T.C.
FATIH UNIVERSITY
INSTITUTE OF BIOMEDICAL ENGINEERING

EVALUATION OF MUSCLE FATIGUE USING SURFACE ELECTROMYOGRAM AND MECHANOMYOGRAM SIGNALS

KEZBAN COŞKUN

MSc THESIS
BIOMEDICAL ENGINEERING PROGRAMME

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T.C.
FATİH ÜNİVESİTESİ
BİYOMEDİKAL MÜHENDİSLİK ENSTİTÜSÜ

YÜZEY ELEKTROMİYOGRAM VE MEKANOMİYOGRAM SİNYALERİ KULLANILARAK KAS YORGUNLUĞUNUN DEĞERLENDİRİLMESİ

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İSTANBUL, HAZİRAN / 2014

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FATIH UNIVERSITY

INSTITUTE OF BIOMEDICAL ENGINEERING

Kezban Coşkun, a **MSc** student of Fatih University **Institute of Biomedical Engineering** student ID 520112018, successfully defended the **thesis/dissertation** entitled "**EVALUATION OF MUSCLE FATIGUE USING SURFACE ELECTROMYOGRAM AND MECHANOMYOGRAM SIGNALS**", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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It is approved that this thesis has been written in compliance with the formatting rules laid down by the Institute of Biomedical Engineering.

Prof. Dr. Sadık KARA
Director

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To my dear father,

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June 2014 Kezban COŞKUN

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ABBREVIATIONS

BB : Biceps Brachii
DWT : Discrete Wavelet Transform
EMG : Electromyogram
FFT : Fast Fourier Transform
FRC : Frequency Ratio Change
FT : Fourier Transform
MDF : Median Frequency
MF : Muscle Fatigue
MMG : Mechanomyogram
MNF : Mean Frequency
MPF : Mean Power Frequency
MVC : Maximum Voluntary Contraction
PSD : Power Spectral Density
RMS : Root Mean Square
SNR : Signal to Noise Ratio
STFT : Short Time Fourier Transform
TB : Triceps Brachii
WT : Wavelet Transform

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SUMMARY

EVALUATION OF MUSCLE FATIGUE USING SURFACE ELECTROMYOGRAM AND MECHANOMYOGRAM SIGNALS

Kezban COŞKUN

Biomedical Engineering Programme

MSc Thesis

Advisor: Assist. Prof. Dr. Şükrü OKKESİM

Muscle Fatigue known as the most general definition, reduction of force generating capacity during muscle contraction. To prevent occupational accidents and to increase the work and sport efficiency the scientists try to measure the muscle fatigue. Although a lot of study to this end, a scoring technique has not been developed for muscle fatigue. Because of the huge differences between muscle structure and individual condition, general evaluation of muscle fatigue is unclear.

Due to the muscle fatigue is not a quantitative value; researchers focus on several measurable parameters which can be used to analyze the muscle fatigue. For this aim, the most commonly used signals are electromyogram (EMG) and mechanomyogram (MMG), which are recorded during muscle contraction.

The aim of this study is to analyze to muscle fatigue during isometric and isotonic contractions using surface EMG and MMG signals and evaluation of quantitative data of muscle fatigue's negative effects on performed work.

Keywords: Muscle Fatigue, Electromyogram, Mechanomyogram, Isometric Contraction, Isotonic Contraction.

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ÖZET

YÜZEY ELEKTROMYOGRAM VE MEKANOMYOGRAM SİNYALERİ KULLANILARAK KAS YORGUNLUĞUNUN DEĞERLENDİRİLMESİ

Kezban COŞKUN

Biyomedikal Mühendisliği Programı

Yüksek Lisans Tezi

Danışman: Yrd. Doç. Dr. Şükrü OKKESİM

Kas yorgunluğu, maksimum kuvvet üretme kapasitesinin tekrarlanan kasılmalar sırasında azalmasıdır. İş ve spor verimliliğini artırmak ve kas yorgunluğuna bağlı çeşitli kazaları önlemek için bilim adamları kas yorgunluğunu nicel olarak ölçme gereksinimi duymuştur. Bu amaçla yapılan çok fazla çalışma olmasına rağmen, kas yorgunluğunun farklı parametrelere bağlı karmaşık bir fizyolojik durum olması, nicel ve evreler arasında sınırları ortaya koyan bir skorlama tablosunun geliştirilememesine sebep olmuştur.

Kas yorgunluğunun nicel bir değer olmamasından dolayı, ölçülebilir parametrelerden dolaylı olarak kas yorgunluğu değerlendirilmesi çalışmaları yapılmaktadır. Bu amaçla kullanılan sinyaller, kas kasılması sırasında kaydedilen elektromyogram (EMG) ve mekanomyogram (MMG) sinyalleridir.

Bu çalışmada izometrik ve izotonik kas kasılmaları esnasında kaydedilen EMG ve MMG sinyallerinden elde edilecek özniteliklerle, nicel olarak kas yorgunluğu analizi yapılmıştır. Ayrıca kas yorgunluğunun yapılan iş üzerindeki negatif etkisi kanıtlanmıştır.

Anahtar kelimeler: Kas Yorgunluğu, Elektromiyografi, Mekanomiyografi, İzometrik Kasılma, İzotonik Kasılma.

CHAPTER 1

INTRODUCTION

1.1 Purpose of the Thesis

Muscle Fatigue (MF) known as the most general definition, reduction of force generating capacity during muscle contraction [1-3]. MF is a continuous process; during continued muscle contraction the maximal force regularly reduce owing to muscle fatigue [4]. Based on this hypothesis, degree of MF can be evaluated with loss of the maximal voluntary force during continuously contraction [5].

MF is hazard for musculoskeletal diseases. To prevent occupational accidents and to increase the work and sport efficiency the scientists try to measure the MF. If it can be measured than some warning systems can be designed for accidents. Also can be increased efficiency of sports activities and to avert muscle strain and quantitative data of positive and negative effects of performed exercises can be evaluated [6]. Although a lot of study to this end, a scoring technique has not been developed for MF. Because of the huge differences between muscle structure and individual condition, general evaluation of MF is unclear [7]. Due to the MF is not a quantitative value; researchers focus on several measurable parameters which can be used to analyze the MF. For this aim, the most commonly used signals are electromyogram and mechanomyoram, which are generated during muscle contraction [8, 9].

Electromyography (EMG) is a common experimental technique involved with the development, recording and evaluating of electrical activity produced by skeletal muscles. Myoelectric signals are generated by physiological variations in the condition of muscle fiber membranes [10]. EMG allows to directly looking into the muscle, measurement of muscular performance, analysis to progress sports activities and detects muscle response in ergonomic studies.

Mechanomyography (MMG) is a signal that reflects the mechanical activity of skeletal muscles[11, 12]. MMG represents a dependable technique to evaluate the mechanical

activity of a contracting muscle by using specific vibration transducers, such as accelerometers, piezoelectric sensors and microphones [13-15]. MMG is applied to observe muscle characteristics in medical rehabilitation area and physiological studies [9, 11]

In the literature there are a lot of methods to analysis MF such as, pH of muscle, blood oxygen level, lactate level, EMG and MMG[16, 17]. If we focus at EMG and MMG studies, the features of MF are increase of amplitude in time domain and transition from high frequency to low frequency in frequency domain [18, 19]. MF can be evaluated with these changes from EMG and MMG signals with different parameters such as, Root Mean Square (RMS), Mean Frequency (MNF) and Median Frequency (MDF) [9, 20].

The aim of this thesis is to analyze to muscle fatigue during isometric and isotonic contractions using surface EMG and MMG which recorded 40 (20 Female, 20 Male) healthy voluntary subjects. EMG and MMG signals were recorded from biceps brachii and triceps brachii muscles that are agonist and antagonist muscles. For feature extraction purposes, we computed root mean square (RMS) in the time domain and mean power frequency (MPF), median frequency (MDF), frequency ratio change (FRC) in the frequency domain, using Discrete Wavelet Transform (DWT) in MatLab.

Also, our further aim was the evaluation of quantitative data of muscle fatigue's negative effects on performed work. For this reason, reaction time experiments were made before and after exercises.

At the end of the study, muscle fatigue on isometric and isotonic exercises were compared, agonist and antagonist muscles were analyzed, negative effects of muscle fatigue was evaluated, the correlation between EMG and MMG were evaluated.

1.2 Arrangement of the Thesis

This thesis is set up as follows:

_In the next chapter, information muscular system, definition and generation, recording process of electromyogram and mechanomyogram signals, MF in EMG and MMG signals and EMG-MMG signal processing are presented.

_In the third chapter, materials and methods of this thesis are represented significantly.

_In the fourth chapter, obtained results also, discussion with conclusions are illustrated too.

CHAPTER 2

BACKGROUND INFORMATION

The purpose of this section is to describe of muscular system, EMG and MMG signals, generation and recording process of the EMG and MMG signals, muscle fatigue in point of EMG and MMG, also signal processing will be illustrated.

2.1 Muscular System

Muscle tissue is one of the four tissue types. Muscle organ is constituted of skeletal muscle tissue, connective tissue and nervous tissue. In human body, muscular system is made up more than 600 skeletal muscles; also skeletal muscles consisted of approximately 40% of human body weight. Each one of muscles has a particular function.

All muscle tissues have irritability, contractility, extensibility and elasticity functional characteristics. The following functions are performed through these features in body.

Muscles perform three primary functions:

(1) Production of movement; running, writing, chewing, walking, depends on muscle contractions.

(2) Heat production; body temperature is held constant through physiological processes.

(3) Maintenance of posture and body support; maintain posture, stabilize the flexible joints, and support the viscera depends on muscle contractions [21].

2.1.1 Muscle Tissue Types

There are three types muscle tissue in human body; smooth, cardiac and skeletal muscles. Each muscle type has different structure, contractile properties, and control mechanisms.

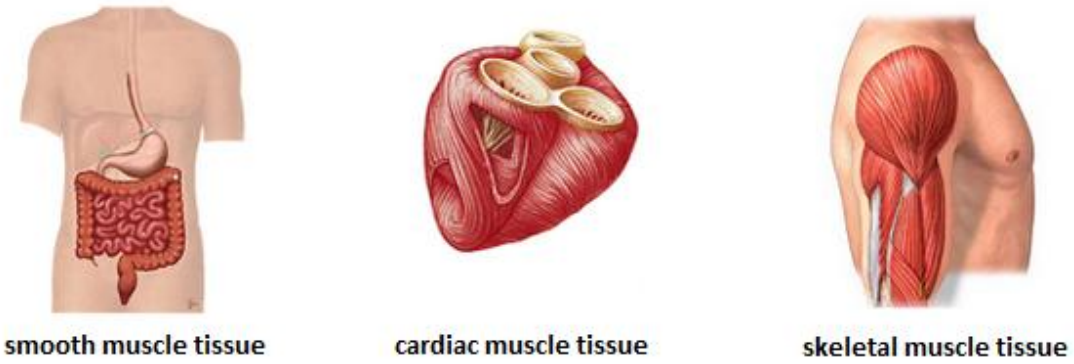


Figure 2.1 Muscle tissue types [22]

Smooth muscle:

Smooth muscle is located in the walls of various hollow organs and tubes, including the stomach, urinary bladder, intestines, uterus, blood vessels, and airways in the lungs. Smooth muscle contraction is an involuntary contraction that regulated by the autonomic nervous system, autocrine-paracrine agents, hormones and local chemical signals.

Cardiac muscle:

Cardiac muscle is the muscle of the heart that is responsible for the rhythmic contractions. Contraction of cardiac muscle fibers is rhythmical; it generates its own stimuli to start a muscle contraction, for this reason cardiac muscle contraction is involuntary. Like smooth muscle, autonomic nervous system, hormones, autocrine-paracrine agents control cardiac muscle contraction.

Skeletal muscle:

A skeletal muscle composed of countless muscle cells called muscle fibers that are tubular, multinucleated, and striated. Each skeletal muscle is typically supplied by one nerve, an artery and one or more veins. Skeletal muscle, as the name implies, is attached mainly to the skeletal bones, and its contraction is dependable for moving and supporting the skeleton. Unlike smooth and cardiac muscles, the contraction of skeletal muscle is always stimulated and initiated by nervous system, thus all voluntary movements are controlled through skeletal muscles[21, 23, 24].

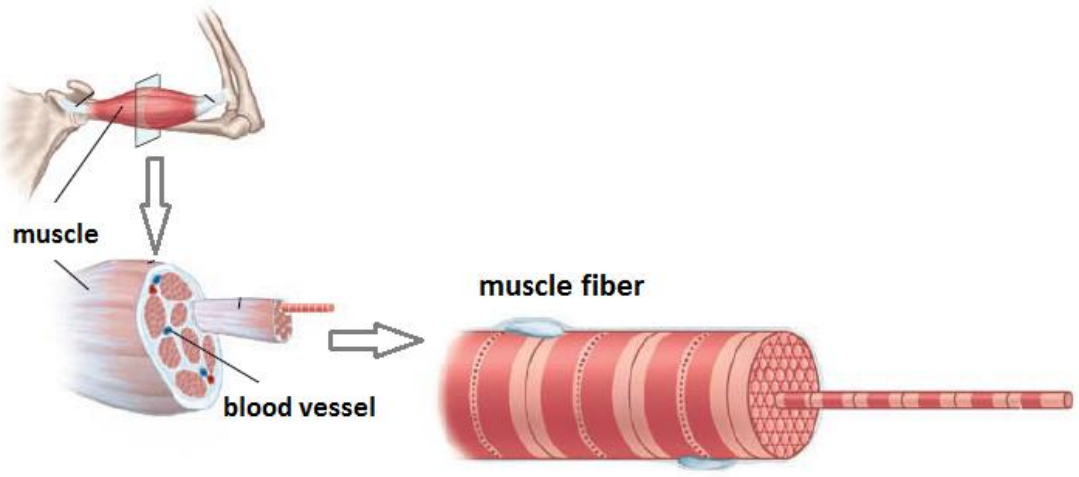


Figure 2.2 Skeletal muscle fiber [24]

2.2 Electromyogram and Theoretical Background

This section contains description of the physiologic information primary to understanding the recording and following study of the electrical activity of muscle using EMG techniques.

Electromyography (EMG) is an experimental procedure involved with the development, recording and evaluating of electrical activity produced through muscular contractions. EMG signals are complex, non-stationary and noisy signals. A raw EMG signal taken during our experiments is shown in figure 2.3.

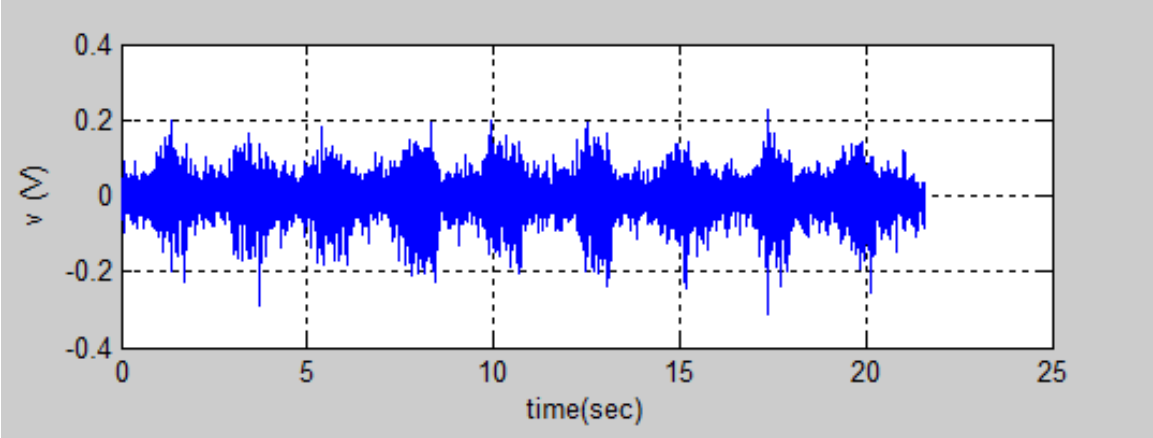


Figure 2.3 A typical EMG Signal

Myoelectric signals are produced by physiological variations in the condition of muscle fiber membranes [8]. If it is used correctly, EMG allows to directly looking into the muscle, measurement of muscular performance, analysis to progress sports activities and detects muscle response in ergonomic studies such as; motor control, neuromuscular physiology, postural control and movement disorders.

2.2.1 Generation of EMG Signal

In the human body there are two type movements; voluntary movement and involuntary movement. Involuntary movements are generated by smooth and cardiac muscles which are under the control of the autonomic nervous system. This muscles works without nervous input. In contrast to voluntary movements are begun by action potentials from motor neurons. Each motor neuron branches and synapses with up to a hundred muscle fibers. These fibers form a motor unit[23].

Process of muscle contraction occurs 3 steps; excitation (stimulation), contraction and relaxation. The number of fibers contracting will determine the force of the contraction of the whole muscle.

Muscle fibers are excited by the central neurosystem by motoneurons which help to transmit the electrical signals. One motoneuron has neural connections to several muscle fibers [21]. The smallest functional unit of this muscle which contains motoneurons and muscle fibers is called motor unit [25]. Motor unit is shown in figure 2.4.

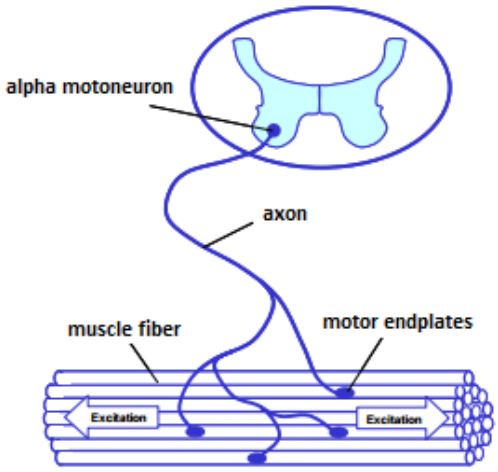


Figure 2.4 Motor unit [14]

The central nervous system controls the motor units in order to optimize the interaction between the environmental factors and our bodies [26]. When an action potential is activated as a result of the impulse coming from the central nervous system by means of motoneuron, potential acetylcoline is created at the end of the neuromuscular connection. This action potential goes further throughout sarcolemma by passing the muscle fibers [23]. The action potential happens in all of the muscle fibers which locate at the motor unit, and immediately after, all muscle cells are excited at the same time in this motor unit [27]. Depolarization which occurs in all of the muscle fibers creates and electrical field around the muscle fibers. This field can be detected by electrodes which are put on the muscle bundles on which this field is created. The result is called the muscle fibers potential. All the muscle fibers potentials combine the Motor Unit Action Potential (figure 2. 5) .

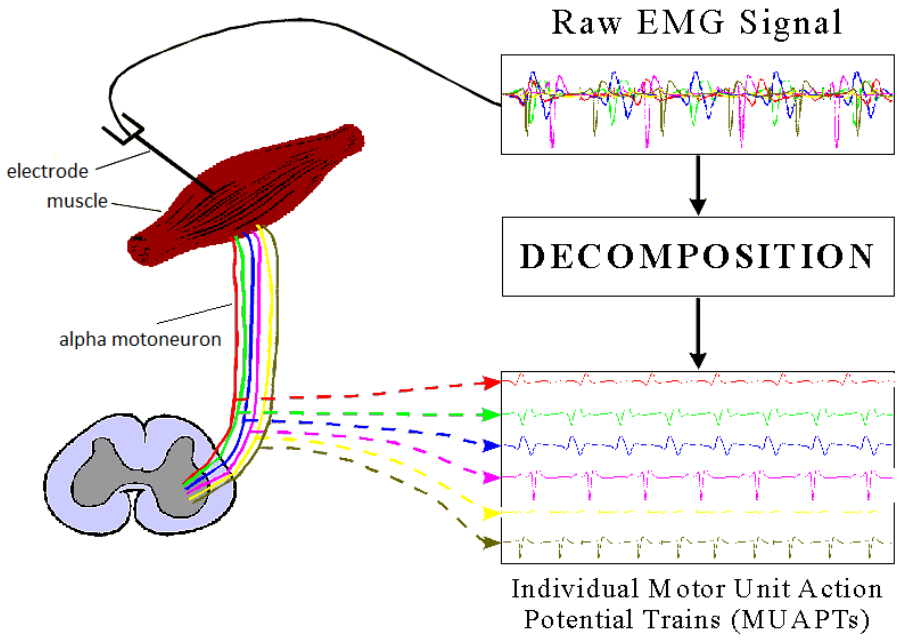


Figure 2.5 Motor unit action potential and EMG signal [28]

2.3 Mechanomyogram and Theoretical Background

MMG is an useful and noninvasive method by which the mechanical activity of muscle is estimated using specific transducers (such as acceloremeter, microphone) to record muscle surface oscillations due to mechanical activity of the motor units [29-32]. MMG signals are complex, non-stationary and noisy signals. A raw MMG signal taken during our experiments is shown in figure 2.6.

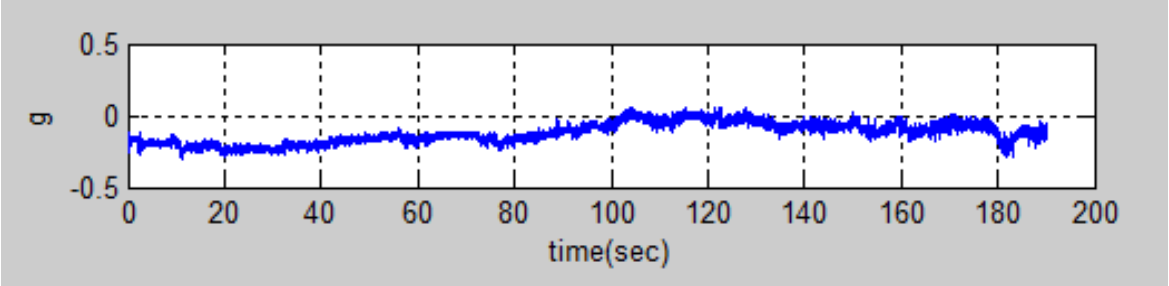


Figure 2.6 A typical MMG signal

MMG recording can provide some advantages over EMG recording. First, MMG is a mechanical signal; therefore, MMG signal is not affected by the change in the skin impedance due to sweating [33, 34]. Second, MMG sensor's placement is not required

spesific region, because of the MMG signal is not influenced by the due to its propagating characteristic through the muscle tissue [35]. In additional, when EMG application is not practicable, such as in fields with high electromagnetic polition, MMG is an available method [9, 13, 14].

2.3.1 Generation of MMG Signal

In human body, owing to the internal muscular vibrations, that are the fundamental components of the muscle contraction, oscillations of the human motor system (such as tremor and clonus), vibration is formed [13, 36]. Under muscular contraction, mechanical vibration occurs due to lateral dimensional changes in active muscle fibers, which generate pressure waves. MMG signals are result of the pressure waves produced by a number of active muscle fibers and represents the mechanical activity of muscle [31, 32]. The amplitude of the MMG signal, depend on the number of recruited motor units. When the firing rate of the motor units increases, the amplitude of the MMG increases.

Because of the mass, viscosity and pressure will differ from person to person, the muscle vibration frequencies will be different for each person. The generally frequency range of muscle vibration lay between 5- 100 Hz [37].

2.4 Muscle Fatigue in Electromyography and Mechanomyography

In spite of the fact that EMG and MMG signals have different natures, each of them gives information about the motor unit recruitment, firing frequency and synchronization that are showed in the amplitude and frequency of the EMG and MMG signals[11, 18, 38].

The features of muscle fatigue are increase of amplitude in time domain and transition from high frequency to low frequency in frequency domain. This changes are occurs on EMG and MMG signals.

When muscle fatigue occurs,

- Firing frequency of the motor unit increase, result of this increasing are observed in amplitude of EMG and MMG signals.
- Low frequency components of the signal increase, due to the reduction in conduction velocity of motor units[9, 39-41].

Soo *et al.*, aimed to estimate the degree of MF quantitatively. MF is a continuous process; during continued muscle contraction the maximal force regularly decrease due to MF. Based on this hypothesis they assumed the degree of MF can be estimated, as equivalent to maximal voluntary force lost during handgrip tasks. Isometric handgrip tasks were given to subjects and surface EMG data's were taken from flexor digitorum superficialis and extensor carpi radialis. Then, a fatigue model was constructed with surface EMG signals. At the end of the study, promising results were obtained, where of the estimated muscle fatigue was less than %10 MVC [20].

Detection of MF by the surface EMG and its application was published by Sakurai *et al*. The features of MF are increase of amplitude in time domain and transition from high frequency to low frequency in frequency domain. Based on this hypothesis, they assumed that muscle recovery process is converse phenomenon from MF. Therefore, the features of recovery processes are decrease amplitude and transition from low frequency to high frequency. For this purpose frequency characteristics were used to evaluate for MF and recovery process and mean power frequency was evaluated [40].Similar study was confirmed to this hypothesis by Soo *et al*. [41].

When MF occurs, some parameters change since increasing of amplitude and the decreasing of frequency, such as Root Mean Square (RMS), Mean Frequency (MNF) and Median Frequency (MDF). Based on this hypothesis, Zaman *et al.* analyzed MF at different Maximum Voluntary Contraction (MVC). For feature extraction purposes, they computed RMS value in time domain and MNF, MDF values in frequency domain. At the end of the study, RMS value increased, MNF and MDF values decreased at different MVC levels. Quantitative results were presented for MF with this study [42].

Portable system was developed and used to analysis of MF. Estimation of MF by using EMG and muscle stiffness was published by Oka. When MF is created, stiffness occurs,

therefore elasticity and viscosity increase, and MNF decreases. For this aim, viscoelasticity and EMG were used in this study. Viscoelasticity was calculated from the biomechanical impedance. Viscoelasticity and EMG measured simultaneously and changes in these variables were examined for isometric and isotonic exercises. With this study results, he showed that these variables would be prudent to estimate MF[43] .

Neuromuscular and metabolic changes cause MF. Influence of muscle blood flow on fatigue during intermittent human handgrip exercise and recovery was published by Pitcher and Miles. The purpose of the present study was to compare the MF and recovery duration under normal condition and when the blood flow to the muscle was mechanically occluded. At the end of the study, when the blood flow to the muscle was mechanically occluded, muscle MF occurs rapidly, endurance time is less than normal condition [44]. In similar study, Jane A. Kent-Braun estimated the relative contributions of central and peripheral factors to development of MF. MF was estimated to decrease of MVC and intramuscular metabolism was measured using magnetic resonance spectroscopy. The results showed that central fatigue contributed approximately 20% to the decrease in MVC, while the intramuscular metabolic milieu was accountable for the rest of the MF [45]. Simultaneously EMG and Near Infrared Spectroscopy (NIRS) measurements were recorded during handgrip exercise by Şayli *et al.* At the end of the study, during MF, MNF, MDF increased, concentration of *deoxyhemoglabin* (Hb) was increased and concentration of *oxyhemoglabin* (HbO_2) was decreased [46].

Mihai T. Tarata recorded simultaneously EMG and MMG signals in 2002. RMS of the EMG and MMG signals increased with muscle fatigue in spite of that, MDF decreased [9].

2.5 EMG and MMG Signal Processing

EMG and MMG signals aren't periodical and deterministic signals. In other words EMG and MMG signals' selected in any time period statistical behaviours are not same exactly. Because these signals don't repeat themselves and they cannot represent EMG and MMG signals obtained from all of a single mathematical expression recording time [47].

Some information can be gained from time domain in signal processing but it will be need frequency analysis for more information. For that reason the Fourier analysis can be exemplified to the used method. Fast Fourier Transform (FFT) is a frequently used method to indentify saved signals' frequency spectrum during the contraction performed at certain times [48]. But EMG and MMG signals are non-stationary signals in terms of frequency, amplitude and wave form [47]. So its certain that using classic methods as the Fourier Transformation (FT) isn't appropriate to process these signals. Short Time Fourier Transform (STFT) was developed in order to be applicable FT to the non-stationary signals. In STFT the signal is divided into small windows and each of the dived windows are accepted as stationary. The only problem in STFT is to perform a good dissolvability in time-scale, in frequency scales the dissolvability is at poor levels at the end of the STFT realized with time-scale and narrow windows. On the other hand when the window is expanded it is observed improvement in frequency dissolvability, in time-scale the dissolvability decreases. For that reasons the Wavelet Transform (WT) was implemented to obtain feature from the EMG and MMG signals in order to make real the most efficient analysis. WT, which includes scale concept providing the time-frequency determination, is quite appropriate for non-stationary signals [49].

CHAPTER 3

MATERIAL AND METHOD

The aim of this thesis is to analyze the muscle fatigue during isometric and isotonic contractions using surface EMG and MMG which recorded from 40 (20 Female, 20 Male) healthy voluntary subjects. EMG and MMG signals were recorded from biceps brachii(BB) and triceps brachii (TB) muscles that are agonist and antagonist muscles. The most common features to evaluate the muscle fatigue in literature are increasing of amplitude in time domain and transition from high frequency to low frequency in frequency domain. MF was evaluated with these features which can compute from EMG and MMG signals.

In addition, our further aim is the evaluation of muscle fatigue's negative effects on performed work, quantitatively. For this reason, reaction time experiments were made before and after exercises.

In order to obtain features, we computed Root Mean Square (RMS) in the time domain and Mean Power Frequency (MPF), Median Frequency (MDF) and Frequency Ratio Change (FRC) in the frequency domain. Discrete Wavelet Transform (DWT), which provides detailed time-frequency resolution in analyzing of non-stationary signals like EMG and MMG was used to compute the frequency domain features. Finally to evaluate the features scientifically statistical analysis was done.

3.1 Recording Procedure for Electromyogram and Mechanomyogram Signals

After ethical approval was received from Fatih University, 40 subjects that 20 of the them to be female are recruited. These volunteers have no complaint about skeleton – muscle, don't interested in any sport as professional and the age range is between the 18 – 30. During the isometric and isotonic contractions, EMG and MMG signals were recorded simultaneously from the biceps brachii (BB) and triceps brachii (TB) muscles. The demographic information about the volunteers and experimental details are given in Table 3.1.

Table 3.1 Demographic information and experimental details

muscles	biceps brachii and triceps brachii
sampling frequency	1000 Hz
contraction types	isometric and isotonic
load	female (2,5 kg) - male (5kg)
the number of volunteers	40 (20 females- 20 males)
age	female (25,5± 1,96)-male (23,86 ± 3,5)
weight	female(62,8± 9,94)kg-male(75,9± 11,26)kg
height	female(1,66±0,06)m-male(1,76±0,06)m

The BB and the TB muscles are the muscles that work antagonist to each other which mean that move opposite to each other. For example; in the flexion movement done by arm while the BB muscle contracts the antagonist of this muscle that is TB extends. In contrast, when BB extends, TB contracts. The BB and the TB muscles places in a body were shown in figure 3.1.

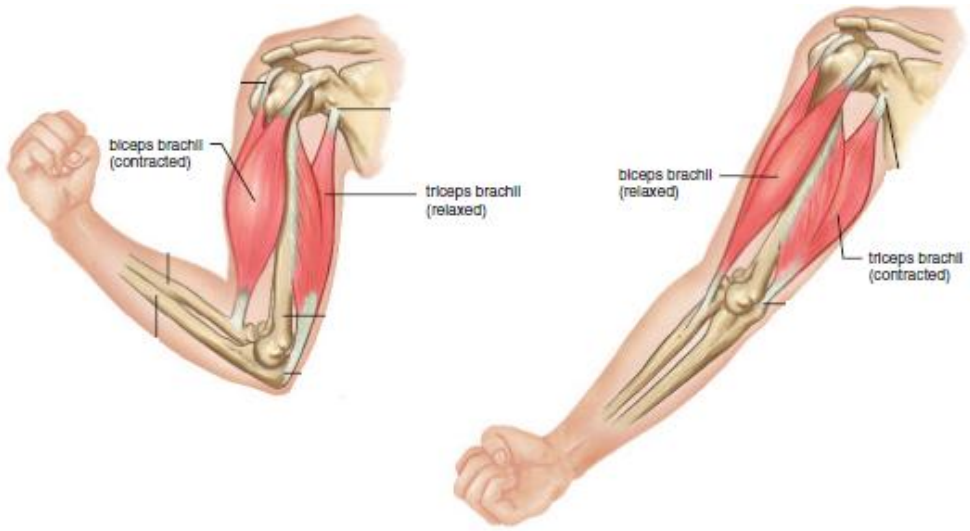


Figure 3.1 Biceps Brachii and Triceps Brachii muscles [50]

In our experiments two type contractions were analyzed that they are isometric and isotonic. During the isometric muscle contraction the length of contraction/muscle remains stable but the muscle tone has changed. On the other hand during the isotonic contraction the length of contraction has changed but the muscle tone remains stable.

Before the exercise the experiment and its reasons were told clearly to the volunteers. Except the exercise arm, keeping body stable as possible as was asked. First of all the relevant regions were cleaned off with biomedical materials in order to remove sediment and the dead layer of skin. Then EMG electrodes and MMG sensors were placed on the muscle bundles. Silver-surface, bipolar, 4 milimeter-radius surface electrodes have been placed on the bundles of muscles which were located by examining manually. And amidst them, MMG sensors have been positioned, and attached on the related muscle region with plasters. The reference electrode has been positioned on the wrist bone of the dominant arm.

In order to record EMG and MMG signals the xyzPlux device (figure 3.2), which can record both of two signal simultaneously was used.

Figure 3.2 xyzPlux device

Table 3.2 Data channels

Channel	Data
1	Biceps Brachii x axis
2	Biceps Brachii y axis
3	Biceps Brachii z axis
4	Biceps Brachii EMG
5	Triceps Brachii x axis
6	Triceps Brachii y axis
7	Triceps Brachii z axis
8	Triceps Brachii EMG

For the isometric contraction experiment it was asked from female holding a 2.5kg dumbbell with their arms in 90° angle for 3 minutes and from male holding a 5kg dumbbell with their non-dominant arms. Sample photos from isometric contraction experiments are shown in figure (3.3).

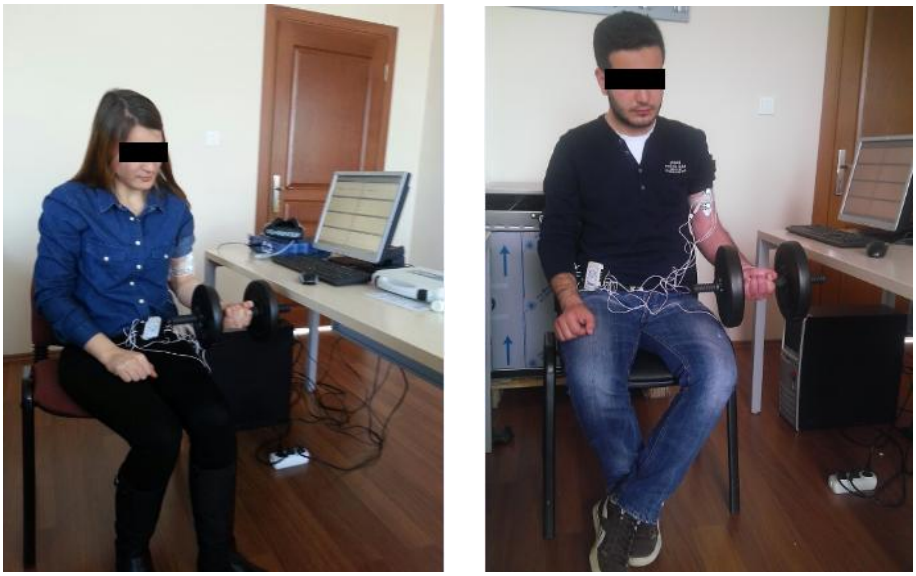


Figure 3.3 Isometric contraction experiment

For the isotonic contraction experiment it was asked from female raising and lowering a 2.5 kg dumbbell and from male a 5kg dumbbells fifteen times with their non-dominant arms. During the exercises EMG and MMG signals were recorded simultaneously. Sample photos from isotonic contraction experiments are shown in figure (3.4).

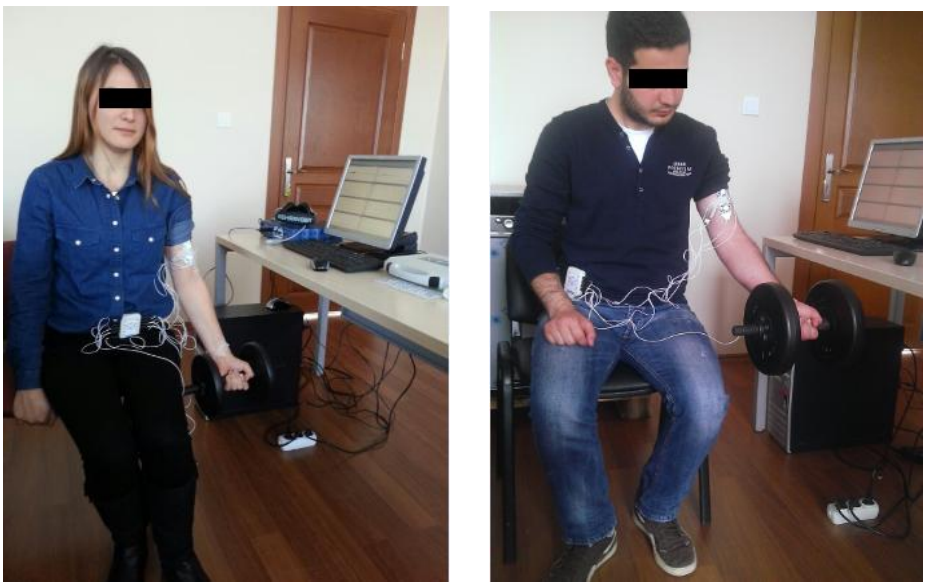


Figure 3.4 Isotonic contraction experiment

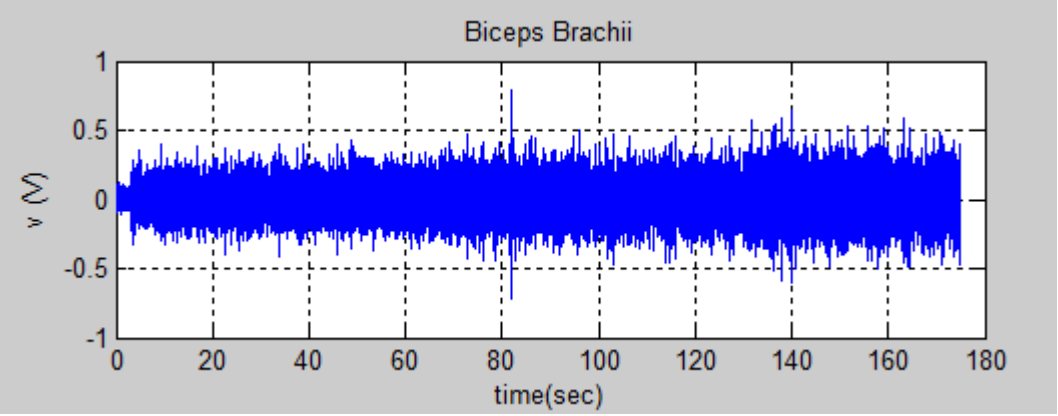


Figure 3.5 A raw EMG data taken during isometric contraction experiment

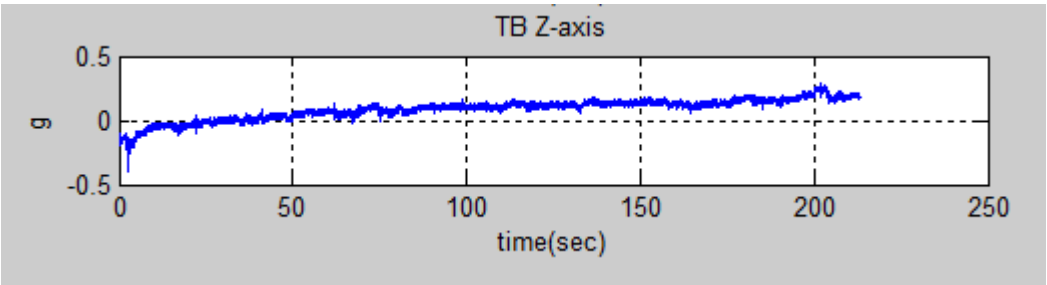


Figure 3.6 A raw MMG data taken during isometric contraction experiment

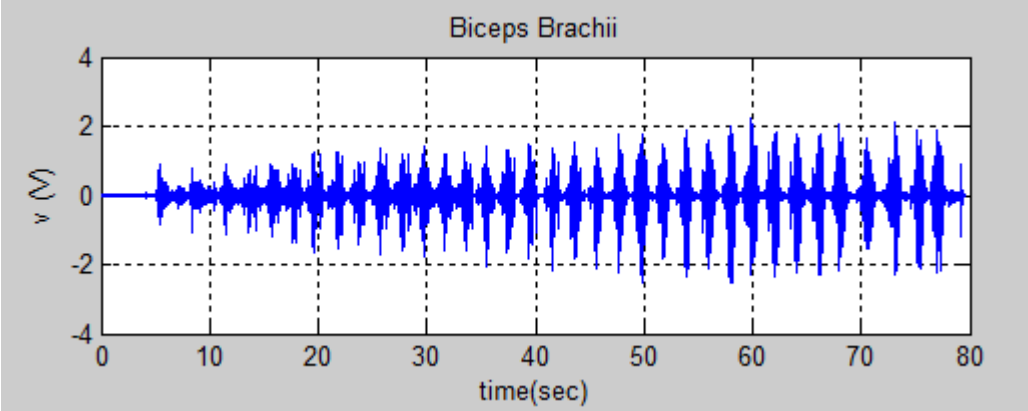


Figure 3.7 A raw EMG data taken during isotonic contraction experiment

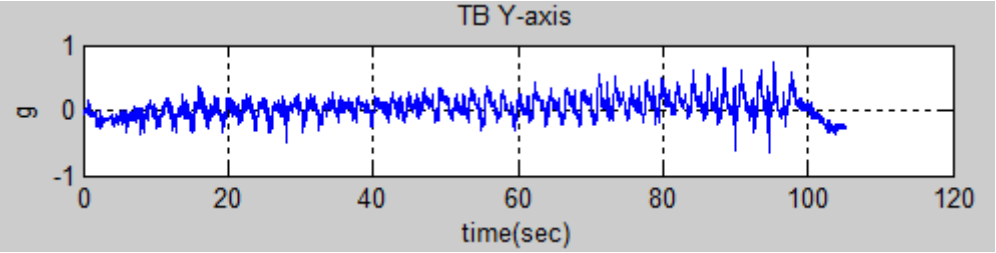


Figure 3.8 A raw MMG data taken during isotonic contraction experiment

3.2 Reaction Time Experiment

In our study the reaction time experiment was done in order to prove the negative effect of MF on the work.

In reaction time experiment, before and after the exercises a signal for 1 min. was given as a stimulator to the subject with closed eyes in a sitting position and asked them to press button which holding-with non-dominant hand when the signals was sensed. Image from the reaction time experiment (figure 3.9). For the reaction time experiment, a computer and MP 36 Data Acquisition unit belongs to BIOPAC Syst. was used.

At the end of the experiment the reaction times in point of muscle fatigue was compared.

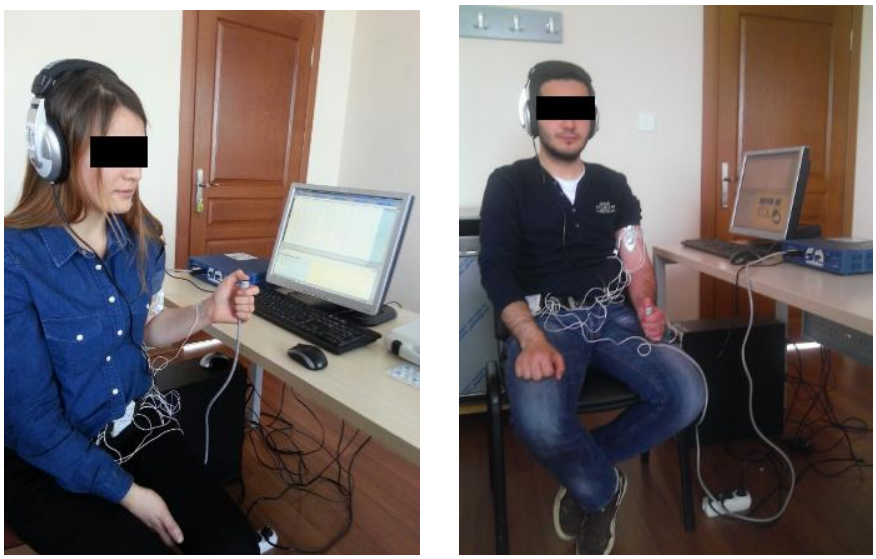


Figure 3.9 Reaction time experiment

3.3 DWT and PSD for Spectral Analysis

DWT analysis simultaneously shows information in defined time and frequency areas belong a signal so it is more advantageous than other transformation methods to identify trends, breakdown points and impermanent in signals. The most important feature of this analysis method, which is used frequently in analyzing of biological signals, is to provide high frequency and low time resolution in low frequencies while it provides high time and low frequency resolution in high frequencies.

The Power Spectral Density (PSD) is the most general function used in frequency domain analysis of the EMG and described as the Fourier transformation of autocorrelation function [48, 51]. The Fourier transformation of a signal can given with (3.1) equation below.

$$x(w) = \int_{-\infty}^{\infty} x(t) e^{-jwt}\, dt \tag{3.1}$$

Autocorrelation function $R_x(t)$ was given in equation(3.2).

$$R_x(\tau) = \frac{1}{T} \int_{0}^{T} x(t).x(t+\tau) dt \tag{3.2}$$

The PSD of a signal is obtained to be get the Fourier transformation of the signal's autocorrelation function (Equation 3.3).

$$\Phi_x(w) = \int_{-\infty}^{\infty} R_x(\tau).e^{-jwt}\, d\tau \tag{3.3}$$

The Power spectrum shows power density in the "w" frequency and measures the signal's power component in each frequency. All of the frequency components' PSD integral which are create the signal, provide to be calculated the total power (Equation 3.4).

$$P = R_x(0) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \Phi_x(w) dw \tag{3.4}$$

The most efficient way to calculate a segment's PSD would be obtained from a long-term data recording is increase the segments which decrease the data loss at least with

the window functions [52]. For that reason in the study (by) 256- Hanning window and for each calculation 128 sample are made by shifting.

3.4 Features Computed From EMG an MMG

3.4.1 Amplitude Analysis

The feature used in amplitude analysis of EMG and MMG signals is the RMS parameter. The mathematical expression for the RMS can given with the (equation 3.5).

$$RMS = \sqrt{\frac{1}{K}\sum_{n=1}^{K} s_n^2} \tag{3.5}$$

K : the number of samples

S_n: the value of the n-th

In order to calculate the RMS parameter in our study each signal was divided in to 5 second windows and these windows' RMS values were drawn in to a graphic. Then the best straight line was drawn and this straight line's slope is founded.

3.4.2 Frequency Analysis

For the frequency analysis of EMG and MMG signals more than one technique can be used. The features frequently used in literatüre for measurement of MF are the MPF (Eq. 3.6) and MDF (Eq. 3.7) features calculated for each window. We also computed a different feature called as Frequency Ratio Change (FRC). For the FRC the frequency axis of PSD graphic was divided into two equal parts and the proportion of the left area of the axis to the right area has been computed.

The MPF is defined as the frequency that divides the power spectrum in two regions having the same amount of power. The mathematical expression for the median frequency MPF is:

$$MPF(t) = \frac{\int_0^{f_s/2} f.S_{E_{t\to t+n}}(f)}{\int_0^{f_s/2} S_{E_{t\to t+n}}(f)} \tag{3.6}$$

Where n lenght of window; S(f) the Power Spectral Density of EMG fragment E(t→t+n); f_s sampling frequency[16].

MDF is the average frequency value of the power frequency region[1]. The mathematical expression for the MNF is:

$$\int_0^{MDF} P(f)df = \int_{MDF}^{\infty} P(f)df$$

$$= \frac{1}{2}\int_0^{\infty} P(f)df \tag{3.7}$$

3.5 Statistical Analysis

To figure out the variation in a quantitative data set statistically Measures of Variability have to compute. The frequently used measures of variability is standard deviation (SD). It is simply a measurement of a sample's deviation from the mean of the distribution and its symbol is σ. SD can compute using Eq 3.8.

$$SD = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{n-1}} \tag{3.8}$$

Each magnitude of the deviation in Eq 3.8 is considered as sample's distance from the mean of the distribution. Using the SD value of two data set which have equal number of sample, less deviated dataset can find. Another measures of variability is Variance and it can compute as the square root of the SD.

Another gradient is variance that inferred average of leaving average of data in dispersion. This state is defined that standard fault of averages is possible fault rate among all samples' averages taken from the bulk and it's shown as SEM in short. SEM will be used as the estimated value of the population mean of the sample mean is a

measure of the reliability and value decreases, so the estimate is finalized. SEM values for a sample standard deviation of the sample about it because it gives the idea of equality as provided in (3.9) of the sample standard deviation to the square root of the sample is calculated by dividing the number of element.

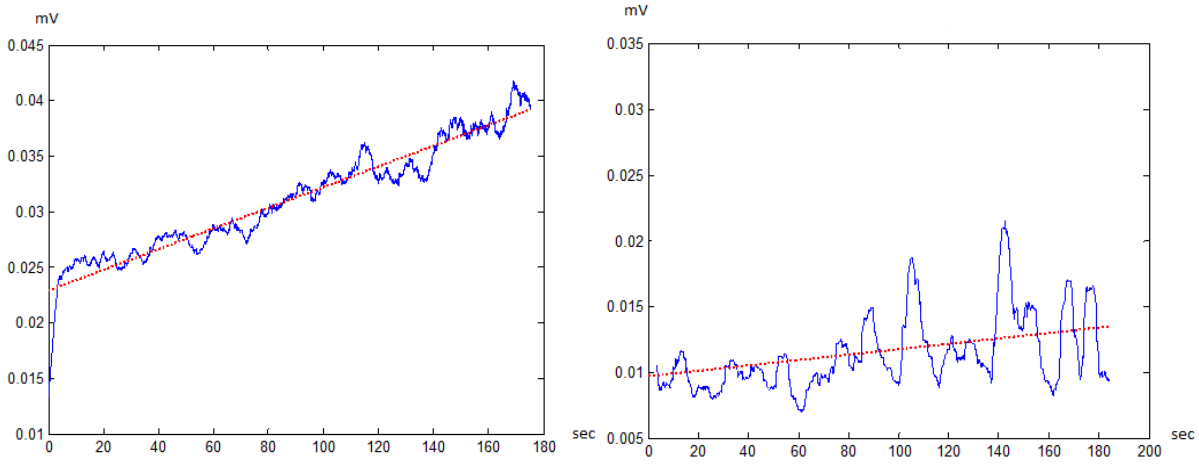
$$SEM = \frac{SD}{\sqrt{n}} \tag{3.9}$$

CHAPTER 4

RESULTS

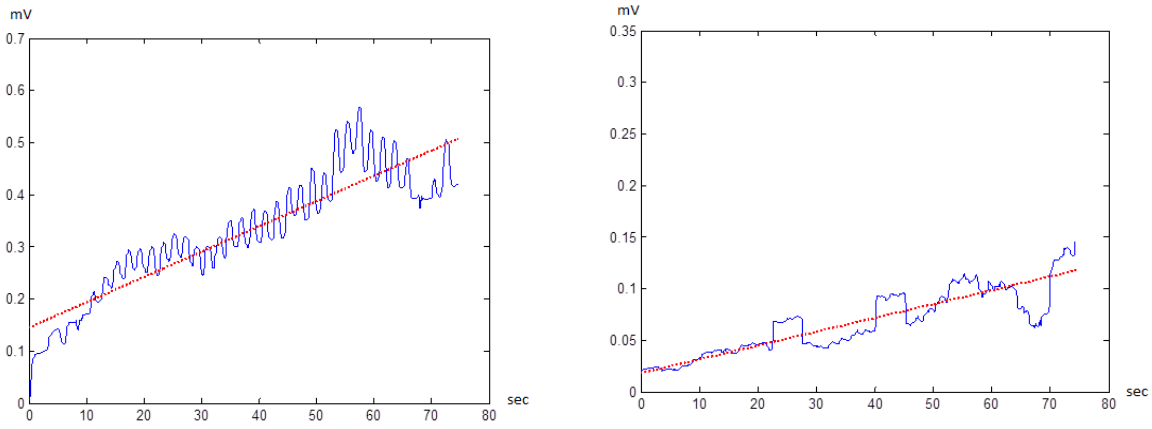
In order to calculate the RMS parameter each signal was divided in to sections. Duration of each section is 5 second. These sections' RMS values were drawn in to a graphic and the best straight line was got then the slope is computed. RMS graphics of one patient and line's slopes are shown in figure 4.1 - 4.2.

In order to calculate the MPF, MDF and FRC features in our study each signal was divided in to 5 second section and these section's PSD values were calculated. Then MPF, MDF and FRC values were drawn in to a graphic and the best straight line was drawn and this straight line's slope is founded. Sample MPF, MDF and FRC graphics and line's slopes are shown in figure 4.3 - 4.8.



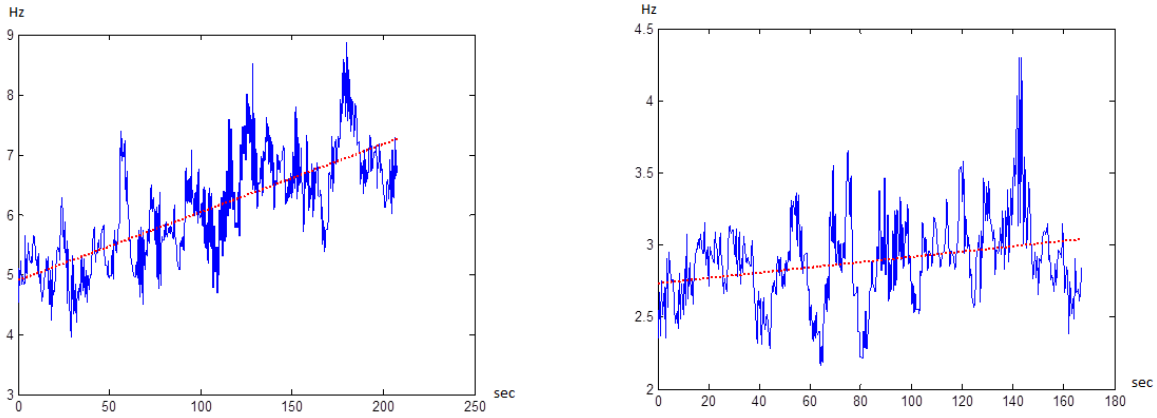
a **b**

Figure 4.1 A sample RMS graph and its slope for EMG (a) and MMG (b) signal's during isometric contraction



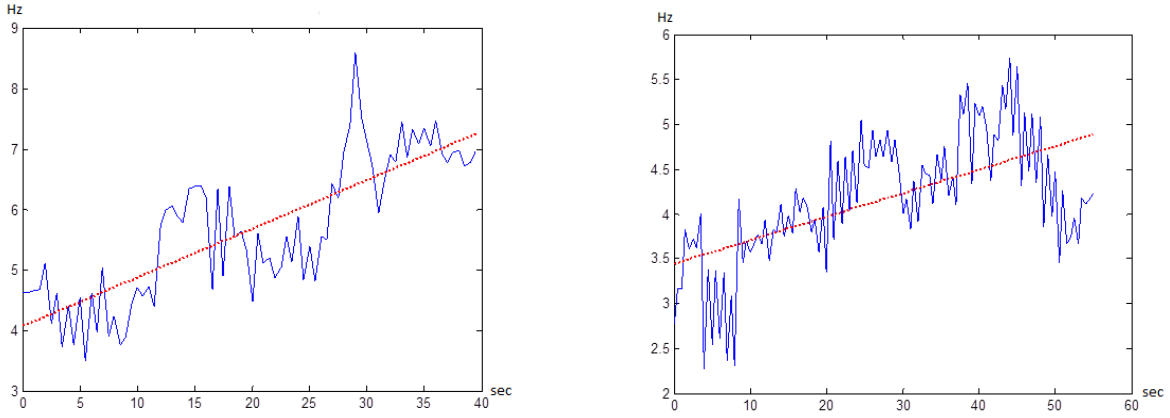
a **b**

Figure 4.2 A sample RMS graph and its slope for EMG (a) and MMG (b) signal's during isotonic contraction



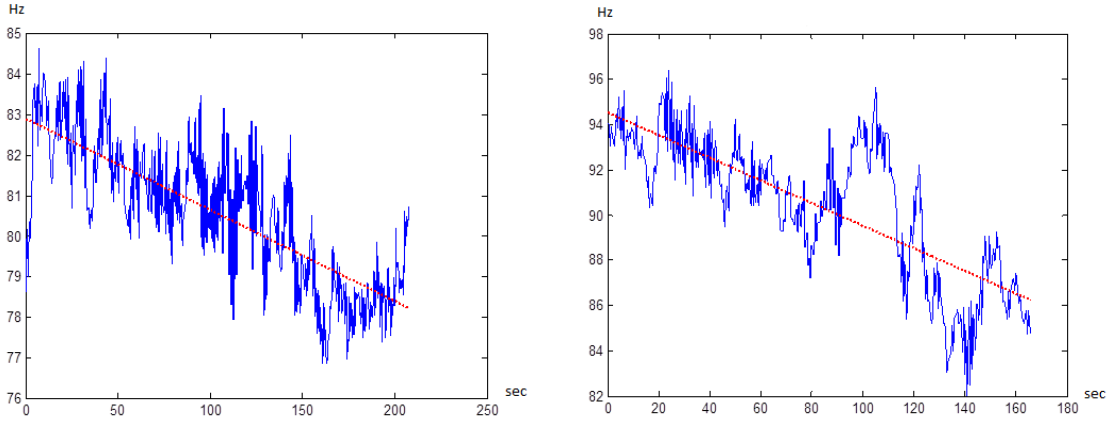
a **b**

Figure 4.3 A sample FRC graph and its slope for EMG (a) and MMG (b) signal's during isometric contraction



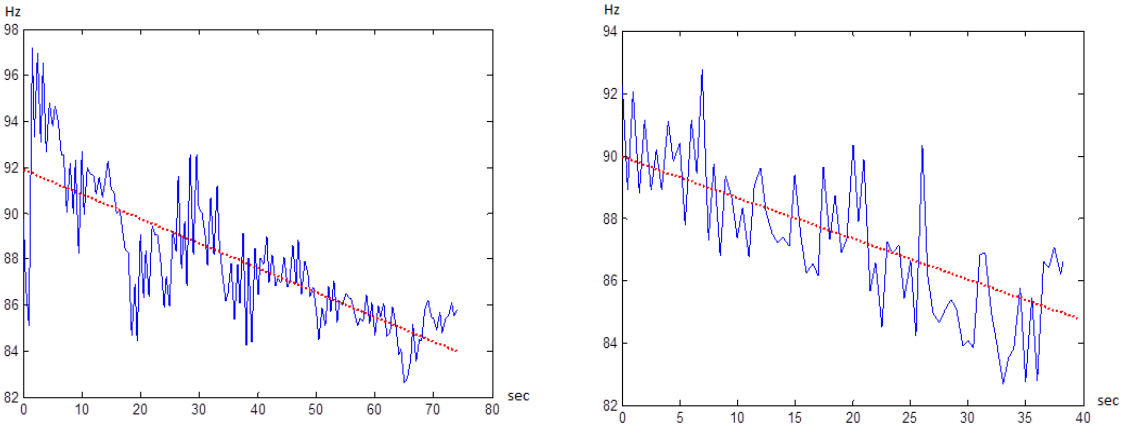
a **b**

Figure 4.4 A sample FRC graph and its slope for EMG (a) and MMG (b) signal's during isotonic contraction



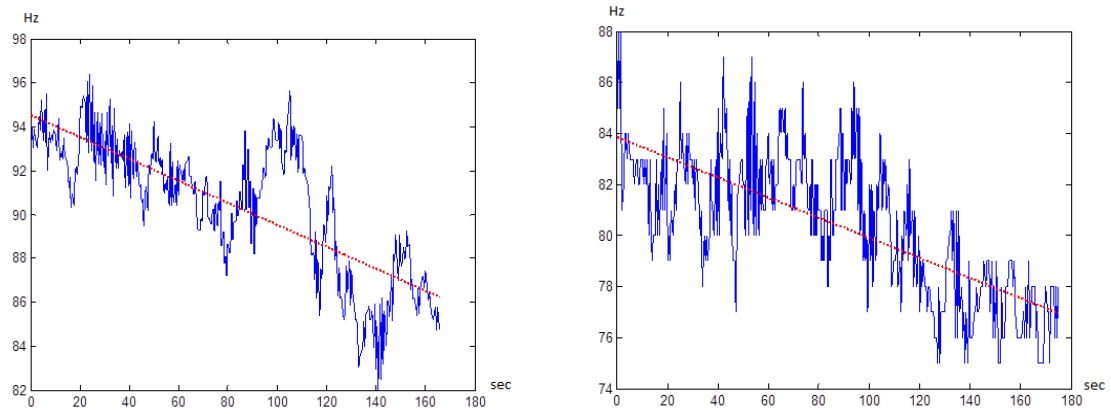
a **b**

Figure 4.5 A sample MPF graph and its slope for EMG (a) and MMG (b) signal's during isometric contraction



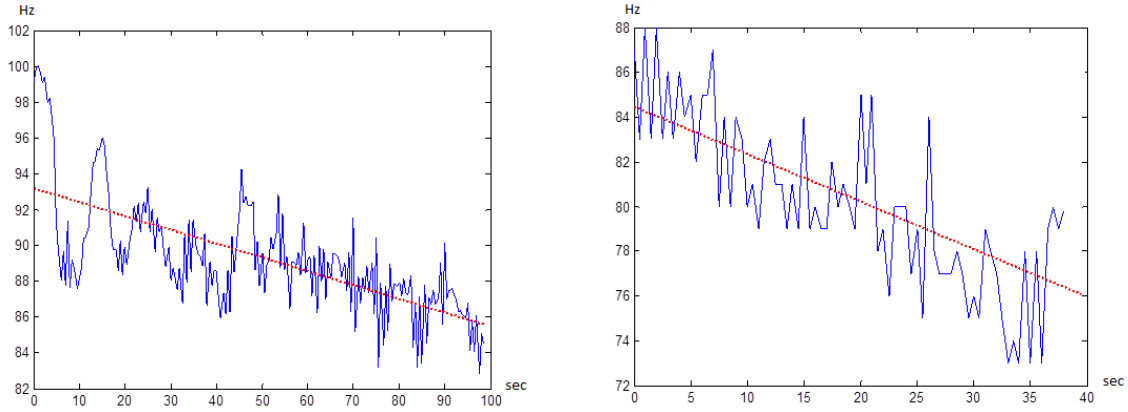
a **b**

Figure 4.6 A sample MPF graph and its slope for EMG (a) and MMG (b) signal's during isotonic contraction



a **b**

Figure 4.7 A sample MNF graph and its slope for EMG (a) and MMG (b) signal's during isometrik contraction



a **b**

Figure 4.8 A sample MNF graph and its slope for EMG (a) and MMG (b) signal's during isotonic contraction

Table 4.1 Female subjects' slopes of RMS lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isometric contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	0,00039	0,00009	0,00002	0,00001
2	0,00008	0,00045	0,00001	0,00000
3	0,00000	-0,00003	-0,00001	0,00002
4	0,00017	0,00004	0,00002	0,00001
5	-0,00028	-0,00002	0,00000	0,00001
6	0,00007	0,00000	0,00001	0,00000
7	-0,00032	-0,00003	-0,00002	-0,00005
8	0,00067	-0,00002	0,00002	0,00000
9	-0,00001	-0,00002	-0,00003	-0,00004
10	-0,00029	0,00009	0,00007	0,00006
Mean ±SEM	0,00004±0,00009	0,00005±0,00004	0,00001±0,00001	0,000002±0,00001

Table 4.2 Male subjects' slopes of RMS lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isometric contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	0,00011	0,00005	0,00001	0,00001
2	0,00071	0,00006	0,00010	0,00012
3	-0,00007	-0,00005	-0,00002	0,00001
4	0,00273	0,00017	0,00020	0,00011
5	0,00141	0,00025	0,00034	0,00013
6	0,00157	0,00006	-0,00019	-0,00017
7	0,00283	0,00010	0,00004	0,00001
8	0,00061	0,00007	0,00009	0,00002
9	0,00049	0,00004	-0,00005	-0,00004
10	0,00109	0,00009	0,00002	0,00000
Mean ±SEM	0.001±0,0003	0,00008±0,00002	0,00005±0,00003	0,00002±0,00002

Table 4.3 Female subjects' slopes of RMS lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isotonic contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	0,00485	0,00032	0,00134	0,00151
2	-0,00023	0,00012	-0,00007	-0,00051
3	0,00080	0,00015	0,00035	0,00067
4	0,00116	0,00020	0,00039	0,00033
5	0,00534	0,00070	0,00004	-0,00007
6	0,00414	0,00022	0,00065	0,00049
7	0,00066	-0,00022	0,00000	-0,00057
8	0,00188	-0,00008	-0,00017	-0,00014
9	0,00135	0,00030	-0,00030	-0,00083
10	0,00393	0,00007	0,00003	0,00008
Mean ±SEM	0,002±0,0003	0,0002±0,00006	0.0002±0,0001	-0,00010±0,002

Table 4.4 Male subjects' slopes of RMS lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isotonic contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	0,00426	0,00036	0,00017	-0,00060
2	0,00463	0,00037	0,00047	0,00031
3	0,00277	0,00026	-0,00068	-0,00017
4	-0,00034	-0,00006	0,00066	0,00023
5	-0,00095	-0,00014	0,00048	0,00036
6	0,00178	0,00009	0,00061	0,00035
7	0,00273	0,00030	-0,00009	-0,00045
8	0,00783	0,00038	0,00051	0,00020
9	-0,00062	-0,00012	-0,00004	0,00020
10	0,00596	0,00045	0,00004	-0,00030
Mean ±SEM	0,03±0,0006	0,002±0,00006	0,0002±0,0001	0,00001±0,00009

Table 4.5 Female subjects' slopes of FRC lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isometric contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	0,00434	0,00660	0,00148	0,00147
2	0,00449	0,00098	0,00054	0,00166
3	0,01594	0,01135	-0,00025	0,00084
4	0,00729	0,00308	-0,00003	0,00037
5	-0,00348	-0,00517	-0,00095	0,00113
6	0,00233	0,01249	-0,00010	0,00259
7	0,01160	0,01503	-0,00276	-0,00023
8	-0,01706	0,00759	0,00012	0,00057
9	-0,00040	0,00616	0,00121	-0,00185
10	-0,01031	0,01208	0,00268	-0,00003
Mean ±SEM	0,001±0,003	0,007±0,001	0,0001±0,0003	0,0006±0,0003

Table 4.6 Male subjects' slopes of FRC lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isometric contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	-0,00436	0,01618	0,00022	0,00106
2	-0,00153	0,01454	0,00105	0,00327
3	0,01263	0,01742	-0,00036	0,01742
4	0,00202	0,03468	0,00665	0,00285
5	0,04827	0,02378	0,00250	0,00359
6	0,00802	0,01197	0,00959	-0,00452
7	0,01838	0,01424	0,01207	0,00037
8	0,03884	0,02702	0,00139	0,00260
9	0,02667	0,04004	0,00127	0,00390
10	-0,00488	0,04317	-0,00016	-0,00661
Mean ±SEM	0,014±0,063	0,024±0,00316	0,0034±0,0012	0,002±0,0018

Table 4.7 Female subjects' slopes of FRC lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isotonic contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	0,07101	0,04244	0,01301	0,00118
2	-0,01091	-0,00436	-0,00846	-0,01618
3	0,05905	0,07120	0,00181	0,01080
4	0,03467	0,02638	0,00358	-0,00295
5	0,09369	0,04080	0,02874	-0,09126
6	0,09268	0,00775	0,00658	-0,01068
7	0,02533	0,06169	0,00007	-0,02113
8	0,00886	0,00057	0,00845	-0,00120
9	0,02033	0,02406	-0,02185	0,01214
10	0,04467	0,01957	-0,02322	0,00177
Mean ±SEM	0,043±0,011	0,029±0,08	0,009±0,05	-0,011±0,09

Table 4.8 Male subjects' slopes of FRC lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isotonic contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	0,07694	0,08049	0,01710	-0,04906
2	0,06130	0,06675	0,02645	0,00009
3	0,02979	0,02249	0,03078	0,00389
4	0,03623	0,02558	-0,00406	-0,01419
5	0,02384	0,03331	0,07563	0,00329
6	0,01477	0,01489	0,00117	-0,02671
7	0,03061	0,02061	0,00344	-0,00448
8	0,05320	0,08058	0,01395	0,00068
9	0,10133	0,19961	0,01095	-0,03025
10	0,04363	0,07508	0,01959	0,01343
Mean ±SEM	0,05±0,009	0,0619±0,02	0,02±0,0069	-0,010±0,006

Table 4.9 Female subjects' slopes of MPF lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isometric contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	0,00338	-0,01695	-0,00742	-0,00673
2	-0,00726	-0,01024	0,00002	-0,01140
3	-0,02246	-0,01491	0,00085	-0,00209
4	-0,00797	-0,00464	-0,00337	0,00026
5	-0,00007	0,01303	0,00548	-0,00547
6	-0,00218	-0,03373	0,00321	-0,01077
7	-0,01853	-0,02480	0,00736	0,00257
8	0,02687	-0,01502	0,00451	-0,00650
9	-0,00181	-0,02210	-0,00635	0,00754
10	0,01416	-0,03799	-0,00755	0,00723
Mean ±SEM	-0,0015±0,004	-0,016±0,0044	-0,0003±0,002	-0,0025±0,002

Table 4.10 Male subjects' slopes of MPF lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isometric contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	0,00296	-0,02739	0,00292	-0,00033
2	0,00767	-0,02636	-0,00126	-0,00993
3	-0,02009	-0,03934	-0,00043	-0,04996
4	0,00120	-0,05245	-0,02257	-0,01366
5	-0,06318	-0,06052	-0,01456	-0,00670
6	-0,01413	-0,02121	-0,04185	0,01280
7	-0,03632	-0,03005	-0,04001	-0,01188
8	-0,03937	-0,05694	-0,01250	-0,01534
9	-0,03703	-0,09939	-0,00530	-0,01188
10	0,00853	-0,10733	-0,00212	0,02196
Mean ±SEM	-0,02±0,0075	-0,052±0,009	-0,013±0,0050	-0,008±0,006

Table 4.11 Female subjects' slopes of MPF lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isotonic contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	-0,11852	-0,10694	-0,02019	-0,01302
2	0,01644	0,01607	0,03657	0,04651
3	-0,08947	-0,10985	-0,01816	-0,05881
4	-0,04466	-0,05936	-0,00991	0,00659
5	-0,12075	-0,03632	-0,11687	0,11950
6	-0,10588	-0,02276	-0,01743	0,02237
7	-0,00470	-0,11462	-0,00701	0,04157
8	-0,00737	0,00158	-0,03478	-0,00049
9	-0,04073	-0,06539	0,06278	-0,03699
10	-0,06688	-0,03753	0,09818	-0,02370
Mean ±SEM	-0,0582±0,0158	-0,053±0,0145	-0,002±0,018	0,010±0,015

Table 4.12 Male subjects' slopes of MPF lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isotonic contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	-0,13484	-0,16307	-0,13105	0,16691
2	-0,16826	-0,18410	-0,09969	0,03299
3	-0,06264	-0,09799	-0,09680	-0,09979
4	-0,07763	-0,07705	0,01954	0,03952
5	-0,00774	-0,07765	-0,07571	0,00276
6	-0,01172	-0,03086	-0,01503	0,05215
7	-0,03899	-0,05628	-0,03704	-0,03164
8	-0,08794	-0,19961	-0,08654	-0,01027
9	-0,18902	-0,37288	-0,06288	0,05880
10	-0,07568	-0,13607	-0,06564	-0,01605
Mean ±SEM	-0,085±0,02	-0,139±0,031	-0,0650±0,013	0,019±0,02

Table 4.13 Female subjects' slopes of MDF lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isometric contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	0,00742	-0,01731	-0,01513	-0,00836
2	-0,00802	-0,01962	0,00069	-0,01899
3	-0,01840	-0,00552	0,00299	-0,00077
4	-0,00281	-0,00153	-0,00597	0,00213
5	-0,00432	0,01580	0,00941	-0,00979
6	-0,00447	-0,03937	0,00601	-0,01426
7	-0,01900	-0,01886	0,00680	0,00631
8	0,02415	-0,01224	0,00722	-0,01157
9	-0,00454	-0,02899	-0,00841	0,01137
10	0,01559	-0,04880	-0,00718	0,01291
Mean ±SEM	-0,001±0,0041	-0,017±0,0056	-0,0003±0,002	-0,0031±0,0034

Table 4.14 Male subjects' slopes of MDF lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isometric contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	0,00138	-0,02392	0,00577	0,00247
2	0,01212	-0,01510	-0,00003	-0,01242
3	-0,02228	-0,04076	0,00066	-0,05435
4	0,00232	-0,04536	-0,03032	-0,01772
5	-0,04951	-0,06893	-0,02160	-0,01055
6	-0,00949	-0,01508	-0,05738	0,01444
7	-0,03590	-0,02918	-0,05255	-0,01890
8	-0,03363	-0,06017	-0,01123	-0,02272
9	-0,02908	-0,11842	-0,00834	-0,01622
10	0,00942	-0,12803	-0,00238	0,02643
Mean ±SEM	-0,015 ±0,0066	-0,054±0,012	-0,017±0,006	-0,010±0,006

Table 4.15 Female subjects' slopes of MDF lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isotonic contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	-0,11926	-0,11496	-0,03740	-0,02813
2	-0,00109	0,05403	0,07438	0,05627
3	-0,10035	-0,10776	-0,02281	-0,08428
4	-0,02269	-0,05791	-0,00788	0,01433
5	-0,07866	0,02153	-0,18308	0,11206
6	-0,06623	-0,02441	-0,01888	0,02689
7	0,02802	-0,09854	-0,02438	0,04392
8	-0,00622	0,00047	-0,04579	-0,00593
9	-0,06685	-0,08448	0,09291	-0,04591
10	-0,05341	-0,02928	0,13225	-0,04118
Mean ±SEM	-0,0486±0,012	-0,044±0,02	-0,004±0,027	0,004±0,02

Table 4.16 Male subjects' slopes of MDF lines which created using shifting windows are given. These are computed from EMG and MMG signals that recorded from BB (EMG1- MMG1) and TB (EMG2 – MMG2) muscles during isotonic contraction

Subject	EMG 1	EMG 2	MMG 1	MMG 2
1	-0,12541	-0,15148	-0,21219	0,19208
2	-0,21411	-0,23981	-0,09482	0,06961
3	-0,07193	-0,11882	-0,10266	-0,14130
4	-0,08258	-0,09056	0,02414	0,04679
5	0,02619	-0,09061	-0,05091	0,00807
6	0,01284	-0,02702	-0,03623	0,04099
7	-0,03455	-0,06334	-0,06460	-0,06272
8	-0,08500	-0,22498	-0,14377	-0,01545
9	-0,16778	-0,36711	-0,07984	0,04916
10	-0,08307	-0,14371	-0,08688	-0,00175
Mean ±SEM	-0,082±0,02	-0,151±0,031	-0,0847±0,02	0,018±0,025

Results of the reaction time experiments done before and after exercises are given separately in the following tables.

Table 4.17 Female subjects' result of reaction time experiment, before and after isometric contraction exercises

Subject	Before Exercise (sec)	After Exercise (sec)
1	0,216 ± 0,02	0,253 ± 0,05
2	0,277 ± 0,04	0,309 ± 0,06
3	0,287 ± 0,04	0.398 ± 0,08
4	0.259 ± 0,03	0.496 ± 0,16
5	0.224 ± 0,03	0,261 ± 0,03
6	0,211 ± 0,04	0,252 ± 0,04
7	0,263 ± 0,05	0,373 ± 0,05
8	0,285 ± 0,03	0,324 ± 0,04
9	0,321 ± 0,04	0,419 ± 0,08
10	0,462 ± 0,12	0,521 ± 0,08

Table 4.18 Male subjects' result of reaction time experiment, before and after isometric contraction exercises

Subject	Before Exercise (sec)	After Exercise (sec)
1	0,187 ± 0,05	0,202 ± 0,04
2	0,259 ± 0,06	0,332 ± 0,06
3	0,341 ± 0,1	0,344 ± 0,1
4	0,184 ± 0,02	0,206 ± 0,03
5	0,254 ± 0,02	0,314 ± 0,07
6	0,186 ± 0,01	0,247 ± 0,23
7	0,235 ± 0,02	0,265 ± 0,01
8	0,284 ± 0,05	0,307 ± 0,03
9	0,248 ± 0,02	0,374 ± 0,13
10	0,304 ± 0,03	0,328 ± 0,03

Table 4.19 Female subjects' result of reaction time experiment, before and after isotonic contraction exercises

Subject	Before Exercise (sec)	After Exercise (sec)
1	0,248 ± 0,04	0,247 ± 0,05
2	0,259 ± 0,03	0,427 ± 0,18
3	0,269 ± 0,03	0,277 ± 0,02
4	0,211 ± 0,04	0,258 ± 0,02
5	0,212 ± 0,04	0,234 ± 0,04
6	0,269 ± 0,04	0,274 ± 0,03
7	0,277 ± 0,04	0,309 ± 0,06
8	0,249 ± 0,05	0,284 ± 0,05
9	0,352 ± 0,02	0,408 ± 0,03
10	0,402 ± 0,03	0,508 ± 0,1

Table 4.20 Male subjects' result of reaction time experiment, before and after isotonic contraction exercises

Subject	Before Exercise (sec)	After Exercise (sec)
1	0,222 ± 0,03	0,241 ± 0,02
2	0,256 ± 0,02	0,278 ± 0,03
3	0,294 ± 0,08	0,314 ± 0,13
4	0,444 ± 0,05	0,581 ± 0,13
5	0,364 ± 0,03	0,420 ± 0,1
6	0,499 ± 0,07	0,599 ± 0,13
7	0,587 ± 0,35	0,661 ± 0,09
8	0,236 ± 0,04	0,273 ± 0,04
9	0,273 ± 0,03	0,290 ± 0,03
10	0,196 ± 0,03	0,275 ± 0,08

CONCLUSIONS AND DISCUSSION

In literature, there are many article proved that muscle fatigue is the caused of isometric exercises can be evaluated by EMG signals. However there is not any standardized criteria or scoring system like sleep for muscle fatigue's quantitative evaluation. For this reason researchers still go on to analyze the muscle system. One of the new approach to this issue is focusing the vibration of muscle fibers. As discussed Chapter 2, vibration of muscle fiber can record using accelerometer and analyzed as MMG signals. But, MMG is newer method as against EMG. So, many researches didn't study about MMG. It's open to dispute that muscle fatigue is the result of isotonic contraction can be evaluated by MMG signals especially. Therefore main of the thesis study is to prove that MMG signals can use to evaluate MF and there is a harmony with EMG and MMG signals in point of MF. In our study, muscle fatigue is happened during isometric and isotonic contractions are evaluated by parameters calculated from surface EMG and MMG signals quantitively, in both fatigue types. Also, muscle fatigue's negative effects like attention deficit, on performed work is proved through reaction time experiments.

For this aims, EMG and MMG were recorded during dumbbell exercises from 60 subjects. The obtained results show that fatigue that happened from isometric and isotonic contractions can be evaluated by EMG and MMG signals.

It is excepted that amplitude of EMG and MMG signals are increased with MF. When results are reviewed, it's seen that increasing the RMS values calculated for both BB and TB muscles, compotible with literature. This situation is valid for both signals.

Frequency components of the high-frequency to low frequency shift consequent decrease are expected in MPF and MDF parameters. MPF from the results obtained in both experimental groups and MDF parameters are seen to be decreased. In FRC parameter PSD graphic is divided into two equal parts, the rate of left and right fields. Sure enough, raise is observed in graphics' slope. When all results are handled, contrary results are taken in 7 results of calculated 64 average values and these belong to MMG signals. Cause of the error during the experiment or the accuracy of the MMG signal can be considered. Calculated parameters only exercise begins and ends the moment the

difference between the calculated values for exercise not reflect the totality of and consistent with the literature values shows. This proves the correctness of the analysis.

When RMS, FRC, MPF and MNF values are observed for both of muscles, it's seen that higher values are obtained for BB muscle. This condition of the controls during the desired BB isometric and isotonic exercises, muscle contraction arises when more activated. In addition, BB and TB muscles examined in the literature are that they work with each other as antagonists also are consistent with our study.

If we want to compare the EMG and MMG, MMG is newer as far as EMG. Fields are different that both of useful. For instance, in electromagnetic noise field MMG is more useful method as far as EMG. However, much lower than MMG signals to the EMG signal amplitude signals are more sensitive. This is evident from the results of our study. However, muscle fatigue can also be analyzed in each of the two signals has been proven once again with our study.

In our study, two types exercise investigated. Isotonic contraction is more difficult than isometric contraction.Unlike isotonic contraction during isometric contraction, there is a movement that has negative effects on the received signals, EMG and MMG signal signal to noise ratio (SNR) value which is smaller than the noise has been spawned. Both of contractions can be analyzed by EMG and MMG signals but the analysis of isometric contraction is easier. In literature, there are a lot of studies about EMG. In our study it's proved that fatigue is happened during isotonic contraction can be analyzed by EMG and MMG signals that rarely seen in literature.

In literature, there are many studies associated with muscle fatigue, especially with EMG, but MMG studies are insufficient yet. During our thesis we did not achieve the same study such ours.

Soo *et al.*, aimed to estimate the degree of MF quantitatively. MF is a continuous process; during continued muscle contraction the maximal force regularly decrease due to MF. Based on this hypothesis they assumed the degree of MF can be estimated, as equivalent to maximal voluntary force lost during handgrip tasks [20]. Isometric handgrip tasks were given to subjects and surface. They used hand grip exercise, whereas in our study we used dumbbell exercises.

Detection of MF by the surface EMG and its application was published by Sakurai *et al*. The features of MF are increase of amplitude in time domain and transition from high frequency to low frequency in frequency domain. Based on this hypothesis, they assumed that muscle recovery process is converse phenomenon from MF. Therefore, the features of recovery processes are decrease amplitude and transition from low frequency to high frequency. For this purpose frequency characteristics were used to evaluate for MF and recovery process and mean power frequency was evaluated [40]. Their differences were analyzing the recovery process. Similar study was confirmed to this hypothesis by Soo *et al*. [41].

When MF occurs, some parameters change since increasing of amplitude and the decreasing of frequency. Based on this hypothesis, Zaman *et al.* analyzed MF at different Maximum Voluntary Contraction (MVC). To this end, they used handgrip exercises like Soo *et al.* For feature extraction purposes, they computed RMS value in time domain and MNF, MDF values in frequency domain. At the end of the study, RMS value increased, MNF and MDF values decreased at different MVC levels[42].

Neuromuscular and metabolic changes cause MF. Influence of muscle blood flow on fatigue during intermittent human handgrip exercise and recovery was published by Pitcher and Miles. At the end of the study, they proved that when the blood flow to the muscle was mechanically occluded, muscle MF occurs rapidly, endurance time is less than normal condition[44]. In similar study, Jane A. Kent-Braun estimated the relative contributions of central and peripheral factors to development of MF [45].

Near Infrared Spectroscopy (NIRS) was used at different studies for analyzing MF. Simultaneously EMG and NIRS measurements were recorded during handgrip exercise by Şayli *et al.* At the end of the study, during MF, MNF, MDF increased, concentration of *deoxyhemoglabin* (Hb) was increased and concentration of *oxyhemoglabin* (HbO_2) was decreased [46].

Mihai T. Tarata recorded simultaneously EMG and MMG signals in 2002. RMS of the EMG and MMG signals increased with muscle fatigue in spite of that, MDF decreased. The major difference with our study is we analyzed isometric and isotonic contraction, but they analyzed only isometric contraction in their study [9].

In our study we analyzed the short-term muscle fatigue as a result of the exercise is fatigue. Long-term exercise or activities such as fatigue, which occurs at the end of the day occurred as a result of fatigue EMG and MMG signals to be analyzed and has not been proven yet. Therefore, further studies should focus on this type of fatigue. Besides, in this study, the analyses are made by just EMG and MMG signals. In literature studies, analysis of muscle fatigue can be made by change of pH level of muscle, oxygen level in blood and lactate level. These kinds of researches can be added and study can be improved.

Also, our further aim was the evaluation of quantitative data of muscle fatigue's negative effects on performed work. For this reason, reaction time experiments were made before and after exercises. As seen in the results, pre-exercise response time is faster than after exercise response time. This proves that the work productivity can be increased when muscle fatigue is analyzed truly and decreased to minimum level.

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