5632	46.80806	77.36315	92.30602	29.13581	71.48667	36.21841	
121.5663	49.52731	30.64868	65.4275	46.45918	64.10821	26.71259	21.6929	74.74724	35.67159	
92.4587	24.70395	44.89401	61.44999	35.99115	180.8697	6.654187	35.29737	70.35014	35.89875	
142.9798	54.63125	28.64309	58.64924	39.08211	78.88526	48.37694	26.47314	64.54527	39.06159	
167.1104	90.79953	29.90051	58.55365	44.00374	166.3046	81.01912	21.8837	64.70675	37.62146	
155.774	38.91462	43.25287	72.18063	33.85191	81.51014	17.84529	38.87421	76.4656	42.39073	
162.2796	42.46155	33.56032	80.13528	35.30008	197.3982	14.81521	40.63376	58.88882	39.73291	
113.9599	8.300258	37.13246	60.43417	40.91479	63.01665	30.35358	21.49486	74.59556	40.2402	
136.7327	87.1694	47.03041	76.46714	43.11546	163.7177	65.26857	20.20962	71.07192	44.79648	
191.4772	14.32651	22.20038	65.40861	49.0735	94.151	80.01234	41.14603	78.47473	43.08309	
133.4312	3.155832	30.41203	67.53061	43.71351	91.80107	88.98535	46.53868	64.93098	33.63483	
78.68162	33.5078	46.89762	76.03216	43.62564	83.9613	73.83402	47.75274	71.95139	39.32647	
145.5133	14.34531	24.4669	74.83086	49.18063	100.4228	4.302651	43.88877	52.89274	30.11624	
116.9991	11.86911	36.71135	65.42502	42.18982	180.4989	22.66845	31.92558	60.83378	30.12445	
70.90912	55.00578	46.5885	79.97517	37.69613	118.4189	42.32783	44.67684	80.81899	35.67876	
170.0333	99.33408	34.53428	67.55203	30.89573	121.632	94.07016	22.90537	74.52433	47.78719	
39.73826	28.59791	8.599891	8.975429	5.047141	41.70059	26.30782	8.763748	9.003221	5.909781	Standard deviation
121.5592	41.1797	35.4043	65.8903	42.2968	114.7516	46.2053	35.2375	66.7471	40.2052	Mean value

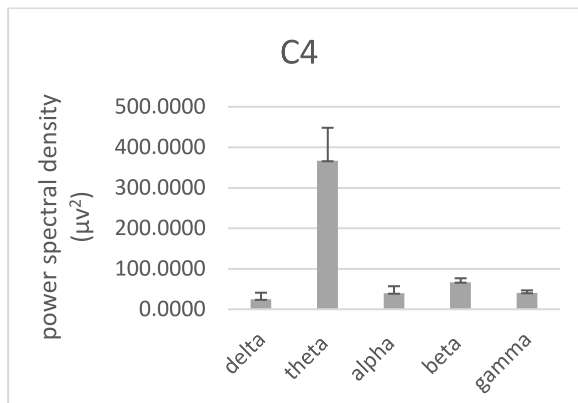
Appendix 3

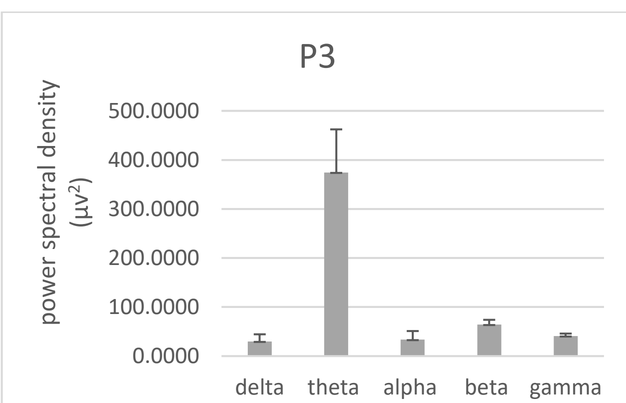
Power spectral density charts (epilepsy cases)

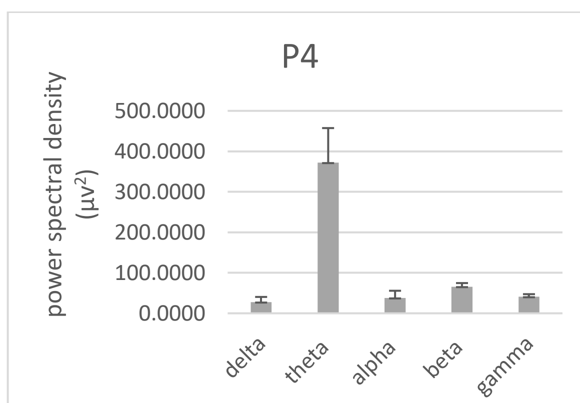


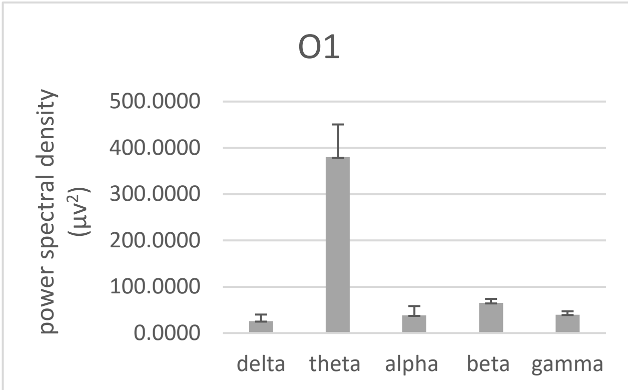


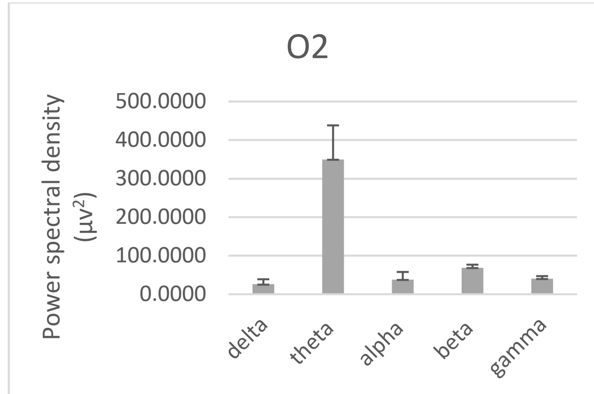






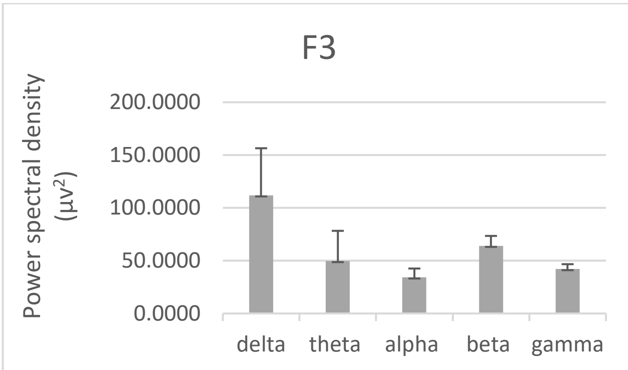


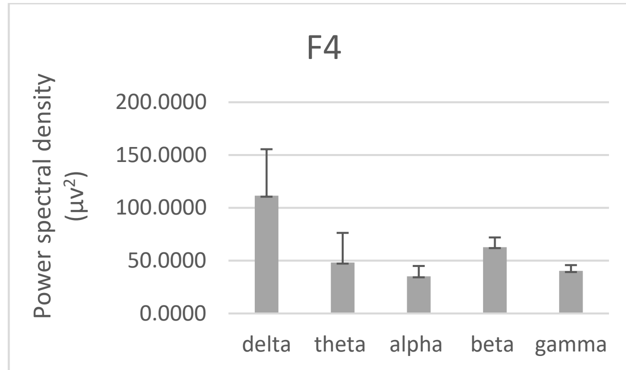

O1
power spectral density (µv²)
500.0000
400.0000
300.0000
200.0000
100.0000
0.0000
delta
theta
alpha
beta
gamma

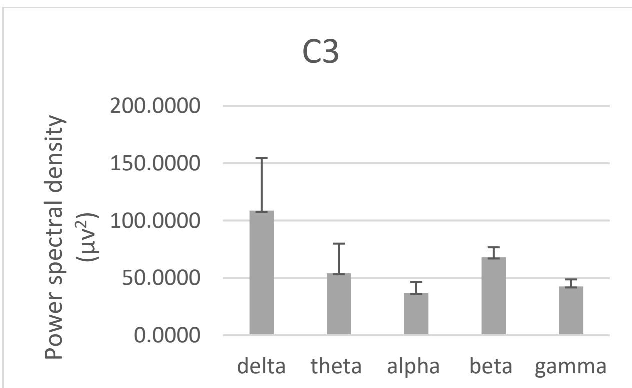

O2
Power spectral density (µv²)
500.0000
400.0000
300.0000
200.0000
100.0000
0.0000
delta
theta
alpha
beta
gamma

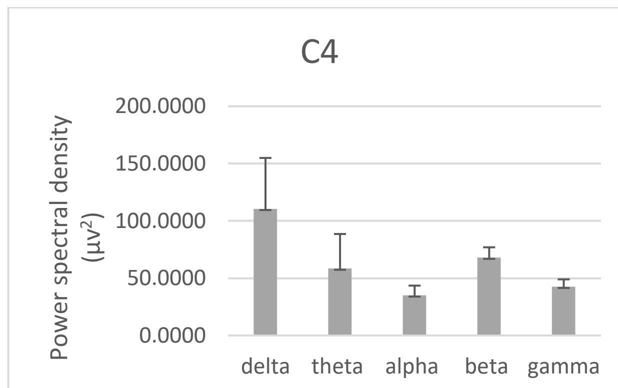
Appendix 4

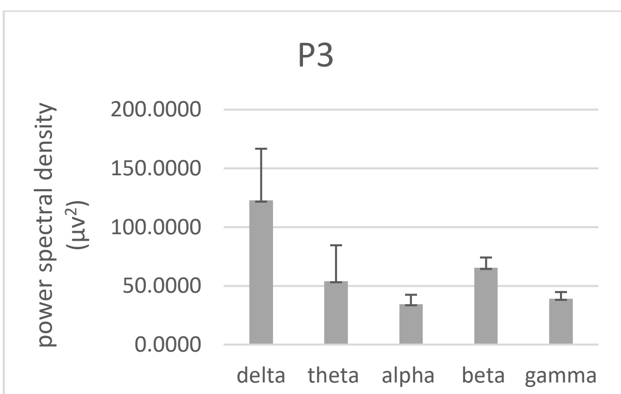
Power spectral density charts (normal cases)

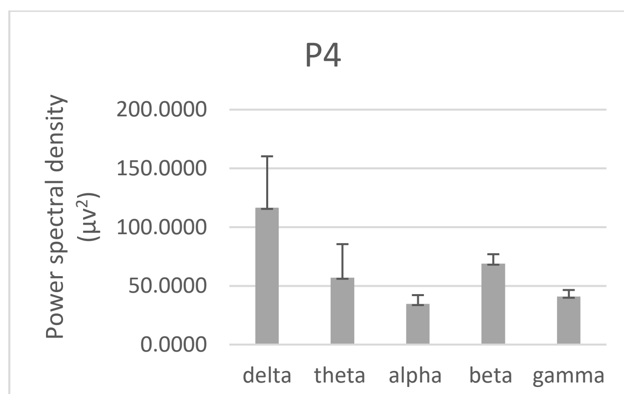


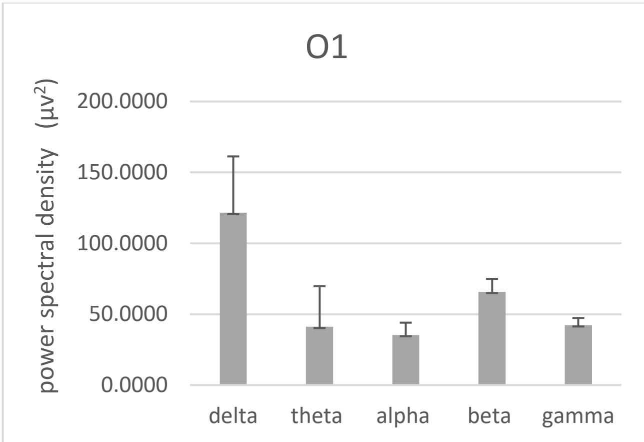


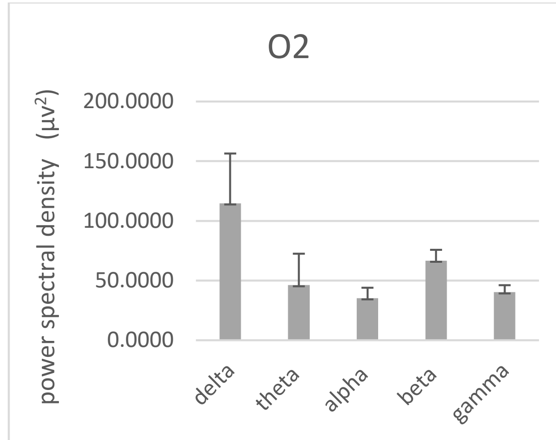






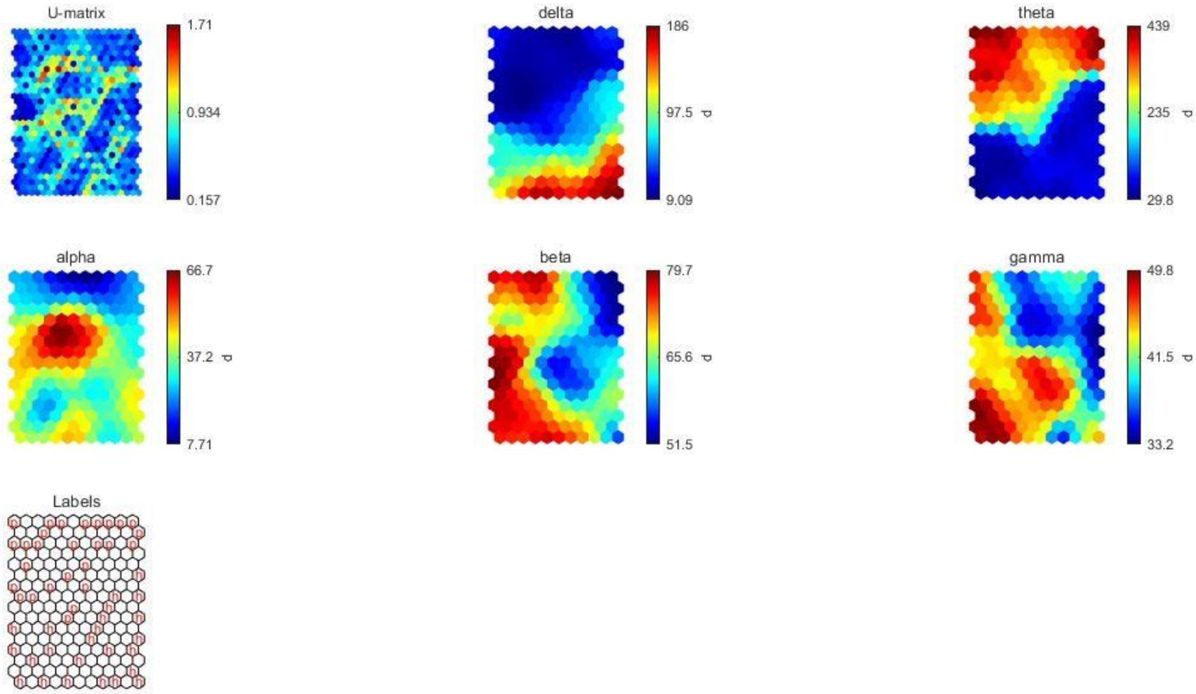



O1
power spectral density (µv2)
200.0000
150.0000
100.0000
50.0000
0.0000
delta
theta
alpha
beta
gamma

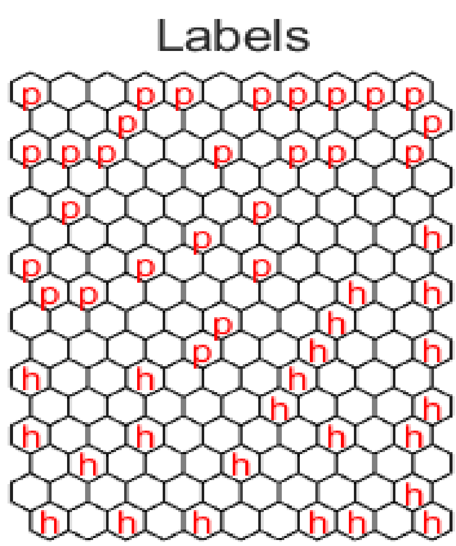

O2
power spectral density (µv2)
200.0000
150.0000
100.0000
50.0000
0.0000
delta
theta
alpha
beta
gamma

Appendix 5

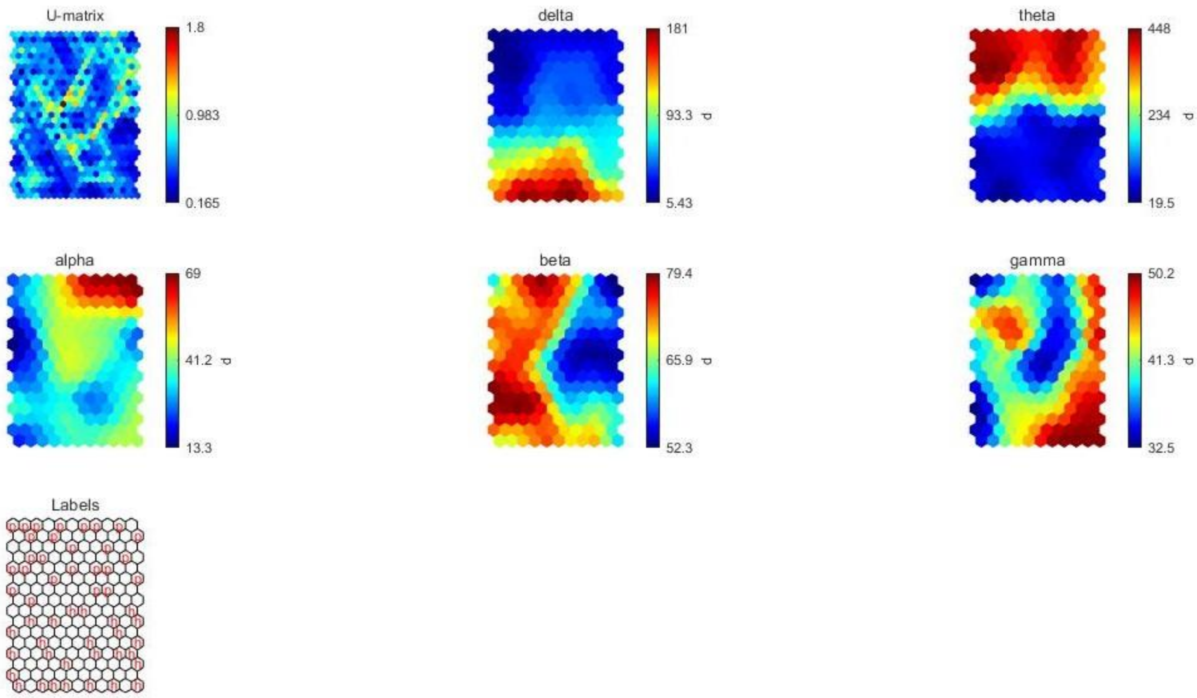
Self-organizing map results



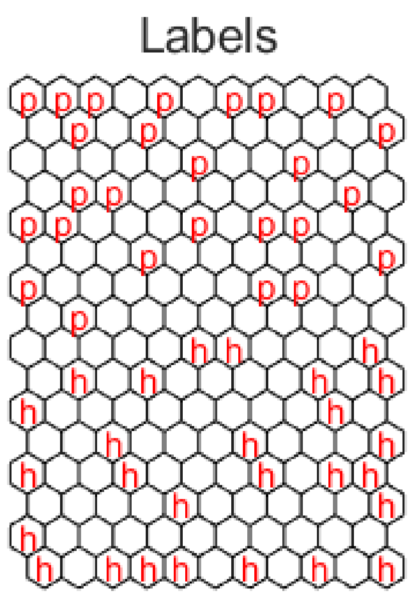
Electrode C3



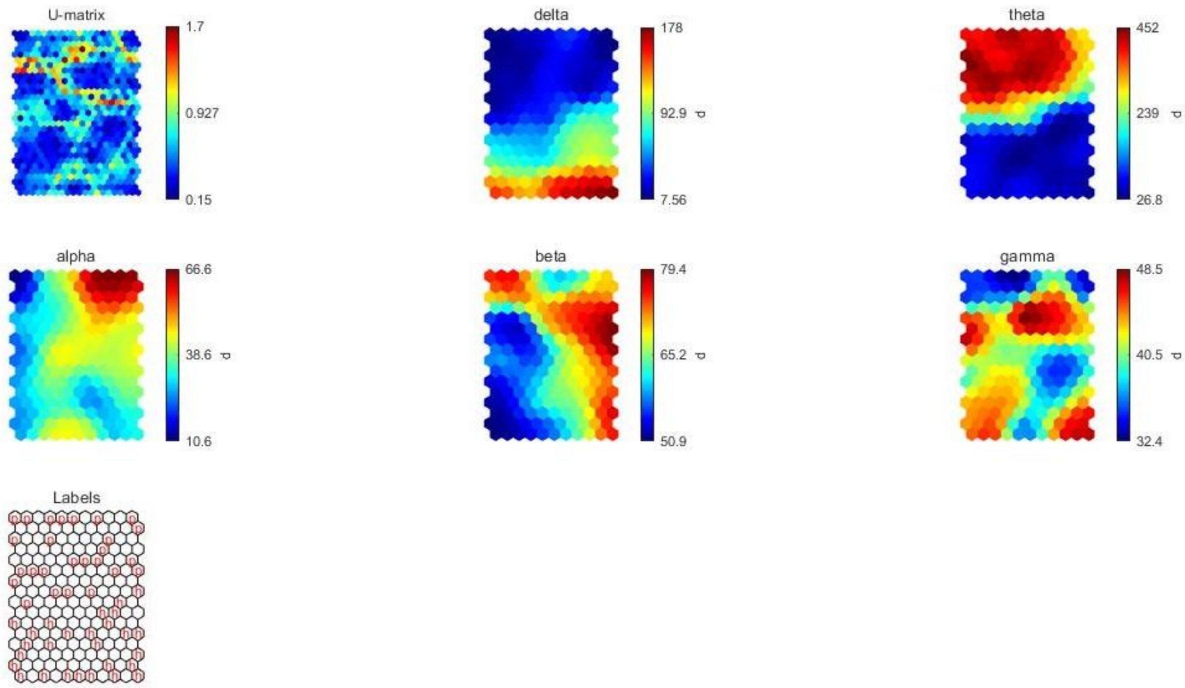
Electrode C3



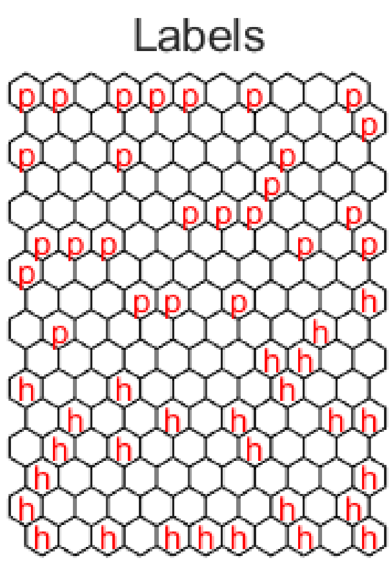
Electrode C4



Electrode C4



Electrode F3



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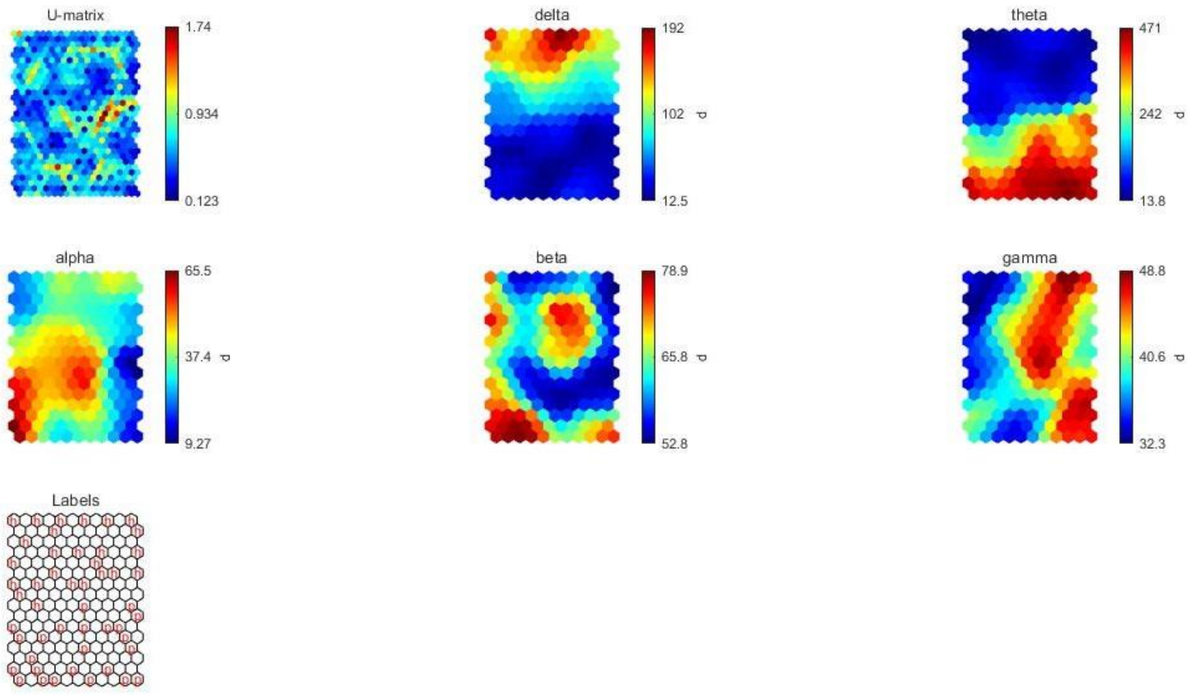

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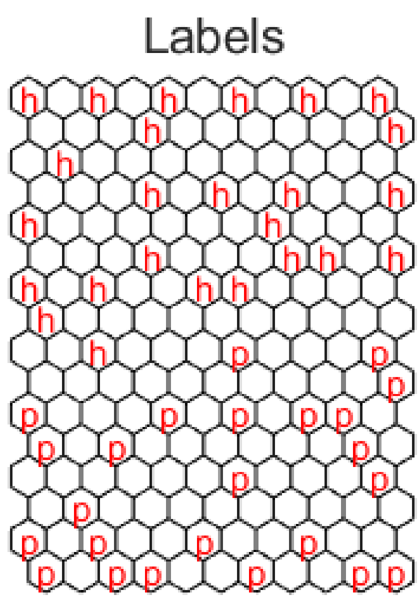
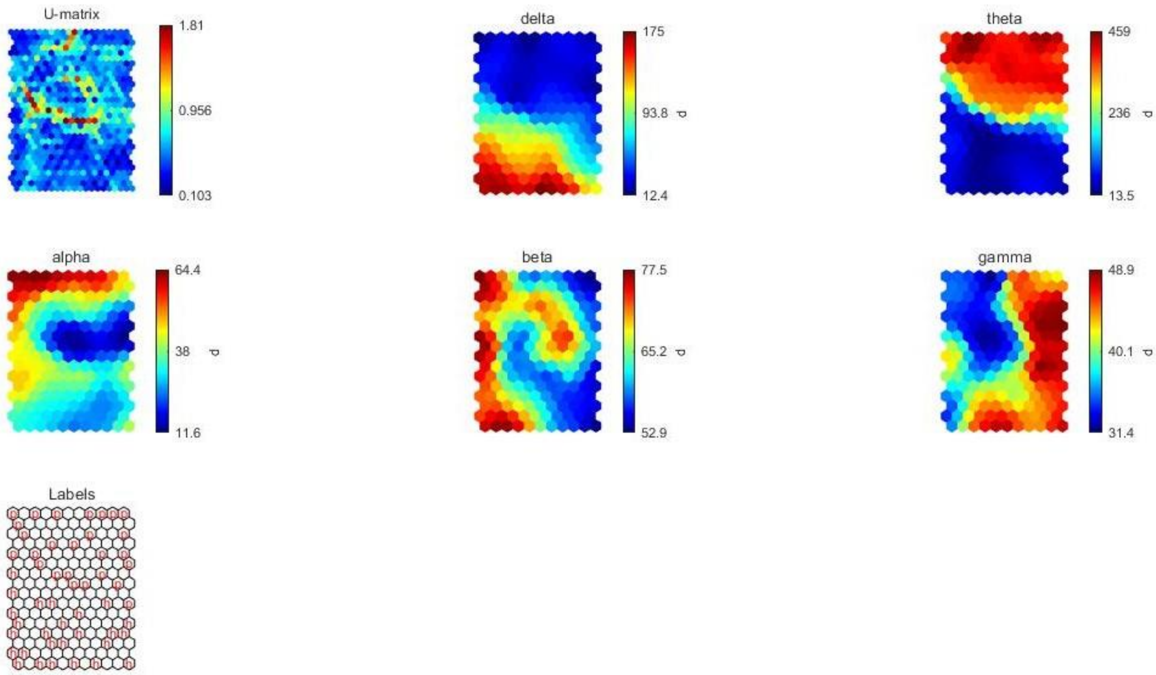
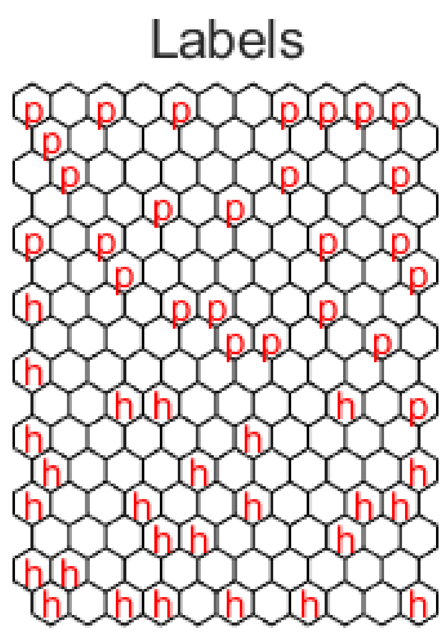


Electrode F4



Electrode O1



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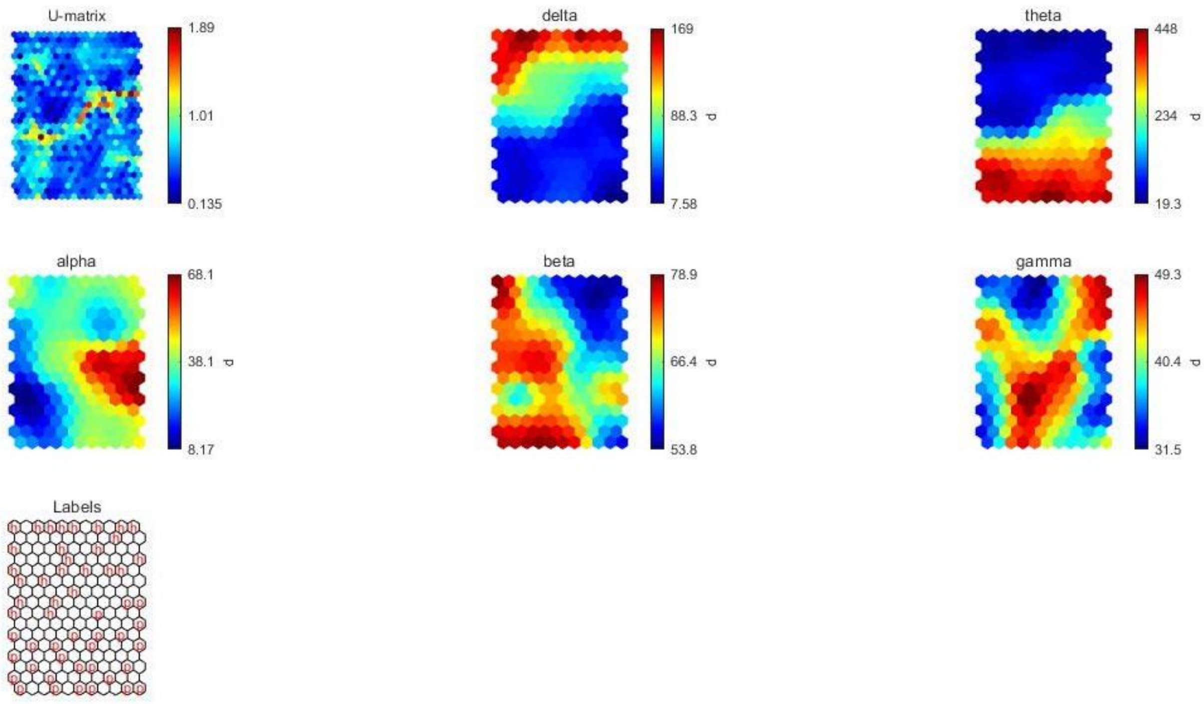

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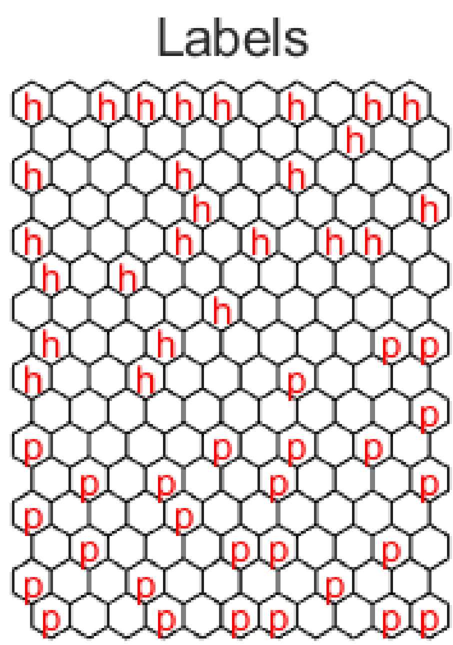

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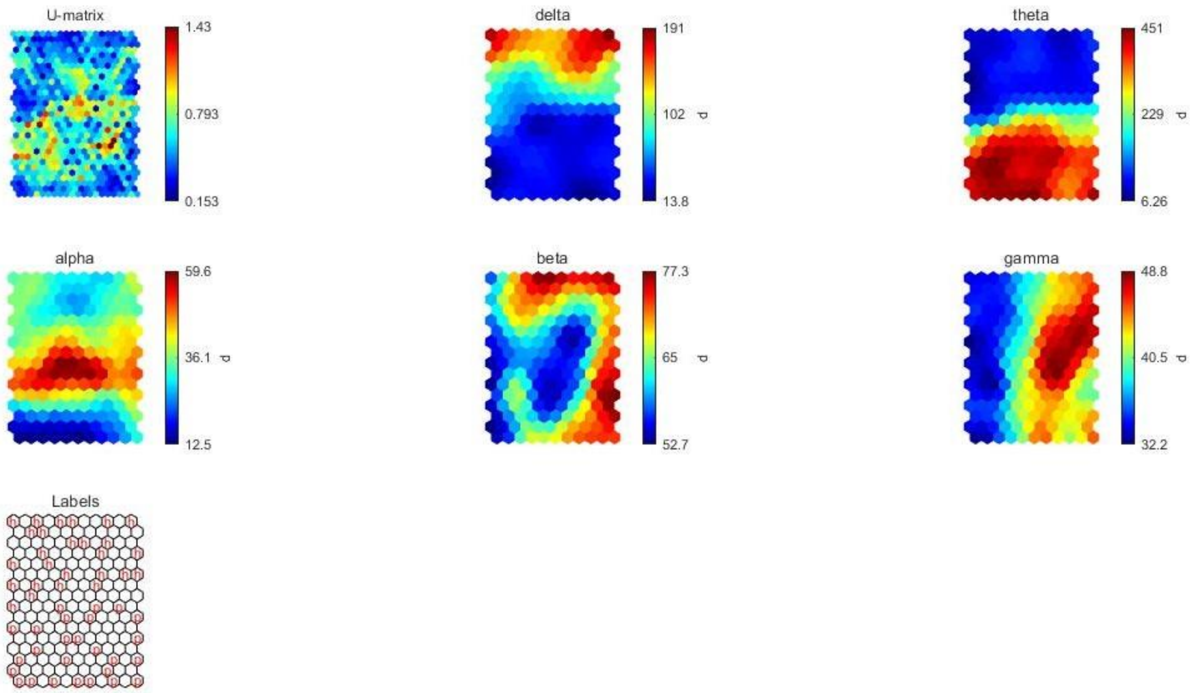
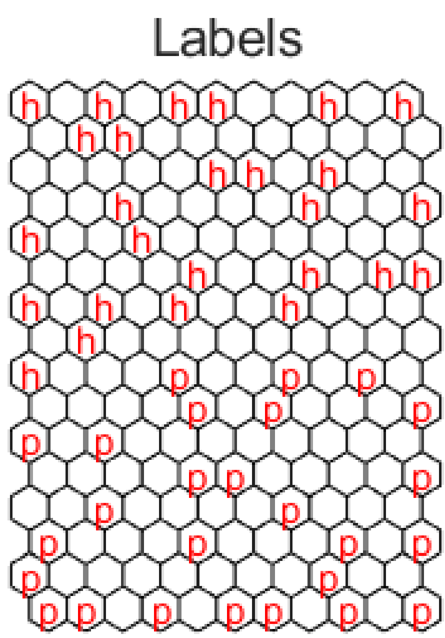


Electrode P3



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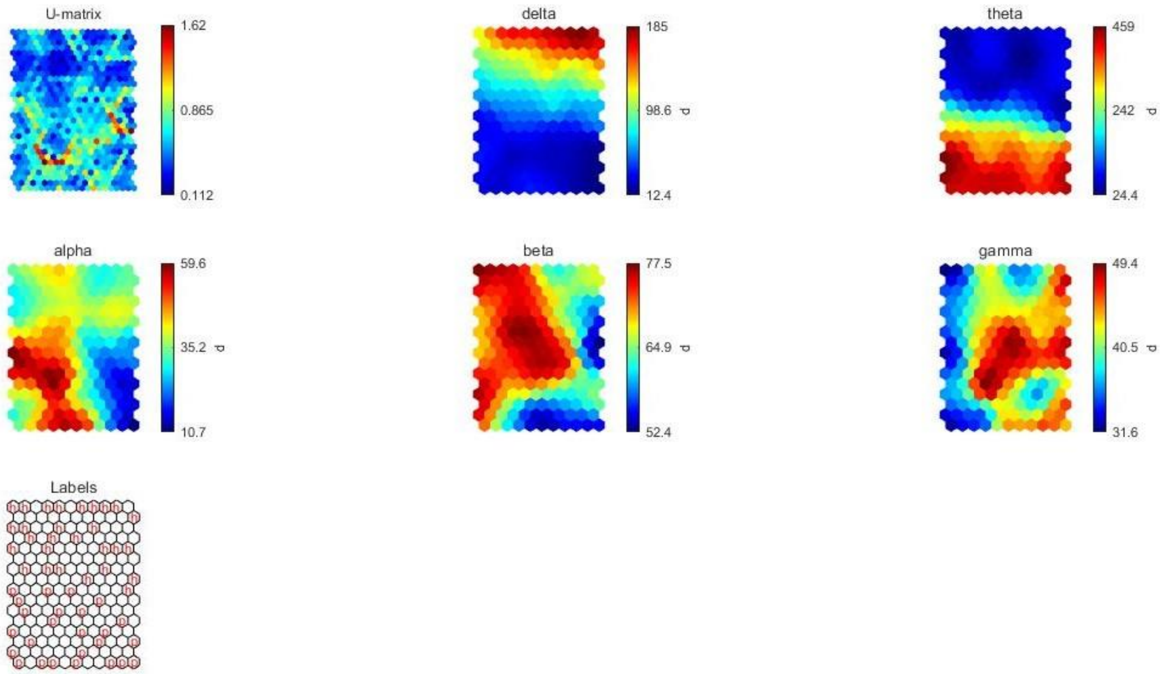

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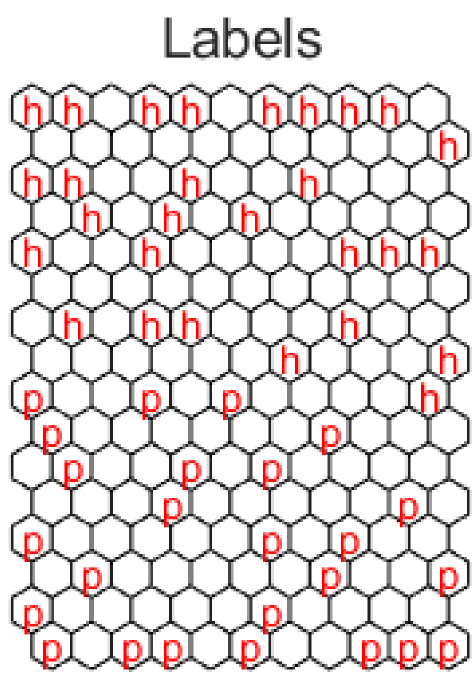

Electrode P4

Appendix 5

Matlab code

```
%% make the data

sD = som_read_data('filename.txt');

sD = som_normalize(sD,'var');


%% make the SOM

sM = som_make(sD,'munits',180);

sM = som_autolabel(sM,sD,'vote');


%% basic visualization

som_show(sM,'umat','all','comp',(1:5),'empty','Labels','norm','d');

som_show_add('label',sM.labels,'textsize',7,'textcolor','r','subplot',7);
```