Determination of Muscle Activity and Work-Done through EMG Analysis during Human Movements in *Salat*

By

(Farzana Khanam)

A thesis submitted in partial fulfillment of the requirement for the degree of
Master of Science in Biomedical Engineering

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Declaration

This is to certify that the thesis work entitled "**Determination of Muscle Activity and Work-Done through EMG Analysis during Human Movements in *Salat***" has been carried out by **Farzana Khanam** in the Department of Biomedical Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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Approval

This is to certify that the thesis work submitted by Farzana Khanam entitled " Determination of Muscle Activity and Work-Done through EMG Analysis during Human Movements in *Salat* " has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of M. Sc. Engineering in the Department of Biomedical Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh in May 2016.

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Farzana Khanam
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Abstract

In this thesis, human movements during *Salat* (the ritual prayer of Muslim) are taken in account to observe this muscle movement patterns as exercise. Since surface electromyography (sEMG) is a proven method to observe the muscle activity based on the generated action potential by the muscles, sEMG method is applied to measure the physical activities from different muscles of the different steps of *Salat*. From these measurements, it has been shown that muscle activity during *Salat* can perform better exercise than walking in treadmill based on muscle fatigue index. The results specify that during *Salat*, Biceps Brachii (BB) and Erector Spine (ES) produce improved EMG level for both male and female subjects in opposition to Treadmill exercise. Therefore, the aftermath of this work gives us a message that the person who performs *Salat* five times in a day is doing exercise of upper limb muscles especially the BB and ES muscles. Furthermore, a modified power spectrum analyzing method is developed. By this proposed method it is proved that mean frequency (MNF) based EMG power spectrum analyzing method is comparatively efficient method than the previously proposed to determine *Salat* associated muscle fatigue and indices. For finding the relation between work done and corresponding sEMG voltage a number of subjects (male and female) are studied with a known work done and their corresponding sEMG voltages are measured. As a result, some approximate mathematical functions are developed by appropriate curve fitting to relate the work done and corresponding EMG voltage. These mathematical functions are proposed for upper limb (Bicep Bracii) muscle and lower limb (Biceps Femoris and Medial Gastrocnemius) muscle. The estimated relationship between work done and sEMG voltage show minimum error when it actually follows second degree function. Based on the work, it is observed that the functions vary from muscle to muscle which means for upper limb and lower limb the relationships follow different mathematical functions. It is also found that the sEMG voltage generated from muscle undergoes saturation after increasing to a certain work done. At last it can be said so far that this work focuses on human movement in *Salat* to prove it as a fresh exercise (no muscle fatigue) mathematically. In addition with that, analytical techniques are developed to determine its muscle indices and fatigue, as well as mathematical relations are established between work done and corresponding sEMG voltage to observe the work done during *Salat*.

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Abbreviations

Elaboration	Abbreviated Form
Average Rectified Value	ARV
Biceps Brachii	BB
Biceps Femoris	BF
Electromyography	EMG
Erector Spine	ES
Fast Fourier Transforms	FFTs
Flexor Carpi Radialis	FCR
Gastrocnemius Medialis	GM
Maximum Voluntary Contraction	MVC
Mean Frequency	MNF
Mean Power	MNP
Medial Gastrocnemius	MG
Median Frequency	MDF
Metacarphophalangeals	MP
Peak Frequency	PKF
Pectoralis Major	PM
Power Spectral Density	PSD
Power Spectrum	PS
Root Mean Square	RMS
Scapula (back)	SC
Surface Electromyography	sEMG
Total Power	TTP
Upper Trapezius	UT
Zero Spectral Moment	SM_0

CHAPTER I

Introduction

1.1 Motivation

Salat is the Arabic word for prayers offered by Muslim worshippers, and it is the second pillar of the Islamic faith. It is a ritual Islamic prayer that's given by all those practicing the Muslim religion five times a day [1]. Therefore it can be said that throughout the world Muslims are participating in *Salat* all the 24 hours in a day as the time is different as its global position.

Salat has precise steps those are followed by all Muslims all over the world. The various movements of *Salat* can be categorized by ***standing***, ***bowing***, ***prostration***, and ***sitting***. During these movements in *Salat*, muscles in human body become active in different manner at different time. The joints that are involved in the movements are the shoulders, wrists, elbows, metacarphophalangeals (MP), proximal interphalangeals, distal interphalangeals, temporomandibular, vertebral column, hip, knee, ankle, subtalar, metatarsophalangeal, and antanto-axial [2]. Therefore, almost all the vital muscles become active when someone performs *Salat*.

Having observed millions of Muslims perform the *Salat* (prayer) regularly at particular times, it can be complemented that *Salat*, along with its various postures, can play an important role in increasing psychological comfort with self-reliance and self-esteem, improving musculo-skeletal fitness, motor behavior, and cerebral blood flow. Eventually, these actions after muscle movement in *Salat* may be beneficial in the rehabilitation of geriatric and disabled persons [2]. In that case of muscle activeness of human body can be measured based on the action potential generated by those muscles. Due to muscle contractions, action potentials are generated which we can measure through electromyography (EMG) analysis. EMG is an electro diagnostic medicine technique for evaluating and recording the electrical activity produced by skeletal muscles which allows the measurement of the change in the membrane potential which is transmitted along the fiber [3]. An EMG is the summation of action potentials from the muscle fibers under the electrodes placed on the skin. Through EMG analysis, any form of force or executed work of human body can be evaluated as numerical value in millivolt unit.

From the above state of affairs, we can say that *Salat* is one kind of great medium to estimate electrical activities and work done using EMG analysis. Because, *Salat*'s different movements have become a great source for the research of muscle activity determination. Although several works has already been done in this field, it is still a challenging area. Furthermore, EMG is an important guide for the investigation of the physiological signal of participants.

1.2 Problem Statements

There are some research results [1], [2], [4]-[8], those show specific *Salat* positions can be useful as warm up exercises, e.g. in [1], it is explained that the positions 'salam and takbir' in *Salat*, as tested on neck extensor, sternocleidomastoideus and biceps brachii muscles, can be a warm-up exercise or strengthening exercise. The comparison and quantification between the specific *Salat* position (takbir, bowing, and prostration) and similar stretching exercise for triceps brachii, biceps brachii, pectoralis major and upper trapezius are studied in [7]. They also found similar muscle activities between postures in *Salat* and stretching exercises in all the investigated muscles except for upper trapezius. The investigation of the EMG activities of the upper body during Takbirul ihram in *Salat* for back scapula (SC), pectoralis major (PM), biceps brachii (BB), and upper trapezius (UT) was executed in [8] and it was concluded in the fact that the effect of posture and movement of *Salat* are as good as stretching exercise because all the upper muscles are being activated. Bowing and prostration can be taken as the Erector Spinae exercise movements because the upper body muscles will contract and relax during repetitive a standing-bowing-standing and sitting-prostration-sitting movements [6].

As mentioned before that, analysis of EMG signals is divided into three main issues: muscle force, muscle geometry and muscle fatigue [9]. To modify the global fatigue indices, mean frequency (MNF) and median frequency (MDF) can be used as a muscle force and fatigue index. The only drawback is its non-linear relationship between muscle force and feature value, especially in large muscles and in cyclic dynamic contractions [10]. In [10] & [11], to solve the non-linear relationship between feature values and muscle loads, some ranges of MNF and MDF are extracted from the consecutive FFTs (Fast Fourier Transforms) showing a linear relationship of feature and muscle force level. A number of literatures [12]–[14] showed a continuous increase of MNF as levels of muscle force increment.

In contrast, MDF and MNF decrease with increasing force levels in a number of studies [15]–[17]. Moreover, in some research works, values of MDF and MNF become unaffected by change in muscle force (independent of the contraction levels) which is quite conflicting [18], [19].

In addition with that, we have also observed that there is no such work that can relates the muscle force and corresponding work done by the muscle. By surface EMG (sEMG) analysis, there are a large number of investigations [4], [20]-[22] by several authors. A relation between muscle force and joint moment is analyzed in [20]. Authors in [21], studied the muscle force with EMG and in [22], authors studied muscle force and sEMG where normalized EMG strength versus increment rate of force carried by muscle was calculated. Through sEMG, joint torque estimating model was proposed in [23]. From these research articles, we do not get any information about the relation between work done and cumulative muscle potential. But it is very necessary information to estimate the total work done from a sEMG signal, however as we know so far, there is no such a model to estimate the total work done from the recorded sEMG.

The goal of this research is to vitally estimate the performed exercise during *Salat* and to point out that performing *Salat* regularly can be an ideal physical exercise to facilitate for the better maintenance of human body. To confirm the conflicting results of MNF and MDF features, modification of frequency-domain features of the universal indices is implemented that can detect both muscle force and muscle fatigue. To overcome the drawbacks of the abovementioned results, it is necessary to develop a mathematical model to estimate the total work done from an EMG signal. As far as we know, there is no exact technique to estimate the mathematical relation between work done and EMG value. Therefore, a mathematical relation is developed between work done and EMG signal. Numerical methods are applied to demonstrate the characteristics of the mathematical relation.

1.3 Objectives

The specific objectives of this research work are summarized as follows:

- To collect sEMG signals of involved muscles and joints during human movements of *Salat*.
- To measure the total amount of exercise, maximum force qualitatively and quantitatively from different healthy subjects of different gender which means male and female for special limbs during different *Salat* positions.
- To investigate Mean and Median Frequency, integrated EMG, RMS EMG and muscle active points in frequency relevant power spectrum during human movements of *Salat*.
- To build up various features to describe the characteristics of EMG signals of human body muscles.
- To develop an approximate numerical model that is properly able to estimate the work done to complete the work from the EMG signal.

1.4 Contributions

The main contribution of the research work can be stated shortly as given below:

- ***Salat* is analyzed and mathematically proved as physical exercise**: This research work mathematically represents *Salat* as in the context of physical exercise and the pattern of muscle movements during *Salat* are studied by electromyographic point of view.
- **A modified EMG power spectrum analyzing method is developed:** Mean Frequency based EMG power spectrum analyzing method is built up with some modification which is comparatively efficient than the other proposal to determine *Salat* associated muscle fatigue and indices.
- **Mathematical functions are developed to relate EMG potential and work done:** This research introduces and develops a new mathematical relationship between performed work done and action potential measured by consequent EMG results.

1.5 Potential Applications of this Research

The applicable scope of this research is quite wide-ranging. Some of them are:

- This research outcome can be used as an indicator of different muscle activation during *Salat*.
- Work done estimation can be performed during different types of physical exercises or work depending on EMG values.
- Estimation of upper and lower limb motions of human body and estimated work done are elementary investigation to enable power-assist robotic systems used for disabled persons.

1.6 Thesis Outlines

Chapter 2: Includes the background knowledge of different muscles of human body, action potential and EMG signal.

Chapter 3: This chapter explores the muscle potential activity and force during *Salat*'s movement and position that can be one of the daily exercise and training for our muscle in course of biomechanical response of human body.

Chapter 4: Mean frequency (MNF) based EMG power spectrum analysis is presented to determine *Salat* associated muscle fatigue and indices in this chapter.

Chapter 5: In this chapter, a mathematical relation is proposed between work done and EMG signal with proper curve fitting and constant parameter correction according to upper muscles and human lower extremity.

Chapter 6: Finally, the conclusion and further research opportunities are discussed.

CHAPTER II

Salat, Human Body Muscles, and Electromyography

2.1 *Salat*

In the Islamic point of view, *Salat* positions are fixed according to the name of Prophet (SWM). The description of the different movement in *Salat* can be summarized as [4],

1) Begins the prayer by standing and raises the hands and speaks aloud a phrase called the *takbir*,

2) Stands while the hands are placed between the chest and stomach and recites Al-Quran,

3) Bows, repeating the *takbir*,

4) Returns to the standing position,

5) Prostrates, placing the forehead, nose, hand, knee, and toes on the floor,

6) Moves to the upright kneeling position,

7) Repeats the act of prostration,

8) Return to the upright kneeling position while reciting *tashahhud* and

9) In the end, *Salat* is accomplished by turning the head at the right and left which called *salam*.

A flow diagram is shown in Figure 2.1 indicating the steps of physical movement with approximate timing of one *raqat Salat*.

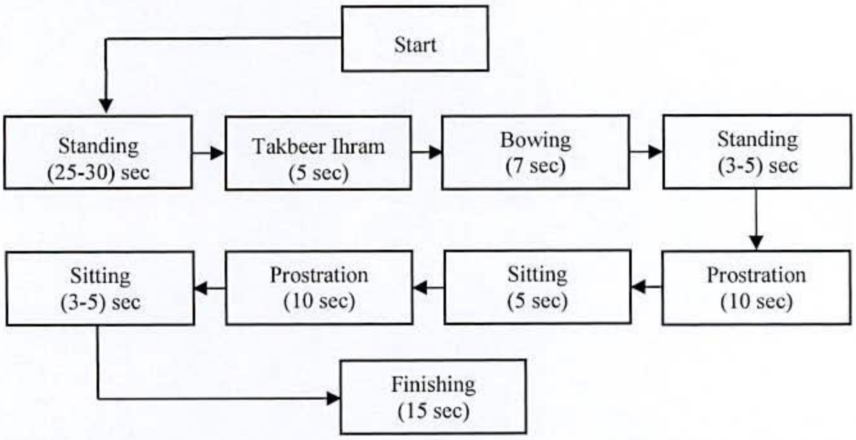
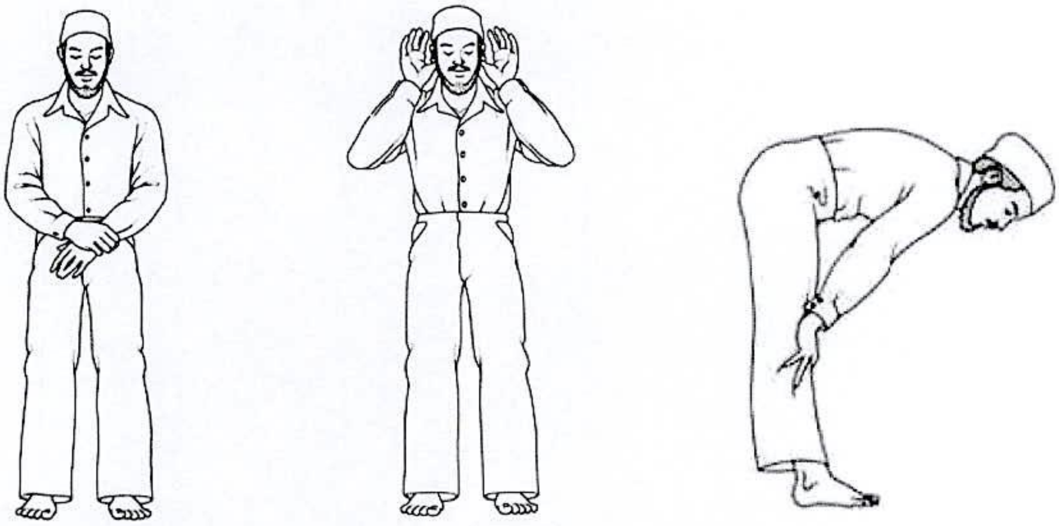


Figure 2.1: Flowchart of the physical movement with approximate timing of one *raqat Salat*.

The physical movements of different steps in *Salat* are graphically shown in the Figure 2.2.



Standing (Al-Qiam) Takbir Bowing (Ruku)

Prostration (Shijda) Sitting Finishing (by Salam)

Figure 2.2: Different positions of *Salat* and corresponding physical movements [24].

2.2 Human Body Muscles

According to the architectural plan of the skeleton, it is known that its firm supports and joint structures make movement possible. However, bones and joints cannot move themselves. They must be moved by something. The large mass of skeletal muscle that moves the framework of the body is the muscular system. Movement is one of the most distinctive and easily observed "characteristics of life." When we walk, talk, run, breathe, or engage in a multitude of other physical activities that are under the "willed" control of the individual, we do so by contraction of skeletal muscle. There are more than 600 skeletal muscles in the body. Collectively, they constitute 40% to 50% of our body weight. And, together with the scaffolding provided by the skeleton, muscles also determine the form and contours of our body [25]. Figure 2.3 depicts the structure of muscle organ and according to the location, name of some selected muscles are grouped in Table 2.1.

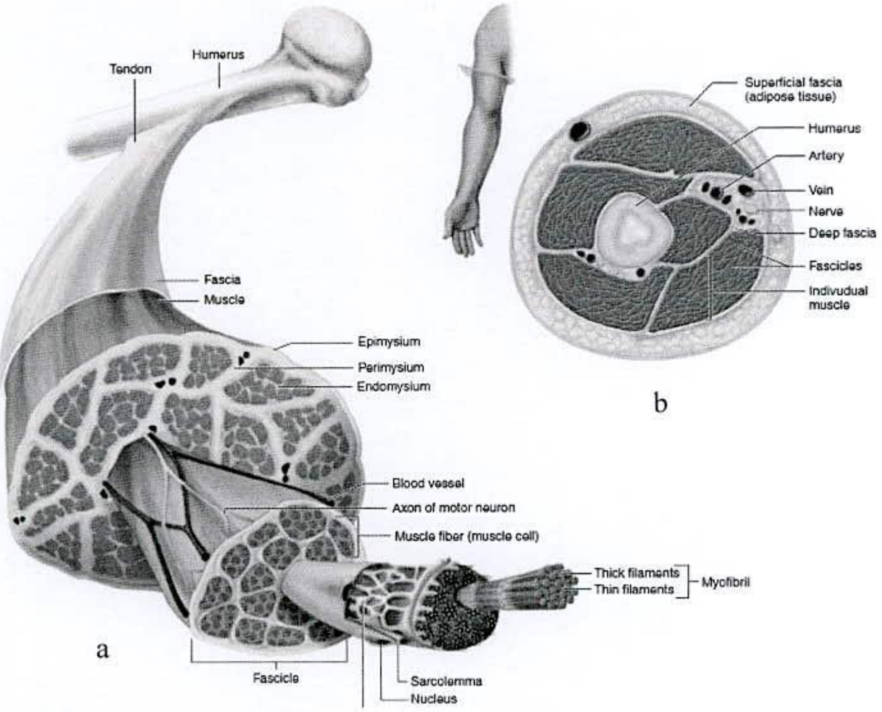


Figure 2.3: Structure of a muscle organ. a: The connective tissue coverings, the epimysium, perimysium, and endomysium, are continuous with each other and with the tendon. b: Diagram showing the arm in cross section [25].

Table 2.1: Selected Muscles Group according to Location

Location	Muscles	Location	Muscles
Neck	Sternocleidomastoid	*Thigh*	
Back	Trapezius	Anterior surface	Quadriceps femoris group: Rectus femoris Vastus lateralis Vastus medialis Vastus intermedius
Chest	Latissimus dorsi Pectoralis major Serratus anterior	Medial surface	Gracilis Adductor group (brevis, longus, magnus)
Abdominal wall	External oblique	Posterior surface	Hamstring group: Biceps femoris Semitendinosus Semimembranosus
Shoulder	Deltoid	*Leg*	
Upper part of arm	Biceps brachii Triceps brachii Brachialis	Anterior surface	Tibialis anterior
Forearm	Brachioradialis Pronator teres	Posterior surface	Gastrocnemius Soleus
Buttocks	Gluteus maximus Gluteus minimus Gluteus medius Tensor fascia latae	Pelvic floor	Levator ani Coccygeus

2.3 Electromyography (EMG)

2.3.1 Definition of EMG and Its Classification:

Electromyography or EMG is an electrodiagnostic medicine technique for evaluating and recording the electrical activity produced by skeletal muscles [3]. EMG is performed using an instrument called an electromyograph, to produce a record called an electromyogram. An electromyograph detects the electrical potential generated by muscle cells when these cells are electrically or neurologically activated [26]. The signals can be analyzed to detect medical abnormalities, activation level, or recruitment order or to analyze the biomechanics of human or animal movement.

EMG signals are electrical signals produced by motor units' activation. These non- stationary signals are normally a function of time and analyzed in terms of their amplitude, frequency and phase. In addition, EMG signals measurement techniques are classified into two types: surface and intramuscular (indwelling). A comparison of the two techniques is shown in Table 2.2 [27].

Table 2.2 Comparison of surface and Indwelling EMG

Characteristics	Surface EMG	Indwelling EMG
Electrode type and position	Flat disk: Placed over selected muscle skin.	Needle, fine wire: inserted into selected muscle.
Pick-up zone	Large.	Smaller than surface.
Cross-talk	Significant.	Not Significant.
Muscles type	Superficial muscles	Profound muscles
Usage	Reprehensive of muscle activities	More selective: good for motor unit studies

2.3.2 A Short History of EMG:

The first documented experiments dealing with EMG started with Francesco Redi's works in 1666. Redi discovered a highly specialized muscle of the electric ray fish (Electric Eel) generated electricity. By 1773, Walsh had been able to demonstrate that the eel fish's muscle tissue could generate a spark of electricity. In 1792, a publication entitled De Viribus Electricitatis in Motu Musculari Commentarius appeared, written by Luigi Galvani, in which the author demonstrated that electricity could initiate muscle contraction. Six decades later, in 1849, Emil du Bois-Reymond discovered that it was also possible to record electrical activity during a voluntary muscle contraction. The first actual recording of this activity was made by Marey in 1890, who also introduced the term electromyography.

In 1922, Gasser and Erlanger used an oscilloscope to show the electrical signals from muscles. Because of the stochastic nature of the myoelectric signal, only rough information could be obtained from its observation. The capability of detecting electromyographic signals improved steadily from the 1930s through the 1950s, and researchers began to use improved electrodes more widely for the study of muscles. The AANEM was formed in 1953 as one of several currently active medical societies with a special interest in advancing the science and clinical use of the technique. Clinical use of surface EMG (sEMG) for the treatment of more specific disorders began in the 1960s. Hardyck and his researchers were the first (1966) practitioners to use sEMG. In the early 1980s, Cram and Steger introduced a clinical method for scanning a variety of muscles using an EMG sensing device.

It is not until the middle of the 1980s that integration techniques in electrodes had sufficiently advanced to allow batch production of the required small and lightweight instrumentation and amplifiers. At present, a number of suitable amplifiers are commercially available. In the early 1980s, cables that produced signals in the desired microvolt range became available. Recent research has resulted in a better understanding of the properties of surface EMG recording. Surface electromyography is increasingly used for recording from superficial muscles in clinical or kinesiological protocols, where intramuscular electrodes are used for investigating deep muscles or localized muscle activity.

There are many applications for the use of EMG. EMG is used clinically for the diagnosis of neurological and neuromuscular problems. It is used diagnostically by gait laboratories and by clinicians trained in the use of biofeedback or ergonomic assessment. EMG is also used in many types of research laboratories, including those involved in biomechanics, motor control, neuromuscular physiology, movement disorders, postural control, and physical therapy [27]-[29].

Usually, an analysis and detection of EMG signals can be divided into three main issues i.e., muscle force, muscle geometry (joint angle), and muscle fatigue [9]. Exercise programming for a young, healthy population incorporates exercises that push the muscular system to high levels of performance. Muscles can exert force and develop power to produce the desired movement outcomes. The lost of strength in the muscles can create a variety of problems, ranging from inability to reach overhead or open a jar lid to difficulty using stairs and getting up out of a chair. Skeletal muscle performs a variety of different function, all of which are important to efficient performance of the human body. The three functions relating specifically to human movement are contributing to the production of skeletal movement, assisting in joint stability, and maintaining posture and body position [28].

2.4 Action Potential

An EMG is the summation of action potentials from the muscle fibers under the electrodes placed on the skin. Due to muscle contractions, action potentials are generated which we can measure through EMG analysis. In physiology, an action potential is a short-lasting event in which the electrical membrane potential of a cell rapidly rises and falls, following a consistent trajectory. Action potentials occur in several types of animal cells, called excitable cells, which include neurons, muscle cells, and endocrine cells, as well as in some plant cells. In neurons, they play a central role in cell-to-cell communication. In other types of cells, their main function is to activate intracellular processes. In muscle cells, for example, an action potential is the first step in the chain of events leading to contraction [30], [31].

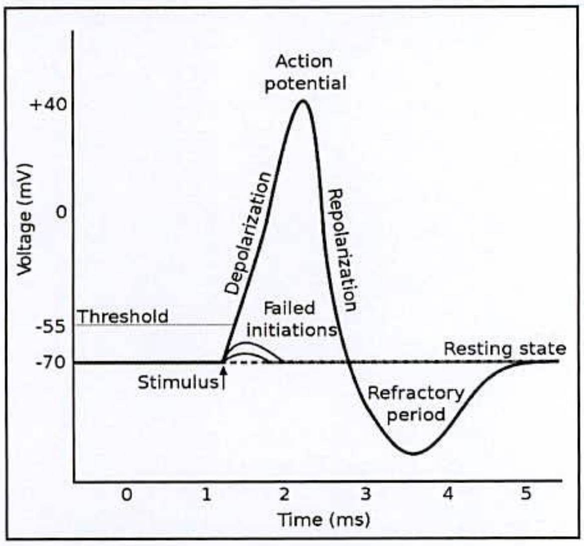


Figure 2.4: Voltage induction process in muscle by Action potential.

Approximate plot of a typical action potential in Figure 2.4 shows its various phases as the action potential passes a point on a cell membrane. The membrane potential starts out at -70 mV at time zero. A stimulus is applied at time = 1 ms, which raises the membrane potential above -55 mV (the threshold potential). After the stimulus is applied, the membrane potential rapidly rises to a peak potential of +40 mV at time = 2 ms. Just as quickly, the potential then drops and overshoots to -90 mV at time = 3 ms, and finally the resting potential of -70 mV is reestablished at time = 5 ms.

All cells in animal body tissues are electrically polarized. In other words, they maintain a voltage difference across the cell's plasma membrane, known as the membrane potential. This electrical polarization results from a complex interplay between protein structures embedded in the membrane called ion pumps and ion channels. In neurons, the types of ion channels in the membrane usually vary across different parts of the cell, giving the dendrites, axon, and cell body different electrical properties. As a result, some parts of the membrane of a neuron may be excitable (capable of generating action potentials), whereas others are not. Recent studies have shown that the most excitable part of a neuron is the part after the axon hillock (the point where the axon leaves the cell body), which is called the initial segment, but the axon and cell body are also excitable in most cases.

Each excitable patch of membrane has two important levels of membrane potential: the resting potential, which is the value the membrane potential maintains as long as nothing perturbs the cell, and a higher value called the threshold potential. At the axon hillock of a typical neuron, the resting potential is around –70 millivolts (mV) and the threshold potential is around –55 mV. Synaptic inputs to a neuron cause the membrane to depolarize or hyperpolarize; that is, they cause the membrane potential to rise or fall. Action potentials are triggered when enough depolarization accumulates to bring the membrane potential up to threshold. When an action potential is triggered, the membrane potential abruptly shoots upward; often reaching as high as +100 mV, then equally abruptly shoots back downward, often ending below the resting level, where it remains for some period of time. The shape of the action potential is stereotyped; that is, the rise and fall usually have approximately the same amplitude and time course for all action potentials in a given cell. In most neurons, the entire process takes place in about a thousandth of a second. Many types of neurons emit action potentials constantly at rates of up to 10–100 per second; some types, however, are much quieter, and may go for minutes or longer without emitting any action potentials [32].

2.5 Human Body Muscles and sEMG

In human body muscle is a source of producing force. The basic functional unit of muscle is motor units. When a subject applies some force an electrical signal is generated on the muscle surface which is a summation of all the action potential generated in motor units. This signal is called EMG signal. In addition with that, surface EMG or sEMG are collected from the surface of human body. Therefore, from our brain command the muscle to act and according to the movement of that muscle generates action potential. This action potential when we collect cumulatively from the surface of that muscle by some electronic devices is actually sEMG in form of millivolt range.

A simple figure can make it clear about the total procedure which is shown in Figure 2.5. As well as the EMG signal and its different possible processed wave shapes are given in Figure 2.6.

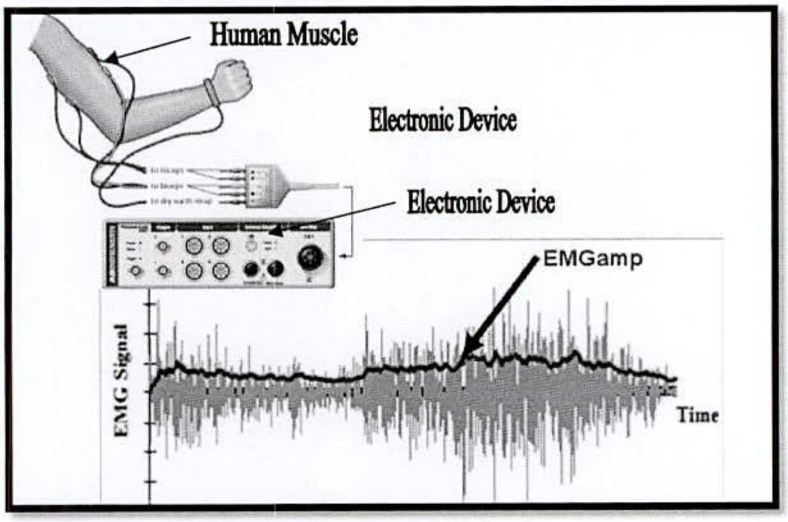


Figure 2.5: sEMG signal acquisition technique from human body muscle.

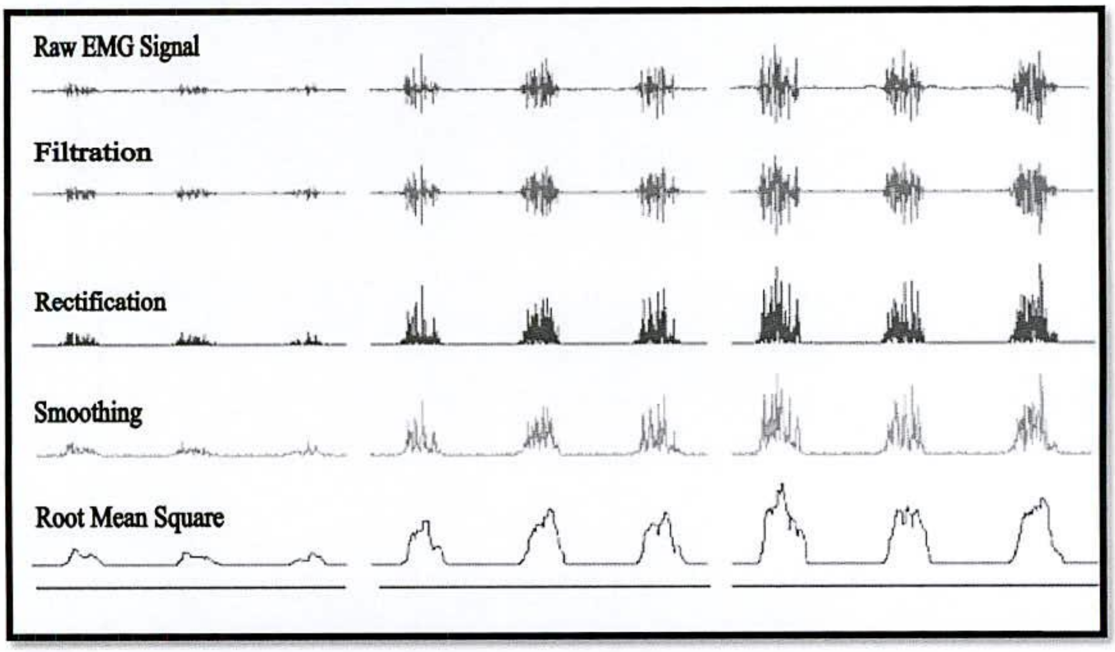
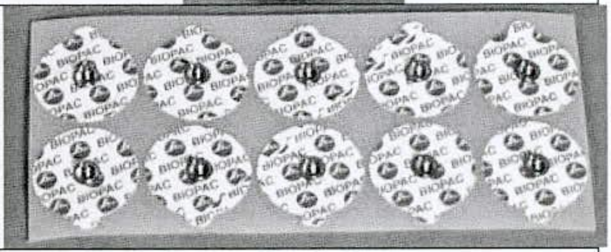


Figure 2.6: Different possible processed wave shapes of sEMG signal.

2.6 sEMG Measuring Device and Significant Features

There exist different types of sEMG measuring devices and they have different types of features as well. Here some sEMG measuring equipments are presented in Table 2.3 those are actually used in this research work.

Table 2.3: sEMG Measuring Devices with Specifications

Measuring Instruments with Specification	Pictorial View
Biopac Data Acquisition Unit: MP36 with power cables	
BIOPAC electrode lead set (SS2L)	
BIOPAC electrode gel (GEL1) and abrasive pad (ELPAD) or Skin cleanser or alcohol prep, Lycra® swim cap (such as Speedo® brand)	
BIOPAC disposable vinyl electrodes (EL503)	
Supportive wrap (such as 3M Coban™ Self-adhering Support Wrap) to press electrodes against head for improved contact	

2.7 Conclusion

This chapter explores about *Salat*, human body muscles as well as EMG individually. Different particular steps of *Salat* are explained point by point. Moreover, pictorial view of different positions of *Salat* is portrayed along with them. Subsequently, human body muscular system is explained which permit us to move our body in a controlled and coordinated way. Human muscle organ structure and location wise selected group of muscles are also tabulated respectively. Due to muscle contractions and relaxations, electrical activity of muscles i.e. action potential generates. EMG is the only electro diagnostic measuring technique which allows detecting action potential from human body muscles. Previous histories of inventing EMG, classification of EMG are described in this chapter. In this research work, we have conducted all experiment through sEMG technique. So, sEMG measuring devices specifications and corresponding significant features are illustrated respectively at the end of this chapter. At the concluding part it can be said that this chapter contains the topic about EMG and its approximate all relevant part equally.

CHAPTER III

Muscle Activity Determination during Human Movements in *Salat*

3.1 Introduction

In this chapter, muscle activities those are related to the physical movement during *Salat* are presented in the context of EMG measurement through Average Rectified Value and Root Mean Square Method analysis. During physical movements in *Salat* for a human body, several muscles become active at different time while some one performs *Salat* either two or three or four *raqat*. In this research work, we present a two *raqat Salat* movement model. That is because two *raqat Salat* is just equivalent to four *raqat Salat* as ½ of its physical work.

According to this chapter's arrangement criteria, it is necessary to recollect the previous related works. As we discussed earlier in Chapter 1 about the previous research works related to the comparison between *Salat* positons and warm up exercises.

The relative and computed results between the specific *Salat* position (takbir, bowing, and prostration) and similar stretching exercise for triceps brachii, biceps brachii, pectoralis major and upper trapezius are illustrated in [7]. They also found similar muscle activities between postures in *Salat* and stretching exercises in all the investigated muscles except for upper trapezius. The investigation of the EMG activities of the upper body during Takbirul ihram in *Salat* was accomplished in [8]. Some other researchers only analyzed in single muscle of lower limb. They concluded that bowing and prostration can be taken as the Erector Spinae exercise movements [6]. In [33], it has been evaluated that the alternative approach of *Salat* and mimicking *Salat* movements and postures, may have beneficial effects for Erectile Dysfunction patients. They also suggested that Muslim prayer movements can be treated as an alternative therapy in the treatment of erectile dysfunction.

From the aforementioned research results, it is clear to be seen that *Salat* can be a great medium to determine the muscles activity of human body. The purpose of this proposed study is to significantly estimate the performed exercise during *Salat* and as well as to spot out that performing *Salat* regularly can be an ideal physical exercise to facilitate for the better maintenance of human body.

3.2 Analytical Methodology

3.2.1 Mathematical Analysis:

EMG is an experimental technique concerned with the development, recording, and analysis of myoelectric signals. Myoelectric signals are formed by physiological variations in the state of muscle fiber membranes [34]. Through EMG analysis, any form of force or executed work of human body can be evaluated. That is why; we performed this experiment to establish a relationship between *Salat* and physical exercise assessing surface EMG analysis. To accomplish our target; we pursued a consequent course of actions all the way through the experiment. Our total exertion is illustrated by the flowchart which is given in Figure 3.1.

In this study, we have analyzed the EMG signals by RMS signal processing. All the recorded EMG data were post-processed using the built-in processing tool in Acqknowledge software, where the RMS values were obtained. In the RMS calculation, the raw signals are rectified and then converted into an amplitude envelope. The RMS envelope is used as an indicator of the total muscle activation. RMS envelope values of all the bursts for each loading period (two *raqat Salat*) are calculated.

EMG envelope calculation procedure consists of two steps: (i) EMG signal is divided into segments with W data point samples (1 window) in order to approximate the raw data with reduced samples and (ii) Square root of the square of the down sampled signal is calculated, which is shown in (3.1).

$$\mu_i = \frac{1}{N}\sum_{W} x_{raw} \tag{3.1}$$

$$x_{ENV} = \sqrt{\mu_i^2} \text{ , where, } i\text{=1, 2… K} \tag{3.2}$$

Here, μ_i, W, x_{raw}, and x_{ENV} represent the average EMG data, 15 sampled raw EMG window, raw EMG data, and RMS envelope of the EMG signal, respectively.

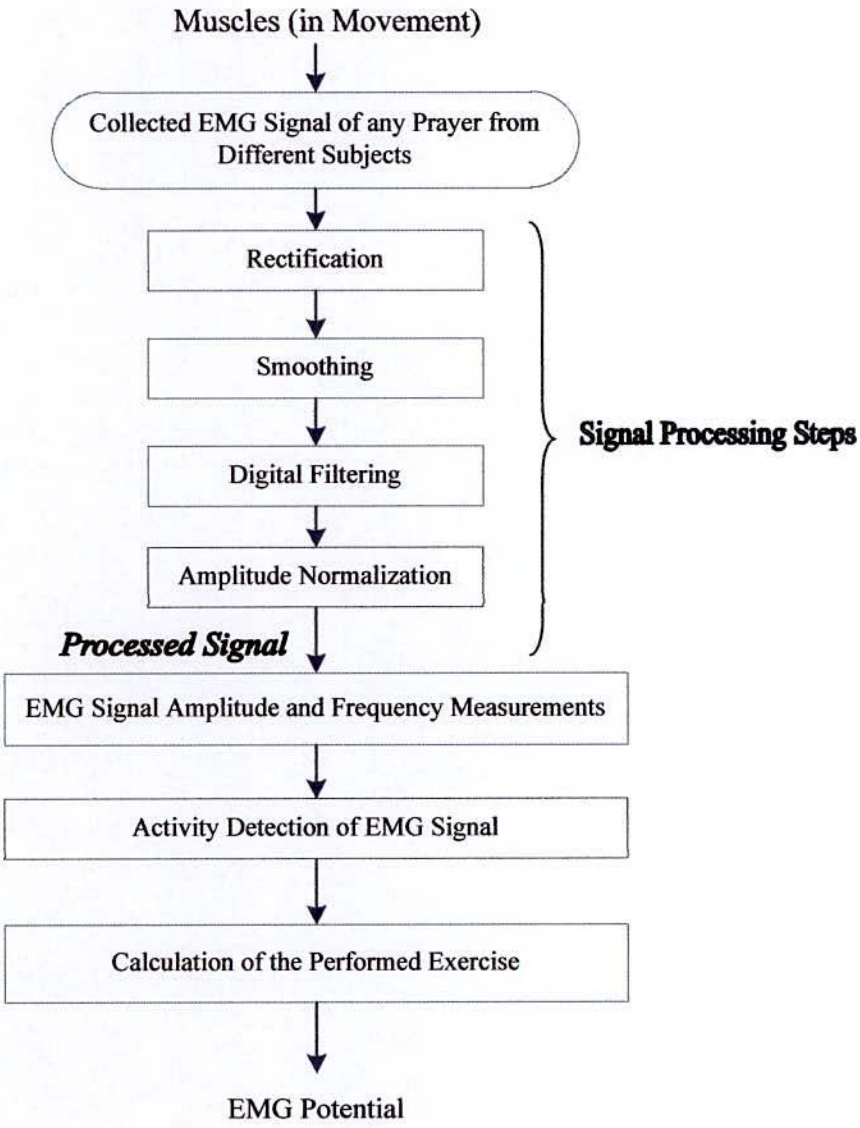


Figure 3.1: Flowchart of the proposed method for muscle force detection.

To get integrated EMG signal, we consider each separate signal as a function of f of given average EMG data μ_i. To integrate the discrete function, Simpson's 3/8 rule [35] was followed. The desired result is I_{ENV}, which is given in (3.3),

$$I_{ENV} = \int_{i}^{i+1} f(\mu_i) d\mu = \frac{3h}{8}\left[f(\mu_0) + 3f(\mu_1) + 3f(\mu_2) + 2f(\mu_3) + 3f(\mu_4) + 3f(\mu_5) + 2f(\mu_6) + ... + f(\mu_k) \right] \tag{3.3}$$

Where, $h = \frac{(i+1)-i}{k}$ and i=1, 2…, K

Rectification is necessary to evaluate the processed EMG signal. Average rectified value (ARV) of EMG is defined as a time windowed mean of the absolute value of the signal. ARV is one of the various processing methods used to construct derived signals from raw EMG data [36] that can be useful for further analysis. A Fourier series [37] decomposes following rectified signal of R_{ENV} expresses,

$$R_{ENV}(t) = \frac{2I_{ENV}}{\pi} - \frac{4I_{ENV}}{\pi} \sum_{i=1}^{\infty} \frac{\cos(i\omega_0 t)}{(4i^2 - 1)} \tag{3.4}$$

Smoothing part removes the noises from the processed signals. A digital filter is characterized by its transfer function, or equivalently, its divergence equation. Mathematical analysis of the transfer function can describe how it will respond to any input. The transfer function for a linear, time-invariant, digital filter [38], [39] can be expressed as a transfer function in the Z-domain, it has the form of filtering output of D_{ENV} is specified as,

$$D_{ENV}(z) = \frac{S_{ENV}(z)}{R_{ENV}(z)} = \frac{s_0 + s_1 z^{-1} + s_2 z^{-2} + \ldots + s_k z^{-k}}{r_0 + r_1 z^{-1} + r_2 z^{-2} + \ldots + r_k z^{-k}} \tag{3.5}$$

Normalized values allow the comparison of corresponding normalized values for different datasets in a way that eliminates the effects of certain gross influences. The mathematical expression for normalizing data [40] is given as,

$$N_{ENV} = \frac{D - D_{\min}}{D_{\max} - D_{\min}} \tag{3.6}$$

With the help of these sets of mathematics, we have acquired the output of the raw EMG signals and investigated them in the course of ARV and RMS technique, through Acqknowledge software.

3.2.2 Subjects:

For this study purpose, special methodical steps were executed such as subject selection, data acquirement using hardware, and finally scrutiny of the EMG data using software. The EMG signal for various states were evaluated in biomedical signal processing laboratory, Department of BME, Khulna University of Engineering & Technology (KUET), Bangladesh. The whole experimental data were collected from several subjects of this university.

Table 3.1: Information of the Subjects

Subject Code	Age	Weight	Muscles	Comment
S1	22	63	BB, ES, MG	Male
S2	21	64	BB, ES, MG	Male
S3	22	64	BB, ES, MG	Male
S4	23	65	BB, ES, MG	Male
S5	23	68	BB, ES, MG	Male
S6	22	56	BB, ES, MG	Female
S7	22	55	BB, ES, MG	Female
S8	21	54	BB, ES, MG	Female
S9	23	56	BB, ES, MG	Female
S10	23	57	BB, ES, MG	Female

A total of five male and five female undergraduates where, (approximate range of age: 22 ± 1 years and range of weight: 60 ± 5.0 Kg) with no medical history and no back pain, were recruited as subjects of the study. Subjects were verbally informed about the experimental protocol. The information about the subjects is shown in Table 3.1.

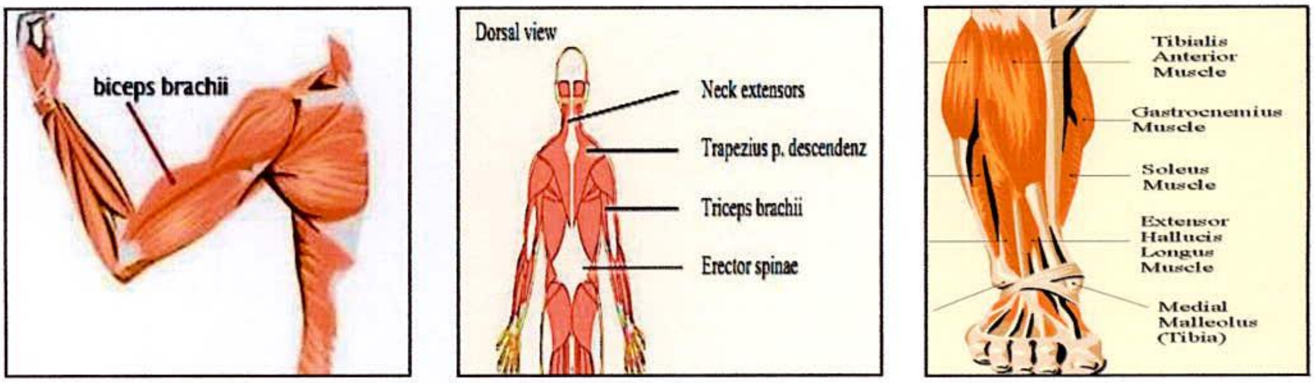
3.2.3 Signal Acquisition:

BIOPAC disposable vinyl electrodes (EL503) along with BIOPAC electrode lead set (SS2L) were affixed over the chosen muscle groups, parallel to their fiber orientation. Prior to the electrodes placement, the skin was cleaned with BIOPAC electrode gel (GEL1) and abrasive pad (ELPAD) or Skin cleanser or alcohol prep, Lycra® swim cap (such as Speedo® brand). Supportive wrap (such as 3M Coban™ Self-adhering Support Wrap) were used to press electrodes against head for improving contact. The electrodes were connected to an EMG data collection system (Biopac Student Lab 3.7 and BIOPAC data acquisition unit (MP36 and MP150) with cable and power). For analyzing the collected or stored data, two types of available software: BIOPAC Student Lab Pro and Acknowledge were used.

3.3 Experimental Procedure

3.3.1 Preprocessing:

Surface electrodes are placed on the skin over a muscle and are mainly used for investigated superficial muscle. With the Surface EMG technique of EMG the electrical impulses generated by muscular contractions, it is possible to determine very precisely which muscle, superficial and deep, contract during a given movement described in [41]. To reduce the impedance of the surface, the skin was cleared prior to the electrodes assignment. For the study, the EMG signals were captured from three different muscles which are Biceps Brachii (BB), Erector Spine (ES) and Gastrocnemius Medialis (GM) of the body. To obtain a stable and maximum pick up area of the EMG signals from each subject, the procedure for the EMG electrodes placement are referred from SENIAM recommendation [42]. Figure 3.2 implies the anatomical view of three involved muscles.

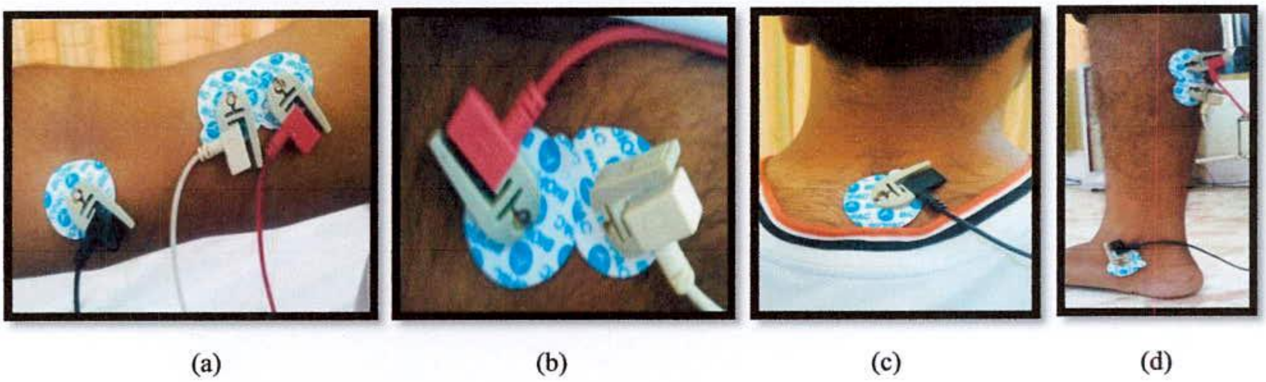


(a) (b) (c)

Figure 3.2: The muscles involved in proposed study are: a) BB, b) ES, and c) GM.

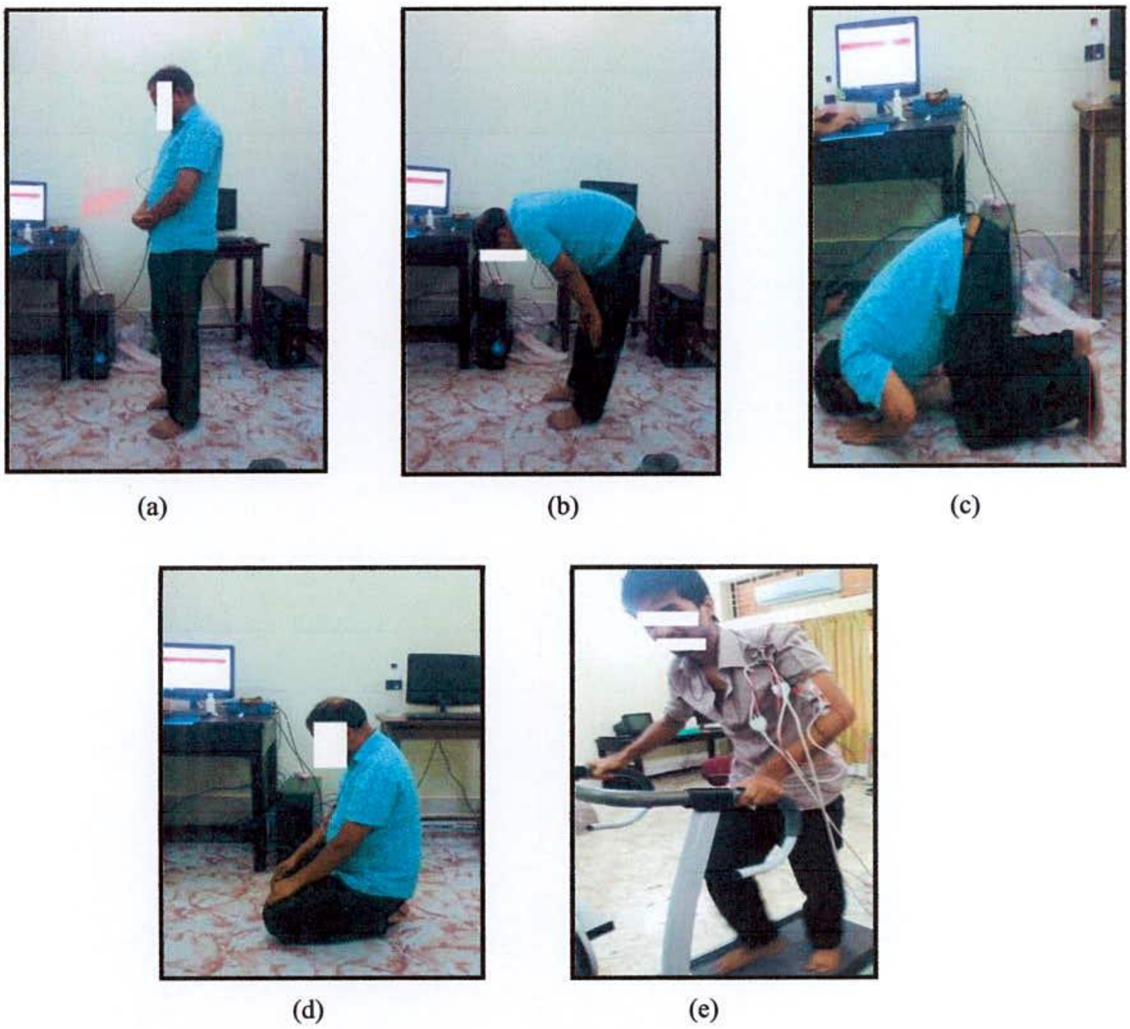
3.3.2 Signal Rectification:

From the raw EMG signals, integrated EMG signals were determined initially. From integrated EMG data, Muscle active points were acquired with the help of aforementioned signal analysis software. Then, the %active time as well as %inactive time for three muscles was determined during the whole test protocol. Figure 3.3 portrays the different electrode placements along involved muscles through sEMG process. Figure 3.4 indicates the data measurement of subjects while saying *Salat* and doing exercise in Treadmill in BME Lab, KUET. RMS EMG values for several intervals were determined. Integrated values of EMG signals are also acquired in the course of the whole experiment.



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

Figure 3.3: Different electrode position at human body (a) Biceps Brachii (surface &ground), (b) Erector Spinae (surface), (c) Erector Spinae (Ground), and (d) Gastrocnemius Medialis (ground and surface) during EMG measuement.



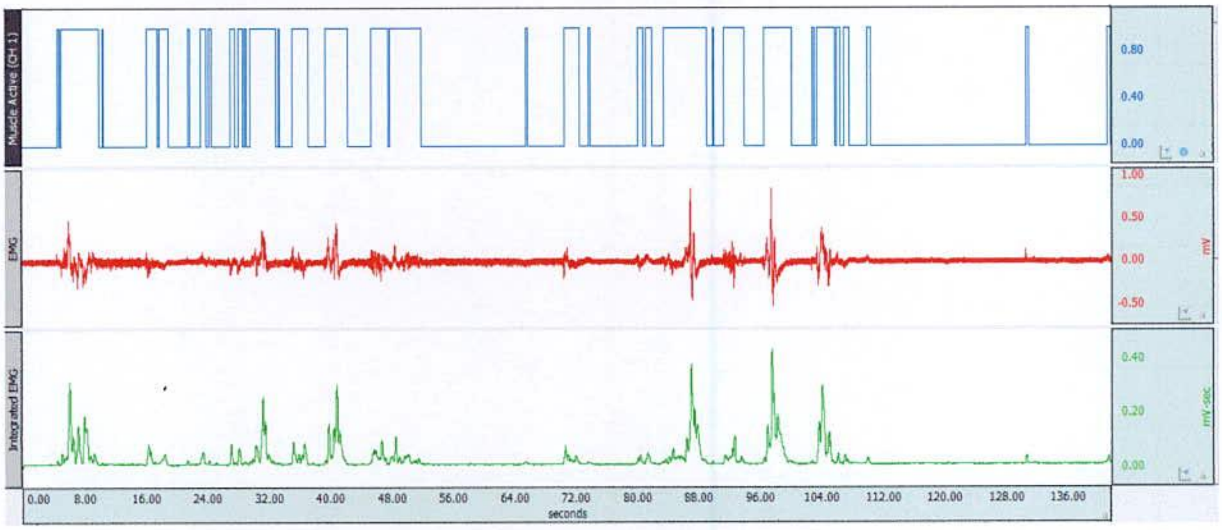
(a) (b) (c)

(d) (e)

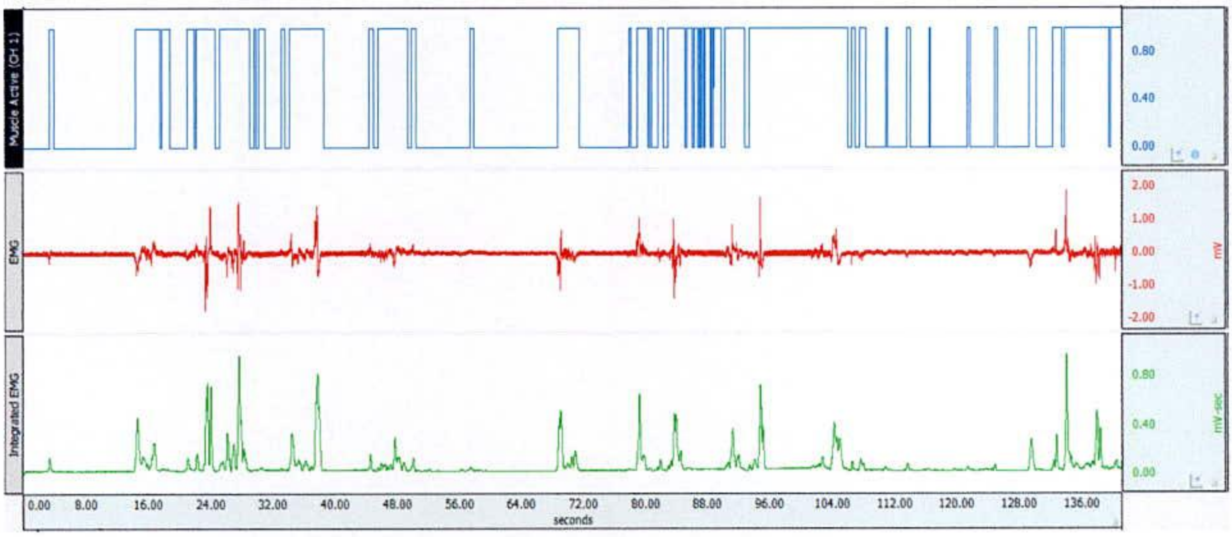
Figure 3.4: Pictorial view of EMG measurement during *Salat* and Treadmill Exercise in BME lab, KUET; positions are: a) Standing & Takbeer, b) Bowing, c) Prostration, d) Sitting & Finishing, and e) Treadmill exercise.

3.4 Experimental Results and Discussion

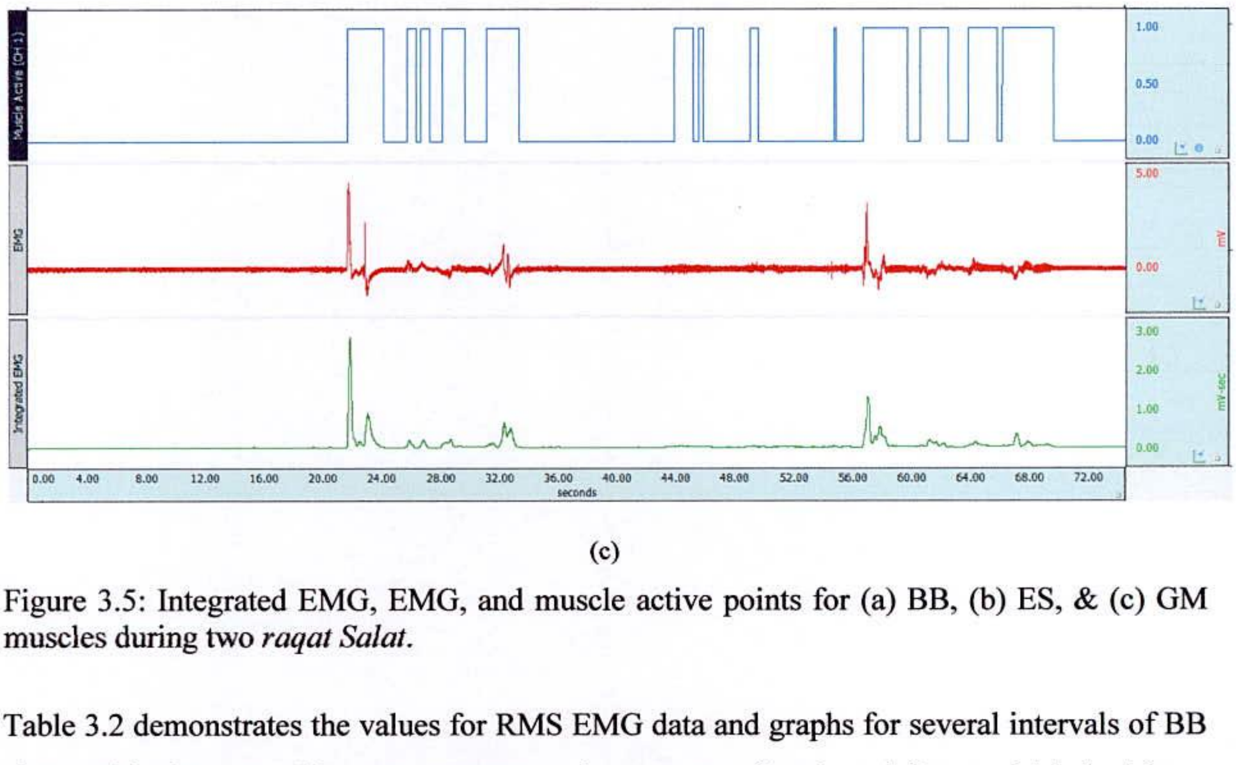
EMG and Integrated EMG data were recorded for several test conditions. Muscle Active points are determined using Acqknowledge software analysis from the recorded EMG and Integrated EMG data. RMS values of the raw EMG data and the area covering these data are also determined. Prior to acquire the RMS EMG data, the raw EMG values are divided into different sampling window. The width of each window was identical. Through the software, each window was analyzed. From the extracted data of different sampled windows, we have chosen the right window to analyze the whole process. From that window, ultimate data were extorted for locating muscle activity points. Figure 3.5 shows various results of muscle activities for a subject during performing the two *raqat Salat* through the whole experiment. The %active and %inactive times during *Salat* and Treadmill exercise are taken from the EMG, integrated EMG, RMS EMG and muscle active points were verified by the Acqknowledge software. From the graphs, we can notice that around 0.80 point describes the activity or dynamic point of BB and ES muscle, but GM muscle's activity is shown at 1.00 point. As the reference is 0.00 point, it represents the motionless position of all muscles.



(a)



(b)



(c)

Figure 3.5: Integrated EMG, EMG, and muscle active points for (a) BB, (b) ES, & (c) GM muscles during two *raqat Salat*.

Table 3.2 demonstrates the values for RMS EMG data and graphs for several intervals of BB along with the area. The area represents the amount of activated force which had been performed by BB.

Table 3.3 and Table 3.4 show that the average %active and %inactive time while undergoing the experimental procedure for male and female subjects, respectively. Here, the total time was divided into 524 segments. The experimental results of the EMG signals for two *raqat Salat* for all the subjects indicate that there were contractions and relaxations for all of the muscles during *Salat* and exercise.

Table 3.2: RMS EMG Wave shapes for Several Intervals of BB

Intervals (sec)	RMS EMG wave shapes of BB	Area (mV/sec)
0.03		2.58
0.15		3.14
0.3		4.17
0.45		4.44
0.6		4.17
0.75		4.17
1.0		4.44
1.15		4.28
1.3		4.28
1.45		4.28
1.6		4.7
1.75		4.28
2.0		4.17
2.3		4.28
2.6		4.28
3.0		4.28

According to male subjects, EMG average in %active time for BB was 49.168% during *Salat* and 21.872% during Treadmill exercise; for ES, 67.756% during *Salat* and 43.4% during Treadmill exercise and for GM, it indicates that 28.01% during *Salat* and 83.282% during exercise which are shown in Table 3.3. BB and ES show that *Salat* creates higher EMG level than Treadmill exercise with differences about 27.296% and 24.356%. That means BB and ES follow better activities through *Salat.* In case of comparing the EMG level for GM, Treadmill exercise shows higher EMG level than *Salat* with differences 55.272% maximum voluntary contraction (MVC).

Table 3.4 also depicts the activity information of female subjects during *Salat* and Treadmill exercise. During *Salat*, BB (27.998%) produces better force than Treadmill exercise with differences of 14.714%. During *Salat*, ES has better activity of 50.846% than Treadmill exercise with differences of 34.402%. Besides, like male subjects during Treadmill exercise, GM illustrates higher EMG level of 45.31% than *Salat* with diversity of 42.51%.

Table 3.3: Data for Average Active and Inactive Time for Male Subjects

Subject Sex	**Male**					
Exercise Type	***Salat for two raqat***			***Treadmill Exercise***		
Selected Muscles	***Average Total time (sec)***	***Average Active time (%)***	***Average Inactive time (%)***	***Average Total time (sec)***	***Average Active time (%)***	***Average Inactive time (%)***
Biceps Brachii	110	49.168	50.238	64.4	21.872	78.142
Erector Spinae	110	67.756	32.244	64.4	43.4	56.6
Gastrocnemius Medialis	110	28.01	71.844	64.4	83.282	16.662

Table 3.4: Data for Average Active and Inactive Time for Female Subjects

Subject Sex	**Female**					
Exercise Type	***Salat for two raqat***			***Treadmill Exercise***		
Selected Muscles	***Average Total time (sec)***	***Average Active time (%)***	***Average Inactive time (%)***	***Average Total time (sec)***	***Average Active time (%)***	***Average Inactive time (%)***
Biceps Brachii	97.314	27.998	72	99.9	13.284	88.714
Erector Spinae	97.314	50.846	48.778	99.9	16.444	83.554
Gastrocnemius Medialis	97.314	45.31	54.71	99.9	87.82	12.164

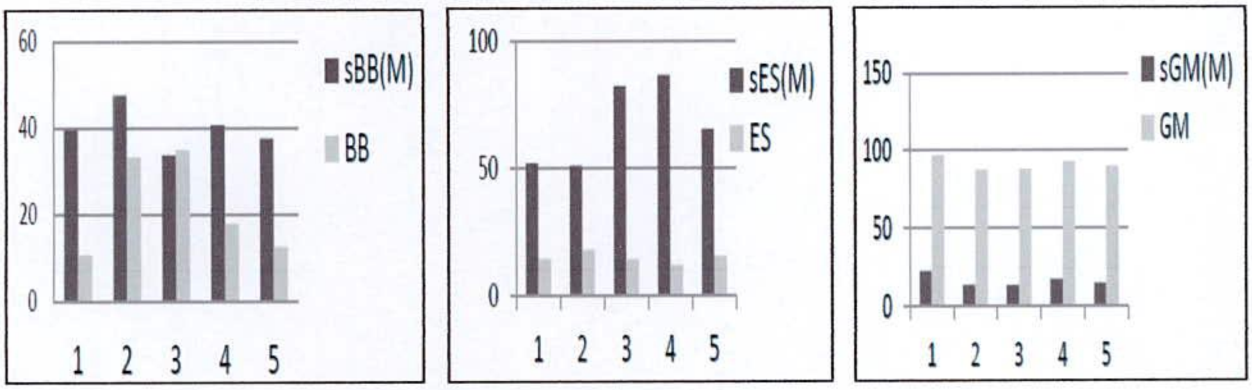


Figure 3.6: Comparison of average % active time for BB, ES, & GM for male subjects during *Salat* and exercise.

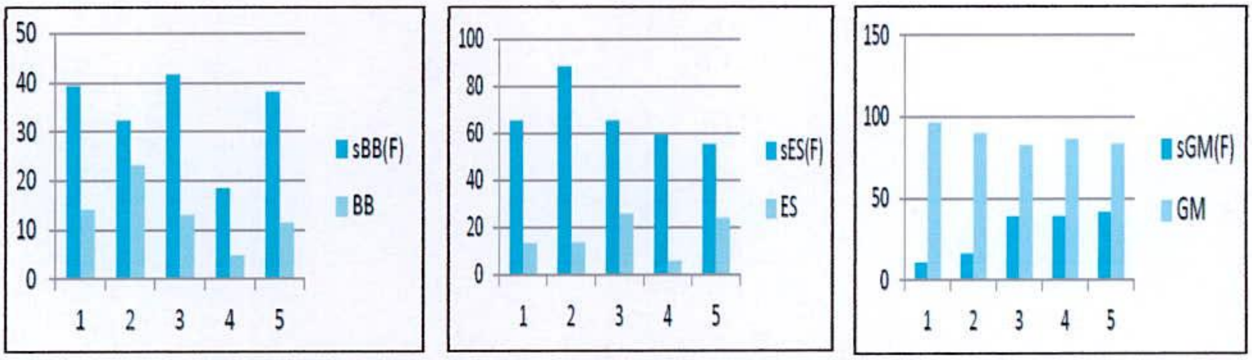


Figure 3.7: Comparison of average %active time for BB, ES, & GM for female subjects during *Salat* and exercise.

Figure 3.6 represents the comparison of average % active time for BB, ES, & GM muscles for five male subjects during *Salat* & exercise. This curve shows identical performance like table analysis which means during *Salat*, BB and ES establish better performance than Treadmill exercise and during Treadmill exercise, GM performs better activity. Figure 3.7 illustrates the comparison of average % active time for BB, ES, & GM muscles for five female subjects during *Salat* & exercise. Here, these curves confirm quite same performance like male subjects.

Accordingly, this study shows that the involved three muscles i.e., BB, ES, and GM play their own roles to produce the standing, bowing, prostration, and sitting movements. There are high EMG levels and moderate amount of force are counted through the investigation without less muscle fatigue against Treadmill exercise. There is a growing realization that regular participation in physical activity can gives us a lot of benefit for our health and muscle therapy.

3.5 Conclusion

This study describes the effect of bowing and prostration on the biomechanical response of human muscles. Muscle contraction and relaxation produce agonist-antagonist response which is essential for physical exercise. We have compared the activities of muscles between *Salat* and physical exercise i.e., Treadmill exercise in a refined way. The results specify that during *Salat*, BB and ES produce improved EMG level for both male and female subjects in opposition to Treadmill exercise. Therefore the aftermath of this work can conclude that, the person who performs *Salat* five times in a day is doing exercise of upper limb muscles especially the BB and ES muscles. In future work, the investigations can be extended to other muscles exercises either involving standing or sitting positions. This study can be useful for therapist in rehabilitation or exercise programs in addition to mankind for beneficial good for human health and longevity.

CHAPTER IV

Frequency Based EMG Power Spectrum Analysis in *Salat* Movement

4.1 Introduction

An EMG feature is a distinct characteristic of the signal which can be described or observed quantitatively, such as being large or small, spiky or smooth, and fast or slow. Generally, EMG features can be computed in numerical form from a finite length time interval and can change as a function of time, i.e. a voltage or a frequency. They can be computed in several domains, such as time domain, frequency domain, time frequency and time-scale representations [43]. However, frequency domain features show the better performance than other-domain features in case of the assessing muscle fatigue [44]. Mean frequency (MNF) is the most useful and popular frequency-domain feature and frequently used for the evaluation of muscle fatigue in surface EMG signals [45]. Time-domain features are frequently used as a muscle force detection tool, whereas their performance in the detection of muscle fatigue is a major drawback for these features. Effective domain of EMG feature analysis for the muscle fatigue detection is relying on frequency information [5].

EMG signal analysis is divided into three main issues: muscle force, muscle geometry and muscle fatigue [9]. To modify the global fatigue indices, mean frequency (MNF) and median frequency (MDF) can be used as a muscle force and fatigue index. Due to a drawback of MNF and MDF, that it has a non-linear relationship between muscle force and feature value, especially in large muscles and in cyclic dynamic contractions [10]. From our recent preliminary studies [10], [11], to solve the non-linear relationships between feature values and muscle loads, some ranges of MDF and MNF extracted from the consecutive FFTs showed a linear relationship of feature and muscle force level. In this study, modified MNF is proposed based on EMG signals recorded from BB muscle and ES muscle during *Salat*.

A number of literatures [12]–[14] showed a continuous increase of MDF and MNF as levels of muscle force increase. In contrast, MDF and MNF decrease with increasing force levels in a number of studies [15]–[17]. Moreover, in some researches, values of MDF and MNF are unaffected by change in muscle force (independent of the contraction levels) [18], [19]. To confirm the conflicting results mentioned above, the experiments are re-tested in this study; moreover, several possible reasons for the conflicting results are discussed. To modify these frequency-domain features to be the universal indices that can detect both muscle force and muscle fatigue, a modification of traditional MDF and MNF is proposed. Further, all literatures presented above were analyzed with EMG signal recorded from BB and ES during *Salat*. Moreover, *Salat* is a sacred Islamic prayer that's given by all those practicing the Muslim religion five times a day. *Salat* has precise steps; standing, bowing, prostration, and sitting etc.; which show muscle contraction and relaxation occur agonist-antagonist response which is good for human body. All muscles of human body become active without muscle fatigue during performing *Salat* according to previous chapter study [41].

In compare to [12]-[17], we have investigated mean and median frequency in frequency reliant power spectrum during saying holy prayer *Salat*. Above and beyond, we have evaluated the differences between mean and median frequency in power spectrum in *two raqat Salat*. But median frequency (MDF) didn't show any significant result to enhance the frequency domain features of EMG spectrum. Therefore, a modification of traditional MNF is proposed to adapt these frequency-domain features which can be used as a muscle force and fatigue index. In prospect works, the proposed method can be used in preference to use multiple features for the EMG signal analysis.

4.2 Proposed Method of Study

4.2.1 Mathematical Investigation:

Frequency-domain or spectral-domain features are usually used to assess muscle fatigue and to transform the EMG signal in the time-domain to the frequency-domain. A Fourier transform of the autocorrelation function of the EMG signal is employed to provide the power spectrum (PS) or the power spectral density (PSD). The MNF of a power spectrum, defined as the normalized, one-sided, first order spectral moment. The MDF defined as the particular frequency that divides the power spectrum into two parts of equal area. MNF is an average frequency which is calculated as the sum of product of the EMG power spectrum and the frequency divided by the total sum of the power spectrum. The definition of MNF is given as,

$$MNF = \frac{\sum_{i=1}^{M} F_i P_i}{\sum_{i=1}^{M} P_i} \tag{4.1}$$

Where, F_i, P_i, and M are frequency value, EMG power, and length of frequency window of frequency packet i, respectively.

MDF is a frequency at which the EMG power spectrum is divided into two regions with equal amplitude which can be equated as,

$$\sum_{i=1}^{MDF} P_i = \sum_{i=MDF}^{M} P_i = \frac{1}{2}\sum_{i=1}^{M} P_i \tag{4.2}$$

If we consider the frequency window as an exponentially distributed process, then the mean or expected value, *E*[*x*] of an exponentially distributed random variable *x* with rate parameter, λ and median of *x*, m[*x*] are given as,

$$E[x] = \frac{1}{\lambda} \tag{4.3}$$

$$m[x] = \frac{\ln(2)}{\lambda} < E[x] \tag{4.4}$$

Thus, the absolute difference between the mean and median can be evaluated by (4.5) accordance with the mean-median inequality.

$$|E[x] - m[x]| = \frac{1 - \ln(2)}{\lambda} < \frac{1}{\lambda} \tag{4.5}$$

Other spectral variables applied in the analysis of EMG signal are total power (TTP), mean power (MNP), peak frequency (PKF). TTP is the aggregation of EMG power spectrum and equal to the zero spectral moment (SM_0).

$$TTP = \sum_{i=1}^{M} P_i = SM_0 \tag{4.6}$$

MNP is an average power of EMG power spectrum. It is defined as,

$$MNP = \frac{\sum_{i=1}^{M} P_i}{M} \tag{4.7}$$

PKF is the frequency at which the maximum EMG power occurs which can be found as,

$$PKF = \max(P_i), \quad i=1, 2, 3\ldots.., M \tag{4.8}$$

With the help of aforementioned mathematical concept, we have acquired all the required features using Acqknowledge software during *Salat*.

4.2.2 Experimental Procedure and Apparatus:

To construct the simulating structure of this study, our main challenge was to collect EMG signals in different positions during *Salat* in proper approach. The EMG signals were recorded and analyzed by BIOPAC acquisition unit (MP36) and BIOPAC Student Lab 3.7 in Biomedical Signal Processing Laboratory, Department of BME, KUET. A total of 5 male and 3 female student subjects (approximate age range: 23 ± 2 years, approximate weight: 60 ± 4 Kg) of the university with no medical report on back pain were recruited as subjects for this study.

Table 4.1: Information of the Subjects

Subject Code	Age	Weight	Muscles	Comment
S11	23	58	BB, ES	Female
S12	23	56	BB, ES	Female
S13	25	58	BB, ES	Female
S14	22	63	BB, ES	Male
S15	21	64	BB, ES	Male
S16	22	64	BB, ES	Male
S17	26	68	BB, ES	Male
S18	23	65	BB, ES	Male

Following Table 4.1 contains detailed information of the concerned subjects. To obtain a stable and maximum pick up area of the EMG signals from each subject, the procedure for the EMG electrodes placement are referred from SENIAM recommendation. Our total working procedure is demonstrated by the flowchart in Figure 4.1 and Figure 4.2 shows the pictorial view of two involved muscles.

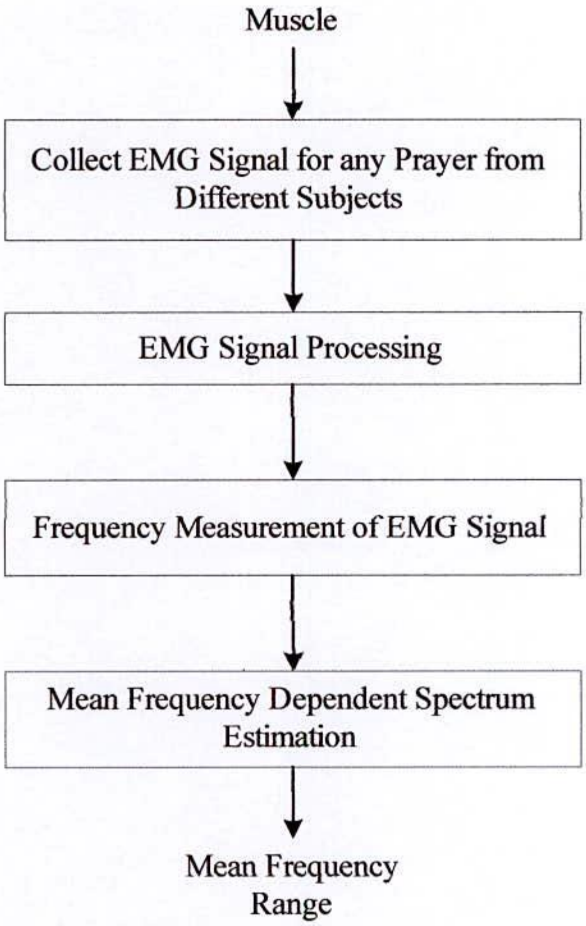
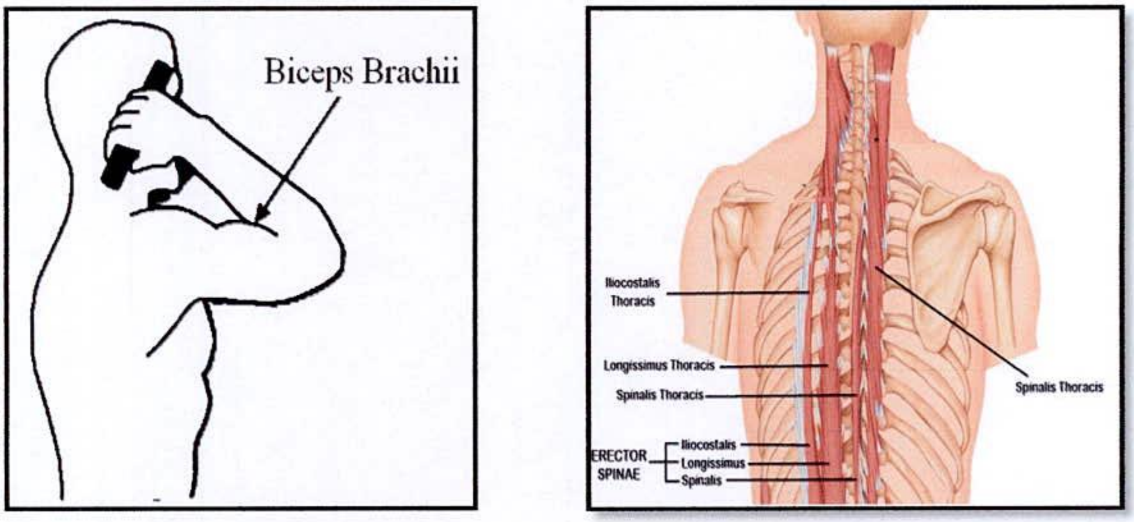


Figure 4.1: Flowchart of the proposed method for estimating mean frequency.



(a) (b)

Figure 4.2: The muscles involved in proposed study: (a) BB and (b) ES

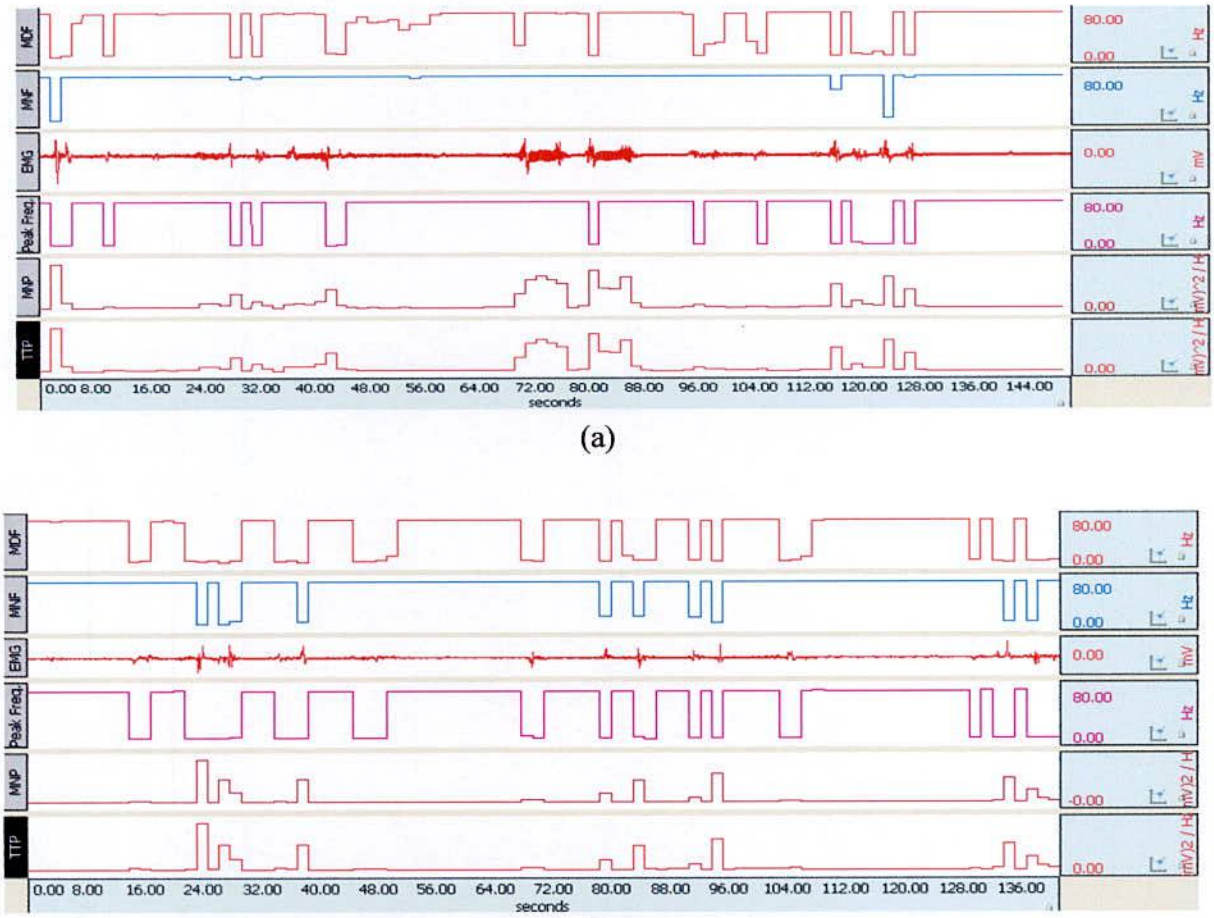
4.3 Data Acquisition

EMG signals were recorded by two surface electrodes on BB and ES muscle and reference electrode was placed on the wrist. The data recording procedures are illustrated by Figure 4.3. The collected EMG signals were sampled gradually at different rate of 256, 384, 512, 768 and 1024 per window for both male and female subject data. All the recorded EMG data were post-processed using Acqknowledge software, where the mean and median values were obtained from sampled data which were divided in separated window.

Figure 4.3: Data measurement during *Salat*; positions are: (a) Standing & Takbeer (b) Bowing (c) Prostration, and (d) Sitting & Finishing.

4.4 Experimental Consequences ad Discussions

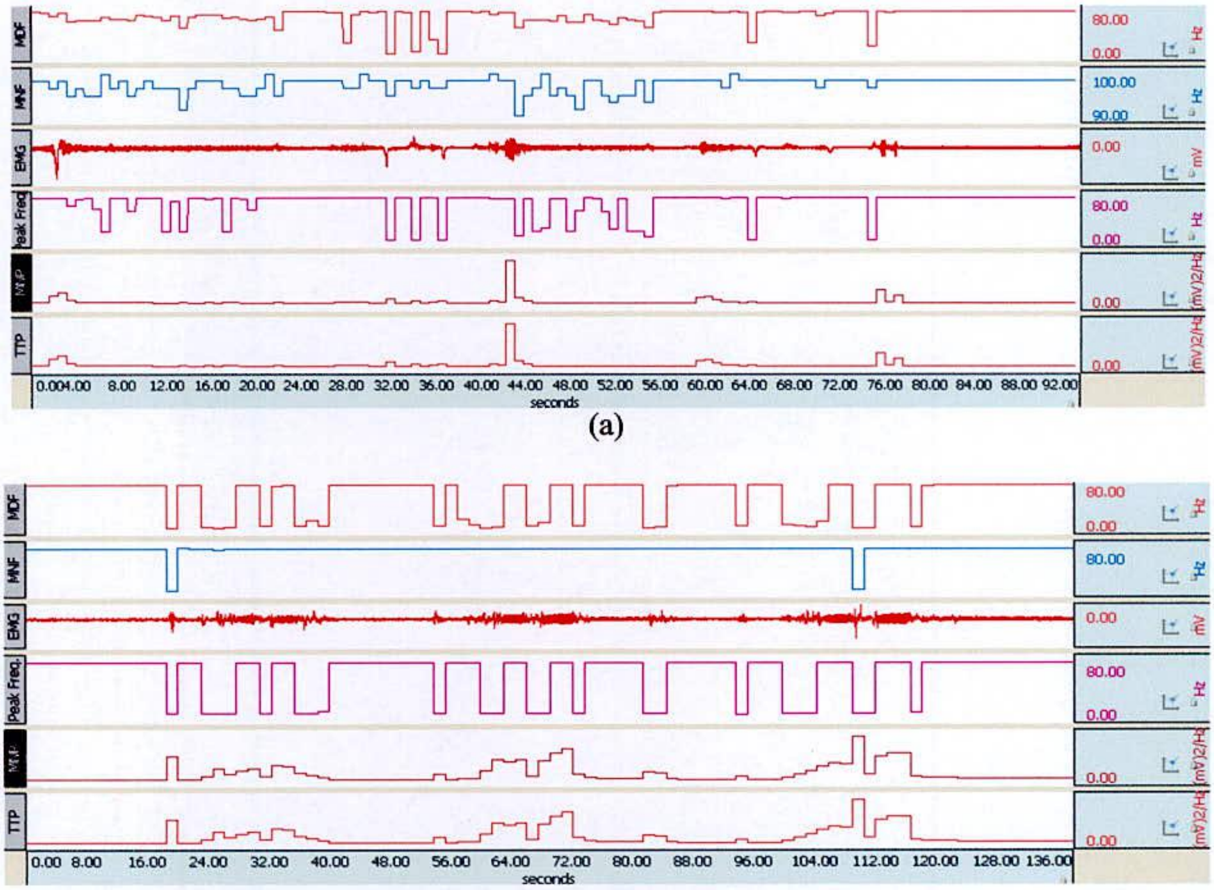
Figure 4.4 represents MDF, MNF, EMG, PKF, MNP, and TTP wave shapes along BB and ES muscle with 768-sample window size for male subjects during *Salat*. Window size 384 and 768 are used in this analysis. Because, 384 and 768 sampled window shows better condition for FB-MNF feature compare to other sampled window. With 768-sample window size for female subjects alongside of both muscles are shown in Figure 4.5. For automatic assessment, we used the same ranges of FB-MNF and FB-MDF to evaluate the correct position of sampled window.



(a)

(b)

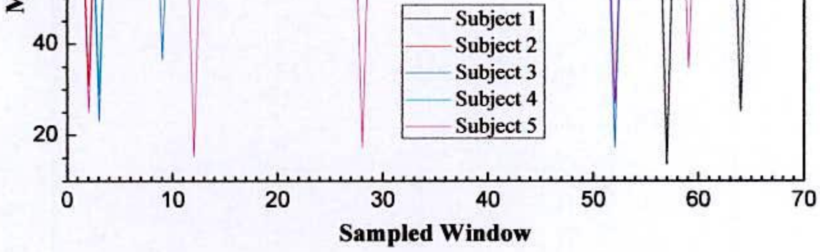
Figure 4.4: MDF, MNF, EMG, PKF, MNP, and TTP waveshapes for male subjects during *Salat* with 768-sample window size along a) Biceps Brachii (BB) muscle, b) Erector Spinae (ES) muscle.



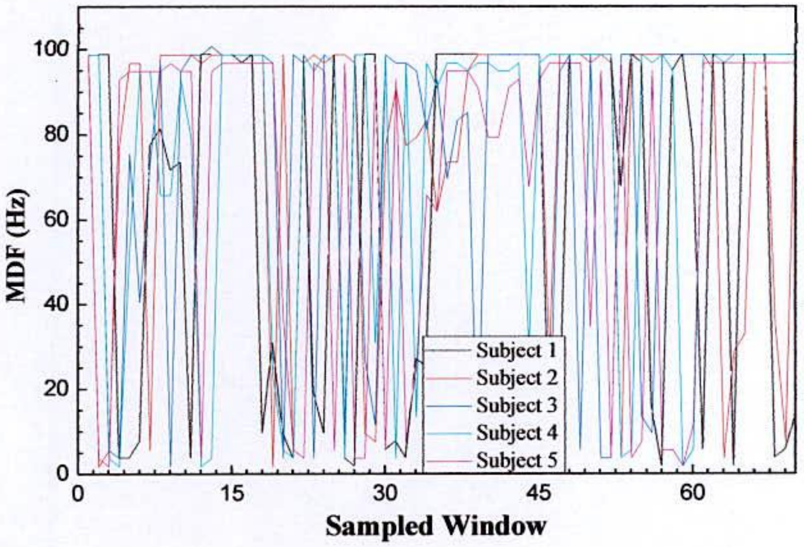
(a)

(b)

Figure 4.5: MDF, MNF, EMG, PKF, MNP, and TTP waveshapes for female subjects during *Salat* with 768-sample window size along a) Biceps Brachii (BB) muscle, b) Erector Spinae (ES) muscle.



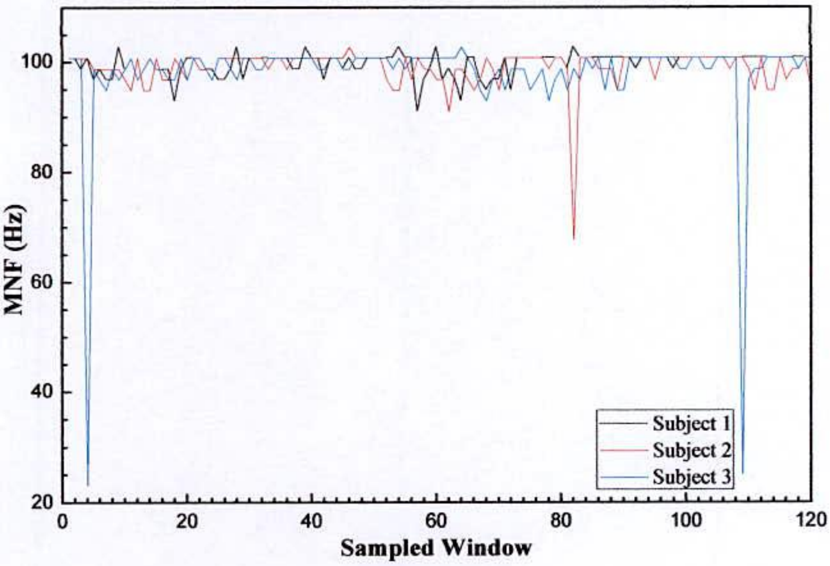
(a)



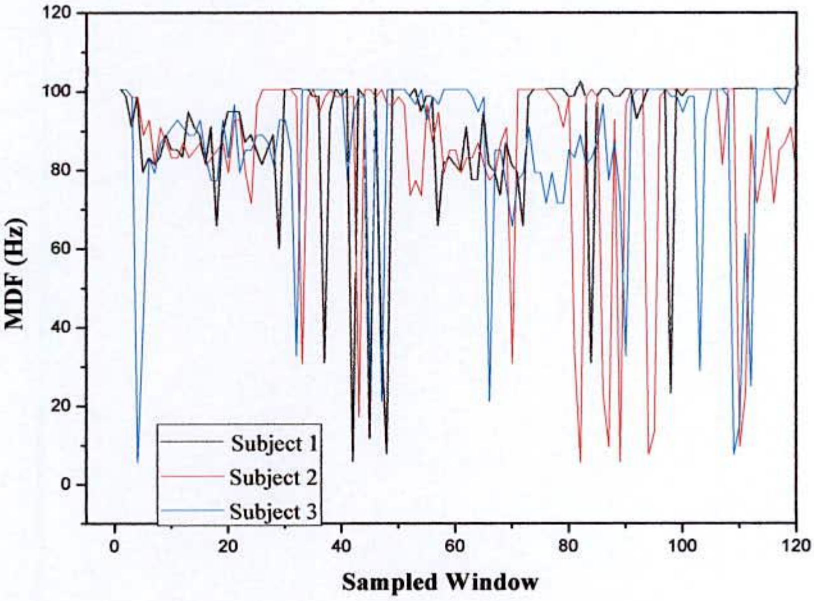
(b)

Figure 4.6: a) FB-MNF and b) FB-MDF of the Biceps Brachii muscle during *Salat* with 768-sample window size for different male subjects.

On top of Figure 4.6 shows FB-MNF and FB-MDF feature with 768-sample window size of BB muscle for different male subjects respectively. Here, FB-MDF curve is very much complex to analyze.



(a)

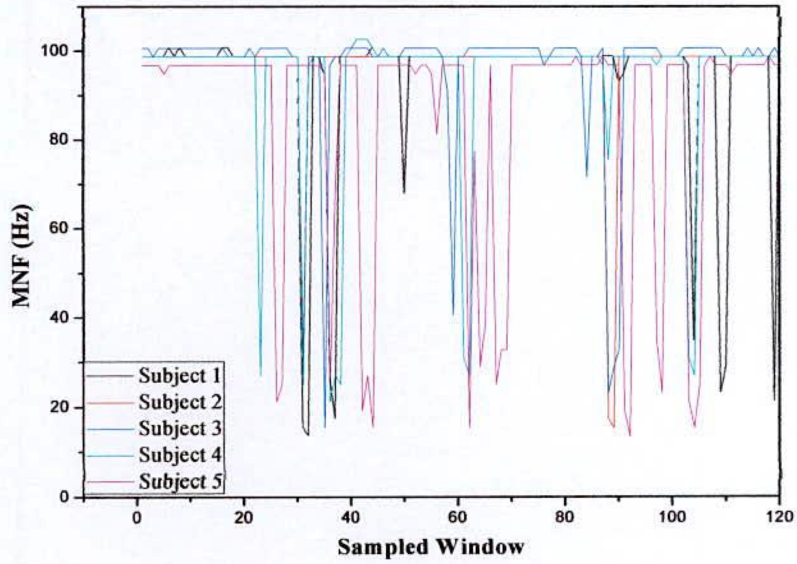


(b)

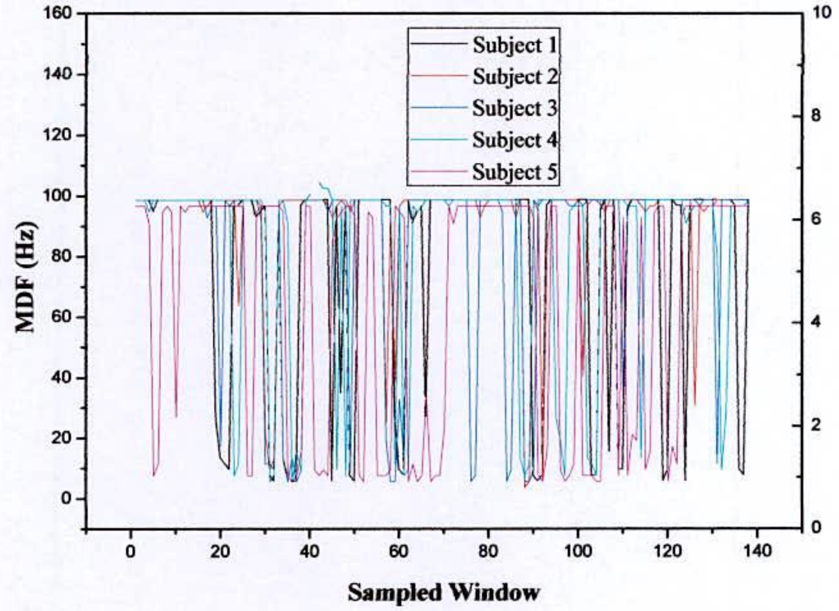
Figure 4.7: a) FB-MNF and b) FB-MDF of the Biceps Brachii muscle during *Salat* with 768-sample window size for different female subjects.

Subsequent Figure 4.7 shows FB-MNF and FB-MDF feature with 768-sample window size of BB muscle for different female subjects, respectively. As we have chosen three female subjects for experiment, so the following curves show features for 3 subjects.

Following Figure 4.8 and Figure 4.9 show FB-MNF and FB-MDF features with 768-sample window size of ES muscle for different male and female subjects respectively.

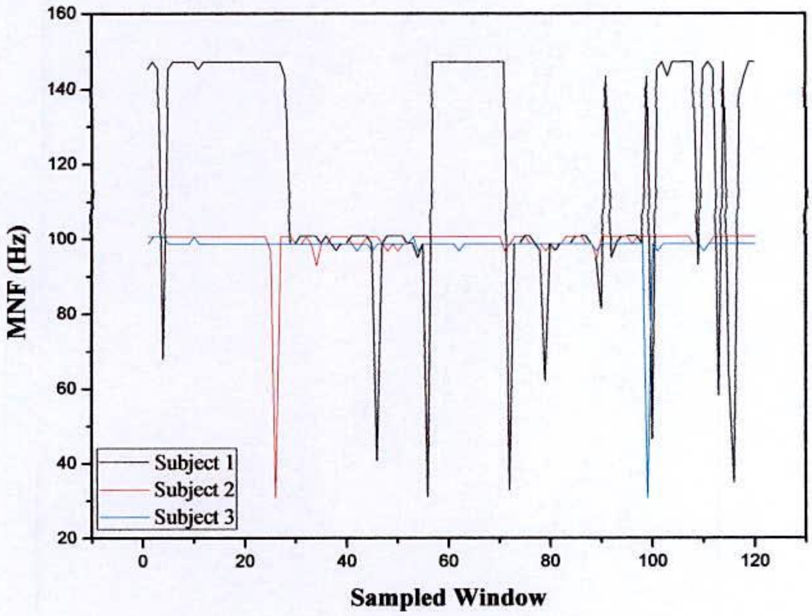


(a)

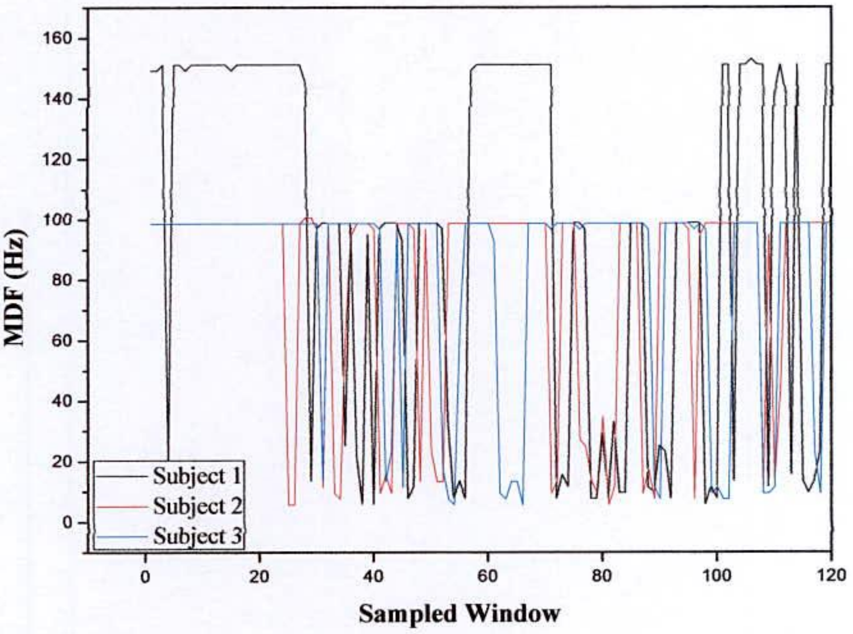


(b)

Figure 4.8: a) FB-MNF and b) FB-MDF of the Erector Spinae muscle during *Salat* with 768-sample window size for different male subjects.



(a)



(b)

Figure 4.9: a) FB-MNF and b) FB-MDF of the Erector Spinae muscle during *Salat* with 768-sample window size for different female subjects.

By similar process, we have plotted all the results of suitable ranges of sample window of FB-MNF values which are reported in Table 4.2 and Table 4.3. Significant difference occurs between selected ranges for different window size, muscle, and gender conditions. From Table 4.2, it is observed that both 384-sample and 768-sample window cover two suitable ranges along side of BB muscle for male subjects. Like Table 4.2, Table 4.3 describes the suitable ranges for ES muscle that for both male and female subjects where 768-sample window wraps the better performance than other windows. In Table 4.2, according to female subjects, only 384-sample window covers the maximum number of suitable range position which is 21.

We also computed both MNP and TTP around 5 MV^2/ Hz, PKF more than 80 Hz in selected range for each male subject in 768-sample window during BB muscle contraction in *Salat*. Comparing the MNP and TTP along ES muscle for male subjects shows quite less value than BB which is around 3.5 MV^2/Hz. On other side, PKF shows approximately 85 Hz higher than BB muscle during the period of muscle contraction. In proportion to female subjects, it appears quite same situation for MNP, TTP and PKF values like male subjects in the contraction period of *Salat*.

Table 4.2: Sampled Window Size with a Suitable Range of FB-MNF for BB Muscle

L	Selected Range Positions		No. of Selected Position	
	Male	***Female***	***Male***	***Female***
384	28-44, 62-76	50-70	17, 15	21
512	27-32, 46-68	62-80	6, 23	19
768	12-26, 32-48	8-25	15, 17	18
1024	12-18, 24-35	6-20	7, 12	15

Table 4.3: Sampled Window Size with a Suitable Range of FB-MNF for ES Muscle

L	Selected Range Positions		No. of Selected Positions	
	Male	***Female***	***Male***	***Female***
384	8-17	32-42	10	11
512	6-12, 52-58	24-37	7, 7	14
768	1-12, 35-43	16-26, 42-46	12, 9	11, 5
1024	1-7, 27-32	13-20	7, 6	8

4.5 Conclusion

In this proposal of frequency based sampled EMG data for different subjects to extract the Mean Frequency feature, we have evaluated the EMG power spectrum during *Salat* that was associated with muscle contraction of human body for both male and female subjects. TTP and MNP consumed per subject were also computed as well as peak frequency is measured during muscle contraction period. Moreover, in our study, the proposed modification of FB-MNF can be used to determine both muscle force and muscle fatigue. However, total experiment was determined through the long period of two *raqat Salat*, which was quite difficult for calculating the whole EMG data.

CHAPTER V

Work Done Estimation in Upper Limb and Lower Limb Muscles

5.1 Motivation

Any human movement is produced by muscular and skeletal systems controlled by the nervous system. Many biomechanical researches have revealed mechanism of the human body dynamics. Some musculoskeletal models of whole body have been developed and reported in a number of investigations [46]. In skeletal muscle, contraction is stimulated by electrical impulses transmitted by the nerves, the motor-neurons (motor nerves) in particular. The electrical potential generated by muscle cells is detected by EMG, when these cells are electrically or neurologically activated. EMG is an electro diagnostic medicine technique for evaluating and recording the electrical activity produced by skeletal muscles which allows the measurement of the change in the membrane potential which is transmitted along the fiber [3]. An EMG is the summation of action potentials from the muscle fibers under the electrodes placed on the skin. Action potential is a short-lasting event in which the electrical membrane potential of a cell rapidly rises and falls. When an action potential is triggered, the membrane potential abruptly shoots upward, often reaching as high as +100 mV. Due to muscle contractions, action potentials are generated which we can measure through EMG analysis. sEMG is a non-invasive technique for measuring the electrical activity of muscle that occurs during muscle contraction and relaxation cycles [41].

Muscle work is an important biomechanical quantity in human movement investigations and has been estimated using different quantities including external, internal and joint work. Measurement of biomechanical work done is critical for understanding due to muscle-tendon function, joint specific contributions and energy-saving mechanisms during gait. Any human movement, produced by muscular and skeletal systems is stimulated by electrical impulses.

The upper and lower-limb motions are very important for the human daily activities, such as any types of work, sitting down, bending down, walking, ascending and descending stairs. For physically disabled persons, it is really difficult to perform daily motions. Recently, power-assist robotic systems have been developed to assist physically weak persons' daily life motions [47]. These power-assist robotic systems are mainly activated based on the user's sEMG signals which directly reflect the muscle activity levels of the user. Earlier, it is said that sEMG is a non-invasive technique, in which surface electrodes are placed on the skin over a muscle and are mainly used for investigated superficial muscle [41]. The work done estimation from EMG signals are important information for power-assist robotic systems to understand how the user intends to move. Therefore, it is important to analyze the relationships between the human upper and lower-limb muscles activities and EMG signals to perform the power-assist of the lower-limb motion. The goal of this study is to investigate the mathematical relationships between work done activities and EMG signal with proper curve fitting.

By sEMG analysis, there are a large number of investigations [4], [20]-[22] by several authors. A relation between muscle force and joint moment is analyzed in [20]. Authors in [21], studied the muscle force with EMG and in [22], authors studied muscle force and sEMG where normalized EMG strength versus increment rate of force carried by muscle was calculated. Through sEMG, joint torque estimating model was proposed in [23]. But there are several research findings that show the relationships between the human lower-limb motions and related muscles activities. Force and moment estimation of lower limb joints is studied in [48]. The survey of muscle and joint forces in the human lower extremity during rising motion is performed in [49]. Authors in [4] and [50] investigated EMG activity of the lower limb muscles such as medial gastrocnemius, lateral gastrocnemius muscle, etc. during *Salat* and specific exercises.

On the basis of wide research studies related to this work, we do not get any information about the direct relation between work done and cumulative muscle potential i.e. EMG signals. As we know that, an EMG is the summation of action potentials from the muscle fibers. But it is really significant proposal to estimate the total work done from an EMG signal. In this study, we have proposed such an efficient expression that is properly able to estimate the work done or how much calorie burn to complete the work from the sEMG signal. In this proposal, at first we have collected a number of data of known work done and corresponding cumulative sEMG signal in mV. After recording the data, the mean sEMG signal in mV are calculated. By this result, we have shown that the cumulative action potential and the corresponding work done obey a linear or a non-linear relationship. By applying linear or parabolic regression, the relationships are established. Furthermore, the procedure to estimate the work done for a specific work from recorded EMG voltage is also presented by mathematical equation.

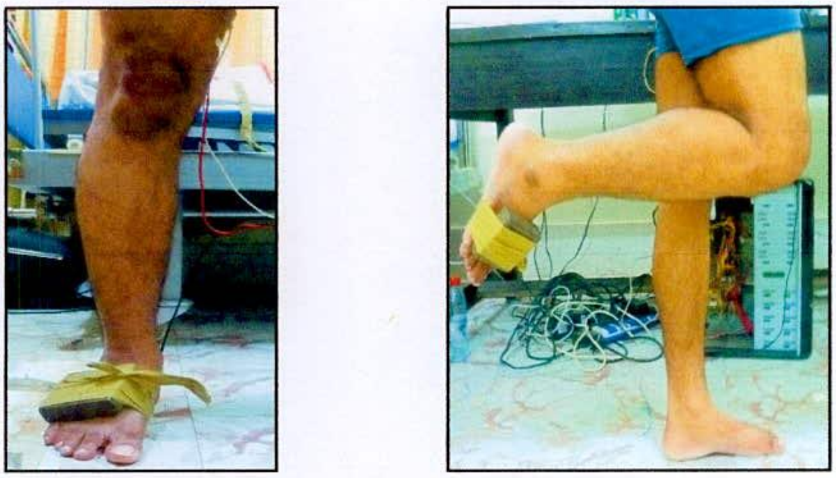
Amount of work cannot be easily measured in vivo. Therefore, the work done from muscles must be assessed, calculated or mathematically modeled during various amount of work done. By this mathematical modeling, we can differentiate as well as compare various kind of work output in terms of calorie or joule which helps to determine muscle fatigue, muscle work done, identify exercise which burnt calorie more or less to keep our human body fit and sound.

5.2 Proposed Methodology

5.2.1 Physical Procedure of the Method:

The maximum force that a limb is able to apply externally varies with angular position. This is because the geometrical arrangement determines the degree of mechanical advantage. We have chosen two muscles Biceps Brachii (BB) and Flexor Carpi Radialis (FCR) from upper limb of human body. Because, when a weight is lifted by right hand; then these two muscles are activated simultaneously which helps to acquire data and electrode placement. In this work, BB was upheld alongside of FCR with angular position approximate 90°. In proportion to lower limb, we have performed the work along Biceps Femoris (BF) and Medial Gastrocnemius (MG) muscles. The physical position of upper and lower limb muscles of human body has been shown in corresponding Figure 5.1 and Figure 5.2 respectively.

Figure 5.1: Approximate 90^0 angular positions between BB and FCR in right hand of upper limb muscles.



(a) (b)

Figure 5.2: Lower limb muscles condition in right leg (a) at parallel of human body, (b) at approximate 90^0 angle between BF and MG.

5.2.2 Work Done Calculation:

In order to accomplish work on an object, there must be a force exerted on the object and it must move in the direction of the force. Basically, there are three types of factors responsible to complete work. They are force, displacement, and direction.

If the work done is due to force F, the displacement is d and the angular movement of the object with the direction of force is θ, then the amount of work done, W by this given force can be expressed mathematically as,

$$W = F \times S \times \cos\theta \tag{5.1}$$

According to this proposed procedure, we have done the work by lifting a weight of m kg against gravity from 0 to h meter, then the equation become as,

$$W = m \times g \times h \tag{5.2}$$

Where, g is the gravitational constant of value 9.81ms^{-2} on earth.

5.2.3 Formulation to Relate Work Done and EMG Potentials:

Basically, we want to relate this physical work done relation with EMG cumulative potentials. For this reason, we have merged the known work done values through corresponding EMG potential result of same work such as lifting different weights towards fixed direction. As a result, we can see that in proportion to increasing work done EMG potential follows a non-linear relationship.

If any set of data is nonlinear which can be considered as parabolic, then in general the set of data can be represented by (5.3), where the value of the coefficients *a*, *b*, and *c* depends on the shape of the curve.

$$y = a + bx + cx^2 \tag{5.3}$$

According to least-square fitting, we have to fitted the parabola to the given points (x_1, y_1), (x_2, y_2),.........., (x_n, y_n). If the error for the estimated value and measured value is *e*, then summation of error, $S = \sum e_i^2 = (y_i - bx_i - cx_i^2)^2$. By the principle of least square, the value of *S* is minimum; therefore,

$$\frac{\partial S}{\partial a} = 0, \frac{\partial S}{\partial b} = 0, \frac{\partial S}{\partial c} = 0 \tag{5.4}$$

By solving (2) and dropping suffix, we have

$$\begin{cases} \sum y = na + b\sum x + c\sum x^2 \\ \sum xy = a\sum x + b\sum x^2 + c\sum x^3 \\ \sum x^2 y = a\sum x^2 + b\sum x^3 + c\sum x^4 \end{cases} \tag{5.5}$$

We can get the values of *a*, *b*, and *c* by solving (5.5). Putting the value of *a*, *b*, and *c* in (5.3), we can get the equation of the parabola for best fit as well as non linear relationship between work done and EMG results for upper and lower limb muscles.

5.2.4 Procedure of Acquiring EMG Signal:

For the data acquisition of the corresponding study several steps are followed properly. Every step for this study is related to the data acquisition mentioned which is shown in Figure 5.3.

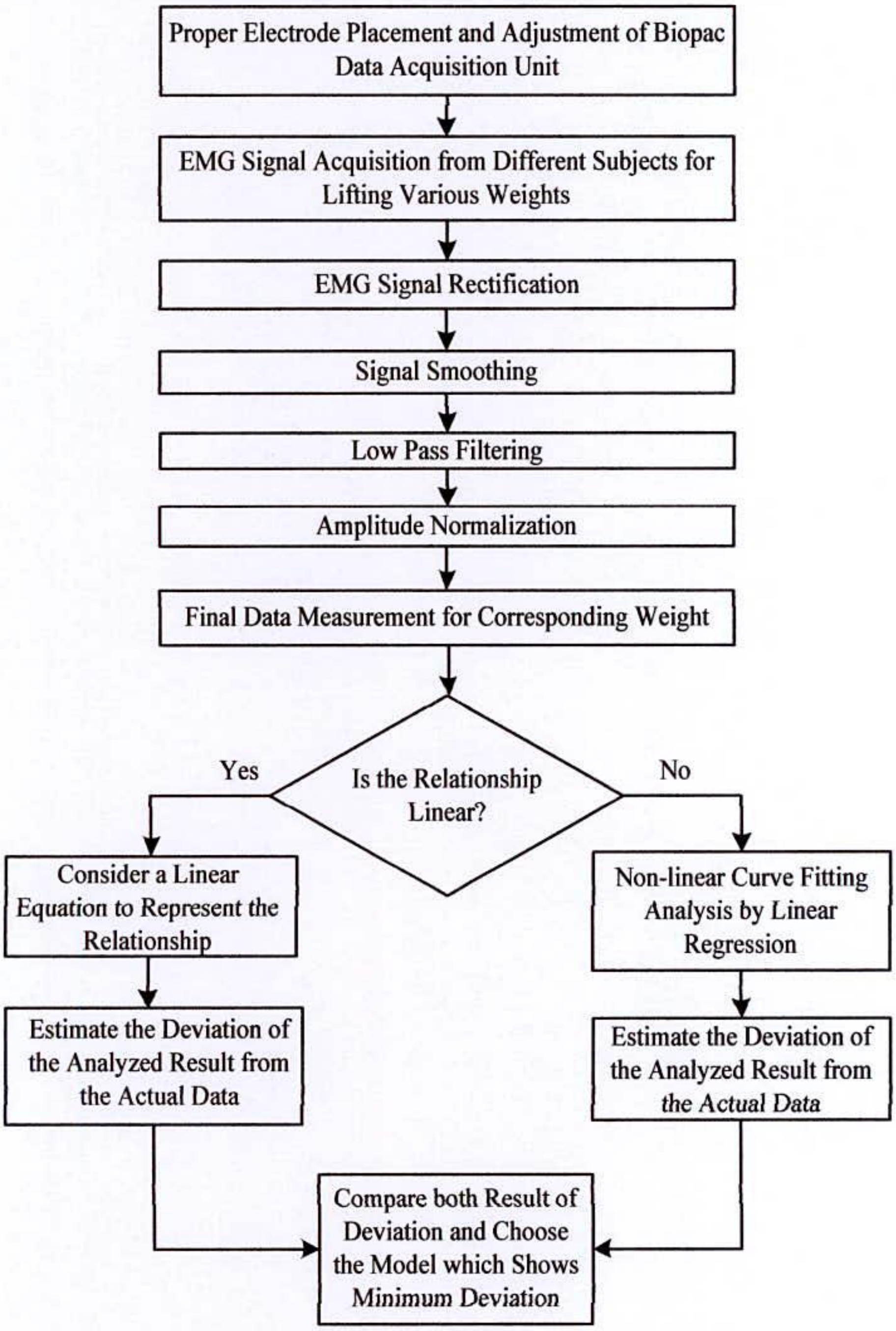


Figure 5.3: Flow chart of the proposed data acquisition procedure

5.3 Experimental Procedure

5.3.1 Data Acquisition Method:

As we know, the muscle movement of our body creates action potential. Therefore, different work done produces different action potential according to the amount of work done. There is no direct procedure to estimate such potential to work done relationship. An indirect procedure can be established for estimating this relationship. For example, by performing a known amount of work done we can collect the cumulative action potential or EMG data. To do this, we demonstrate a procedure through some practical step in our laboratory which can be described by the following steps:

Step 1: First of all, we select a height where lifting a weight maintain approximate 90 degree angle between the Biceps Brachii (BB) and Flexor Carpi Radialis (FCR), while the Biceps Brachii will be at the parallel of upper limb of the body as shown in Figure 5.1. For lower limb position, we selected Biceps Femoris (BF- upper portion) and Medial Gastrocnemius (MG- lower portion) muscles of right leg to lift the weights.

Step 2: We choose some weights to lift which were available in our laboratory. The weights were 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, 2, 2.25, 2.5, 2.75, and 3 kg which we can easily lift in the height level from floor to 0.50 meter.

Step 3: The EMG data have been collected from the subjects performing to lift different weights from floor= 0 m to 0.50 meter. In this case, we selected Biceps Brachii muscle of right hand and Medial Gastrocnemius muscle of right leg to lift the weights.

Step 4: After collecting the EMG data which resembles the action potential of the BB, BF and MG, we have plotted different curves weight (kg) versus action potential (mV) for male and female subjects respectively.

Step 5: These curves show approximate non-linear parabolic relationship between weight load and EMG data i.e. action potentials. On the basis of the non-linearity, we executed interpolation and extrapolation.

5.3.2 Subject Selection and Laboratory Specification:

The total experiment was divided into two parts. First part was for upper limb muscles and second part for lower limb muscles.

For upper limb muscle experiment:

The experimental data for this study were collected from 14 subjects among them eight are male and six are female subjects (approximate age: 25 ± 2 years and weight: 63 ± 6 kg) with no medical problems. All information is tabulated in Table 5.1 which is given below. The total experiment was performed in Biomedical Signal Processing Laboratory, Department of BME, Khulna University of Engineering & Technology (KUET), Bangladesh.

Table 5.1: Information of the Subjects (For Upper Limb Muscles)

Subject Code	Age	Weight	Muscles	Comment
S19	26	68	BB, FCR	Male
S20	25	58	BB, FCR	Female
S21	26	68	BB, FCR	Male
S22	26	68	BB, FCR	Male
S23	23	68	BB, FCR	Male
S24	25	60	BB, FCR	Female
S25	29	52	BB, FCR	Female
S26	25	60	BB, FCR	Female
S27	25	63	BB, FCR	Male
S28	26	68	BB, FCR	Male
S29	21	52	BB, FCR	Female
S30	25	58	BB, FCR	Female
S31	26	68	BB, FCR	Male
S32	26	68	BB, FCR	Male

For lower limb muscle experiment:

A total of eight healthy male subjects without any disease were recruited as subjects to acquire the experimental data of this study. Entire information is charted in Table 5.2 which is given on next page.We did not experiment on female subjects due to difficult physical terms of lower limb muscles. Subject's age, height, and weight ranges were 25± 1 years, 165±5 cm, and 66 ± 3 kg respectively. The diameter of leg was 50±5 cm. The total experiment was performed in same Biomedical Signal Processing Laboratory, Department of BME, Khulna University of Engineering & Technology (KUET), Bangladesh. Subjects were verbally informed about the experimental protocols, and they read and signed a consent form prior to participating in the experiments.

Table 5.2: Information of the Subjects (For Lower Limb Muscles)

Subject Code	Age	Weight	Muscles	Comment
S33	26	68	MG	Male
S34	26	68	MG	Male
S35	26	68	MG	Male
S36	26	68	MG	Male
S37	23	62	MG	Male
S38	25	63	MG	Male
S39	25	63	MG	Male
S40	26	68	MG	Male

5.3.3 Apparatus Specification:

Prior to electrode placement, the skin was cleaned with abrasive pad and BIOPAC electrode gel (GEL101) was applied beneath the electrodes to reduce line impedance. BIOPAC disposable vinyl electrodes (EL503) with a diameter of one cm were affixed over the chosen muscle groups, parallel to their fiber orientation at the muscle belly. To press electrodes, 3M Coban Self-adhering Support Wrap were applied against head for improving contact. The electrodes were associated to an EMG data collection system (Biopac Student Lab 3.7 and BIOPAC data acquisition unit) (MP36). For analysing the collected data, Acqknowledge 4.1 software was used. Electrode placement and arrangement along Biceps Brachii of subjects are shown in Figure 5.4.

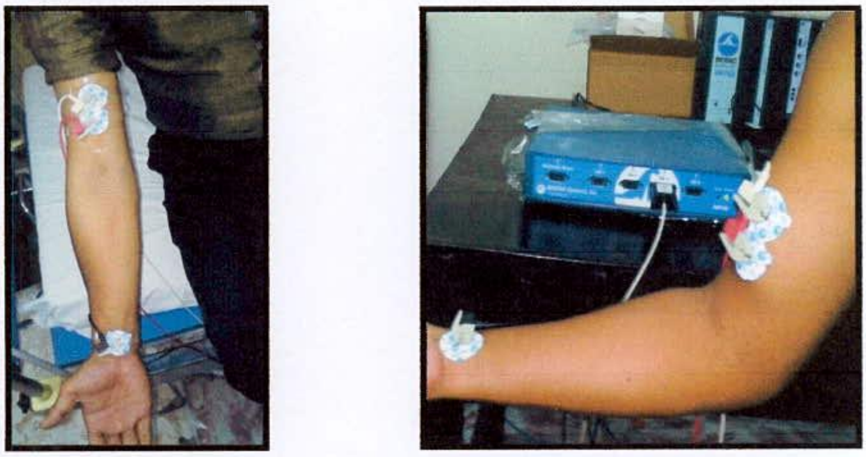


Figure 5.4: Electrode placement and lead setting arrangement along Biceps Brachii of subjects.


(a) (b)

Figure 5.5: Electrode placement on lower limb muscles (a) BF, (b) MG.

For lower limb experiment, electrodes were attached to the right leg over the belly of the Biceps Femoris (BF) and Medial Gastrocnemius (MG). The electrodes together with BIOPAC electrode lead set (SS2L) were fixed on BF and MG muscles. The electrodes were placed according to the SENIAM recommendation [33]. The location of electrodes on lower-limb muscles is shown in Figure 5.5.

5.4 Experimental Outcomes and Discussions

According to the aforesaid statement, the total study is divided into two parts: i) for upper limb and ii) lower limb. That is why the experimental results and corresponding discussions are also presented here in two different subsections.

5.4.1 Results and Discussions for Upper Limb:

We have chosen six types of mass such as, 0.25kg, 0.50 kg, 1 kg, 1.5 kg, 2 kg and 2.5 kg. The height is selected as 0.50 meter and it is well known to all that the standard of gravity, g =9.81 ms^{-2}. Therefore, for lifting *m* kg mass, the amount of work will be $W= (m\times 9.81\times 0.50)$ joule or $W/4.2$ calorie (cal) [4.2 joule = 1 calorie]. The EMG signals of some weight lifting from our experiment are shown in Figure 5.6. During lifting weights, incrementing weight over 2 kg undergoes in saturated EMG potential. It resembles the fatigue point of that muscle as the experiment is based on BB muscle. In addition, the various weight and corresponding work done is tabulated in Table 5.3.

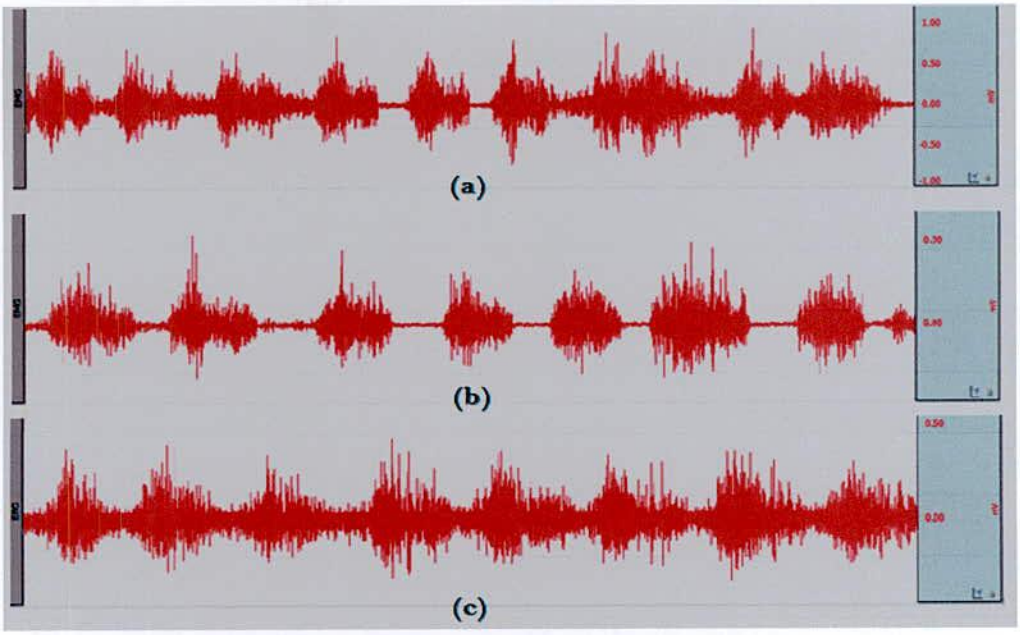


Figure 5.6: Sample EMG signal in Acqknowledge 4.1 software- for (a) 2.5 kg, (b) 2 kg, and (c) 1 kg weight lifting.

Table 5.3: Work Done and Calorie Burn for Different Weights (Upper Limb)

SL#	Weight in Kg	Work Done (J)	Calorie (Cal)
1	0.25	1.22625	0.2919
2	0.50	2.4525	0.58392
3	1.00	4.905	1.16785
4	1.50	7.3575	1.751
5	2.00	9.81	2.335
6	2.50	12.2625	2.919

As shown in Figure 5.6, by the help of Acqknowledge software, the mean EMG voltage for every subject is acquired and among them; data of 3 male and 3 female are given by Table 5.4 and Table 5.5. In these tables, mean and standard deviation of the data are also determined and tabularized. From the data tables, we can observe that an approximately (not exactly) linear relationship exists between work done and action potential or EMG voltage.

Table 5.4: Measured Action Potential Value for Different Weights (Male)

SL#	Wt. (Kg)	S1 (mV)	S2 (mV)	S3 (mV)	Mean (mV)	St. Dev (mV)
1	0	0.22807	0.20498	0.21182	0.214957	0.011860
2	0.25	0.25574	0.26347	0.24607	0.255093	0.008718
3	0.50	0.37129	0.36925	0.36233	0.367623	0.004696
4	1.0	0.58430	0.57751	0.56895	0.57692	0.007692
5	1.5	0.69906	0.70258	0.68294	0.69486	0.010472
6	2.0	0.78043	0.76568	0.76201	0.769373	0.009750
7	2.5	0.90514	0.88703	0.86878	0.886983	0.018180
Mean Standard Deviation=0.010195 mV						

Table 5.5: Measured Action Potential Value for Different Weights (Female)

SL#	Wt. (Kg)	S1 (mV)	S2 (mV)	S3 (mV)	Mean (mV)	St. Dev (mV)
1	0	0.20902	0.21417	0.22402	0.2157367	0.0076217
2	0.25	0.25021	0.26112	0.26951	0.26028	0.0096774
3	0.50	0.37672	0.36931	0.37258	0.37287	0.0037135
4	1.0	0.56912	0.58483	0.57388	0.5759433	0.0080557
5	1.5	0.69112	0.68135	0.68013	0.6842	0.0060239
6	2.0	0.76844	0.77474	0.78018	0.7744533	0.0058752
7	2.5	0.90262	0.89214	0.93426	0.9096733	0.0219280
Mean Standard Deviation=0.008985054 mV						

From the results tabulated in Table 5.4 and Table 5.5, we took the mean voltage value from all subjects and plotted it against work done which is shown in Figure 5.7.

From linear regression analysis the relationship between weight-EMG is given in (5.6),

$$y_{line} = 0.2111 + 0.05569x \tag{5.6}$$

From Figure 5.7, it is observed that the results, we got through our experiment is not exactly linear. The relation can be considered as approximately parabolic.

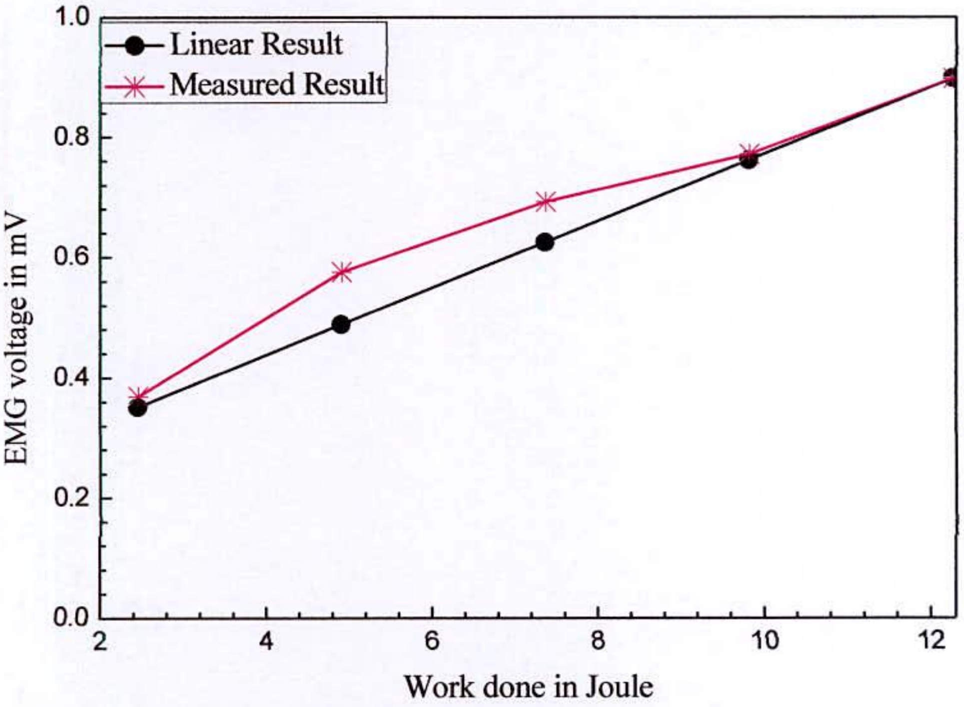


Figure 5.7: Deviation of measured and conceptual relationship

Basically, this apparently linear consideration is not correct at all. Therefore to reach the more accuracy of the measure result a nonlinear curve fitting is performed on the measured data. By nonlinear curve fitting the mathematical relationship we get, is given in (5.7),

$$y = 0.2111 + 0.3842x - 0.0455x^2 \tag{5.7}$$

The EMG voltage can be evaluated by (5.7) when the independent variable 'x' is considered as weight. From (5.7), it is also mentionable that when we consider the lifting weight is zero, then the EMG voltage will be 0.2111 which is exactly as our experimental value. It means that, without lifting any weight, according to our working procedure muscle extract EMG voltage is 0.2111mV. Nevertheless, our target is to relate EMG with work done. Therefore, another mathematical relation is also depicted to relate EMG voltage and work done which is given in (5.8),

$$Y_2 = 0.2111 + 0.0783i - 0.0019i^2 \tag{5.8}$$

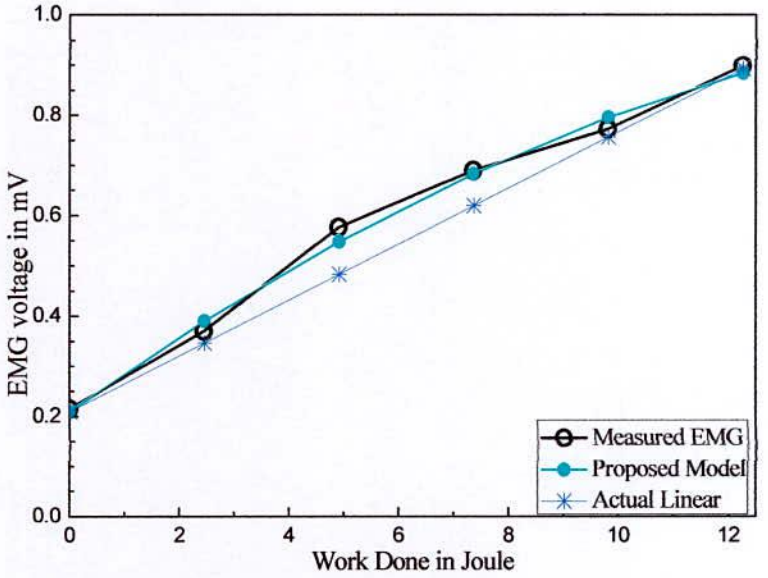


Figure 5.8: Impact of proposed mathematical model in error declination.

As a result, the actual relationship between work done and EMG voltage can be evaluated from (5.8) when the independent variable 'i' is considered as the work done in Joule. Furthermore, the EMG voltage from (5.7) and (5.8) will be in mV unit. From (5.7), we have calculated the voltage level of the given work done and their result and error is given in Table 5.6. Eventually to prove the accuracy of our result we choose two different weights (0.75 kg and 1.75 kg) and evaluate their corresponding EMG voltage from the Figure 5.8 by interpolation. After that, we invite two different subjects for the study of the mentioned weight i.e. 0.75 and 1.75 kg from each. The result of the study is given in Table 5.7 where it is found that very low level of error exists between our proposed mathematical model and measured result. As the result we get successfully provide strong evidence of the accuracy of our proposed hypothesis on the relation between work done and cumulative action potential (EMG voltage).

Table 5.6: Error Measurement after Constant Correction

SL#	Work done, J	Measured voltage in mV, M	Estimated value in mV, E	Error, |M-E|
1	0	0.21534	0.2111	0.00424
2	2.4525	0.3702465	0.3917	0.02145
3	4.905	0.57643165	0.5494	0.02703
4	7.3575	0.68953	0.6843	0.00523
5	9.81	0.77191315	0.7964	0.02448
6	12.2625	0.89832815	0.8856	0.01272

Table 5.7: Accuracy Testing of the Proposed Hypothesis

SL#	Work done in Joule	Measured voltage in mV (Subject 1)	Measured voltage in mV (Subject 2)	EMG voltage from graph	Error
1	3.67875	0.4725	0.4674	0.4734	0.00345
2	8.58375	0.7428	0.7314	0.7432	0.00611

Table 5.8: Work Done and Calorie Burn for Different Weights (Lower Limb)

Serial No.	Weight in Kg	Work Done in Joule	Amount of Burnt Calorie (cal)
1	0.25	1.22625	0.2919
2	0.50	2.4525	0.58392
3	0.75	3.67875	0.87589
4	1.00	4.905	1.16785
5	1.25	6.13125	1.45982
6	1.50	7.3575	1.751
7	1.75	8.58375	2.04375
8	2.00	9.81	2.335
9	2.25	11.03625	2.62767
10	2.50	12.2625	2.919
11	2.75	13.48875	3.211607
12	3.0	14.715	3.5035

5.4.2 Results and Discussions for Lower Limb:

We choose some weights to lift which were available in our laboratory. The weights were 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, 2, 2.25, 2.5, 2.75, and 3 kg which we can easily lift in the selected height level. The EMG data have been collected from the subjects performing to lift different weights from floor= 0 m to 0.50 meter. In this case, we selected BF (upper portion) and MG (lower portion) muscles of right leg to lift the weights. In addition, the various weight and corresponding work done which we have used in this experiment are charted in Table 5.8.

We have extracted all EMG data of different subjects in different trials. Then the right window is chosen to analyze the whole process. From that window, ultimate data were extorted for locating muscle activity points for both muscles. We have measured peak to peak point value of each activity level point. Then all the data were tabulated in a chart. Among them, we took out mean EMG value of each subject including different trials. Acquired EMG potential, mean value, and corresponding standard deviated value for BF and MG muscles are given in Table 5.9 and Table 5.10, respectively. According to data we got, different curves of weight (kg) versus action potential (mV) are plotted to demonstrate the characteristics of two aforementioned parameters.

Table 5.9: Measured Action Potential Value for Different Weights for BF Muscles

SL #	Wt. (Kg)	S1 (mV)	S2 (mV)	S3 (mV)	Mean (mV)	St. Dev (mV)
01	0	0.86832	0.82415	0.87076	0.85441	0.02142
02	0.25	0.9292	0.90145	0.93647	0.92237	0.01508
03	0.5	1.00453	0.96412	1.10243	1.02369	0.05806
04	0.75	1.31286	1.32246	1.29415	1.30982	0.01175
05	1	1.47847	1.48920	1.45621	1.47462	0.01374
06	1.25	1.51443	1.48651	1.53241	1.51112	0.01888
07	1.5	1.53076	1.52884	1.54278	1.53413	0.00616
08	1.75	1.55518	1.54512	1.58416	1.56148	0.01655
09	2	1.65832	1.66241	1.64219	1.65430	0.00872
10	2.5	1.66457	1.70169	1.68292	1.68306	0.0151
11	3	1.67324	1.72294	1.69260	1.69626	0.02045

Table 5.10: Measured Action Potential Value for Different Weights for MG Muscles

SL #	Wt. (Kg)	S1 (mV)	S2 (mV)	S3 (mV)	Mean (mV)	St. Dev (mV)
01	0	0.28485	0.30412	0.29919	0.29605	0.0081
02	0.25	0.32318	0.3154	0.3314	0.32332	0.0065
03	0.5	0.57571	0.60147	0.5811	0.58609	0.0110
04	0.75	0.62817	0.64159	0.61101	0.62692	0.0125
05	1	0.64983	0.65147	0.6249	0.64206	0.0121
06	1.25	0.68787	0.67498	0.69467	0.68584	0.0081
07	1.5	0.71513	0.70846	0.70145	0.70834	0.0055
08	1.75	0.72014	0.71498	0.70625	0.71379	0.0057
09	2	0.71591	0.7245	0.72930	0.72324	0.0055
10	2.5	0.72416	0.73495	0.74214	0.73375	0.0073

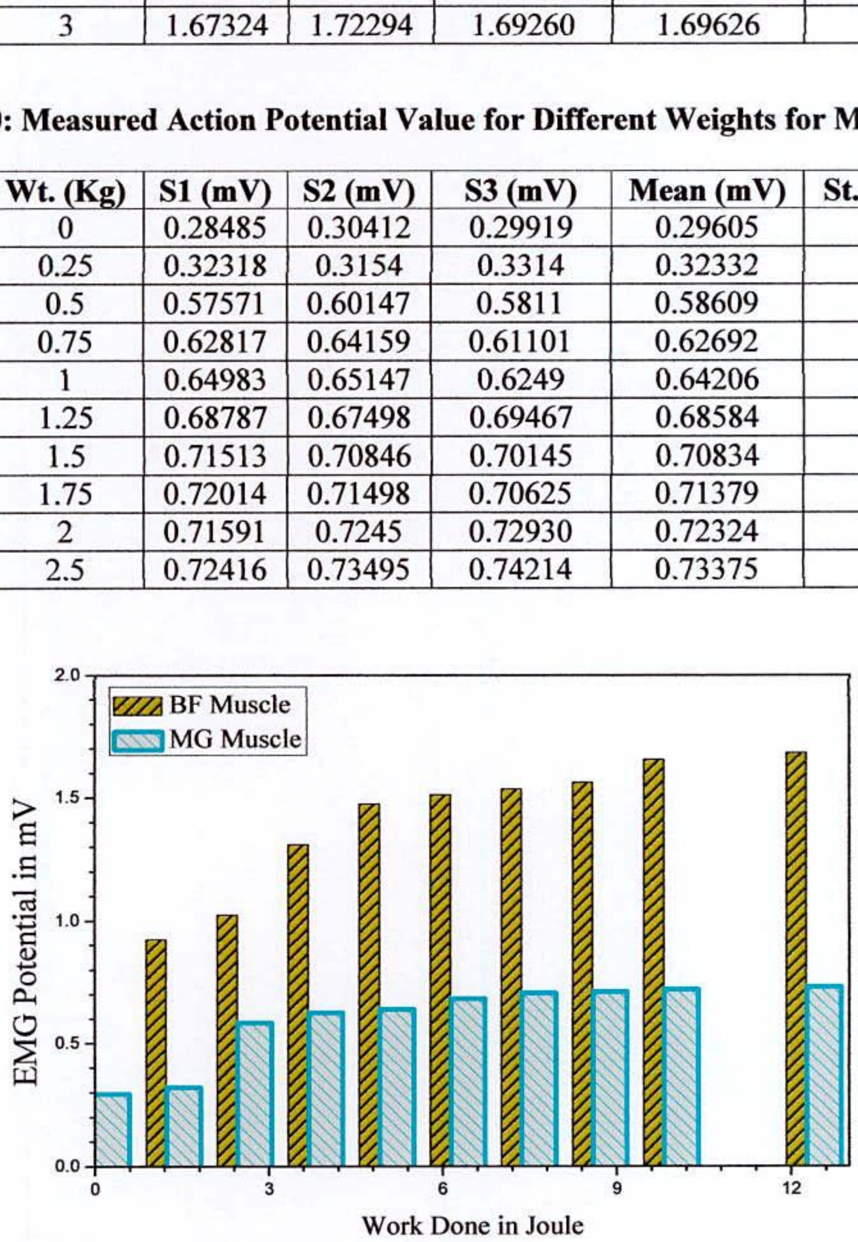


Figure 5.9: Non-linear characteristics between work done and EMG potential values for BF muscle and MG muscle of lower limb.

The plotted curves of BF and MG muscles which depict the non- linear characteristics are represented in Figure 5.9. To describe the mathematical relation between work done and EMG potential value of BF and MG muscles, we have to achieve more accuracy of the measured results and a nonlinear curve fitting is performed on the measured data. From linear regression analysis, we have estimated a mathematical relationship between work done and corresponding EMG potential generated from BF and MG muscle are given in following (5.9) and (5.10), respectively.

$$Y_{BF} = 0.8085 + 0.1437x - 0.0058x^2 \tag{5.9}$$

$$Y_{MG} = 0.2976 + 0.0954x - 0.0051x^2 \tag{5.10}$$

Table 5.11: Accuracy Testing of the Proposed Mathematical Relation for BF Muscle

SL. #	Work Done in J	Measured EMG Potential	Calculated EMG Potential	Absolute Error
01	0	0.85441	0.8085	0.04591
02	1.22625	0.92237	0.9759907	0.05362
03	2.4525	1.02369	1.1260387	0.10234
04	3.67875	1.30982	1.2586438	0.05117
05	4.905	1.47462	1.3738062	0.10081
06	6.13125	1.51112	1.4715257	0.03959
07	7.3575	1.53413	1.5518025	0.01767
08	8.58375	1.56148	1.6146364	0.05315
09	9.81	1.6543	1.6600276	0.00572
10	12.2625	1.68306	1.6984816	0.01542
11	14.715	1.69626	1.6672	0.02906

Table 5.12: Accuracy Testing of the Proposed Mathematical Relation for MG Muscle

SL. #	Work Done in J	Measured EMG Potential	Calculated EMG Potential	Absolute Error
01	0	0.2961	0.2976	0.00155
02	0.25	0.3233	0.4069	0.08359
03	0.50	0.5861	0.5009	0.08519
04	0.75	0.6269	0.5795	0.04738
05	1.00	0.6421	0.6428	0.00077
06	1.25	0.6858	0.6908	0.00496
07	1.50	0.7083	0.7234	0.01508
08	1.75	0.7138	0.7407	0.02692
09	2.00	0.7232	0.7427	0.01942
10	2.50	0.7338	0.7006	0.03318

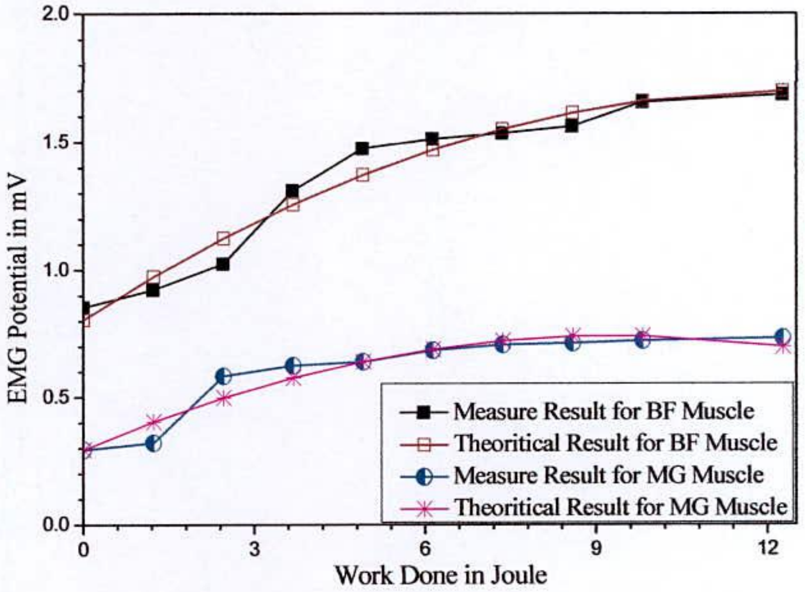


Figure 5.10: Comparison between measured and theoretical result for both BF and MG muscle.

According to our proposed mathematical model, we have calculated the EMG potential for each of the weight associated work done. In Table 5.11 and Table 5.12, a comparison between experimental mean result and the result from our proposed mathematical model is given. Additionally, absolute numerical deviation (error) between the measured and theoretical result are also shown. Here, few deviation exists between the measured and theoretical result which is due to the measured result are taken as mean from different subject. It should be mentioned here that person to person this result can vary slightly. Therefore, this proposed mathematical relation gives us the approximate relation between work done and EMG potential.

In Figure 5.10, both the measured and theoretical results for BF and MG muscles are illustrated. Figure 5.10 states that with the increment of work done by human muscle, EMG potential goes through saturation. Here, we can observe that the MG muscle is gone to saturation after 6 Joule and the BF muscle is gone to that saturation level after the work-done amount 9 Joule.

5.5 Conclusions

The contribution of this work is to introduce and develop a new mathematical relationship between performed work and consequent EMG results. In this effort, we have explored the cumulative action potential value extracted from EMG signals. All sEMG signals were collected from different male and female healthy subjects through BIOPAC acquisition unit maintaining appropriate experimental protocol. The process of calibration and standardization of EMG signals have been conducted. Then, we have plotted a curve among mean EMG value corresponding weight versus work done deviated from exact parabolic curve. To reduce this difference, we have approached a mathematical model considering all the facts of errors. We have also ensured the accuracy of this equation by putting two random weights with unknown EMG values. The calculated results show negligible errors comparing with measured values. The comparison between measured value and proposed model value will help researchers encounter the perfect method for analyzing EMG signals. Our goal was quite complex to convert a numerical methodology into a direct mathematical relation. Estimated work done from human upper and lower limb motions will also facilitate researchers to enable robotic systems. In our future work, we will justify our mathematical model to estimate work done from EMG signals of different exercise.

CHAPTER VI

Conclusions and Future Work

6.1 Conclusions

Human body muscle and its work done are important biomechanical quantities in human movement investigations. Measurement of biomechanical work done is critical for understanding due to muscle-tendon function, joint specific contributions and energy-saving mechanisms during different working activities. EMG measures cumulative action potential by means of voltage from our muscles which means; it is related to work done. But it is really complex to determine and analysis appropriate EMG signals along body muscles. Considering all this criteria, I decided to do research on these topics regarding an exceptional but complete medium of work like *Salat*.

In the earlier part of this thesis work, the locations of muscle activity were determined through average rectified value and root mean square method analysis. This study mathematically confirms that the muscle potential and force during *Salat*'s movement and position that can be one of the daily exercise and training for our muscle in course of biomechanical response of human body.

On the next part of this thesis work, three parameters of muscle index have been explored according to different mathematical analysis. Mean frequency (MNF) based EMG power spectrum analysis is proposed to determine *Salat* associated muscle fatigue and indices concerning linear relationship.

At the final part, two different numerical relationships have been developed to relate work done and sEMG potential values of upper limb (BB) and lower limb muscles (BF & MG), respectively. These work outcomes will be really helpful to enable power-assist robotic systems used for disabled persons.

In summary of conclusion it can be said that, in the context of physical exercise, *Salat* movements and activity has been mathematically proven in this thesis work. Besides, a modified mean frequency power spectrum analysis method is recommended to relate muscle indices. Moreover, two numerical relations have been developed between work done and action potential for upper and lower limb muscles, respectively.

6.2 Scopes for Future Work

In this whole research experiment, we have pursued all EMG data acquisition through single channel along single muscle of human body. It is really difficult to collect the EMG data of whole body at a time during *Salat* or other working medium in the course of single channel strategy. For this drawback, we could not collect enough data from different muscles of organs. So, there is scope to analyze the same process of work under multichannel and to find out the effect on performances of this scheme in course of whole human body. I think multichannel access EMG data acquisition will help us to collect optimum amount of data at a time during *Salat* considering maximum muscles. Moreover, we can also locate out a model of total force mapping distribution of human body during *Salat* comparing with other working activities. As well as, there is a scope to evaluate work done mapping of human body. This topic can be the initiative to open the field of different research aspects in Biomedical Engineering.

References

[1] M. K. M. Safee, W. A. B. Wan Abas, F. Ibrahim, and N. A. Abu Osman, "Electromyographic activity of the upper limb muscle during specific *Salat*'s position and exercise," *International Journal of Applied Physics and Mathematics*, vol. 2, no. 6, November 2012.

[2] M. F. Reza, Y. Urakami, and Y. Mano, "Evaluation of a new physical exercise taken from *Salat* (prayer) as a short duration and frequent physical activity in the rehabilitation of geriatric and disabled patients," *Annals of Saudi Medicine*, vol. 22, pp. 3-4, 2002.

[3] W. C. Mackenzie, The action of muscles: including muscle rest and muscle re-education, New York P.B. Hoeber, 1921 Forgotten Books, 2013.

[4] M. K. M. Safee, W. A. B. Wan Abas, F. Ibrahim, N. A. Abu Osman, and M. H. R. Salahuddin, "Electromyographic Activity of the Lower Limb Muscles during *Salat* and Specific Exercises," *Journal of Physical Therapy Science*, vol. 24, pp. 549-552, July 2012.

[5] S. Thongpanja, A. Phinyomark, P. Phukpattaranont, and C. Limsakul, "Mean and Median frequency of EMG signal to determine muscle force based on time-dependent power spectrum," *Elektronika ir Elektrotechnika*, vol. 19, no. 3, pp. 51-56, ISSN 1392-1215, 2013.

[6] M. K. M. Safee, W. A. B. Wan Abas, N. A. Abu Osman, and F. Ibrahim, "Activity of upper body muscles during bowing and prostration tasks in healthy subjects," BIOMED, IFMBE Proceedings, no. 35, pp. 125–129, 2011.

[7] F. Ibrahim and S. A. Ahmad, "Investigation of electromyographic activity during *Salat* and stretching exercise," *IEEE EMBS International Conference on Biomedical Engineering and Sciences*, Langkawi, December 2012.

[8] F. Ibrahim and S. A. Ahmad, "Assessment of upper body muscle activity during *Salat* and stretching exercise: a pilot study," *Proceedings of the IEEE-EMBS International Conference on Biomedical and Health Informatics*, pp. 412-415, Hong Kong and Shenzhen, China, Jan 2012.

[9] A. D. Cechetto, P. A. Parker and R. N. Scott, "The effects of four time-varying factors on the mean frequency of a Myoelectric signal," *Journal of Electromyography and Kinesiology, Elsevier*, vol. 11, no. 5, pp. 347–354, 2001.

[10] S. Thongpanja, A. Phinyomark, P. Phukpattaranont, and C. Limsakul, "Time-dependent EMG power spectrum parameters of Biceps Brachii during cyclic dynamic contraction," in *Proc. of the 5th Kuala Lumper Int'l Conf. on Biomedical Engineering*, pp. 233–236, 2011.

[11] S. Thongpanja, A. Phinyomark, P. Phukpattaranont, and C. Limsakul, "Time-dependent EMG power spectrum features of Biceps Brachii during isotonic exercise," *Journal of Sports Science and Technology, Sports Science Society of Thailand*, vol. 10, no. 2S, pp.314–318, 2010.

[12] M. Muro, A. Nagata, K. Murakami, and T. Moritani, "SEMG power spectrum during increasing force of contraction," *American Journal of Physical Medicine*, vol. 61, no. 5, pp. 244–254, 1982.

[13] R. E. Gander and B. S. Hudgins, "Power spectral density of the surface Myoelectric signal of the Biceps Brachii as a function of static load," *Electromyography and Clinical Neurophysiology, Elsevier*, vol. 25, no. 7–8, pp. 469–478, 1985.

[14] T. Moritani and M. Muro, "Motor unit activity and surface Electromyogram power spectrum during increasing force of contraction," *European Journal of Applied Physiology and Occupational Physiology, Springer*, vol. 56, no. 3, pp. 260–265, 1987.

[15] W. Li, K. Sakamoto, "The Influence of Location of Electrode on Muscle Fiber Conduction Velocity and EMG Power Spectrum during Voluntary Isometric Contraction Measured with Surface Array Electrodes," *Applied Human Science, Japan Society of Physiological Anthropology*, vol. 15, no. 1, pp. 25–32, 1996.

[16] A. Rainoldi, G. Galardi, L. Maderna, G. Comi, L. Lo Conte, and R. Merletti, "Repeatability of Surface EMG Variables during Voluntary Isometric Contractions of the Biceps Brachii Muscle," *Journal of Electromyography and Kinesiology, Elsevier*, vol. 9, no. 2, pp. 105–119, 1999.

[17] P. A Kaplanis, C. S. Pattichis, L. J. Hadjileontiadis, and V. C. Roberts, "Surface EMG Analysis on Normal Subjects Based on Isometric Voluntary Contraction," *Journal of Electromyography and Kinesiology, Elsevier*, vol. 9, no. 2, pp. 105–119, 1999.

[18] M. Hagberg and B. E. Ericson, "Myoelectric Power Spectrum Dependence on Muscular Contraction Level of Elbow Flexors," *European Journal of Applied Physiology and Occupational Physiology, Springer*, vol. 48, no. 2, pp. 147–156, 1982.

[19] G. F. Inbar, O. Paiss, J. Allin, and H. Kranz, "Monitoring Surface EMG Spectral Changes by the Zero Crossing Rate," *Medical and Biological Engineering and Computing, Springer*, vol. 24, no. 1, pp. 10–18, 1986.

[20] T. S. Buchanan, D. G. Lloyd, K. Manal, and T. F. Besier, "Estimation of muscle forces and joint moments using a forward-inverse dynamics model," *Journal of the American College of Sports Medicine*, vol. 37, no. 11, pp. 1911–1916, November 2005.

[21] H. U. Kuriki, F. Mí. Azevedo, L. S. Takahashi, E. M. Mello, R. F. N. Filho, and N. Alves, "The relationship between electromyography and muscle force: EMG methods for evaluating muscle and nerve function," *Intech Publisher*, January, 2012.

[22] G. C. Ray and S. K. Guha, "Relationship between the surface emg and muscular force," *Medical & Biological Engineering & Computing*, vol. 21, no.5, pp. 576-586, September 1983.

[23] M. H. Jali, T. A. Izzuddin, Z. H. Bohari, H. Sarkawi, M. F. Sulaima, M. F. Baharom, and W. M. Bukhari, "Joint torque estimation model of sEMG signal forearm rehabilitation device using artificial neural network techniques," *ARPN Journal of Engineering and Applied Sciences*, vol. 9, no. 7, July 2014.

[24] Available in: http://islamicquestion-answer.blogspot.com/2014/09/how-to-take-position-for-namaz-or-salah.html

[25] Anatomy of the Muscular System, Chapter 10, Unit 2: Support and Movement, second edition, Willis Publication, 1978.

[26] N. Hogan, R. Mann, "Myoelectric signal processing: optimal estimation applied to electromyography-Part1: derivation of the optimal myoprocessors," *IEEE Transactions on Biomedical Engineering*, vol. BME-27, no.7, July 1980.

[27] AD Instruments, 2010. available in : http://www.adinstruments.com.

[28] S. Siegler, H. J. Hillstrom, W. Freedman, G. Moskowitz, "Effect of myoelectric signal processing on the relationship between muscle force and processed EMG," *American Journal of Physiology and Medicine,* vol. 64, no. 3, pp. 130-149, June 1985.

[29] Kamen and Gary, Electromyographic Kinesiology, In Robertson, DGE et al. Research Methods in Biomechanics. Champaign, IL: Human Kinetics Publ., 2004.

[30] M. W. Barnett and P. M. Larkman; "The action potential," *Pract Neurol*, vol. **7,** no. 3, pp. 192–197, June 2007.

[31] N. L. Golding, W. L. Kath and N. Spruston, "Dichotomy of action-potential backpropagation in CA1 pyramidal neuron dendrites," *Journal of Neurophysiol*, vol. 86, no. 6, pp. 2998–3010, December 2001.

[32] P. E. MacDonald and P. Rorsman, "Oscillations, intercellular coupling, and insulin secretion in pancreatic beta cells", *PLoS Biol.*, vol. 4, no. 2, February 2006.

[33] F. Ibrahim, T. C. Sian, K. Shanggar and A. H. Razack, "Muslim prayer movements as an alternative therapy in the treatment of erectile dysfunction: a preliminary study," *Journal of Physical Therapy Science*, vol. 25, no. 9, pp. 1087-1091, April 2013.

[34] P. Konrad, The ABC of EMG: A Practical Introduction to Kinesiological Electromyography, Noraxon INC. USA, version 1.4, March 2006.

[35] Atkinson and E. Kendall, An introduction to Numerical Analysis. John Wiley & Sons. 2nd ed., ISBN 0-471-50023-2.

[36] http://www.biopac.com/researchApplications.asp?Aid=41&AF=366&Level=3. Access date: 21/04/2015, title: Automated EMG Analysis.

[37] http://www.rfcafe.com/references/electrical/periodic-series.htm. Access date: 21/04/2015, title: Fourier Series of Periodic Functions.

[38] A. Antoniou, Digital Filters: Analysis, Design, and Applications. McGraw-Hill, New York, NY: academic, 1993.

[39] J. O. Smith III, Introduction to Digital Filters with Audio Applications. Center for Computer Research in Music and Acoustics (CCRMA), Stanford University, September 2007.

[40] Y. Dodge, The Oxford Dictionary of Statistical Terms, Sixth Edition, *The International Statistical Institute*, 2006.

[41] F. Khanam, S. Islam, M. A. Rahman, and M. Ahmad, "Muscle activity estimation through surface EMG analysis during *Salat*," 2nd International Conf. on Electrical Engineering and Information Communication Technology (ICEEICT), Bangladesh, pp. 1-6, 2015, May 21-23.

[42] Surface Electromyography for the Non-Invasive Assessment of Muscles at http://www.seniam.org

[43] R. Boostani and M. H. Moradi, "Evaluation of the forearm EMG signal features for the control of a prosthetic hand," *Physiological Measurement, Institute of Physics Publishing*, vol. 24, no. 2, pp. 309-319, 2003.

[44] M. R. Al-Mulla, F. Sepulveda, and M. Colley, "sEMG techniques to detect andpredict localised muscle fatigue," *EMG Methods for Evaluating Muscle and Nerve Function, Mark Schwartz*, pp. 157-186, InTech, Rijeka, Croatia, 2012.

[45] A. Phinyomark, C. Limsakul, and P. Phukpattaranont, "A novel feature extraction for robust EMG pattern recognition," *Journal of Computing*, vol. 1, no. 1, pp. 71-80, 2009.

[46] S. L. Delp, F. C. Anderson, P. Loan, A. Habib, C. T. John, E. Guendelman, and D. G. Thelen "Open-source software to create and analyze dynamic simulations of movement," *IEEE Trans. on Biomedical Engineeiring*, vol. 54, no. 11, pp. 1940-1950, November 2007.

[47] H. He, K. Kiguchi, and E. Horikawa, "A study on lower-limb muscle activities during daily lower-limb motions," *International Journal of Bioelectromagnetism*, vol. 9, no. 2, May 2007.

[48] S. Chowdhury and N. Kumar, "Estimation of forces and moments of lower limb joints from kinematics data and inertial properties of the body by using inverse dynamics technique," *Journal of Rehabilitation Robotics*, vol. 1, no. 2, pp. 93-98, November 2013.

[49] Y. N. Jo, M. J. Kang, and H. H. Yoo, “Estimation of muscle and joint forces in the human lower extremity during rising motion from a seated position,” *Journal of Mechanical Science and Technology*, vol. 28, no. 2, pp. 467-472, February 2014.

[50] M. K. M. Safee, W. A. B. W. Abas, N. A. A. Osman, and F. Ibrahim, “Electromyographic activity of the medial gastrocnemius and lateral gastrocnemius muscle during *Salat*’s and specific exercise,” *World Academy of Science, Engineering and Technology*, vol. 78, June 2013.

List of Publications

[1] **Farzana Khanam**, Shadli Islam, Md. Asadur Rahman, and Mohiuddin Ahmad, "Muscle Activity Estimation through Surface EMG Analysis during *Salat*", 2nd *International Conference on Electrical Engineering and Information & Communication Technology*, 21-23 May, 2015. (iCEEiCT 2015), Jahangirnagar University, Dhaka, Bangladesh.

link: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?reload=true&arnumber=7307402

[2] **Farzana Khanam** and Mohiuddin Ahmad, "Frequency Based EMG Power Spectrum Analysis of *Salat* Associated Muscle Contraction," 1st *International Conference on Electrical & Electronic Engineeering,* 4-6 November, 2015. (ICEEE 2015), RUET, Rajshahi, Bangladesh.

[3] **Farzana Khanam**, Md. Asadur Rahman, and Mohiuddin Ahmad, "A Mathematical Approach to Determine the Work-done from EMG Analysis," 2nd *International Conference on Electrical Information and Communication Technology,* 10-12 December, 2015. (EICT 2015), KUET, Khulna, Bangladesh.

[4] **Farzana Khanam** and Mohiuddin Ahmad, "Estimation of Work-Done in Lower Limb using EMG," 1st *IEEE International WIE Conference on Electrical and Computer Engineering,* 19-20 December, 2015. (Wiecon-ECE 2015), BUET, Dhaka, Bangladesh.