T.C.
FATIH UNIVERSITY
INSTITUTE OF BIOMEDICAL ENGINEERING

INVESTIGATION OF THE EFFECT OF CLASSICAL TURKISH MUSIC MAKAMS BY USING EEG WAVEFORMS

SERRA NUR AKER

MSc /Ph.D. THESIS
BIOMEDICAL ENGINEERING PROGRAMME

İSTANBUL, JULY/ 2014 (DEFENSE)

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T.C.
FATİH ÜNİVESİTESİ
BİYOMEDİKAL MÜHENDİSLİK ENSTİTÜSÜ

TÜRK MÜZİĞİ MAKAMLARININ ETKİLERİNİN EEG DALGA FORMLARI İLE İNCELENMESİ

SERRA NUR AKER

YÜKSEK LİSANS / DOKTORA TEZİ
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To my lovely family and advisor,

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LIST OF SYMBOLS

ψ	Mother function
u	Translating parameter
s	Scaling parameter
$C\psi$	Admissibility condition
L(z)	Low Pass Filter
H(z)	High Pass Filter
cl(k)	Lowest half of the frequency content coefficient
ch(k)	Highest half of the frequency content coefficient

ABBREVIATIONS

CTM : Classical Turkish Music
DWT : Discrete Wavelet Transform
EEG : Electroencephalography
M1 : Music 1
M1 : Music 2
PSD : Power Spectral Density
STFT : Short Time Fourier Transform
Std. dev.: Standart Deviation
R1 : Resting 1
R2 : Resting 2
R3 : Resting 3

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SUMMARY

INVESTIGATION of the EFFECT of CLASSICAL TURKISH MUSIC MAKAMS by USING EEG WAVEFORMS

Serra Nur AKER

Biomedical Engineering Programme

MSc / Ph.D. Thesis

Advisor: Assist. Prof. Dr. Saime AKDEMİR AKAR

The purpose of this study is to investigate the effect of classical Turkish music makams by using EEG waveforms. Two different makams were used in study; Kuçek and Rast Makams. EEG was recorded during silence and music (as a stimulus) periods. Healthy students participated in this test. Recorded signals analyzed and investigated with signal processing methods. Signals decomposed into their frequency bands (delta, theta, alpha, beta) with the help of Discrete Wavelet Transform. Power Spectral Density method helped to measure two basic characteristic of bands; power and amplitude. The Paired Sample t Test statistical analysis method was used to compare music and resting periods of variables. Results were used to interpret the physiological effects of Turkish Music Makams on humans.

Keywords: Turkish Music Makams, EEG, wavelet transform, power spectral density, paired samples t-test.

ÖZET

TÜRK MÜZİĞİ MAKAMLARININ ETKİLERİNİN EEG DALGA FORMLARI İLE İNCELENMESİ

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Biyomedikal Mühendisliği Programı

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Bu çalışmanın amacı, normal bireylerde Türk Müziği makamlarının etkisinin EEG dalga formlarıyla araştırılmasıdır. Çalışmada Kuçek ve Rast Makamları kullanılmıştır. Sessizlik ve uyaran olarak müzik eşliğinde EEG kaydedilmiştir. Deneye sağlıklı öğrenciler katılmıştır Kaydedilen sinyaller sinyal işleme yöntemleri ile analiz edilmiş ve incelenmiştir. Sinyal Discrete Dalgacık Dönüşümü metoduyla alt bantlarına ayrılmıştır (delta, teta, alfa, beta). Güç Spektral Yoğunluğu yöntemiyle, ayrıştırılan bantların iki temel özelliği; güç yoğunlukları ve genlikleri hesaplanmıştır. Hesaplanan değişkenlerin; müzik ve dinlenme periyodları arasında karşılaştırılmalarında Eşleştirilmiş Örneklemler t- testi istatistik analiz yöntemi kullanılmıştır. Sonuçlar, Türk Müziği Makamlarının insanlar üzerinde etkisinin fizyolojik olarak yorumlanmasında kullanılmıştır.

Anahtar kelimeler: Türk Müziği Makamları, EEG, dalgacık dönüşümü, güç spektral yoğunluğu, eşleştirilmiş örneklemler t-testi.

FATİH ÜNİVERSİTESİ -BİYOMEDİKAL MÜHENDİSLİK ENSTİTÜSÜ

CHAPTER 1

INTRODUCTION

1.1 Literature Survey

Many studies were done to understand the music effect to human soul, health, mood and etc. . Music therapists from all over the world discussed the music therapy need of the world [1]. Studies were showed that music has relaxing effect on infants in the first year of their life [2], children [3] and adults [4]. Music has also been used in a lot of health care units; maternity units [5], coronary care [6], cancer care [7], outpatient departments and intensive care [8]. Researchers also demonstrated that music has reduction in respiratory rate, anxiety when compared with control group in hospital patients. However it was showed in that study music has no difference in heart rate and severity of pain. Satisfaction, pain, mood tests were done in questionnaire form [9, 10]. In a similar study they showed that fast rhythm music influences short term memory, reduces the ability of voluntary movement. This study indicated that classical music has more positive effect than pop music on concentration and memory [11]. There is not so much study about Classical Turkish Music (CTM) effect on brain, however in a study researchers found that CTM influences the brain electrical response [12]

In studies that determine music effect; respiratory rate, heart rate, blood volume pulse were used mostly as physiological parameters [2, 10, 11, 13, 14]. However, Electroencephalography was used to measure music effect to humans [2, 15, 16, 17, 18]. While examining the effect of music on EEG brain waves many music types were used; metal, sonata [19], jazz, classical, rock, Japanese ballad [18] and etc.

1.2 Purpose of the Thesis

The purpose of this study is to investigate and learn the effect of classical Turkish music makams by using EEG waverforms. Understand the EEG results difference between music and resting periods in healthy subjects.According to these differences determine the effects of Turkish music makams to people. Correlation between physiological tests and extracted features of recorded signals.

1.3. Hypothesis

Farabi classified the effects of Rast and Kuçek makams as; rast makam gives joy and kuçek makam gives sadness to human soul in his book ‘Musiki-ul-kebir’. Many papers and physiological tests indicate music effects to human mood. If these makams’ effects are same with Musiki-ul Kebir then they must show their effects on EEG characteristics, EEG bands.

CHAPTER 2

In this chapter music, makams and their relationship between music therapy have been discussed. Turkish music makams effects and music therapy in Turks were mentioned.

2.1 Music

Music, is an art, consists of sound and silence. Its basic elements are; rhythm(and its associateds parameters meter, articulation, and tempo), dynamics, pitch and the sound qualities of texture and timbre [20]. Music has many genres and subgenres. Philosophers from India and Greece described music as harmonies ordered vertically as tones ordered horizontally and as melodies [21]. So music is, a wave that has acoustic frequencies, formed with horizontally and vertically ordered sounds [22]. Altough John Cage who was a composer, considered that every sound can be music and he supported his idea with this sentence “There is no noise, only sound” [21].

Above all, the music has more importance than concepts that is inspired from charming forms of architecture and nature. Music is important for people since the past times. People have tried to explain their sadness, pleasure, excitement and other emotions with music [23]. “Music is a mediator between the physical being and spiritual being of individuals” Nietzsche. And famous musician Beethoven also said for music “Music is the one incorporeal entrance into the higher world” [24].

2.1.1. The Relationship between Music and Therapy

From early ages of history, music has been used as a common method in many civilizations to; reinforce religious feelings, to treat diseases [23**]**. Actually, the main reason of emergence of music was; treat patients.

Music has no side and harmful influence, consequently it is offered that can be used as a treatment side therapy method for many diseases. The estimated effect of music for therapy recommended that, due to lower analgesics and sedatives there can be cost savings. And at the same time if music therapy is accomplished patients can protect themselves from side effects of drugs. When literature part is considered it appears that; researchers found music has reducing effect on anxiety of patients that will be operated surgically [10]. In another study they showed that music is related with patient satisfaction [25] and music can raise heart rate variability decrease blood pressure and thus it is useful for cardio-vascular disease patients [14] . Music provides higher brain functions [26]. Music is also good for early emotional formation. Because it is associated with emotion [27] and babies are sensitive to music [28]. Music can be used for preschoolers too; it was proved that music improves spatial practice [29].

2.2. Makams and Music Therapy in Turks

2.2.1. Makams

Makam is a term used to encode of scale frames, melodic characteristics and internal frames in Turkish Music. There are many types of Turkish music makam; rehavi, büzürk, kuçek, hüseyni, hicaz, buselik and etc. Turkish music has approximately 600 kinds of makams. Turkish music "makam" is roughly same as "scale" that in western music. Six Turkish makams in tetrachods and pentachords are seen in Figure 2.1 [30]

Figure 2.1 Tetrachords and pentachords of six Turkish Music Makams [30]

2.2.2. Music Therapy in Turks

In Middle Asian Turks they combine dance, imitation and music during session to treat patient. They believed that the exact healing was became when the patient enter into trance state during this combination.

In Islamic Civilization especially Sufis used and made music. They thought that music treat mental and nervous diseases. Farabi explained the relationship between music, physics and astronomy in his book 'Musiki-ul-kebir'. He classified the effects of Turk Music Makams to human soul as;

1. Rast Makam: Gives joy
2. Rehavi Makam: gives sense of survival
3. Kuçek Makam: Gives sadness
4. Büzürk Makam: Gives fear
5. Isfahan Makam: Gives sense of trust
6. Neva Makam: Gives sense of comfort, relief
7. Uşşak Makam: Gives sense of laugh
8. Zirgüle Makam: Gives sleepiness
9. Saba Makam: Gives courage and strength
10. Buselik Makam: Gives strength
11. Hüseyni Makam: Gives relief and peacefulness
12. Hicaz Makam: Gives humility

He classified the effects of Turk Music Makams to human soul according to time as;

1. Rehavi Makam: effective in time of the twister morning
2. Hüseyni Makam: effective in the morning
3. Rast Makam: effective while sun's length 2 spears
4. Buselik Makam: effective in midmorning
5. Zirgüle Makam: effective towards noon
6. Uşşak Makam: effective at noon
7. Hicaz Makam: effective in the afternoon
8. Irak Makam: effective in late afternoon
9. Isfahan Makam: Gives effective at dusk
10. Neva Makam: effective in evening
11. Büzürk Makam: effective after sunset
12. Zirefkend Makam: effective at close to sleeping

Mawlānā Jalāl ad-Dīn Rûmi is a famous thinker, poet and sufi. Rumi's father (borned in 1207) brought instruments like reed, 'rebab', 'çeng', 'kudüm (a small double drum)' while he came to Anatolia. Itri, İsmail Dede Efendi got into classical Turkish Music (musiki) in time. In Ottoman Palace many valuable musicians (musikişinas) grown like; II. Murat, II. Beyazıt, II. Mustafa, III. Ahmet, III. Selim, II. Mahmut. During this time famous music masters appeared like; Itri, İsmail Dede Efendi, Recep Efendi, Zekai Dede, Kantemiroğlu.

Ibn Sina applied music therapy in Nurettin Hospital (hospital that in Damascus) to treat mental illnesses. Musa bin Hamun (Ottoman palace physician) applied music therapy to treat dental illnesses and psychological illnesses.

Chief Physician, Sir Gevrekzade Hasan explained effects of Turk Music Makams to children's diseases in his book 'Emraz-ı Ruhaniyeyi Negama-ı Musikiye' as;

1. Irak Makam: Helpful to meningitis
2. Isfahan Makam: Gives clarity of mind. Protects from inflammatory disease and cold.
3. Zirefkend Makam: Good for paralysis and back pain.
4. Rehavi Makam: Good for headaches, paralysis, pituitary illnesses, facial paralysis.
5. Büzürk Makam: Good for brain, cramps pain, slenderness.
6. Zirgüle Makam: Good for heart, brain, menengitis, heat of stomach.
7. Hicaz Makam: Good for urinary tract diseases.
8. Buselik Makam: Good for headache, eye diseases, hip pain.
9. Uşşak Makam: Good for leg pain and insomnia.
10. Hüseyni Makam: Good for heart, liver, hidden fiver, seizures.
11. Neva Makam: Good for hip pain, happiness.

Because of it has lots of coma sound, Turkish Music has power to sophisticated statement and important for psychotherapy. [23].

2.3. EEG and Music

Feeling of music has interaction with mental state and emotional state of listener. This sensorial process's neuronal explanation is difficult without neuroanatomical exploration [17]. Many psychologist and musicologists investigated different types of music effects based on observation and verbal tests [16]. EEG can be used on empirical and theoretical grades as brain-based measurements for emotional regulatory process and can be correlated with effects of music quantitatively [31]. It is effective method to verify the effect of music to human brain activity [19].

CHAPTER 3

MATERIALS AND METHODS

Participant characteristics, affective stimuli of the test, data acquisition system, electroencephalogram (and etc.) subjects are explained briefly in this chapter.

3.1. Participant Characteristics

This study was conducted with university students. In this study 15 female results were used for analyzing. All of them are healthy students. They were selected according to active using of right hand. This selection is done because of usage of brain lobes.

Table 3.1 Participant Characteristics and Their Proportions

Variables		N	%
age	18-21	8	53
	22-25	7	47
dominant hand	Right	15	100
	Left	0	0
gender	Male	0	0
	Female	15	100

3.1.1. Exclusion Criteria

Table 3.2 Exclusion Criteria for Subjects

• Any medication	• Musician
• Pathological, endocrinological, cardiovascular disorders	• Physical exercises

• Pregnant and lactating female	• Substance abuse disorders (including alcohol abuse)

I prefer to chose "medication taking" as an exclusion criterion because, chemicals can affect brain communication system. And brain system nerves communicate each other with chemicals (neurotransmitter). All medications don't have this effect. But we prefer to exclude the participants who have taken any medication (in 48 hours) for our experiment to prevent bad results (substance abuse also included in this) [32].

Hormones changes during pregnancy. Therefore pregnant physiology changes too. This influence continues after birth. Because of hormonal changes alters brain functioning we did not take pregnant and lactating female [33]. As it explained above hormonal changes affect brain function and endocrine disorders are completely associated with hormones. However according to studies; increase in heart disorder risks can decrease brain functions [34]. For these reasons, patients with pathological, endocrinological, cardiovascular disorders were excluded from the experiment.

Because the test is based on music, 'hear losing' was taken as an exclusion criterion. Physical exercises changes brain working; improves mental performance enhances brain function. To avoid different reference characteristics of participants 'physical exercises' was taken as an exclusion criterion [35, 36].

3.2. Affective Stimuli

Participants listened the music and resting periods in the sitting position. It was paid attention that there was no voice or noise in the room where the test was performed. Lights and curtains were closed in the room. The audio stimulus was listened with earphones and participants eyes were closed during this period.

Table 3.3 Signal recording Periods

2 min.	**2 min.**	**2 min.**	**2 min.**	**2 min.**
Resting 1	Music 1 (Kuçek Makam)	Resting 2	Music 2 (Rast Makam)	Resting 3

Total recording is 10 minutes

As shown in table the whole period was 10 minutes. Period started with 2 minutes silence-Resting 1 (R1). 2 minutes Kuçek Makam Piece followed this silence-Music 1 (M1). After that there was 2 minutes silence again-Resting 2 (R2). 2 minutes Rast Makam Piece followed this silence-Music 2 (M2). At the end of the period there was 2 minutes silence-Resting 3 (R3). With this part, the test period was ended. The beginning and end silences were for best comparison of music effect and for correct results.

Kuçek Makam music name was; Turkish Ottoman Kanun Taksim. Rast Makam music name was; Darıldın mı Cicim Bana? Kuçek Makam gives sadness. Rast Makam gives joy. The reason of selecting makams that gives two totally different emotions is, to measure more clearly the reality of makams effect.

3.3. Data Acquisition System

This system records up to 16 leads of EEG with the help of software features. A lot of stimulus/ response events can be possible to be understood with this EEG system.

3.3.1. Electroencephalogram Amplifier- EEG 100 C

Electroencephalogram Amplifier is used to amplify the EEG signals that are caused by neuronal activity of brain. EEG 100C amplifier can be used for unipolar and bipolar measurements (Figure 3.1) [37].

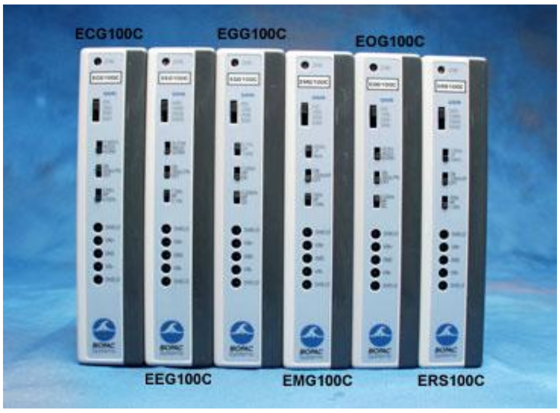


Figure 3.1. Electroencephalogram Amplifier [37]

Each input amplifier has one connection place for one electrode. The output of amplifier can be switched between normal EEG output and Alpha wave detection.

3.3.2. Electrode Cap System

This cap provides to record many EEG channels at the same time. This helps reducing the application time.

19 electrodes are imbedded in the lycra stretch cap (Figure 3.2). Electrodes are pre placed according to 10-20 system. It is practical method to minimize electrode placement errors. A colorful ribbon cable comes from the cap through connection with each electrode. The other colorful cable (that has cable for each electrode) mates the first colorful cable. When the cap is placed correctly, the recording gel is injected into electrodes that will be used with the help of with the help of blunt-tipped syringe.

Figure 3.2 Electrode Cap System [38]

The cap has four sizes to provide best recording: Infant (45-50cm); Small (50-54cm); Medıum (54-58cm); and Large (58-62cm). CAP 100C is connected to electrode inputs of the EEG 100C Amplifier. A Velcro stripped belt is placed on top of the chest. The snap fasteners that come from the bottom of the ear portion of the cap connect this belt. This process is done to anchore the electrode cap. Electro gel is used to provide conductivity between the cerebral cortex and electrodes [38].

In this study F3, F4, T3, T4, P3, P4 electrodes (according to International 10-20 System- Figure 3.3) were used to analyze brain waves. F electrodes were used because frontal lobe is associated with emotions. T electrodes were used because; temporal lobes contain the primary auditory cortex. They are associated with recognition of auditory stimuli. P electrodes were used because parietal lobe is associated with perception of stimuli.

3.4. Electroencephalogram

Electroencephalography is a method of recording electrical activity of brain. This electrical activity is caused by ionic flow within brain neurons [39]. This electrical activity is divided into bands with frequency. For a better analysis, these bands are named according to their intervals.

Table 3.4 EEG Bands Comparison [40]

Comparison of EEG bands				
Band	**Frequency (Hz)**	**Location**	**Normally**	**Pathologically**
Delta	< 4	frontally in adults, posteriorly in children; high-amplitude waves	• adult during sleep • in babies	• subcortical lesions • diffuse lesions • metabolic encephalopathy hydrocephalus •
Theta	4 – 7	Found in locations not related to task at hand	• higher in young children • drowsiness in adults and teens • idling	• focal subcortical lesions • metabolic encephalopathy • deep midline disorders • some instances of hydrocephalus
Alpha	8 – 15	posterior regions of head, higher in amplitude on non-dominant side. Central sites at rest	• relaxed/reflecting • closing the eyes • inhibition control	• coma

Beta	16 – 31	both sides, symmetrical distribution, most evident frontally; low-amplitude waves	• range span: active calm -> intense -> stressed -> mild obsessive • active thinking, focus, hi alert, anxious	• benzodiazepines
Gamma	32 +	Somatosensory cortex	• Displays during cross-modal sensory processing (perception that combines two different senses, such as sound and sight) • Also is shown during short-term memory matching of recognized objects, sounds, or tactile sensations	• A decrease in gamma-band activity may be associated with cognitive decline, especially when related to the theta band; however, this has not been proven for use as a clinical diagnostic measurement
Mu	8 – 12	Sensorimotor cortex	• Shows rest-state motor neurons.	• Mu suppression could indicate that motor mirror neurons are working. Deficits in Mu suppression, and thus in mirror neurons.

3.4.1. Short History and Clinical Use of EEG

In 1890, Adolf Beck who is Polish physiologist had an investigation about spontaneous electrical activity of the brain that changed by light of dogs and rabbits. Vladimir Vladimirovich Pravdich-Neminsky, Russian physiologist, investigated and published the first animal EEG and evoked potential of the dog in 1912 [41]. The first human EEG was recorded by Hans Berger who is German psychiatrist and physiologist. Since it was discovered by Hans Berger, the electroencephalogram has been commonly used for many clinical diagnosis and practices [42]. It has been used to human sensibility ergonomics, biofeedback, Human System Interface, diagnosis of epilepsy, determining the level of anesthesia of a patient under anesthesia. [43]. Electroencephalography is furthermore to diagnose sleep disorders, brain death, coma, and encephalopathy. EEG can be used for first-line test of diagnosis for stroke, tumors and other focal brain diseases [44]. EEG cannot be imitated; it is autonomous [45].

EEG makes its measurement by attaching sensor to a scalp and amplifies voltage. Measurement is done by special points called as 10- 20 electrode system [18].

3.4.2. 10-20 System of EEG

10-20 system is internationally recognized system to indicate location of scalp electrodes in the case of an EEG test. This system was improved to provide standardized well settled method. So that subjects' results can be compared over time and subjects can be compared each other too. This method places is based on cerebral cortex area. The '10' and '20' numbers are used in naming because distances between adjacent electrodes are either 10% or 20% of the total front–back or right–left distance of the skull.

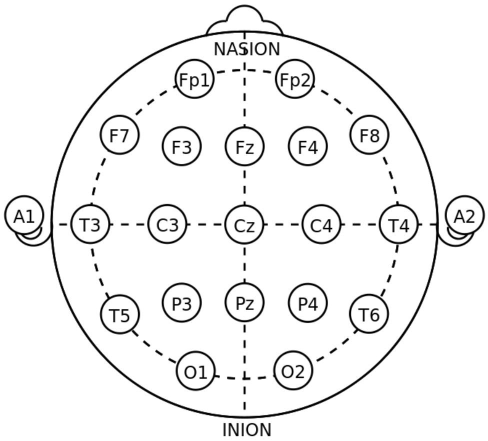


Figure 3.3 Electrode localizations [46]

Figure 3.3 shows that two anatomical points are utilized for localizing EEG electrode sites; nasion that is nasofrontal suture's middle point (just above the nose bridge), inion that is skull's the lowest point (projection of the occipital bone). Each electrode placement has a letter to state the lobe and a number to state the hemisphere. The letters are; F, T, C, P & O. Their expansions are respectively; frontal, temporal, central, parietal and occipital (lobes). But there is no central lobe; it is only for determination points. Even numbers (2, 4, 6, and 8) are for right hemisphere electrode positions. Odd numbers (1, 3, 5, and 7) are for left hemisphere electrode positions. Additionally Fp points are for frontal polar sites, Pg points are for nasopharyngeal sites and A points are for earlobes [46].

3.5. Signal Processing Methods

EEG is nonstationary signal. If a stationary signal is used for transformation, then Fourier Transform is useful for this process. But Wavelet Transform is better than Fourier Transform for these nonstationary signals. Unlike Fourier; Wavelet Transform has wide windows for low frequencies and narrow windows for high frequencies. So, optimum time-frequency resolution can be achieved in all frequency intervals [47]. In Figure 3.4 graphs for representation of different transformations. As shown in section (a), Fourier Transform does not use any windowing during transformation of signal. However in section (b) and (c) sections Short Time Fourier Transform and Wavelet Transform use windows while analyzing signal. Windowing process makes these two transformation system suitable for nonstationary signal processing.

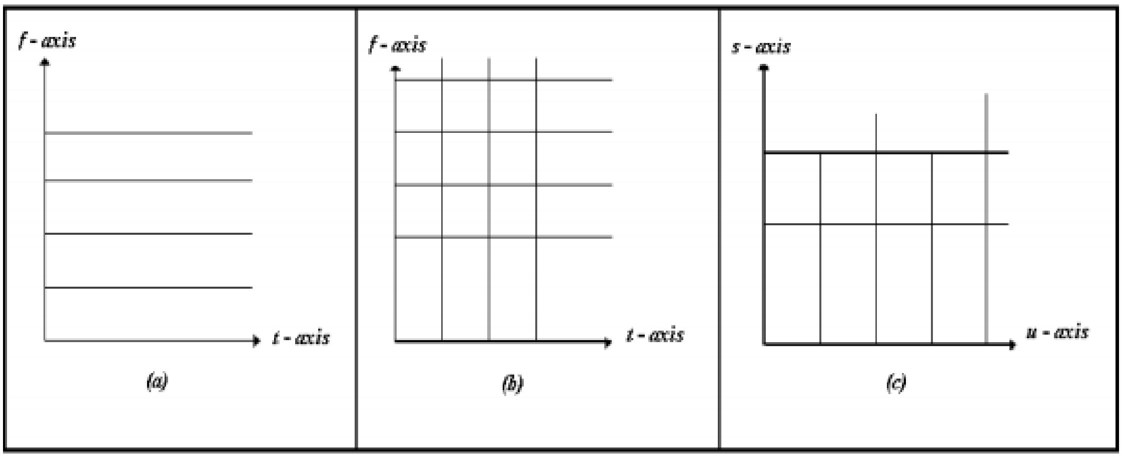


Figure 3.4 Time-frequency representations for different transforms. (a) Fourier Transform, (b) STFT (c) Wavelet Transform [48]

3.5.1. Wavelet Transform

Wavelet transforms are formed with small wavelets. Wavelet functions oscillate locally and are limited in the time domain. This method is a tool that is used to analyze frequency of time- varying signal. Daubechies found a different approach for frequency analysis within a given time window [49]. Fourier Transform is orthogonal expansion of time-domain signals in terms of only sine and cosine basis function. But wavelet has ∞ number of basis functions sets. There are two types of wavelet transform; continuous and discrete wavelet transform. As seen in Figure 3.5 Continuous Transform uses translated and scaled mother wavelets.

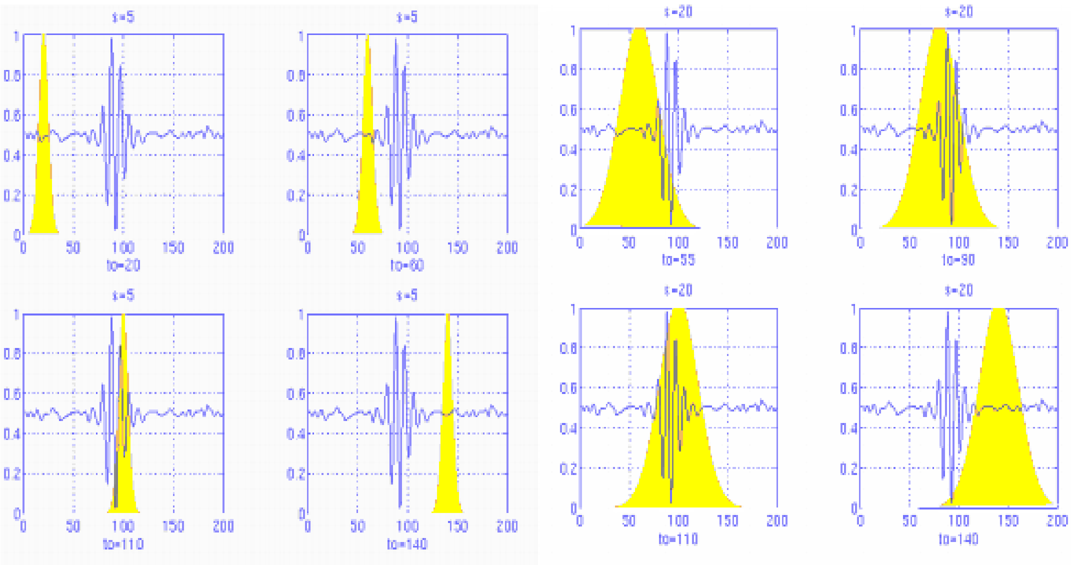


Figure 3.5 Continous wavelet transform for a non-stationary signal with different scaling parameters [50].

The other application of wavelet transform is Discrete Wavelet Transform (DWT). DWT applies some filtering process to signal and decompose it to approximation and detail coefficients. These coefficients yield good signal view with given frequency and time location.

3.5.1.1. The Continuous Wavelet Transform

In Continuous Transform a function, called as 'mother' ψ (t) ϵ $L^2(R)$, is limited in time domain means taking values in a limited region. Normalization is done through wavelets and they have zero mean property.

Mathematically, these properties are shown in Eq.(3.1);

$$\int_{-\infty}^{\infty} \psi(t)dt = 0$$

$$\|\psi(t)\|^2 = \int_{-\infty}^{\infty} \psi(t)\psi^*(t)dt = 1 \tag{3.1}$$

The mother wavelet forms basis set and indicated as Eq. (3.2);

$$\left\{\psi_{s,u}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-u}{s}\right)\right\}, u \in R, s \in R^+ \tag{3.2}$$

u is translating parameter and s is scaling parameter.

Mapping one dimensional signal *f(t)* to dimensional coefficients *Wf(s,u)*. These parameters are used locate an accurate frequency (s) at a time instant (u).

Continuous Wavelet Transform is shown in Eq. (3.3);

$$\begin{aligned} Wf(s,u) &= \langle f(t), \psi_{s,u} \rangle \\ &= \int_{-\infty}^{\infty} f(t)\psi_{s,u}^{*}(t)dt \\ &= \int_{-\infty}^{\infty} f(t)\frac{1}{\sqrt{s}}\psi^{*}(\frac{t-u}{s})dt \end{aligned} \tag{3.3}$$

And the inverse continuous wavelet transform is given as Eq. (3.4);

$$f(t) = \frac{1}{C_\psi}\int_{0}^{\infty}\int_{-\infty}^{\infty} Wf(s,u)\frac{1}{\sqrt{s}}\psi\left(\frac{t-u}{s}\right)du\frac{ds}{s^2} \tag{3.4}$$

$C\psi$ in Eq. (3.5) is defined as;

$$C_\psi = \int_{0}^{\infty}\frac{|\psi(w)|^2}{w}dw < \infty \tag{3.5}$$

$\psi\ (w)$ is fourier transform of mother wavelet $\psi(t)$. $C\psi$ is also called as admissibility condition [48].

Taking discrete samples of s and u parameters helps to calculate continuous wavelet transform, and this calculation is called as wavelet series.

Wavelet series are calculated as Eq. (3.6);

$$Xwt_{m,n} = \int_{-\infty}^{\infty} x(t)\psi_{m,n}(t)dt \quad \text{with } \psi_{m,n} = s_0^{-m/2}\psi(s_0^{-m}t - nu_0) \tag{3.6}$$

In this equation; m and n integers direct wavelet dilatition and translation.

3.5.1.2. Discrete Wavelet Transform

DWT do its calculation with multiresolution and specific wavelet filters.

3.5.1.2.1. Filter Banks

Filters that are for decompose of signals into their frequency bands, constitute filter banks. Signals are decomposed into their frequency bands by lowpass (L(z)) and high pass (H(z)) filters. Filter outputs are subjected to downsampling by factor 2. And signals are upsampled by 2 and passed through synthesis $L_0(z)$ and $H_0(z)$ filters during reconstruction process. After reconstruction process, a reconstructed signal is formed [51]. Upsampling and downsampling process can be seen in Figure 3.6

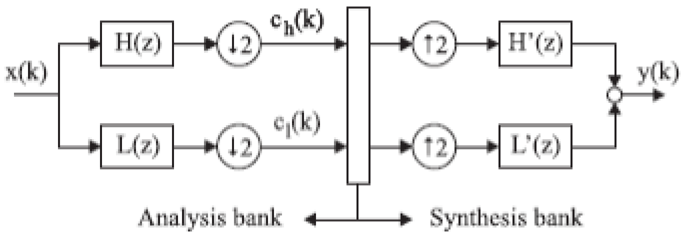


Figure 3.6 Two channel filter bank [51]

For perfect construction distortion and aliasing must be prevented. As shown in Figure.. signal is decomposed in two frequency bands with the help of low pass L(z) and high pass H(z) filters; Eq. (3.7). For two channel filter banks, synthesis filter can be designed as to prevent aliasing [52];

$$L'(z)=H(-z)$$
$$H'(z)=-L(-z) \quad (3.7)$$

To prevent distortion, a product filter is shown in Eq. (3.8)

$$P_0'(z)=L'(z)L(z) \text{ [53].} \quad (3.8)$$

So a perfect reconstruction filter bank can be designed with these steps;

1. A low-pass filter P_0 satisfying the equation given above can be formed.

2. P0(z) is factored L'(z)L(z) and H'(z) and H(z) are calculated using equations given above.

Resolution can be multilevel;

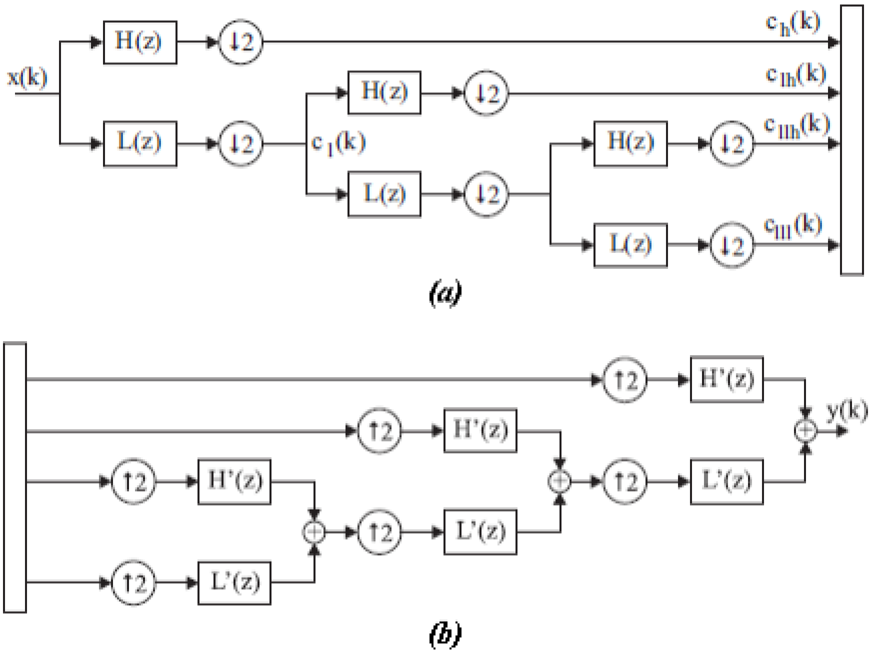


Figure 3.7 Three level filtration a)analysis b) synthesis [51]

Filtration can be designed according to desired resolution (Figure 3.7). It should be known that downsampling by factor 2 process is done after each filtration step.cl(k) coefficients the lowest half of the frequency content of the frequencies in x[k] and ch(k) coefficients are the highest frequency content steps. After each step, lowest and highest frequency components are shown by low pass and high pass filter outputs. For a specific filters set L(z) and H(z) , the process is called as DWT and filters are called wavelet filters [51]

3.5.1.2.2. Fundemental Wavelet Families

Wavelet transform includes many set of several types of wavelets. Varied wavelet types have different characteristics whether they have good resolution in frequency or time domain [54]. For example; Daubechies Wavelets are wavelet types that have been designed for a given vanishing moment p, minimum size of discrete fitler [48]. Wavelet subclasses described with iteration level, number of vanishing moments and the number of coefficients [54]. Certain wavelet family examples are shown in the Figure 3.8.

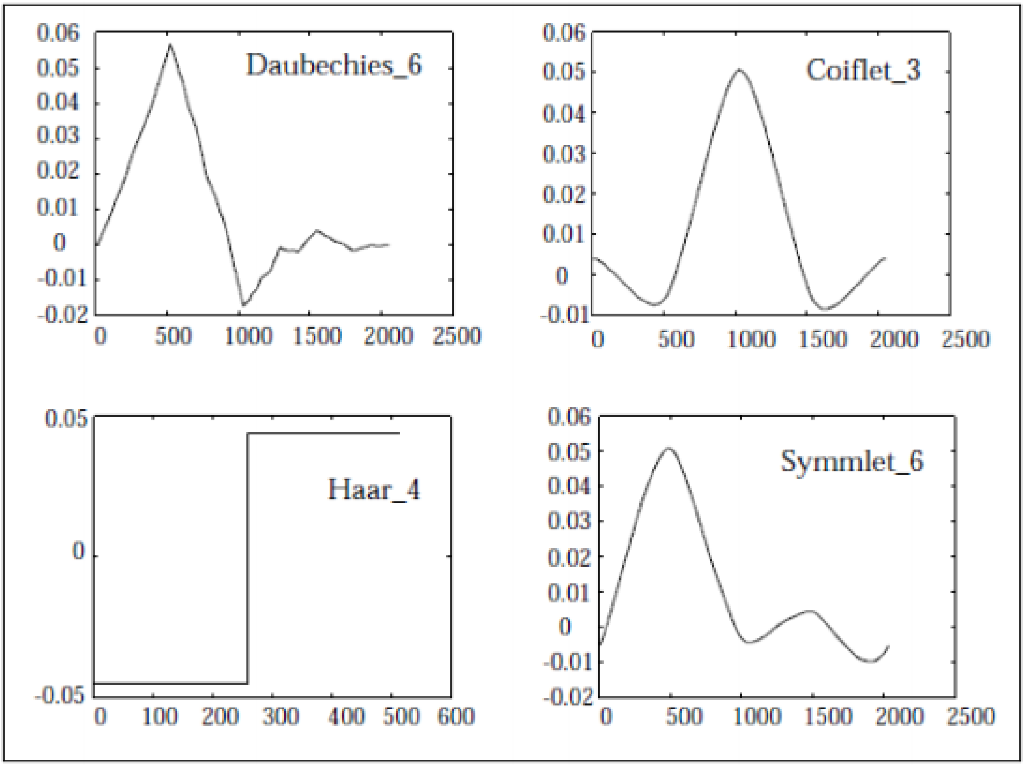


Figure 3.8 Different wavelet families examples [54].

3.5.2. Welch Power Spectral Density

Power Spectral Density (PSD) is used for measuring the power of a signal at different frequencies. This method is based on periodogram a spectrum estimate that is the process of converting a signal from time domain to frequency domain. Prediction of power spectra includes sectioning the signal, sections' modified periodograms are taken, and these periodograms are averaged [55]. Periodogram decreases noise in the measured power spectra, does this by reducing the frequency resolution. This noise is the noise that caused finite and defective data [56].

3.6. Extracted Features/ Data Analysis

Signals decomposed into their frequency bands (delta, theta, alpha, beta) with the help of Discrete Wavelet Transform. Power Spectral Density method helped to measure two basic characteristic of bands; power and amplitude. Figure 3.9 shows power distribution of signal bands. Two main features acquired after signal processing; power and amplitude.

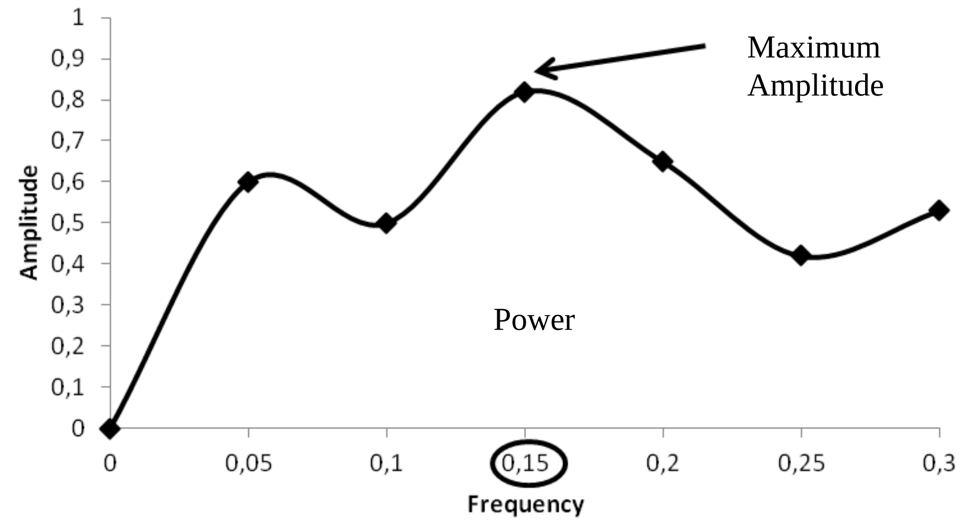


Figure 3.9 Components of EEG. The area under the curve states Power, the highest peak in the graph states maximum amplitude [57].

3.7. Statistical Analysis

Statistical interference that states all discrete random variable possible values and their possible probabilities is probability distribution. The t- distribution (Figure 3.9) is a distribution that predicts population mean that suitable to normal distribution and standart deviation (std. dev.) [58].

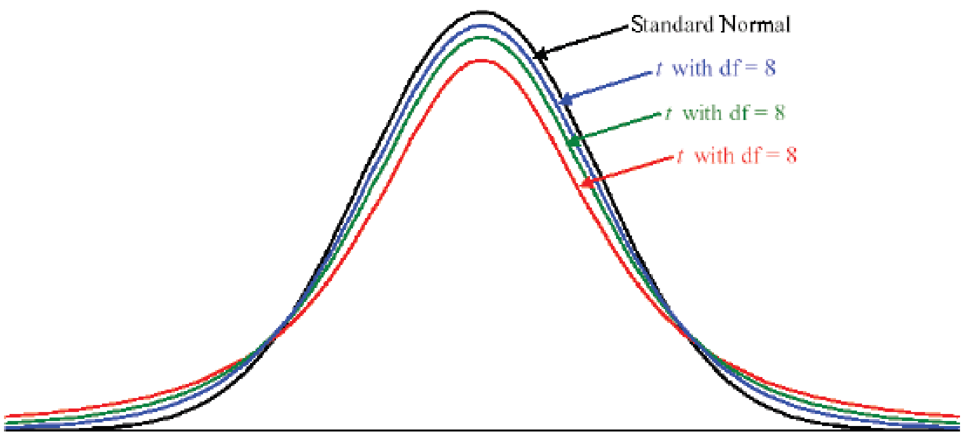


Figure 3.9 t- distribution [58]

3.7.1. Paired Sample t Test

The Paired Sample t Test used for samples that are in same group and comparison of vairables in this group are done with this method. Paired Sample t Test compares two groups' paired values and evaluates variations within each group produces t value seen in Eq. (3.9)

$$t = \frac{\frac{\Sigma d}{N}}{\sqrt{\frac{\Sigma d^2 - \frac{(\Sigma d)^2}{N}}{N(N-1)}}} \tag{3.9}$$

In this Formula N is number of samples and d is the difference between matched samples [59].

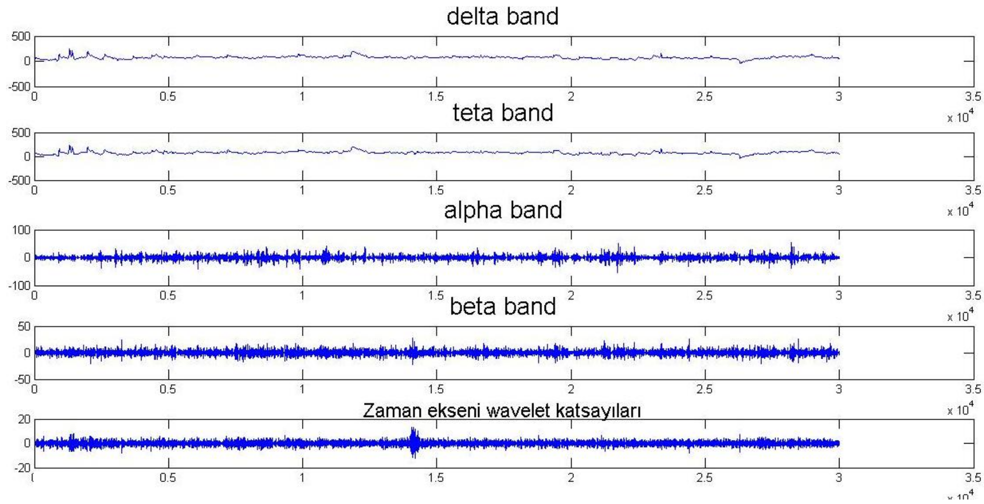
CHAPTER 4

RESULTS

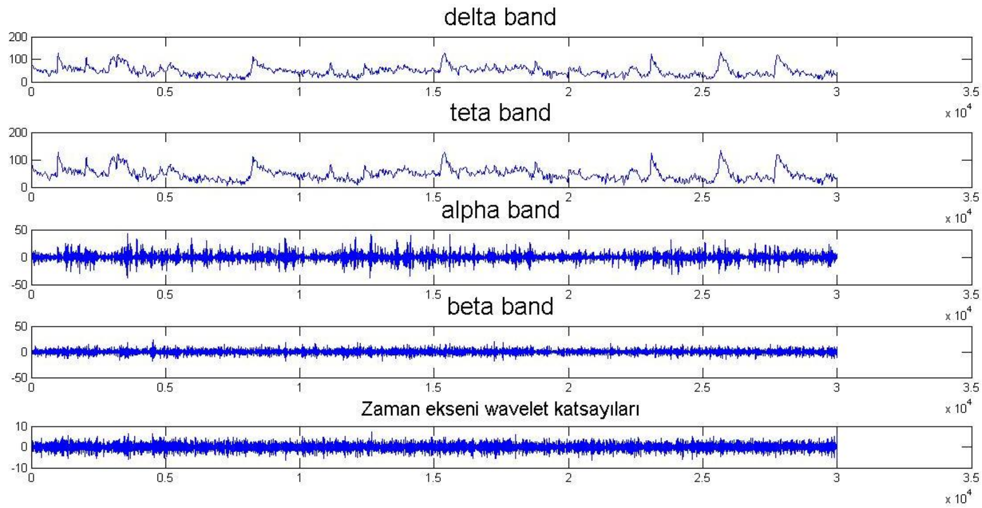
In this chapter, results of analyzed EEG signals exist. These signals were collected from 15 healthy, female students. Subjects' average age was 21,5± 1,8 MATLAB® software algorithms (v. 7.6.0. R2008a) was used to signal processing and SPSS® (v.20) software was used to do statistical analysis. Before these analyses EEG recording was done with BIOPAC® system and BIOPAC® Software. Figure 4.1 indicates BIOPAC® Software Interface during EEG recording signals from a subject.

Figure 4.1 BIOPAC Software Interface screenshot during a data recording

Signals decomposed into their frequency bands(delta, theta, alpha, beta) with Discrete Wavelet Transform. Bands power and amplitude were measured with Power Spectral Density method. All these measurements were done by MATLAB. Figures 4.2-7 shows MATLAB results of EEG bands during procedure.

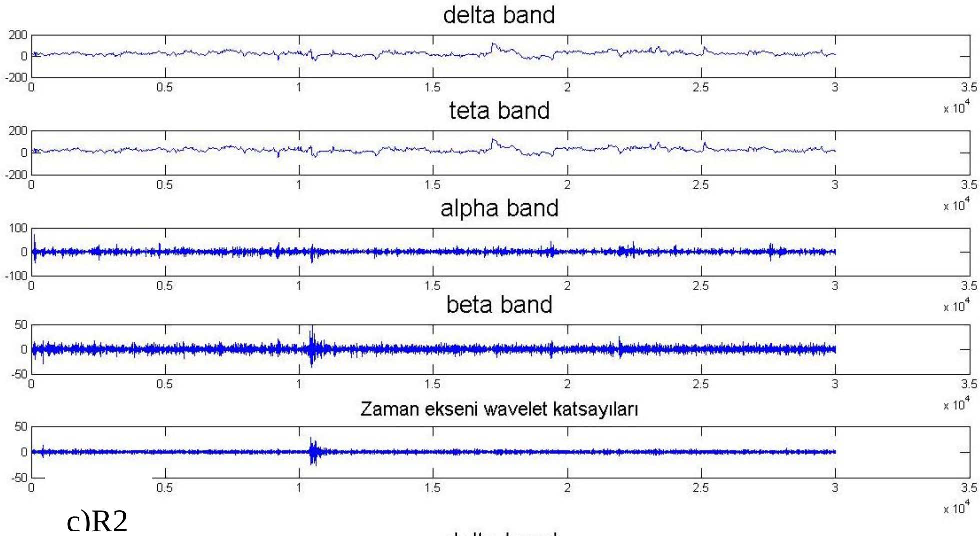


a)R1

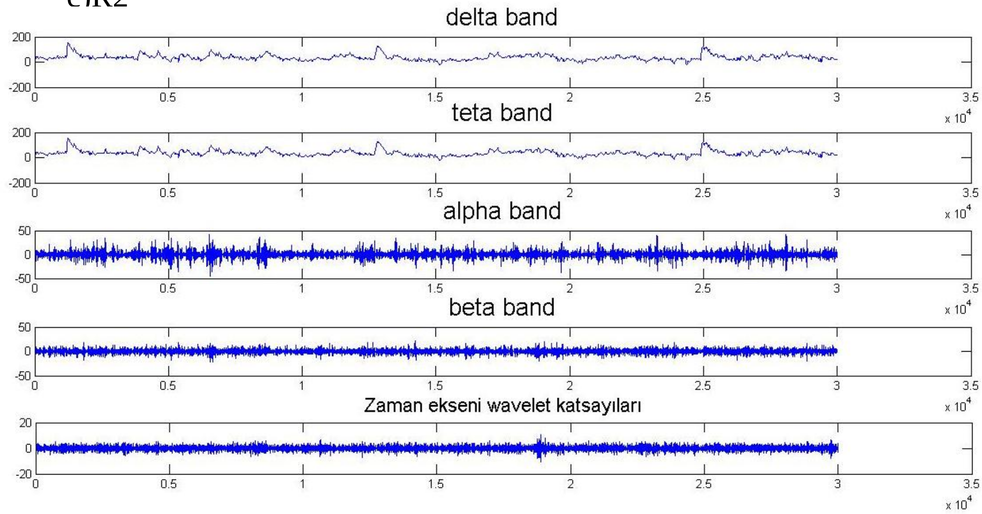


b)M1

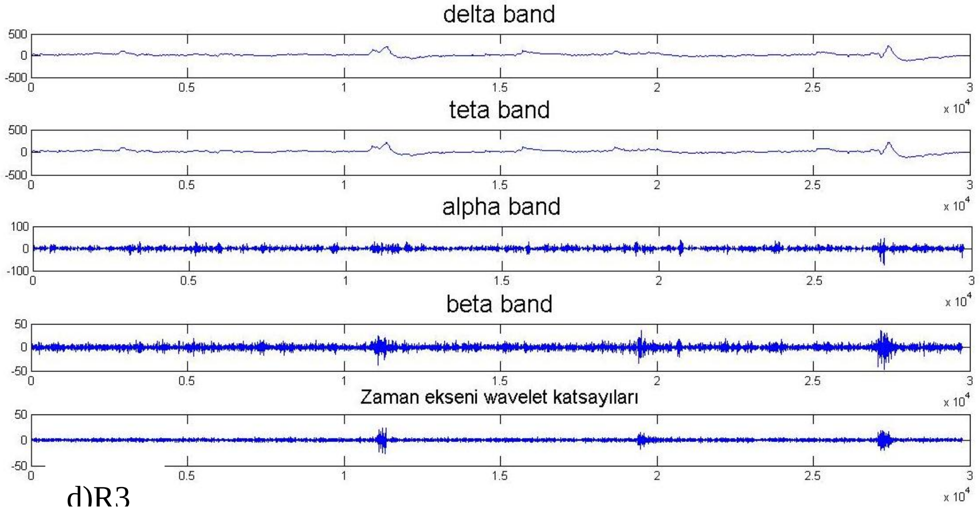
Figure 4.2 Matlab result of EEG bands changes in the first channel (F3). Between a) R1. b)M1



c)R2

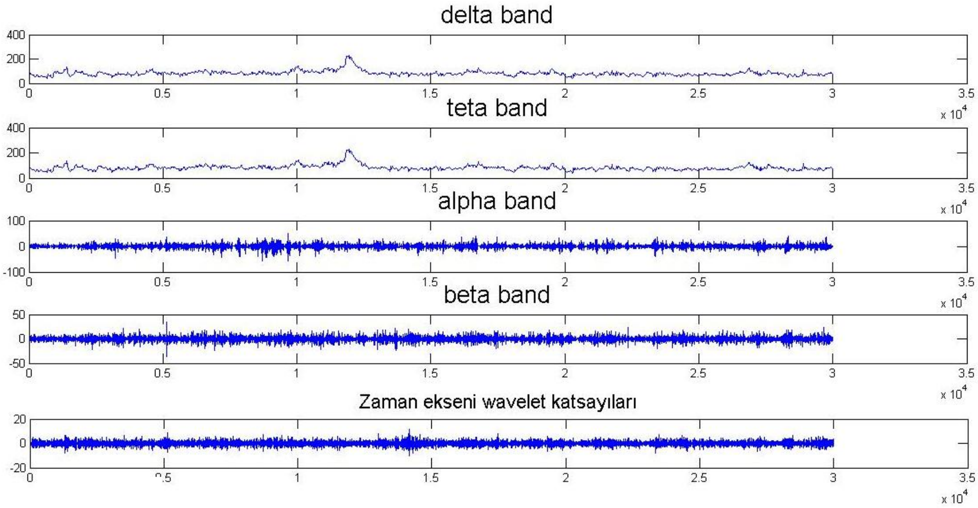


d)M2

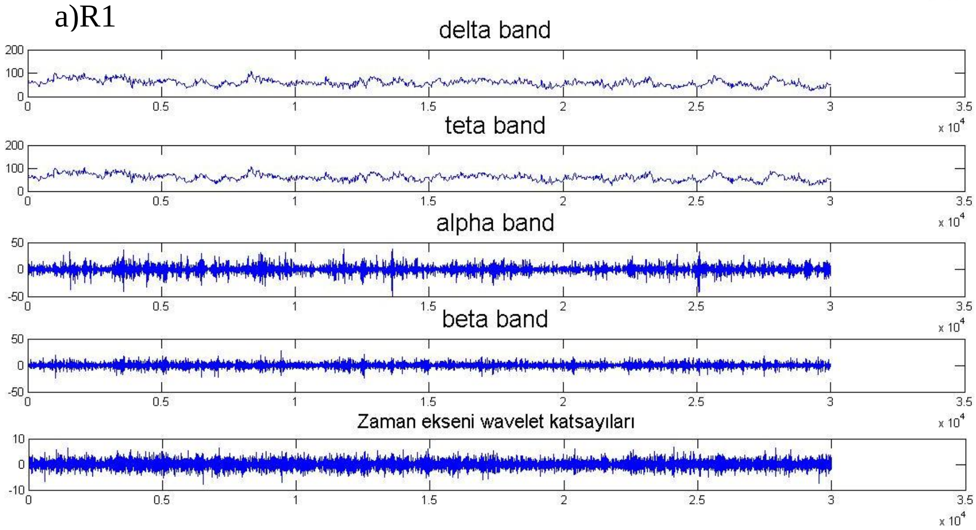


d)R3

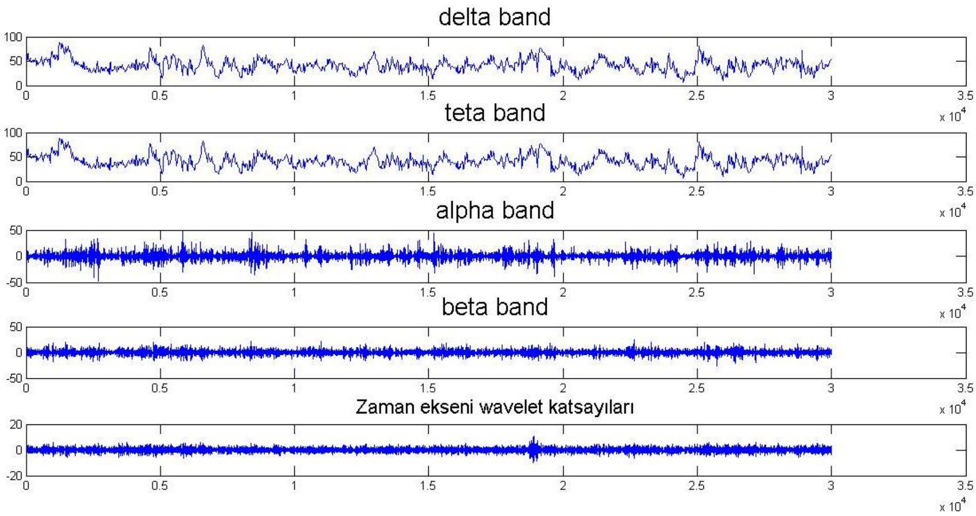
Cont. Figure 4.2 Matlab result of EEG bands changes in the first channel (F3). c)R2 d)M2 e)R3



a)R1

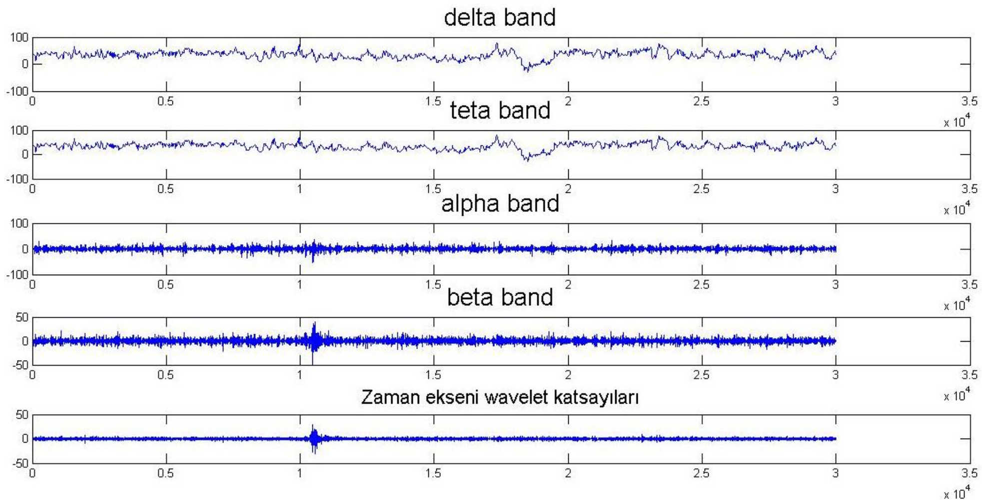


b)M1

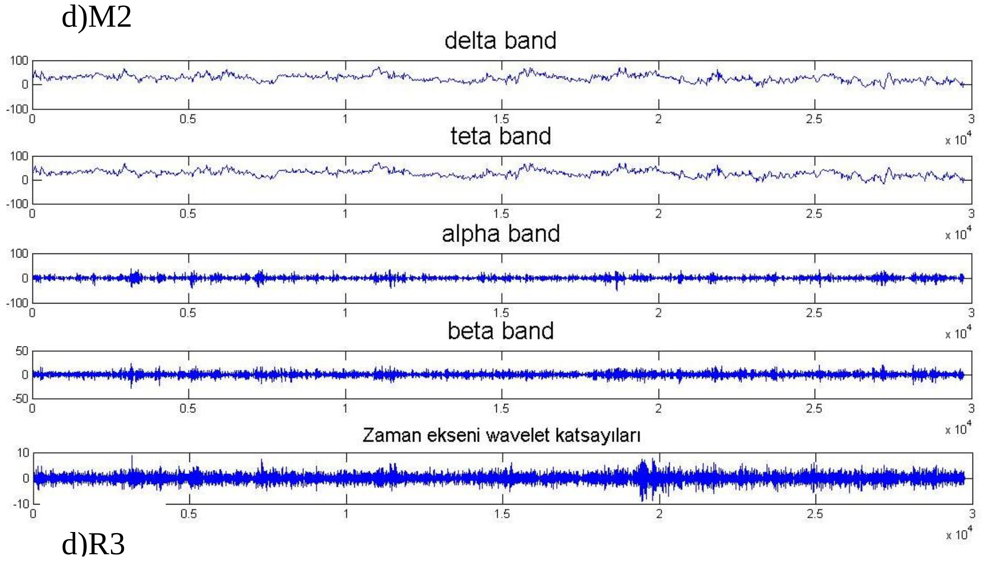


c)R2

Figure 4.3 Matlab result of EEG bands changes in 2nd channel (P3). a)R1 b)M1 c)R2

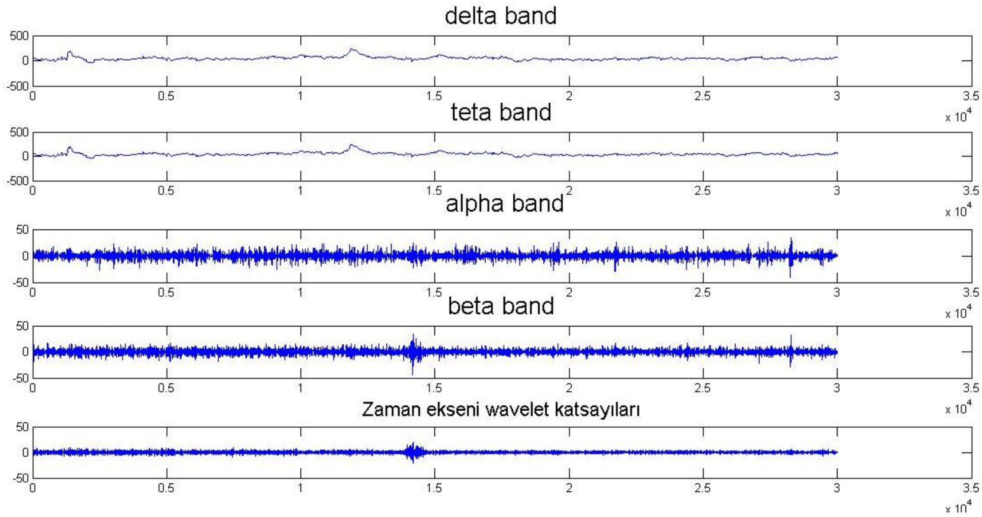


d)M2

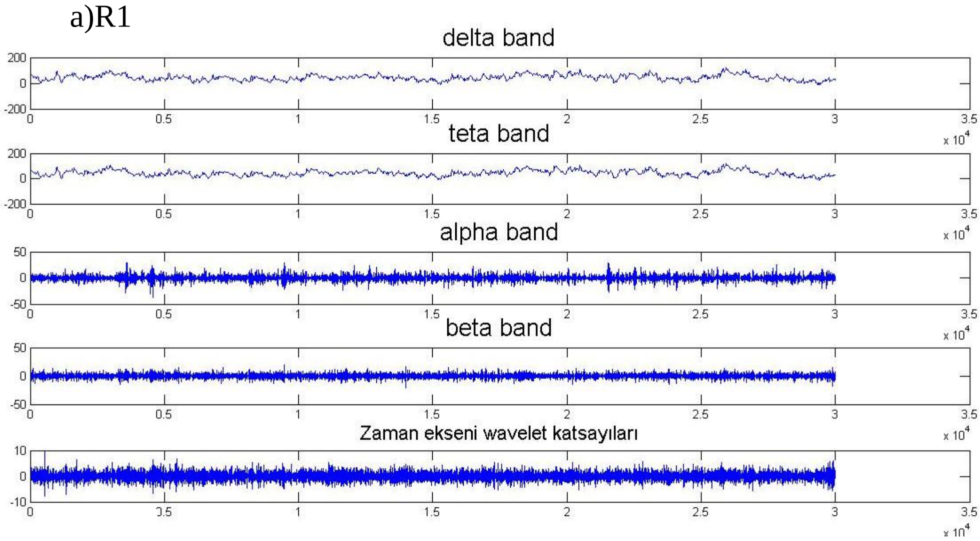


d)R3

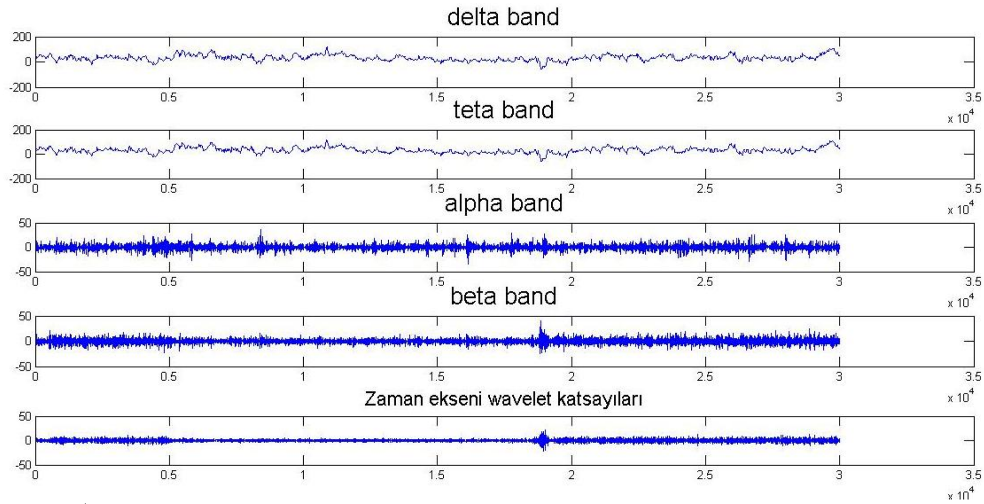
Cont. Figure 4.3 Matlab result of EEG bands changes in the second channel (P3). d)M2 e)R3.



a)R1

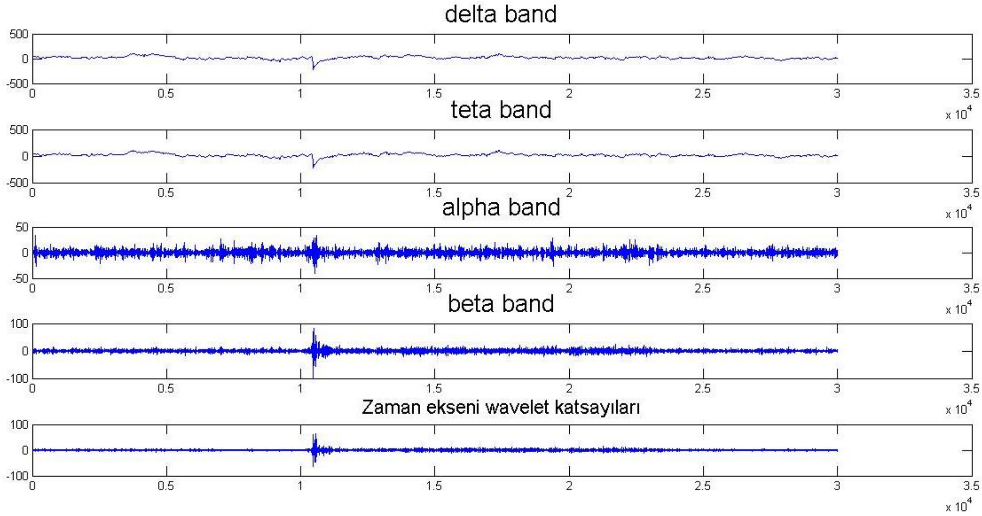


b)M1

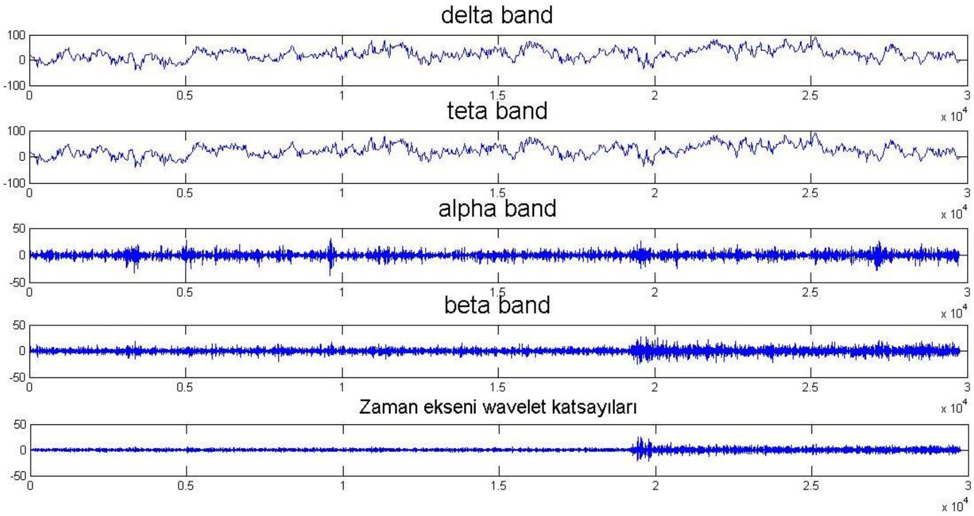


c)R2

Figure 4.4 Matlab result of EEG bands changes in the third channel (T3). a)R1 b)M1 c)R2



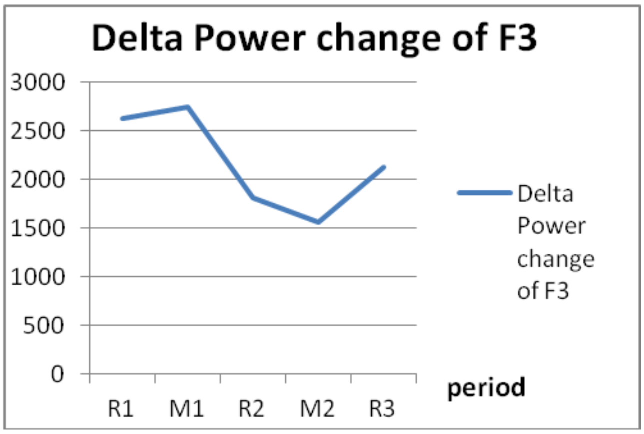
d)M2



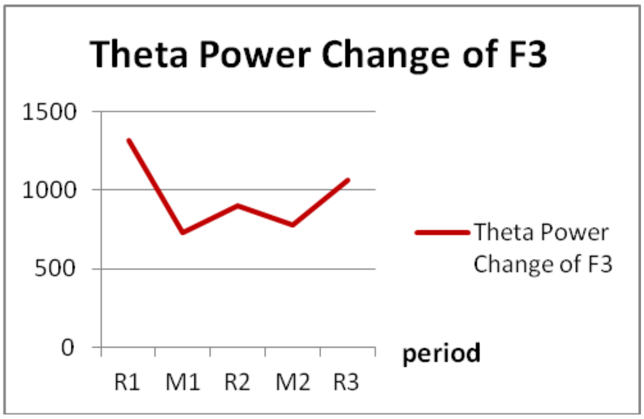
e)R3

Cont. Figure 4.4 Matlab result of EEG bands changes in the third channel (T3). d)M2 e)R3

After DWT, signal decomposed to its bands and after PSD method was applied; delta, theta, apha and beta band powers and amplitudes were obtained. Figure 4.5 is the graph of changes in EEG signal band powers of each channels during periods.

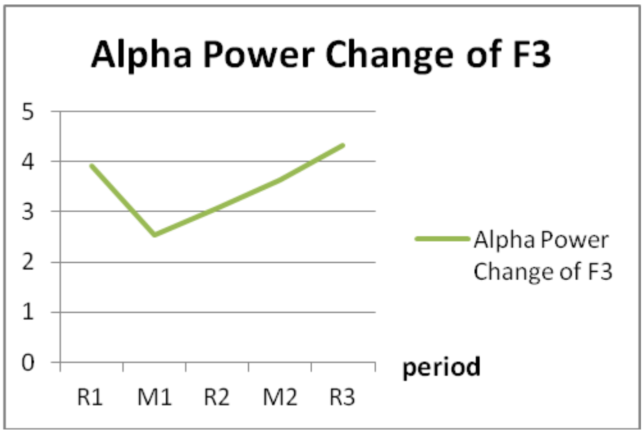


a)Changes in the delta band power of F3 channel

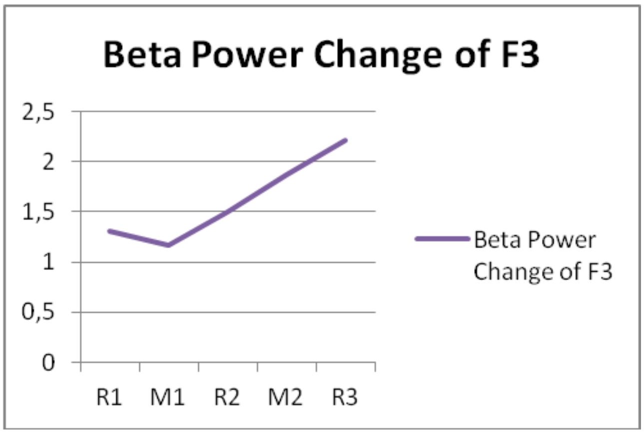


b)Changes in the theta band power of F3 channel

Figure 4.5 changes in a)delta b)theta c)alpha d)beta band powers of F3 channel during R1, M1, R2, M2, R3 periods

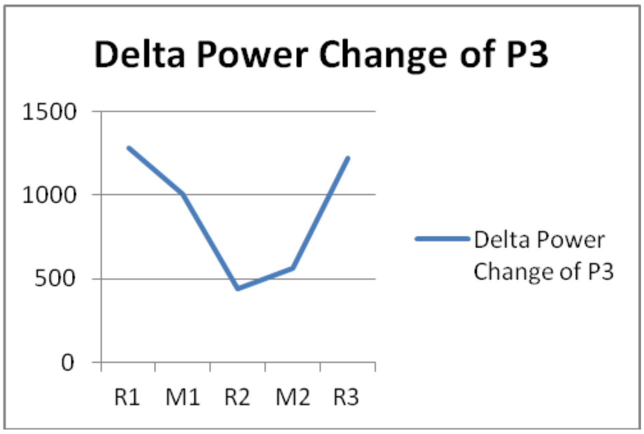


c)Changes in the alpha band power of F3 channel

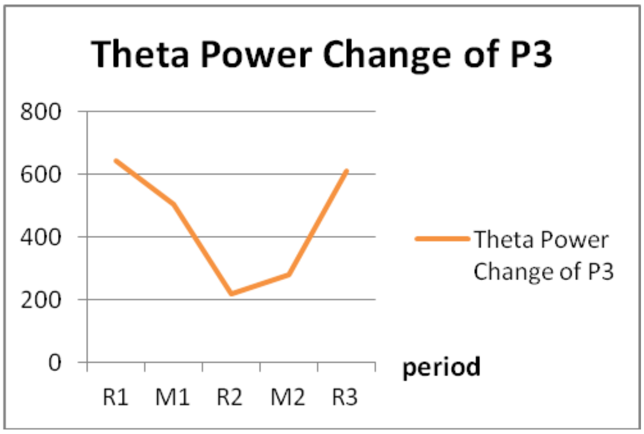


d) Changes in the beta band power of F3 channel

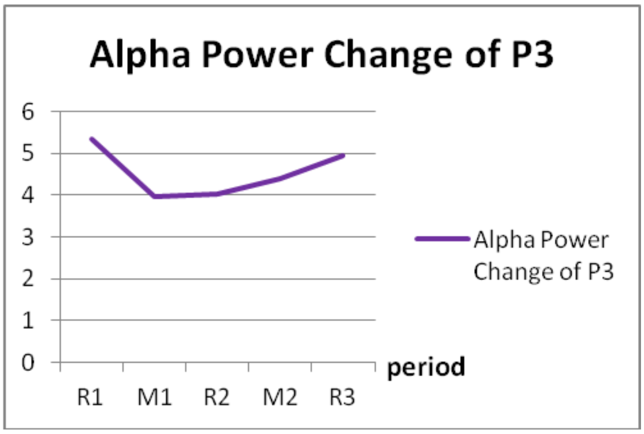
Cont. Figure 4.5 changes in a)delta b)theta c)alpha d)beta band powers of F3 channel during R1, M1, R2, M2, R3 periods



a)Changes in the delta band power of P3 channel

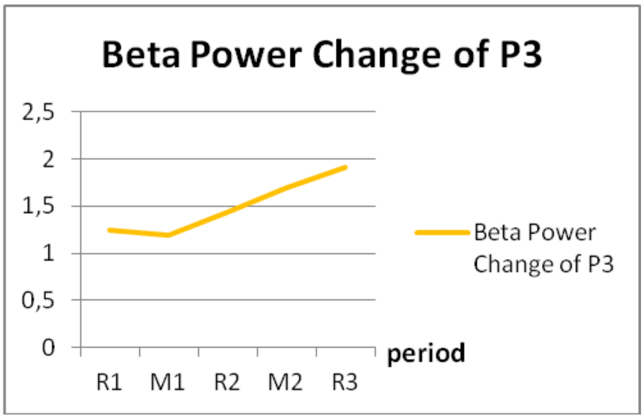


b)Changes in the theta band power of P3 channel



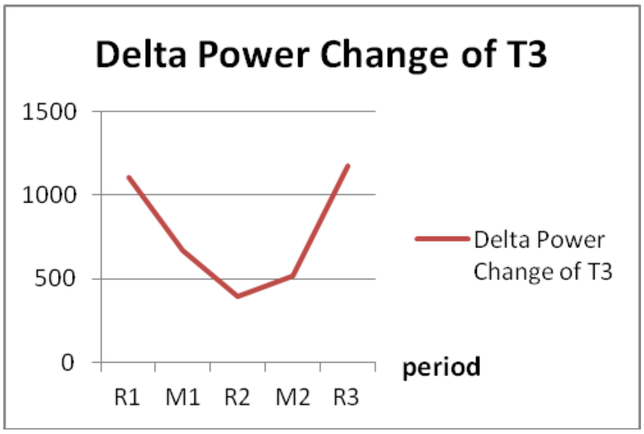
c)Changes in the alpha band power of P3 channel

Figure 4.6 changes in a)delta b)theta c)alpha d)beta band powers of P3 channel during R1, M1, R2, M2, R3 periods

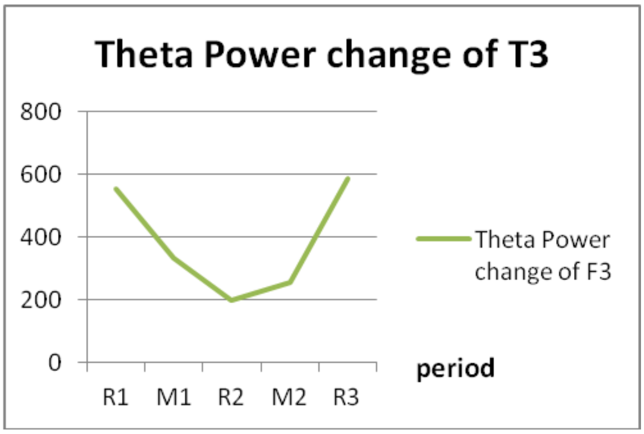


d) Changes in the beta band power of P3 channel

Cont. Figure 4.6 changes in a)delta b)theta c)alpha d)beta band powers of P3 channel during R1, M1, R2, M2, R3 periods

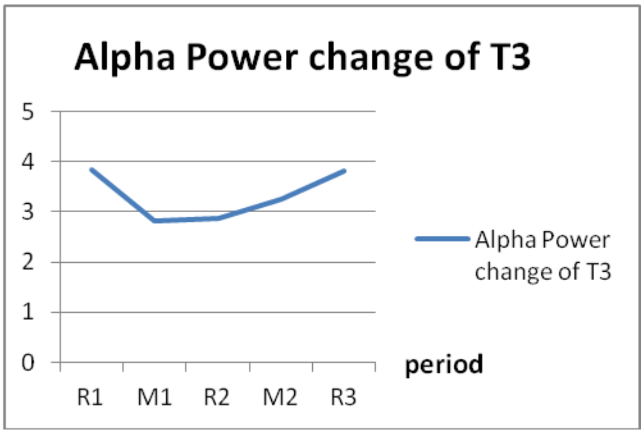


a)Changes in the delta band power of T3 channel

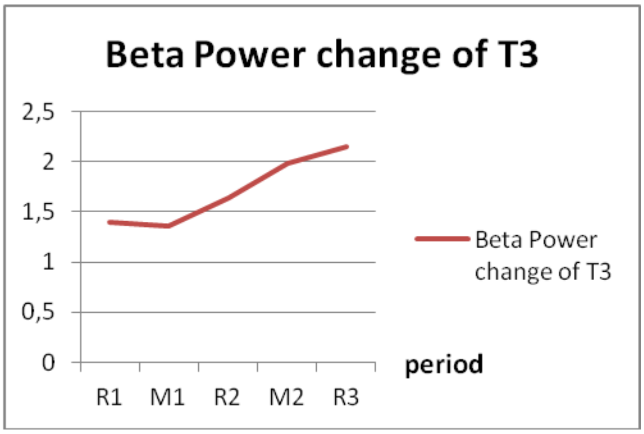


b)Changes in the theta band power of T3 channel

Figure 4.7 changes in a)delta b)theta c)alpha d)beta band powers of T3 channel during R1, M1, R2, M2, R3 periods

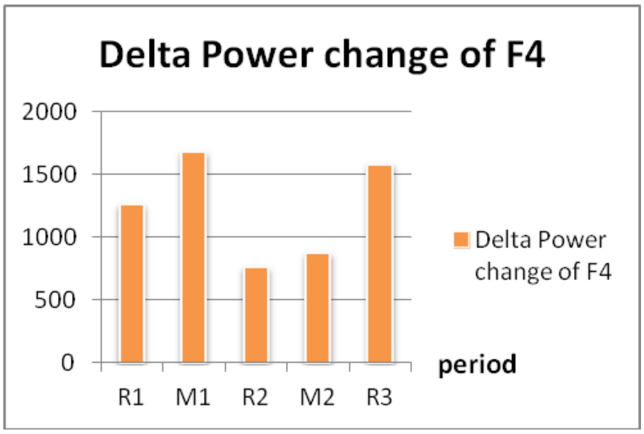


c)Changes in the alpha band power of T3 channel



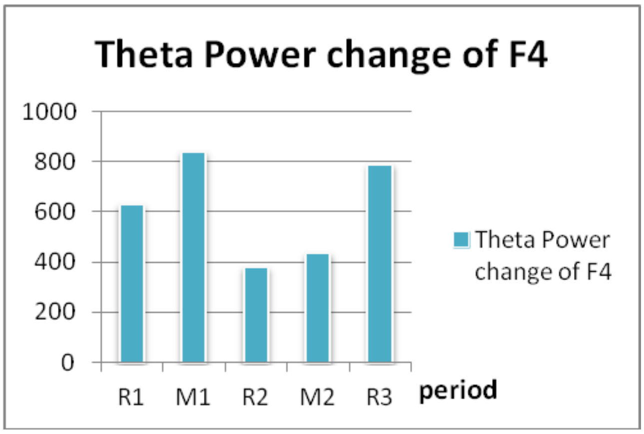
d) Changes in the beta band power of T3 channel

Cont. Figure 4.7 changes in a)delta b)theta c)alpha d)beta band powers of T3 channel during R1, M1, R2, M2, R3 periods

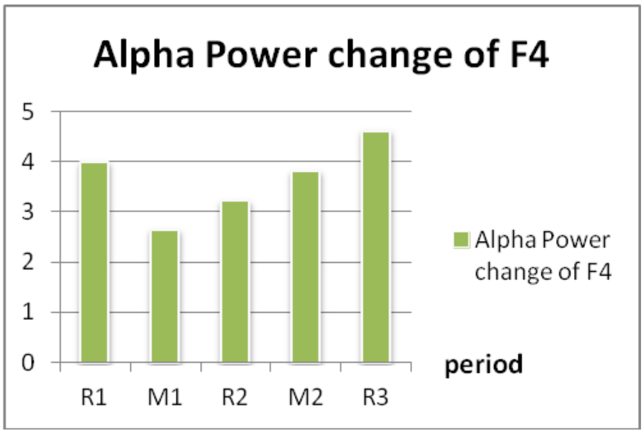


a)Changes in the delta band power of F4 channel

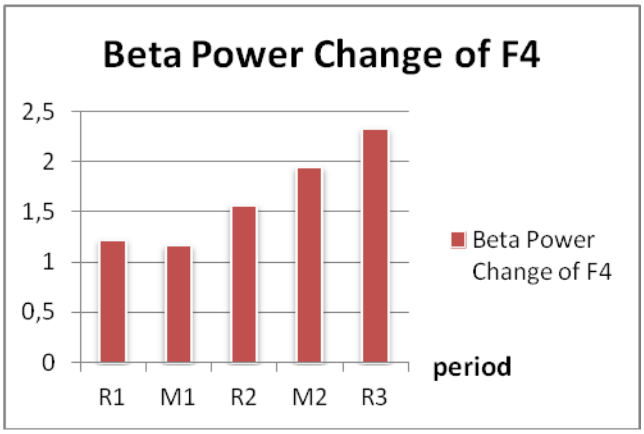
Figure 4.8 changes in a)delta b)theta c)alpha d)beta band powers of F4 channel during R1, M1, R2, M2, R3 periods



b)Changes in the theta band power of F4 channel

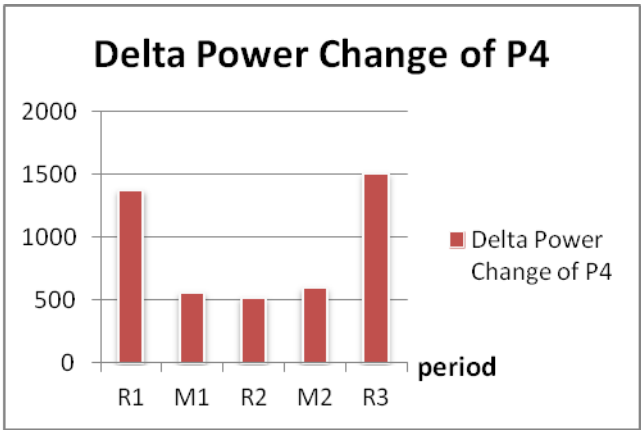


c)Changes in the alpha band power of F4 channel

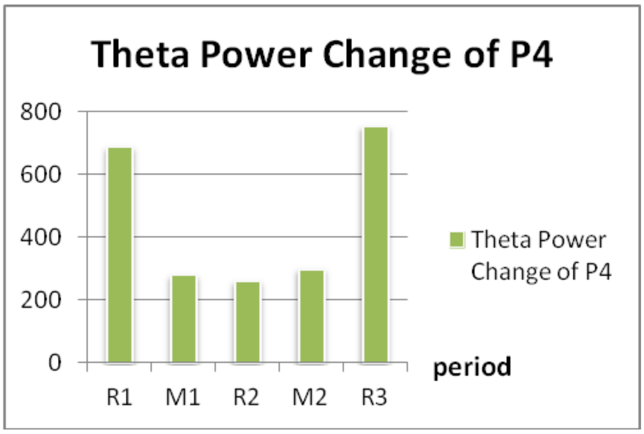


d) Changes in the beta band power of F4 channel

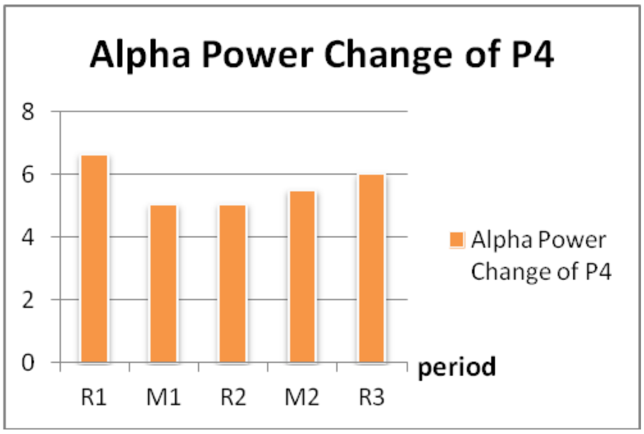
Cont. Figure 4.8 changes in a)delta b)theta c)alpha d)beta band powers of F4 channel during R1, M1, R2, M2, R3 periods



a)Changes in the delta band power of P4 channel

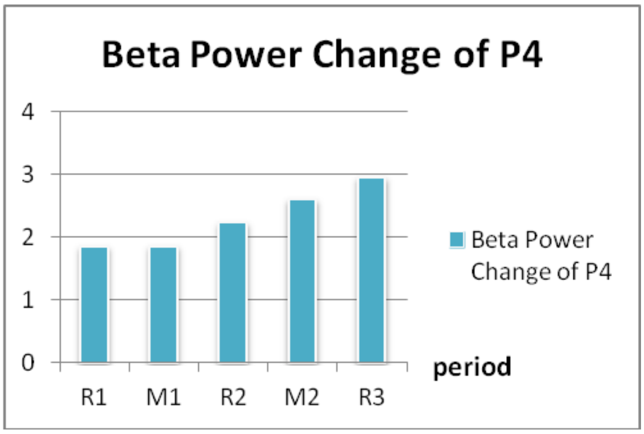


b)Changes in the theta band power of P4 channel



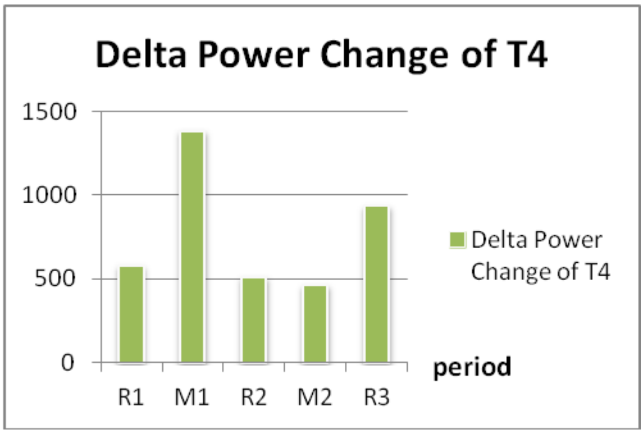
c)Changes in the alpha band power of P4 channel

Figure 4.9 changes in a)delta b)theta c)alpha d)beta band powers of P4 channel during R1, M1, R2, M2, R3 periods

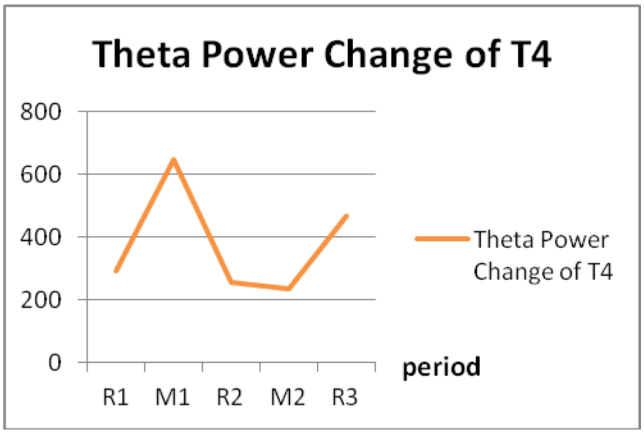


d) Changes in the beta band power of P4 channel

Cont. Figure 4.9 changes in a)delta b)theta c)alpha d)beta band powers of P4 channel during R1, M1, R2, M2, R3 periods

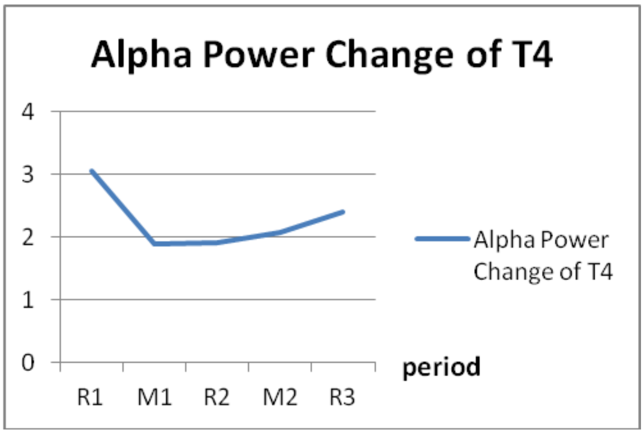


a)Changes in the delta band power of T4 channel

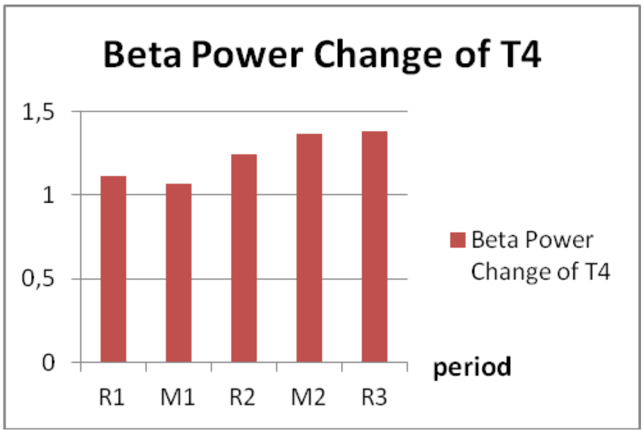


b)Changes in the theta band power of T4 channel

Figure 4.10 changes in a)delta b)theta c)alpha d)beta band powers of T4 channel during R1, M1, R2, M2, R3 periods



c)Changes in the alpha band power of T4 channel



d) Changes in the beta band power of T4 channel

Cont. Figure 4.10 changes in a)delta b)theta c)alpha d)beta band powers of T4 channel during R1, M1, R2, M2, R3 periods

Paired sample Student's t-test was applied to datas, for analyzing the difference between periods. Confidence level was taken as 95%. Significant difference was approved when p value is less than 0,05. Statistical comparisons was performed within each channel. p values and mean comparisons between periods of each channel are shown in Tables 4.1-4.6 .

Table 4.1 Comparison EEG bands’ characteristics of F3 channel between periods

		Paired Sample Test of F3 channel							
Bands	Periods	Mean	Std. Deviation	p Value	Bands	Periods	Mean	Std. Dev.	p Value
delta band	R1-M1 (power)	-122,760	4200,966	,911	alpha band	R1-M1 (power)	1,362	4,783	,289
delta band	M1-R2 (power)	944,215	3667,615	,336	alpha band	M1-R2 (power)	0,542	1,234	,111
delta band	R2- M2 (power)	243,189	1366,621	,502	alpha band	R2- M2 (power)	0,544	1,957	,300
delta band	M2-R3 (power)	-567,552	2402,042	,376	alpha band	M2-R3 (mean)	0,701	2,141	,225
delta band	R1-M1 (amplitude)	21237,94	379251,687	,831	alpha band	R1-M1 (amplitude)	35,814	121,055	,271
delta band	M1-R2 (amp.)	88408,920	339587,300	,330	alpha band	M1-R2 (amp.)	7,840	16,515	,087
delta band	R2- M2 (amp.)	23970,140	127923,006	,480	alpha band	R2- M2 (amp.)	-5,663	29,252	,466
delta band	M2-R3 (amp.)	-48118,507	200367,753	,368	alpha band	M2-R3 (amp.)	-17,221	54,031	,237
theta band	R1-M1 (power)	587,104	3288,720	,501	beta band	R1-M1 (power)	0,146	0,595	,356
theta band	M1-R2 (power)	-176,492	2929,559	,819	beta band	M1-R2 (power)	-0,337	0,669	,071
theta band	R2- M2 (power)	121,712	683,237	,502	beta band	R2- M2 (power)	-0,372	0,928	,143
theta band	M2-R3 (power)	-283,755	1201,099	,376	beta band	M2-R3 (power)	-0,347	0,603	,043
theta band	R1-M1 (amp.)	-10618,000	189628,909	,831	beta band	R1-M1 (amplitude)	2,302	7,453	,251
theta band	M1-R2 (amp.)	44206,353	169796,895	,330	beta band	M1-R2 (amp.)	-3,755	6,256	,036
theta band	R2- M2 (amp.)	11983,640	63956,464	,480	beta band	R2- M2 (amp.)	-5,599	16,552	,211
theta band	M2-R3 (amp.)	24058,320	100182,455	,368	beta band	M2-R3 (amp.)	-8,523	27,563	,251

Table 4.2 Comparison EEG bands' characteristics of P3 channel between periods

		Paired Sample Test of P3 channel							
Bands	Periods	Mean	Std. Deviation	p Value	Bands	Periods	Mean	Std. Dev.	p Value
delta band	R1-M1 (power)	278,294	3057,801	,730	alpha band	R1-M1 (power)	1,397	5,156	,312
delta band	M1-R2 (power)	566,679	2310,267	,358	alpha band	M1-R2 (power)	0,090	0,878	,696
delta band	R2- M2 (power)	-118,988	330,917	,185	alpha band	R2- M2 (power)	-0,340	0,786	,117
delta band	M2-R3 (power)	-659,369	2434,536	,312	alpha band	M2-R3 (power)	-0,557	2,299	,364
delta band	R1-M1 (amplitude)	16080,000	270114,158	,821	alpha band	R1-M1 (amplitude)	45,277	131,318	,203
delta band	M1-R2 (amp.)	52749,267	212216,227	,352	alpha band	M1-R2 (amp.)	5,527	25,363	,413
delta band	R2- M2 (amp.)	10503,667	29742,371	,193	alpha band	R2- M2 (amp.)	-0,914	13,545	,798
delta band	M2-R3 (amp.)	54045,600	202704,410	,319	alpha band	M2-R3 (amp.)	-15,296	55,558	,304
theta band	R1-M1 (power)	139,078	1528,679	,730	beta band	R1-M1 (power)	0,052	0,676	,771
theta band	M1-R2 (power)	283,310	1155,008	,358	beta band	M1-R2 (power)	-0,249	0,614	,139
theta band	R2- M2 (power)	-59,520	165,505	,185	beta band	R2- M2 (power)	-0,263	0,412	,027
theta band	M2-R3 (power)	-329,564	1217,173	,312	beta band	M2-R3 (power)	-0,211	0,705	,265
theta band	R1-M1 (amp.)	8210,629	135079,110	,817	beta band	R1-M1 (amplitude)	0,794	9,233	,744
theta band	M1-R2 (amp.)	26019,888	106213,097	,359	beta band	M1-R2 (amp.)	-2,013	6,097	,222
theta band	R2- M2 (amp.)	-5252,267	14871,852	,193	beta band	R2- M2 (amp.)	-4,043	5,641	,015
theta band	M2-R3 (amp.)	27022,733	101352,064	,319	beta band	M2-R3 (amp.)	-3,235	8,362	,156

Table 4.3 Comparison EEG bands' characteristics of T3 channel between periods

		Paired Sample Test of T3 channel							
Bands	Periods	Mean	Std. Deviation	p Value	Bands	Periods	Mean	Std. Dev.	p Value
delta band	R1-M1 (power)	440,315	1872,215	,378	alpha band	R1-M1 (power)	1,013	4,998	,446
delta band	M1-R2 (power)	274,099	1208,707	,395	alpha band	M1-R2 (power)	166,487	644,883	,334
delta band	R2- M2 (power)	-119,324	229,182	,063	alpha band	R2- M2 (power)	166,052	644,487	,335
delta band	M2-R3 (power)	-660,125	2362,445	,297	alpha band	M2-R3 (power)	-0,552	2,455	,398
delta band	R1-M1 (amplitude)	26861,083	158295,142	,522	alpha band	R1-M1 (amplitude)	27,175	125,063	,414
delta band	M1-R2 (amp.)	25049,567	112063,628	,401	alpha band	M1-R2 (amp.)	0,297	18,272	,951
delta band	R2- M2 (amp.)	10488,800	20453,013	,067	alpha band	R2- M2 (amp.)	-2,898	7,928	,179
delta band	M2-R3 (amp.)	54101,533	196819,186	,305	alpha band	M2-R3 (amp.)	-16,102	54,188	,269
theta band	R1-M1 (power)	220,200	936,054	,378	beta band	R1-M1 (power)	0,039	0,734	,841
theta band	M1-R2 (power)	137,040	604,369	,395	beta band	M1-R2 (power)	-0,278	0,535	,064
theta band	R2- M2 (power)	-59,643	114,522	,063	beta band	R2- M2 (power)	-0,354	0,612	,042
theta band	M2-R3 (power)	-329,970	1180,909	,297	beta band	M2-R3 (power)	-0,167	0,835	,451
theta band	R1-M1 (amp.)	16307,123	78359,892	,434	beta band	R1-M1 (amplitude)	-0,091	11,608	,976
theta band	M1-R2 (amp.)	12310,054	56057,467	,409	beta band	M1-R2 (amp.)	-1,606	4,816	,217
theta band	R2- M2 (amp.)	-5279,021	10375,584	,069	beta band	R2- M2 (amp.)	-6,051	10,738	,047
theta band	M2-R3 (amp.)	- 26408,909	98669,561	,317	beta band	M2-R3 (amp.)	-4,164	11,400	,179

Table 4.4 Comparison EEG bands' characteristics of F4 channel between periods

		Paired Sample Test of F4 channel							
Bands	Periods	Mean	Std. Deviation	p Value	Bands	Periods	Mean	Std. Dev.	p Value
delta band	R1-M1 (power)	-418,479	4531,381	,726	alpha band	R1-M1 (power)	1,346	4,874	,303
delta band	M1-R2 (power)	919,141	4013,645	,390	alpha band	M1-R2 (power)	-0,571	1,179	,082
delta band	R2- M2 (power)	-114,729	432,479	,322	alpha band	R2- M2 (power)	-0,594	1,995	,268
delta band	M2-R3 (power)	-709,435	2296,893	,251	alpha band	M2-R3 (power)	-0,807	2,118	,162
delta band	R1-M1 (amplitude)	49009,267	412267,235	,652	alpha band	R1-M1 (amplitude)	36,410	122,334	,268
delta band	M1-R2 (amp.)	85951,467	372043,060	,386	alpha band	M1-R2 (amp.)	-7,969	16,400	,081
delta band	R2- M2 (amp.)	-9138,837	38976,903	,379	alpha band	R2- M2 (amp.)	-6,832	27,003	,344
delta band	M2-R3 (amp.)	59292,763	190783,575	,249	alpha band	M2-R3 (amp.)	18,296	52,745	,201
theta band	R1-M1 (power)	29847,476	116591,238	,338	beta band	R1-M1 (power)	0,059	0,687	,746
theta band	M1-R2 (power)	459,684	2006,711	,390	beta band	M1-R2 (power)	-0,399	0,709	,047
theta band	R2- M2 (power)	-57,312	216,209	,322	beta band	R2- M2 (power)	-0,379	0,991	,161
theta band	M2-R3 (power)	-354,784	1148,532	,251	beta band	M2-R3 (power)	-0,382	0,617	,031
theta band	R1-M1 (amp.)	25154,217	206052,122	,644	beta band	R1-M1 (amplitude)	0,836	8,917	,722
theta band	M1-R2 (amp.)	42975,867	186024,332	,386	beta band	M1-R2 (amp.)	-4,218	6,270	,021
theta band	R2- M2 (amp.)	-4475,279	19315,400	,385	beta band	R2- M2 (amp.)	-5,759	15,408	,170
theta band	M2-R3 (amp.)	-29138,989	95695,615	,258	beta band	M2-R3 (amp.)	-8,718	24,982	,198

Table 4.5 Comparison EEG bands's characteristics of P4 channel between periods

		Paired Sample Test of P4 channel							
Bands	Periods	Mean	Std. Deviation	p Value	Bands	Periods	Mean	Std. Dev.	p Value
delta band	R1-M1 (power)	815,938	1606,183	,069	alpha band	R1-M1 (power)	1,616	6,336	,340
delta band	M1-R2 (power)	38,529	272,592	,593	alpha band	M1-R2 (power)	-0,023	1,805	,961
delta band	R2- M2 (power)	-77,912	254,178	,255	alpha band	R2- M2 (power)	-0,438	1,147	,162
delta band	M2-R3 (power)	-908,765	3153,998	,283	alpha band	M2-R3 (power)	-0,524	2,606	,449
delta band	R1-M1 (amplitude)	86467,144	145591,326	,037	alpha band	R1-M1 (amplitude)	51,159	159,192	,234
delta band	M1-R2 (amp.)	3889,390	24998,116	,556	alpha band	M1-R2 (amp.)	10,997	34,385	,236
delta band	R2- M2 (amp.)	-6371,333	22885,738	,299	alpha band	R2- M2 (amp.)	-5,330	31,025	,517
delta band	M2-R3 (amp.)	-75579,867	264010,491	,286	alpha band	M2-R3 (amp.)	-16,979	61,927	,306
theta band	R1-M1 (power)	407,960	803,110	,069	beta band	R1-M1 (power)	-0,003	0,920	,990
theta band	M1-R2 (power)	19,243	136,358	,593	beta band	M1-R2 (power)	-0,377	1,148	,225
theta band	R2- M2 (power)	-38,979	127,091	,255	beta band	R2- M2 (power)	-0,370	0,718	,066
theta band	M2-R3 (power)	-454,278	1576,739	,283	beta band	M2-R3 (power)	-0,348	0,964	,183
theta band	R1-M1 (amp.)	49924,677	74411,933	,021	beta band	R1-M1 (amplitude)	0,787	12,755	,815
theta band	M1-R2 (amp.)	2516,223	12424,209	,446	beta band	M1-R2 (amp.)	-1,412	10,142	,598
theta band	R2- M2 (amp.)	-3562,290	11384,053	,246	beta band	R2- M2 (amp.)	-10,120	26,058	,155
theta band	M2-R3 (amp.)	-37788,533	132000,219	,286	beta band	M2-R3 (amp.)	-16,566	59,003	,295

Table 4.6 Comparison EEG bands's characteristics of T4 channel between periods

		Paired Sample Test of T4 channel							
Bands	Periods	Mean	Std. Deviation	p Value	Bands	Periods	Mean	Std. Dev.	p Value
delta band	R1-M1 (power)	-806,323	4038,732	,452	alpha band	R1-M1 (power)	1,153	4,932	,381
delta band	M1-R2 (power)	873,842	3970,211	,408	alpha band	M1-R2 (mean)	-0,022	0,388	,833
delta band	R2- M2 (mean)	48,057	800,206	,819	alpha band	R2- M2 (mean)	-0,152	0,355	,119
delta band	M2-R3 (mean)	-471,868	2309,328	,442	alpha band	M2-R3 (mean)	-0,320	2,253	,590
delta band	R1-M1 (amplitude)	-80206,848	365928,549	,410	alpha band	R1-M1 (amplitude)	30,067	125,296	,368
delta band	M1-R2 (amp.)	81002,890	366470,748	,406	alpha band	M1-R2 (amp.)	-1,525	7,497	,444
delta band	R2- M2 (amp.)	4285,160	71336,580	,819	alpha band	R2- M2 (amp.)	-0,479	6,272	,772
delta band	M2-R3 (amp.)	38743,959	192869,408	,450	alpha band	M2-R3 (amp.)	12,953	54,246	,371
theta band	R1-M1 (mean)	-403,102	2019,233	,452	beta band	R1-M1 (mean)	0,047	0,751	,812
theta band	M1-R2 (mean)	436,899	1984,975	,408	beta band	M1-R2 (mean)	-0,179	0,573	,247
theta band	R2- M2 (mean)	24,000	399,980	,820	beta band	R2- M2 (mean)	-0,126	0,301	,128
theta band	M2-R3 (mean)	-235,922	1154,633	,442	beta band	M2-R3 (mean)	-0,016	0,528	,910
theta band	R1-M1 (amp.)	-40693,788	182816,239	,403	beta band	R1-M1 (amplitude)	-0,131	11,869	,967
theta band	M1-R2 (amp.)	40599,699	183210,821	,405	beta band	M1-R2 (amp.)	-1,283	3,255	,149
theta band	R2- M2 (amp.)	2186,837	35664,574	,816	beta band	R2- M2 (amp.)	-2,624	5,267	,074
theta band	M2-R3 (amp.)	19371,213	96433,529	,450	beta band	M2-R3 (amp.)	-0,583	3,296	,504

The results showed that there is significant difference between M1 (first music) and R2 (second resting) periods amplitudes (p=0,036), M2 (second music) and R3 (last resting) periods powers (p=0,043) in beta bands of F3 channel, R2 and M2 periods powers (p=0,027), R2 and M2 periods amplitudes (p=0,015) in beta bands of P3 channel, R2 and M2 periods powers (p=0,042), R2 and M2 periods amplitudes (p=0,047) in beta bands of T3 channel, M1-R2 periods powers (p=0,047), M2- R3 periods powers (p=0,031), M1-R2 periods amplitudes (p=0,021) in beta bands of F4 channel, R1 (first resting) and M1 periods amplitudes (p=0,037) in delta band of P4 channel, R1- M1 periods amplitudes (p=0,021) again in delta band of P4 channel, In T4 channel it is seemed that there is no significant difference between periods. After consecutive period comparisons, Paired Sample t-test was applied to T channels between only music periods. T electrodes were used in this comparison because, they are associated with recognition of auditory stimuli. When music periods were compared between each other, significant difference seen in beta band power and amplitude.

Table 4.7 Comparison EEG bands's characteristics of T channels between music periods

T3 channel	Music Periods	Comparisons		T4 channel	Music Periods	Comparisons	
Bands	Mean	Std. Deviation	p value	Bands	Mean	Std. Deviation	p value
Delta (power)	154,774	1247,464	,638	Delta (power)	921,899	3818,71	,366
Theta (power)	77,396	623,735	,638	Theta (power)	460,899	1909,20	,366
Alpha (power)	-,435	1,595	,308	Alpha (power)	-,174	,636	,308
Beta (power)	-,632	1,078	,040	Beta (power)	-,304	,676	,103
Alpha (amp.)	-2,6	25,214	,696	Alpha (amp.)	-2,004	10,375	,467
Beta (amp.)	-7,656	13,915	,051	Beta (amp.)	-3,906	8,206	,086

When plotting graphs of variables; because the power and amplitude magnitudes does not relevant with negativity, variables were taken as absolute value. In F3 beta band powers and amplitudes had significant difference. Figure 4.11 and Figure 4.12 shows variations of F3 beta band.

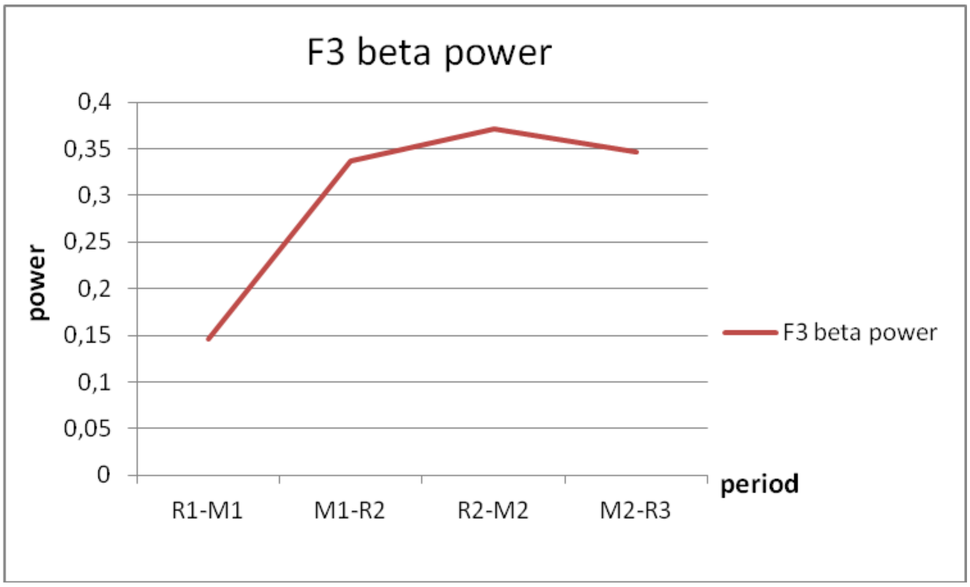


Figure 4.11 F3 beta band powers comparison during periods

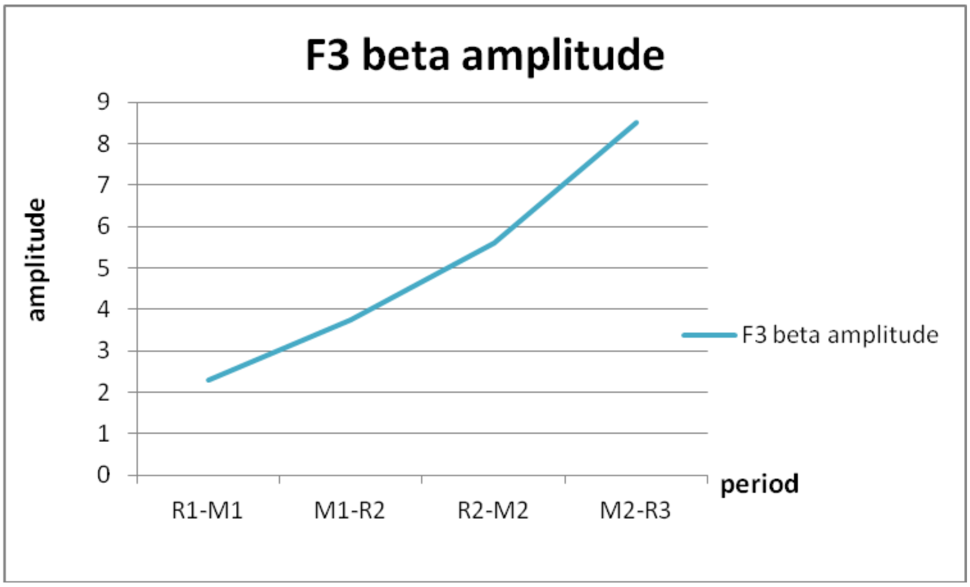


Figure 4.12 F3 beta band amplitudes comparison during periods

Significant difference was seen in P3 beta band. Figure 4.13 and Figure 4.14 shows variations of F3 beta band powers and amplitudes.

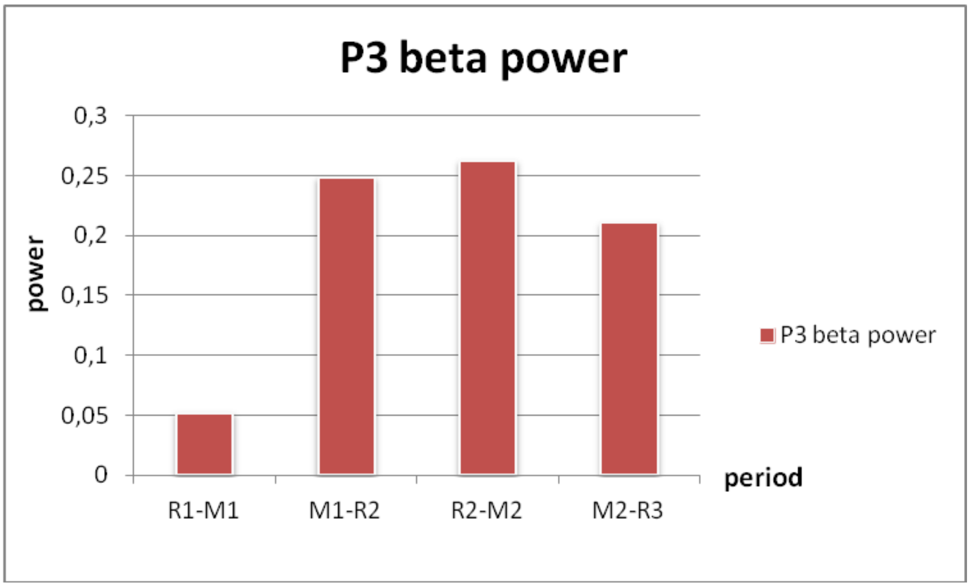


Figure 4.13 P3 beta band powers comparison during periods

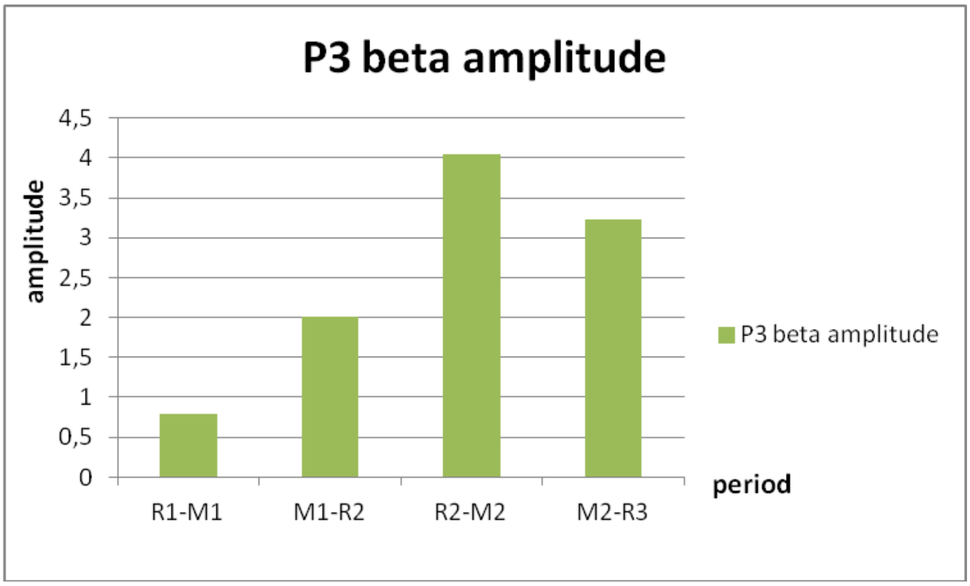


Figure 4.14 P3 beta band amplitudes comparison during periods

There was significant difference in beta band of T3 channel. Figure 4.15 and Figure 4.16 shows variations of T3 beta band powers and amplitudes.

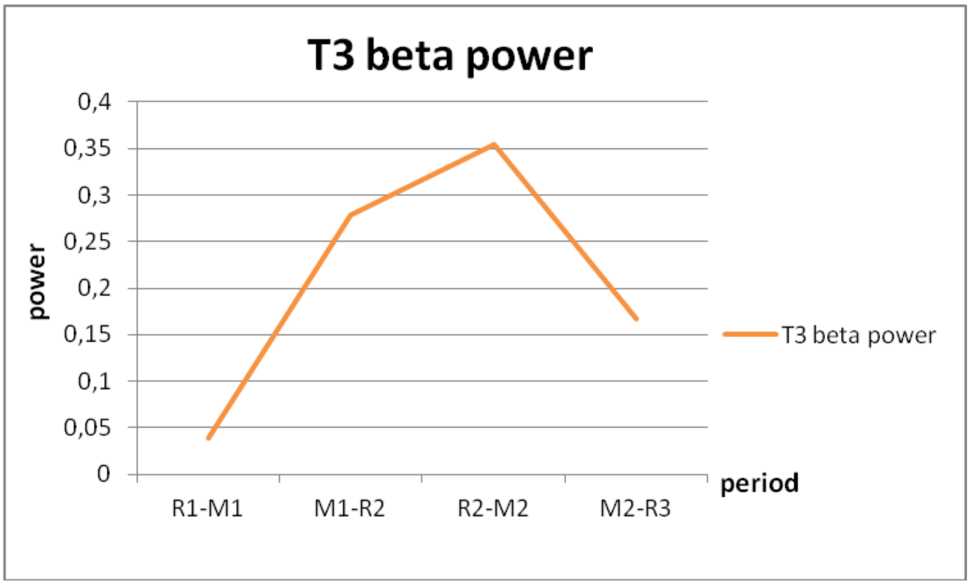


Figure 4.15 T3 beta band powers comparison during periods

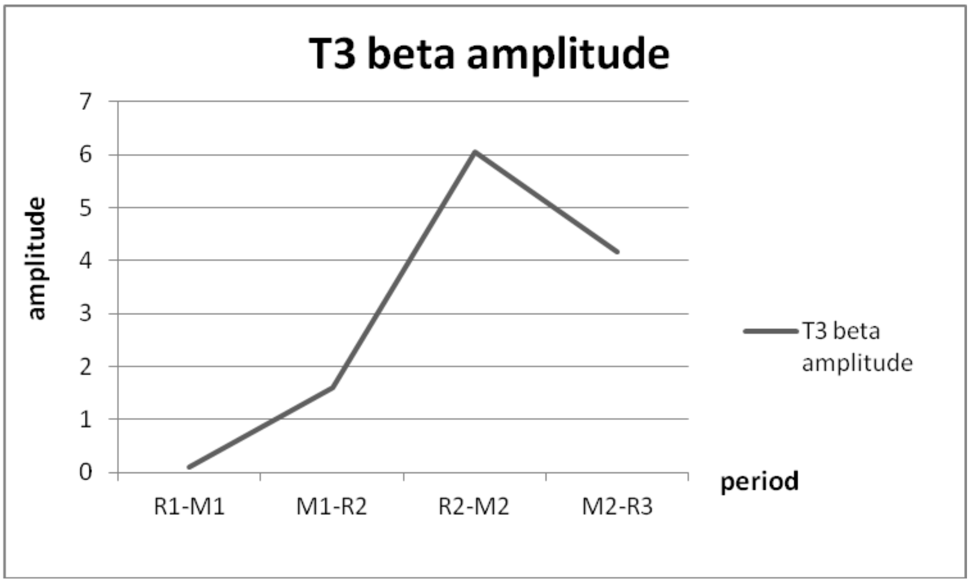


Figure 4.16 T3 beta band amplitudes comparison during periods

In F4 beta band means and amplitudes had significant difference. Figure 4.17 and Figure 4.18 shows variations of F4 beta band.

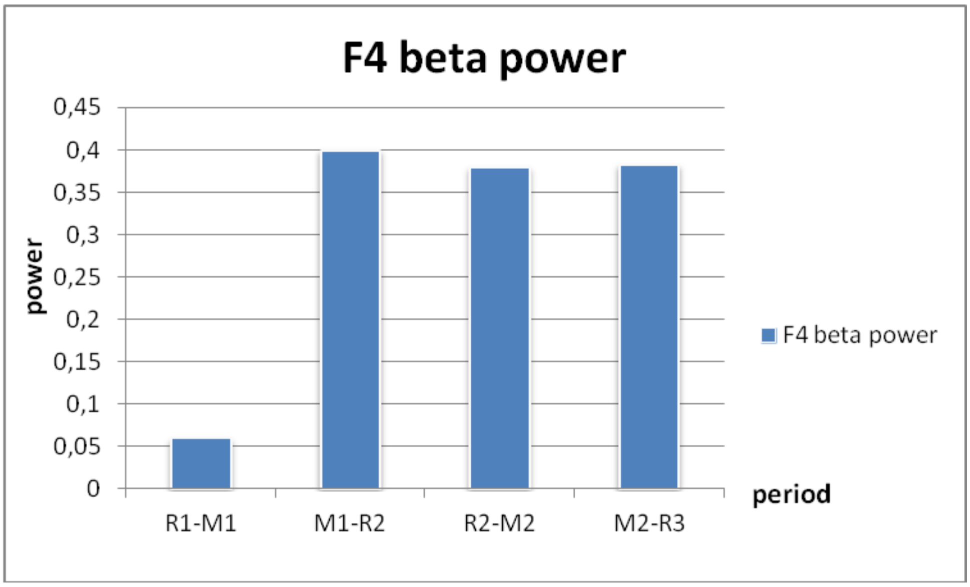


Figure 4.17 F4 beta band powers comparisons during periods

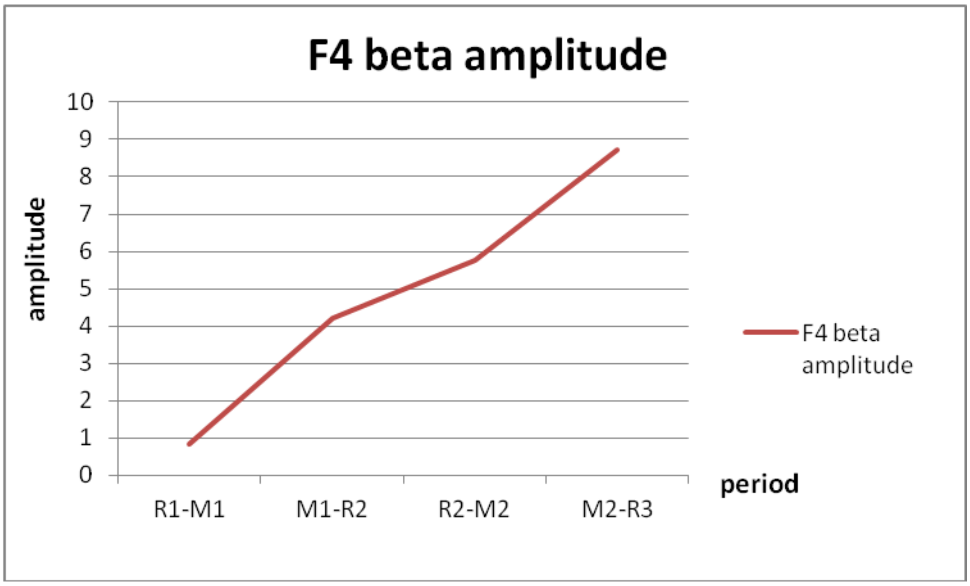


Figure 4.18 F4 beta band amplitudes comparison during periods

In F4 delta band amplitudes had significant difference. Figure 4.19 shows variation of F4 beta band amplitudes..

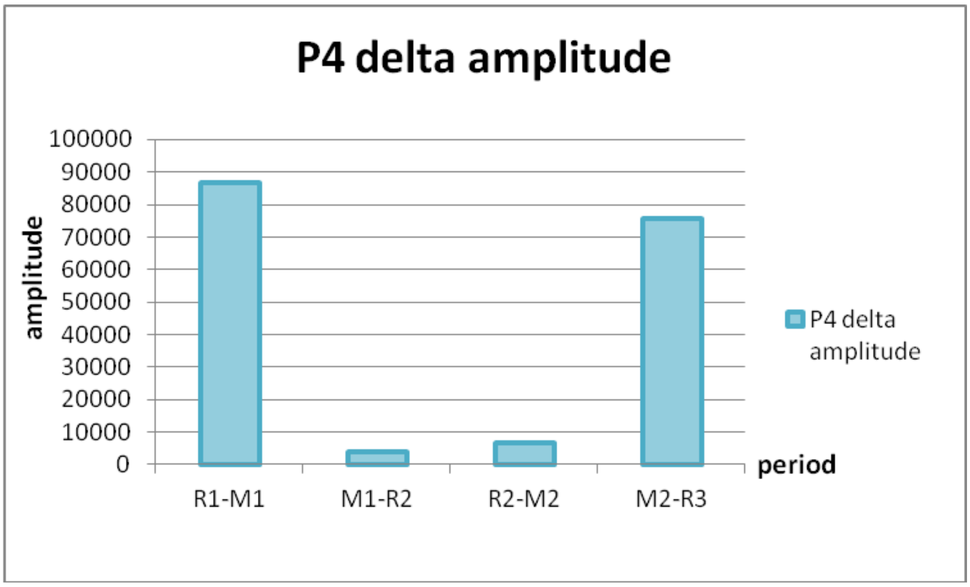


Figure 4.19 P4 delta band amplitudes comparison during periods

CHAPTER 5

DISCUSSION

This study is aimed to understand the real effect of Turkish Music makams to human brain functions. There are studies about the effect of music to brain waves, but in these studies researchers used musics other than Turkish Music [18, 19].

Many researches about music therapy around the world and Farabi's statements about Turkish music makams have been the main points of this study. Starting from this base electrical activity of brain during listening music was taken. Two elected makam is used; Kuçek Makam and Rast Makam. When Kuçek makam gives negatively effect, Rast makam gives positive impact to subject is primarily discussed in this study [23]. Music is the main determinant here and the main discussed proposal, importance of choosing the right music to brain interaction[60].

After signal processing, band powers showed a difference between periods. But when compared statistically significant results only seen in certain bands.

In F3 channel; EEG bands (except beta band) did not show significant difference. Beta band showed significant difference between music and resting periods. R2-M2 comparison of beta power showed change in this channel.

EEG bands (again except beta band) didn't show significant difference in P3 channel. Between music and resting periods beta band showed significant difference. Beta power and beta amplitude had significant difference in the comparison of R2-M2 periods.

In T3 channel; delta, theta, alpha EEG bands didn't have significant difference. Beta power showed significant difference in comparison of R2-M2 periods. Beta amplitude had significant difference in comparison of R2-M2 periods.

Delta, theta alpha bands have no significant difference in F4 channel. Between music and resting periods beta band showed significant difference. Beta power showed significant difference in comparison of M2-R3 periods. Its amplitude have significant difference between M1-R1 periods.

T channels beta band power and amplitude showed significant difference when only music periods're compared between each other. T4 channel bands had no significant difference through all periods (p >.0,05). According to this result; T4 has less sensitivity to the music stilimuli. Left hemisphere is more relevant with active behavior and positive emotions. Right hemisphere is more relevant to descendent behavior [45]. The location of the T4 electrode is in right hemisphere. It can be said that these makams does not very associated with withdrawal behavior.

Theta waves are associated with drowsiness of an individual. Frontal midline theta (named like this because of its localization on scalp) is seen during a large variety of tasks like mental calculation. According to a study, pleasant music increases frontal midline theta power [61]. In my study, theta power of each channel showed different reaction to music. And except P4 channel there was no significant difference in statistical comparisons. We may say these musics does not much related to drowsiness of individual and aren't very effective on theta power.

Alpha waves are connected with relaxation of human [45]. A study shows that when subjects listened to sonata music, EEG alpha power shows increase activity [19]. F3 and F4 channels are most used electrode sites for alpha activity measurement [62]. Significant difference wasn't seen alpha waves of F3 and F4 channels and other channels during periods. We can say that Kuçek and Rast Makams have not much relaxation effect.

Hence; the response of beta band of most channels is more significant for Kuçek and Rast Makams. Beta band is high frequency band. Beta waves are connected with active brain and alert state of mind [45]. Means increase of the neuronal activity. In a study, it was showed that listening to music increased EEG beta power of the bulk of posterior of the scalp [17]. In this study, Music 2 period has showed significant difference and has increased the beta power over all channels. So as expected Rast Makam is a Makam that may gives joy. Other Makams may show same or better effect for different bands.

Kuçek and Rast Makams have been less effective than expected. Test procedure may influenced these results. In another study the procedure can be changed. Ten minutes procedure with eyes closed, may felt long to subjects. Time can be shortened. Procedure can be only a resting and a music period. In this way, different types of makam can be tested at different times. Because it was difficult to convince the subjects to procedure, there was not much subject. More subjects can be used for more accurate statistic muasurements.

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APPENDICES

Appendix A

Deney Koşullarına Uygunluk

Teste gönüllü kişinin Adı, Soyadı:	Tarih:
Yaş:	Cinsiyet:

	Evet	Hayır
24 saat içerisinde alkol tüketimi	☐	☐
Electro Convulsive Therapy deneyimi	☐	☐
Düzenli kullanılan ilaç	☐	☐

Figure A.1 Compability to the experimental conditions

Bilgilendirilmiş Onam Formu

Fatih Üniversitesi'nde "Normal Bireylerde Türk Müziği Etkisinin Electroencephalogram ile İncelenmesi" isimli tez çalışması kapsamında katılımcılardan bazı elektrofizyolojik kayıtlar alınacaktır.
Çalışma kapsamında EEG (electroencephalography)ölçümünün yapılması planlanmaktadır. İşitsel uyaran olarak Türk müziği makamlarından; zirgüle, rast ve kuçek makamları kullanılacaktır. Hiçbir girişimsel işlemde bulunulmayacak ve herhangi bir ilaç verilmeyecektir. Çalışmaya gönüllü katılımcılar alınacaktır. Ayrıca kişisel bilgi formu doldurulacaktır.

Çalışma kapsamında elde edilen tüm verilerin ve katılımcıların isimlerinin gizli tutulacağı, bilimsel bir amaçla bu verilerin toplandığı ve sadece bilimsel çalışma kapsamında kullanılacağı, bana bildirildi. Bu çalışmaya kendi rızam ile katılmayı kabul ediyorum.

Katılımcı:
Tarih:
İmza:

Figure A.2 Participant Consent Form

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