CHARACTERIZATION OF BICEPS BRACHII MUSCLE ACTIVITY DURING CONTRACTIONS USING SURFACE ELECTROMYOGRAPHIC SIGNAL ANALYSIS

by

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CHAPTER 1

INTRODUCTION

1.1 Background

The analysis of the electromyography (EMG) signals generated by living individuals is an established area of research that was initiated by Francesco in 1666, Walsh in 1773, and Galvani in 1792 (Murguia et al., 2009; Reaz et al., 2006a). Since then, it has been widely accepted that the processing of EMG signals is essential for understanding how muscular activity (during contraction) generates electrical signals that control the joint movements in the human body (Benedetti et al., 2001). According to a research article published by Putatunda, each muscle in the human muscular system is composed of thousands of tiny fibres and cells, and these control the movement of the various parts of the human body (Putatunda, 2009).

In general, EMG signals are generated from these skeleton muscles in the human body as a result of the contraction of the muscles fibres, and these signals are always stochastic (random) (Komi & Viitasalo, 1976). Biceps brachii (BB) is one of the active skeleton muscles in the upper extremity, and EMG signals are repeatedly generated by this muscle during contraction due to the elbow flexion-relaxation phenomenon (Clark et al., 2003). As a result, these random raw and integrated EMG signals need to be recorded for further analysis. There are 2 types of recording processes that are mainly used to record the signals generated by muscle contraction: needle (invasive) and surface (non-invasive) EMG procedures. Compared with the needle-based process, the surface EMG sensor (electrode) is used more frequently because it is preferred by the subjects and because it is a non-invasive and painless technique that minimizes the signal interference (Mandryk et al., 2006; Pullman et al., 2000). Based on these advantages of the surface EMG technique, this research work has used surface EMG sensor to record the EMG signals from the subjects. It is therefore important to understand how well the surface EMG signals of motor units represent the activity of the BB muscle in the upper extremity.

1.1.1 Anatomical Study of the Biceps Brachii Muscle

One of the fundamental challenges of this thesis is to analyze and characterize the muscle activity of the BB muscle during voluntary contractions with respect to different measurement parameters. Therefore, it is essential to understand the elementary characteristics (anatomy and physiology) of the BB, the rationale underlying the characterisation of activity of this muscle, and how electrical signals are generated from this muscle. According to the anatomical and muscle-mechanics perspective (see Figure 1.1; the image was obtained from the Google database) of the human upper extremity, the BB muscle is normally described as a two-headed muscle that originates proximally through a long head and a short head (Rai et al., 2007). This muscle extends from the shoulder to the elbow on the front of the upper extremity and is responsible for moving the upper limb in different angles due to the strong connectivity of 2 biceps tendons (Naito, 2004). The lower tendon is called the distal tendon, and the upper tendon is called the proximal tendon (*i.e.*, short and long heads, respectively) (Muscle, 2008). These tendons are composed of a huge number of parallel collagen fibres that run the length of the tendon and play the pivotal role in muscle control (Valour et al., 2003).

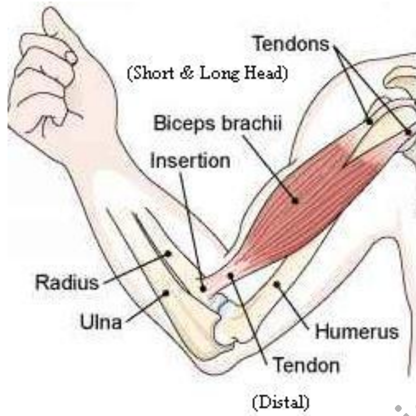

Figure 1.1: Frontal view of the upper arm BB muscle

The muscle fibres are innervated by neurons, the cell bodies of which are located in the spinal cord. The nerve fibres or the axons of these motor neurons leave the spinal cord and are circulated to the motor nerves. Each motor axon branches several times and innervates a large number of muscle fibres (Presentation, 2012), and the collection of a single motor neuron with all of the muscle fibres that it innervates is denoted a motor unit (MU). In summary, the MU is a component of the entire neuromuscular system and includes an anterior horn cell, its axon, and all of the connected muscle fibres. The motor units have overlapping territories, although the muscle fibres of a particular motor unit tend to be situated close to one another. A muscle fibre depolarizes as the signal is reproduced next to its surface and the fibre twitches (contracts) in response to an action potential from the neuron. This depolarization action generates an electric field in the surrounding area of the muscle fibres that can be identified by a skin surface electrode or sensor situated close to the generated field or by a fine-wire electrode inserted in the muscle. The resultant signal is known as the muscle fibre action potential, and the combination of the muscle fibre action potentials from all of the muscle fibres of a particular motor unit is the motor unit action potential (MUAP). All of the muscle fibres in a motor unit are fired each time that a motor unit fires, and the recurring firing of a motor unit generates a train of impulses called the motor unit action potential train (MUAPT). In addition, the summation of the electrical activity generated by each active motor unit is called myoelectrical or electromyography (EMG) signals (Figure 1.2, available from: www. gatlineducation.com).

Therefore, the detection, analysis, and characterization of this EMG signal using appropriate and advance methodologies are becoming an essential tool in the biomedical signal decomposition, and normalization and processing area. To record the process used to understand these signals, this thesis recorded and investigated EMG signals generated by the BB muscle contraction using a non-invasive approach.

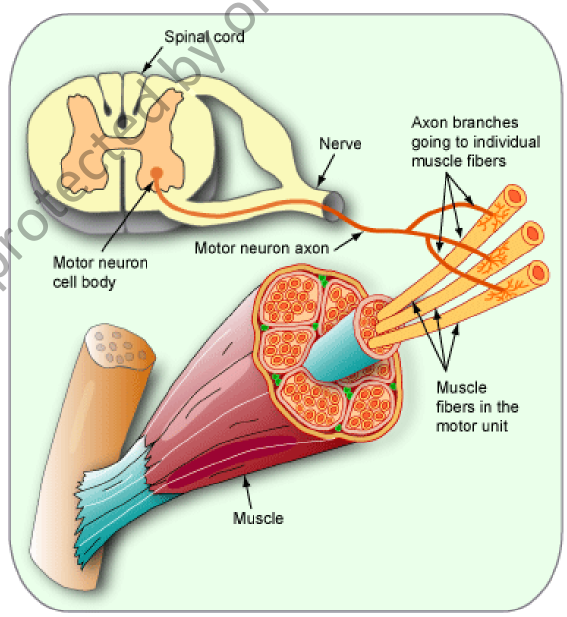

Figure 1.2: MUAP generated from the muscle fibres

The main reasons for this thesis interest in the analysis of the EMG signals generated by this particular muscle (BB) are:

i) It can easily be activated with good control and shows maximum recruitment of motor units during its contractions.

ii) It is in good agreement with the previous findings by other authors.

iii) It considered as the most important muscle from the superior limb because it helps to control movements in the shoulder, elbow and proximal radioulnar joints.

iv) It is a typical fusiform (having a spindle-like shape that is wide in the middle and tapers at both ends) muscle and has muscle fibers running parallel to each other and also parallel to the skin.

v) It is easy to locate the fibre direction during sensor placement.

1.1.2 Surface EMG Responses

Although the Electromyogram is the summation of the motor unit action potentials appear during the muscle contraction and that evaluate by a sensor (electrode) placement on the muscle. However, the voltage potential of the surface EMG signal detected by sensors depend on various issues, like signal varying between the individuals and also over time within an individual (Halaki & Ginn, 2012; Sousa & Tavares, 2012), because surface EMG serves as an indicator of underlying physiological processes. The same characteristics also observed on the BB muscle and EMG was used broadly to assess this muscle functions for the last three decades (Illyes & Kiss, 2005), since EMG is one of the fundamental recording processes that can detect the exact muscle strength, coordination and function from a global perspective. Another important feature of EMG is that it can easily capture and measure the electrical movement, and changes of muscle electric potential making it possible to investigate muscle synergies and predominance in specific patterns of movement (Farina et al., 2003; Scheepers et al., 1997). These raw EMG signals can possible to record when tiny electrical signals emanate from a contractile muscle (Bouisset & Maton, 1972; Luca, 1997).

Subsequently, the analysis of the appropriate muscle activation pattern is a key element for the analysis of body movement and is only possible through EMG signal analysis, which is one of the preferred methods for the measurement of the tiny electrical signals generated from contractile muscles during contraction and uses sensors that are positioned on the skin in a non-invasive way (De Luca 1997; Reaz et al., 2006a). According to the various EMG researchers, the diversity of the processes used to record and analyze the EMG signal generated by the BB muscle may be affected by various physiological and external factors, such as the exact sensor placement location on the muscle (*i.e.,* parallel to the muscle fibre direction), the movement range of the elbow angle, the different levels of contractions, anthropometric parameters, the maintenance of the parameters of the detection system, variations in the impedance, the subject's performance parameters (considered mainly during sports activities), and different psychological conditions influenced by the temperature (Eberstein & Beattie, 1985; Farina et al., 2002; Hussain & Mamun, 2012; Ollivier et al., 2005; Stegeman et al., 2000). Of all these factors that influence the signal, a combination of experimental results obtained from sensor placements at multiple locations, various anthropometric and performance parameters, and different ranges of the elbow joint angle show that the measurement of the BB muscle activity during contraction is mostly affected by external forces. A systematic analysis of these factors would therefore be helpful for the signal characterisation of the BB muscle.

1.1.3 Influence of Sensor Placement Location

In general, EMG signals are detected and recorded by placing the minimum number of single-channel connected 2 sensors over the skin that has a negative-positive conductor. The electrical signals are generated between the sensor and the skin when the myoelectric signals are produced due to contraction. The third sensor, which is known as a reference sensor, is placed on a neutral area and is used to cancel the generated noise that can otherwise interfere with the signals from the other 2 sensors. A number of research studies on EMG have been published, and researchers have demonstrated that the amplitude and frequency components of surface EMG are observably influenced by the sensor conditions, such as the diameter of the surface electrodes, the inter-electrode distance, the relative position of the bipolar electrode to the muscle belly, and the angle of the sensors to the direction of the muscle fibres (Li & Sakamoto, 1996). Similarly, researchers have found that EMG signals are influenced by the sensor lead placement on the BB muscle, and most investigators prefer to place the active sensors over the muscle belly (middle) region (Holobar et al., 2010; Mercer et al., 2006).

However, it is essential to know the exact signal characteristics of the other parts of the BB muscle, such as the lower part of the muscle belly, which is between the BB muscle endplate region and the distal tendon insertion, and over the medial belly of each head (long and short head), *i.e.*, parallel to the muscle fibres and below the proximal tendon (Hermens et al., 2000; Sargon et al., 1996), because EMG exhibit stochastic features during movement. However, excessive care is usually taken when placing the sensors to avoid the innervations zone (the location where the nerve terminals and muscle fibres are connected) and the tendons (end of muscle fibre), because the length of BB is a relatively small than other muscles (Farina 2001; Saitou et al., 2000).

1.1.4 Influence of Anthropometric Parameters

As mentioned, the muscle activity is likely affected by the sensor placement location; however, it is also influenced by various anthropometric parameters. These variables are a set of non-invasive and quantitative measurements that define an individual's body structure and are determined by recording, measuring, and analyzing the exact dimensions of the body, *e.g.,* height, weight, skin-fold thickness, bodily circumference, type of gender, and dominant and non-dominant arm (Heymsfield et al., 1982; Keogh et al., 2009). These parameters provide a physical estimation of the muscle strength (Wang et al., 2005). Similar to the other muscles in the body, the amplitudes of the EMG signal generated by the BB muscle are also influenced by anthropometric characteristics, including the subject's height, weight, BB circumference, skin fold, dominant and non-dominant arm, and gender. Therefore, the motor unit activation strategy also changes based on these parameters; thus, the electrical signals generated by an individual's BB muscle are inconsistent. Very few studies have revealed the necessity of analyzing the dependence of the BB muscle activity on the anthropometric characteristics. It is therefore essential in the EMG research area to identify the characteristics of the BB muscle during contraction based on anthropometric factors.

1.1.5 Influence of the Performance Parameter

Another parameter that influences the amplitudes of the EMG signals generated by the muscle is the subject's performance activities. This parameter is mainly considered during forceful sports and exercise activity profiles and represents a player's behaviour other than a form of entertainment. Some examples of studies that have used this variable to compare EMG signals are the following: (1) between professional and amateur athletes, (2) between winners and losers (*e.g.,* during combat movement sports, such as arm wrestling, karate punch, and judo), (3) during different movements in phase-based sports (*e.g.,* golf, pitching, and cricket bowling), (4) level of contractions (during exercise), (5) throwing activities in terms of velocity, and (6) other forceful sports activities (Arampatzis et al., 2001; Emam et al., 2001). The main reason in the analysis of this type of parameter is to understand the exact modulation in the amplitude of the EMG generated by the BB muscle, as well as the muscular force performance and firing rate. However, very few research studies have attempted to assess the BB muscle activity based on performance variables, especially during the contractions from arm wrestling and cricket bowling activities.

Based on the previous EMG analyses that assessed these 2 external parameters (anthropometric and performance), it is notable that the amplitudes of the signal generated by the BB depend on the extension and relaxation of the elbow (arm posture and attempted movement), as is discussed in the next section.

1.1.6 Influence of the Elbow Joint Angle

Although the anthropometric and performance parameters cause changes in the EMG signal, the movement of the elbow joint at different angle ranges play an important role to detect and compare the differences in the BB muscle contraction. Because an elbow is connected to bones, tendons, and three joints (forearm, upper arm, and the corresponding joint in the forelimb of a quadruped), which makes possible to move the arm and thus causes the BB muscle to contract and relax (Andersson et al., 1996). Moreover, the range of the elbow joint angle changes the relationship between the force and the amplitude of the EMG signal generated by the BB muscle (Doheny et al., 2008).

Thus, one important goal of the present thesis is to analyze the complex factors that influence the BB muscle activity at different ranges of the elbow angle, which is involved in the evaluation of the need and demand for improving the muscle performance and for understanding the muscle characteristics through an analysis of the EMG amplitudes (Ervilha et al., 2004a; Taylor et al., 1997). Additionally, the analysis of the elbow angle range is useful for the physical rehabilitation of disabled individuals, individualised sport training, and human-computer interactions (Søgaard et al., 2006). However, the range of the elbow joint angle during arm contraction and relaxation depends on the EMG-force relationship, as presented in the next section.

1.1.7 Muscular Force

Many researchers have shown that the amplitude of the EMG signal is influenced by various factors through an experiment in which the signals generated by active and contracted muscles are recorded for comparison purposes. It is easy to characterize and compare the EMG signal amplitudes from the generating muscular force, *i.e.*, from an active or contracted muscle (Zhou & Rymer, 2004). Therefore, in order to generate muscular force, it is required to contract the muscle at either a maximal or sub-maximal level to obtain adequate signals. These muscular forces generate the signal from the motor unit, and the firing patterns of the motor unit are changed as a result of voluntary actions or movements of the associated muscles. These voluntary movements of the muscle force rely on several factors. Like, the size of the muscle influences the force because large muscles contain more fibres and can produce additional force as compared with smaller muscles.

The amount and the type of motor units activated, *i.e.*, a serial release from neurons innervate various groups of muscle fibres, can also affect the muscle force. In addition, the preliminary length of the muscle plays a vital role when it stimulated. Because muscles are flexible, stretching results in the storage of force, which can be freed during muscle action, and maximum force is produced when the muscle is elongated to a length that is approximately 20% larger than its inactive length. The joint angle of the muscle also generates force because each joint has an optimal angle at which it functions, which depends on the comparative locations of the tendinous insertions on the bone and the weight being moved. Moreover, the most important factor is the speed at which the muscle exerts the action, which depends on the static and dynamic contractions generated by the body movements, such as during load-holding task, sports movement, gripping any objects, and other force-generating actions (Milner-Brown & Stein, 1975; Zhou & Rymer, 2004). Therefore, one of the prime objectives of this study is to measure the surface EMG signal from the BB muscle during static and dynamic contractile actions.

1.1.8 Static and Dynamic Contractions

The EMG signals generated by the BB muscle from external muscular forces are recorded and analyzed in a systematic way during muscle tension, which may cause the muscle to lengthen, shorten, or remain the same. This behavioural pattern of muscle tension is called contraction. Suetta *et al*., reported that the muscle force characteristics are accompanied by significant increases in the EMG amplitudes during contraction (Suetta et al., 2004). Additionally, the dependence of the form of the EMG-force relationship on key motor neurons and muscle properties relies on the muscle contraction (Zhou & Rymer, 2004). A voluntary contraction (striated muscles that can be controlled voluntarily by themselves) is mainly divided into 2 parts to produce an EMG signal on the specific contracted muscle: static and dynamic contractions (Hazell et al., 2007; Vedsted et al., 2006). Static contraction is generally known as isometric contraction. In this type of contraction, the muscle retains its length as the tension in the muscle is increased. It occurs when holding or gripping any object in a motionless position for specific period of time (Antony & Keir, 2010). Alternatively, the length of the muscle changes (shortens/ lengthens) during dynamic contraction, which is divided into 3 parts; eccentric (muscle lengthening), concentric (muscle shortening), and isokinetic (muscle lengthening and shortening at a constant speed) (Mercer et al., 2006).

The EMG signals generated by the BB muscle can be measured at either the maximal or a sub-maximal intensity level during static and dynamic contractions. Figure 1.3 (available from http://sportsscience.com) presents an example of contractions as the subject holds and lifts a load with his upper extremity, which causes the BB muscle to contract and thus produce the signals. These muscle contractions frequently occur in day-to-day life activities as an individual holds or grasps any objects and uses force to move the object. Additionally, BB muscle contractions occur during sports and exercise activities performed by the upper extremity. As a result, the characterization of the EMG signals generated by the BB muscle through these contractions during load force (load-holding tasks), grip force (gripping tasks) and sports movement (a combination of force-producing functions) with the effect of sensor placement, elbow joint angle (arm mechanics), anthropometric and performance variables, are still a matter of discussion and require further investigation.

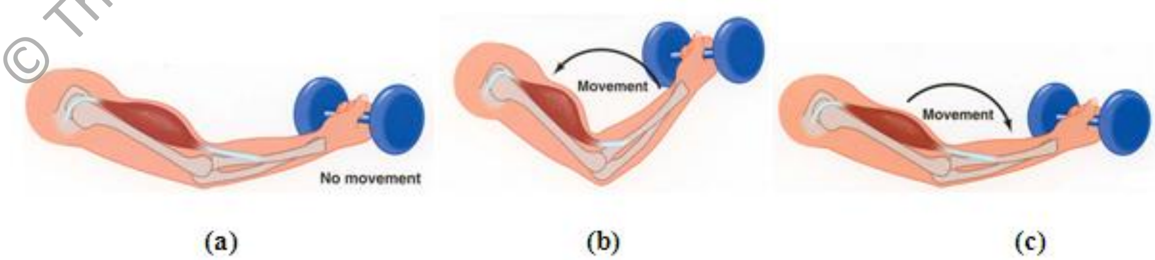

Figure 1.3: Three types of contractions that occur during a load-holding task (a): static (isometric), (b): dynamic (concentric), and (c): dynamic (eccentric)

1.1.8.1 Load Force

The load force is the resisting force that an individual exerts while holding of lifting any type of light or heavy object. Therefore, the load force generates muscular functional activity to contract the muscle either at a maximal or sub-maximal conditional level during a load-holding task (Lee & Lee, 2002). Both static and dynamic (3 types of contractions) contractions can be generated through this type of load-holding activity. Lifting, holding, and carrying tasks (either one-handed or both-handed) with any type of light or heavy object are frequent daily activities that may cause damage to the BB muscle. Moreover, various industrial jobs that require the manual handling of materials require the employees to hold or lift objects with different weights and shapes from one plate to another. For these reasons, several employees face a high risk of lifting-related injuries to their upper limb muscles, especially on the BB (Chen et al., 2006; Elser et al., 2011). Thus, it is necessary to investigate the BB muscle activity, fatigue, coordination and signal variability during load holding activities.

1.1.8.2 Hand-grip Force

Another way that the BB muscle can generate an electrical signal is through the grip force associated with grasping and gripping tasks. The analysis of the amplitude of the EMG signal generated from this type of task is important in various fields, such as bioengineering, biomechanics, and ergonomics. The evaluation of the hand-held weight placed on the musculoskeletal system is important for the assessment and reduction of the risk of injury and to develop the hands-free control systems for assistive/rehabilitation devices (Hashemi, 2012). It is also essential to investigate the muscle activation patterns, fatigue, strength, coordination, stiffness, signal variability and fidelity during gripping activities. One important issue is that most researchers use the handgrip force to produce static or isometric contraction because these do not require any movement by the muscles of the hand joint. The generated force is usually measured by a handgrip dynamometer.

Figure 1.4 presents an example of the generation of an electrical signal by the BB muscle using a handgrip dynamometer.

Figure 1.4: Static (isometric) contraction generated by the gripping task

1.1.8.3 Sports Movement

Similar to other external forces, strength training and competitive sports can also generate static and dynamic contractions (Asmussen, 1981; Komi et al., 2000; Mitchell et al., 2005), because sports movement is the combination of various types of forces that produce repetitive contractions and that cause variations in the amplitudes of the signals generated by the muscles. The force during sports movement can be categorized according to the type and strength of the exercise being performed and with the risk of a physical wound from any conflict. However, it is complex and difficult to analyze the activity of the muscles of the entire body during the performance of multifarious motor skills because there are more than 400 skeletal muscles in the human body and both complex and irregular muscle connections may occur during sports movements. Additionally, the measurement of the EMG signal from an individual performing a sports movement, such as overhead throwing, football kicking, arm wrestling, volleyball serving and spiking, basketball scoring and passing, cricket bowling, and other sports kinesiological activities, requires a specific technological and methodological approach that can be adjusted to the sport conditions. Therefore, biomechanics analyses also play a significant role in the measurement and analysis of the amplitudes of the EMG signals generated during sports movements. Some sports activities that activate the upper extremity muscles are presented in Figure 1.5.

However, to characterize the acceptable amplitudes of the EMG signal generated by the BB muscle during sports movements, this thesis identified 2 sports activities that utilize upper extremity movement and are relatively new in the sports medicine (EMG) research community: arm wrestling (human vs. human) and cricket bowling. Information on the all of the features of the muscular action generated during these activities, including an assessment of the feedback processes, should allow the optimization of movement, injury prevention, training possibilities, and sports performance (Clarys & Cabri, 1993).

Figure 1.5: Some active sports movements that generate contractions on the upper limb

Of these 2 types of sports activities, arm wrestling is more likely related to the gripping (grip force) task. Although grip force can generate only static contraction (mentioned previously in this chapter), the EMG signals generated by the BB muscle during arm wrestling in this experiments were recorded and normalized as static and dynamic contractions because the 2 competitors use a single arm to produce the force: each competitor places his elbow on a solid surface, clasp the palm of their competitor, and attempts to push the other individual's arm until it hits the ground (ArmWrestling, 2004). The EMG signals are mainly generated from the following upper limb muscles during arm wrestling: pectoralis major, biceps brachii, triceps brachii, pronator teres, flexor carpi ulnaris, latissimus dorsi, and infraspinatus (Hong et al., 2011; Silva et al., 2009). However, the main concern of this thesis is to ascertain the function of the BB muscle during this type of voluntary contraction (at the maximal and sub-maximal contraction levels).

The other sport chosen for EMG signal analysis was cricket bowling, which is related to a low-load holding task but also requires the high-velocity movement of the upper extremity during ball delivery. This sport is one of the oldest organized sport and the world's second most popular game, *i.e.*, it is played in many countries worldwide, particularly British Commonwealth nations (Farhadian et al., 2013; Finch et al., 1999). Cricket is a field-based sport between 2 teams of 11 players, and the players are needed to field and bat throughout the game. Each player assumes different roles throughout the match, and one of these roles is bowling (delivery of the ball) a 155.92-g cricket ball toward a batsman or his wicket. It typically requires approximately 1 second for the ball to reach the batsman (Gregory et al., 2002; Justham et al., 2006a; Stuelcken et al., 2007). This bowling step is a complex skill that can be categorized as either fast bowling, which indicates that the ball is delivered at a fast pace (120-160 km/h), or spin bowling, which indicates that the ball is delivered slowly (60-90 km/h) but with some spin such that it bounces at an angle off the bowling pitch (Justham & West, 2009; Justham et al., 2006b). A cricket bowler demonstrates dynamic movement similar to that exhibited by other athletes who utilize overhead throws during which the upper limb muscles are active, such as softball pitching, volleyball serving and spiking, javelin throwing, and handball throwing (Rojas et al., 2009; Rokito et al., 1998; Takada & Okada, 2003). Although a cricket bowler does not throw the ball during delivery and the International Cricket Council (ICC) laws on illegal bowling actions states that a ball is not an illegal delivery if the bowler does not extend his elbow more than 15º from when the upper arm is horizontal (which is not translated to arm reaching shoulder level as it is only the upper arm that needs to reach this level) to when the bowler releases the ball (which is the first frame that the ball is not in contact with any part of the hand) (Marshall & Ferdinands, 2003). However, during the delivery of the ball, the upper limb muscles that are mostly active are the BB, pectoralis major, deltoid, trapezius, latissimus dorsi, infraspinatus, trapezius, serratus anterior, and supraspinatus muscles (Burden & Bartlett, 1990a; Rokito, et al., 1998; Shorter et al., 2010).

Although cricket is a non-contact sport, similar to baseball, softball, and basketball, playing cricket can result in a number of injuries. Furthermore, injuries for overuse of the upper arm are frequent and related to the physical demands of high-level cricket. These injuries most likely occur during ball delivery through either fast or spin bowling because the bowling action involves repetitive twisting, extension, contraction, and rotation of the upper limb (Finch, et al., 1999). Imperfect too-frequent executions of these movements may lead to damage of the muscles involved. Recently, the Australian Cricket Board (ACB) declared that high-level fast bowlers exhibit a significantly enhanced risk of injury if their bowling workload exceeds more than 20 to 30 bowls during the period of 1 week (Davies et al., 2008; Orchard & James, 2003). Similarly, Stretch reports that 41% of the injuries that are sustained by cricket bowlers are due to frequent bowling (Stretch, 2001, 2003). Although other upper limb muscles are active and affected during cricket bowling, this thesis chose to study only the BB muscle due to the lack of EMG-based studies on this muscle, especially during fast bowling, which is becoming increasingly recognized as a cause of prominent BB muscle injury due to repetitive motion (Milsom et al., 2008;

Pandey, 2012; Portus et al., 2000). Moreover, the principal function of the BB is to provide elbow flexion torque during bowling; therefore, the BB muscle is one of the most common upper limb muscles of bowlers that is most commonly affected by biceps tendonitis, strain, fatigue, acute injury, and rupture (Belliappa & Barton, 1991; Portus et al., 2000).

Therefore, it is essential to know when and how much the BB muscle is active during these 2 sports activities because this information will prove useful to bopmedical engineers, physicians, physical therapists, trainers, and coaches in the design of proper treatment, training, and rehabilitation protocols for athletes in these sports and will help yield a better understanding of the injury mechanism.

1.1.9 EMG Signal Processing

Appropriate EMG signal amplitude processing methods need to be applied in all of the abovementioned experiments to compare the signals obtained during muscle activation. To date, researchers have used different types of methodologies for processing the EMG amplitudes. Some important examples of these include smoothing the rectified signal through a low-pass filter with a given time constant, using the mean value of the rectified EMG over a time interval T, which is defined as the Average Rectified Value (ARV) or Mean Amplitude Value (MAV), and using the entire amplitude information during muscle activity to calculate the Root Mean Square (RMS). Some researchers also used the Integrated EMG (IEMG), which indicates that the signal is integrated (not filtered) over a specified time interval (thus, IEMG is the area under a voltage curve and is measured in V/s) (Merletti, 1999). Of these methods, the amplitude of the EMG signals RMS generated by the BB when it is contracted and normalized in this study. This quantity (amplitudes) is characterized over a particular time interval T, which must be specified. The smoothed, low-pass filtered, average-rectified, and RMS values are voltages and are thus measured in micro- or mili-volts. Moreover, if an EMG researcher needs to know how active a muscle is, or how long it is active for, the raw EMG is often processed, for instance, using RMS procedure (Burden, 2010). If EMGs that are processed in this approach, as opposed to being processed in the frequency domain, are to be compared between trials that require reapplication of electrodes, between muscles, or between individuals, also need to be normalized (Criswell 2010; De Luca, 1997). Also, normalization of EMG is essential because of the many technological, anatomical and physiological factors that can influence the EMG magnitude. Because, the amplitude and frequency characteristics of the raw EMG signal have been shown to be highly variable and sensitive to many factors, like extrinsic includes: sensor configuration; sensor placement with respect to the motor points in the muscle and lateral edge of the muscle as well as the orientation to the muscle fibers; skin preparation and impedance; and perspiration and temperature.

Alternatively, the intrinsic factors include: physiological, anatomical and biochemical characteristics of the muscles such as the number of active motor units; fiber type composition of the muscles; diameter of the muscle fiber; the distance between the active fibers within the muscle with respect to the electrode; and the amount of tissue between the surface of the muscle and the electrode. These factors vary between the individuals, between days within an individual and within a day in an individual if the electrode set up has been altered and hence the voltage recorded from a muscle would be difficult to describe in terms of a level if there is no reference value to which it can be compared. As a result, interpretation of the amplitude of the raw EMG signal is challenging except some kind of normalization procedure is performed. This normalization refers to the conversion of the signal to a scale relative to a known and repeatable value. It also will be a factor contributing the between subject variability as measured by coefficient of variations (CV) in the current thesis studies. To address this, normalization of the EMG signals needs to be conducted. It is common practice to use the maximum activation levels of the muscles (commonly obtained using maximum voluntary contractions or MVC) which allows for estimation the activation levels as a percent of maximum capacity (Cram & Rommen, 1989; De Luca, 1997; Halaki & Ginn, 2012; Schanne & Chaffin, 1970).

Figure 1.6 presents an example of the raw EMG signal obtained during muscle contraction (Konrad, 2005). The results obtained after amplitude processing provide a correlation between the force and the EMG signal, and it is common to normalize the force and its respective EMG relative to the values obtained during maximal voluntary contraction (100% MVC).

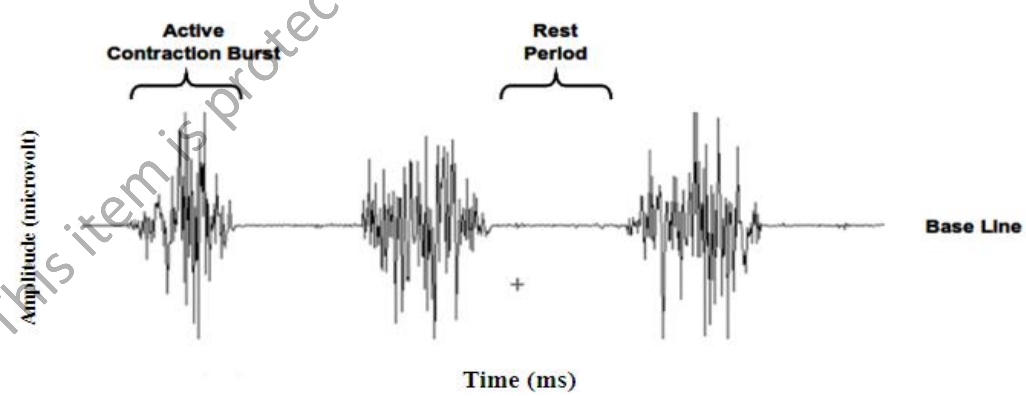

Figure 1.6: Raw EMG signal recorded from 3 levels of maximum contractions

1.1.10 Data Acquisition System for EMG Monitoring

Up to now, this thesis had shown how the BB muscle can generate EMG signals during contractions, how these signals are generated by the muscular forces, how these signals are influenced by other parameters, and how the amplitude of EMG signals from contractile muscle can be normalized. However, it is necessary to develop a better hand-held EMG data acquisition system using a state-of-the-art technique for recording and analyzing EMG signals because the recording process of the electrical signals generated by the abovementioned movements, contractions, and other activities depends on the use of a suitable, up-to-date, convenient, user-friendly, real-time, portable, and low-cost EMG data acquisition system.

Additionally, these EMG-assisted acquisition devices would have many applications in other fields, such as sports medicine, rehabilitation, health centre, home-care service, and physical therapy (Clarys, 2000; Geister, et al., 1975; Wallmann, et al., 2005). As a result, the design of an automatic, hand-held EMG data acquisition and monitoring system is of major interest in the kinesiological (the area of physiology that studies the mechanics and anatomical features of human movement) research field because patients, physiotherapists, sports personnel, researchers, and other end users are completely dependent on a reliable and robust apparatus to detect signs of muscle strength. A graphical view of a portable EMG-assisted data acquisition system is presented on Figure 1.7; as shown in the diagram, the subject is evaluating his upper and lower limb muscle activity during walking and is viewing the signal, which is shown on a large desktop computer.

Based on the difficulties associated with viewing the EMG signal on a large desktop computer, hand-held personal digital assistance (PDA)-based EMG acquisition systems have become progressively more common in daily applications due to their portability, lower price, enhanced product performance, robustness, signal accuracy, lesser weight, and extensibility. In fact, a number of commercial systems are currently available for measuring muscle disorder, muscle strength, the biofeedback of muscle stimulation, and other biomedical concerns (Mohamed et al., 2002). Most of these available commercial systems were developed for the measurement of only EMG signals, whereas others can monitor

EMG and other physiological signals simultaneously. Some well-known vendors that have developed EMG data acquisition systems are Noraxon, Biopac System, Delsys, Shimmer, Phywe Systeme GmbH & Co., and ADI Instruments. The specifications of these devices can range from wired to wireless, costly to inexpensive, and a few (minimum 1) or a huge number of channels. Additionally, most of these are usually set up in a fixed lab setting and require the use of a keyboard, mouse, and a large monitor screen.

Figure 1.7: EMG DAQ system for monitoring muscle function
(a): desktop computer for signal monitoring, storing, and processing; (b): EMG sensor attached to the muscle; (c): EMG data acquisition system; and (d): surface EMG sensor

Since the advent of automated EMG data acquisition systems, the use of wireless instead of wired systems has become a consideration for the accurate accomplishment of medical tasks. However, there are still potential advantages associated with the use of wired technology for physical signal monitoring systems, particularly systems that require less signal interference, because no transreceiver needs to be designed, which increases the cost-effectiveness of this system. Other drawbacks of wireless systems are the need for additional hardware, increased power consumption, unfaithful real-time data streaming, intermittent connection, and decreased data reliability and security. Consequently, a wide range of survey of the existing wired and wireless EMG-supported recovery systems was performed to determine the most important features that should be taken into account during the design of a new EMG data monitoring system (Burns et al., 2010; Pantelopoulos & Bourbakis, 2010).

1.2 Problem Statement and its Significance

The problem statements and the entire significance are as follows:

i) Most of the research works in EMG signal characterization (in terms of normalized EMG amplitude comparison) has done with single parameter comparison (for example, only sensor placement effect during contraction). Therefore, it needs to identify the muscle activity and observe the relationship with EMG and multiple parameters (such as sensor placement sites and anthropometric variables).

ii) The BB muscle, of the upper extremity muscles, is frequently associated with pain, disability, weakness, tenderness, and dysfunction due to the overuse of upper arm movements in our daily activities. So, further study is important for proper analysis of the EMG signal in BB muscle.

iii) Insufficient studies have been conducted to allow a clear understanding of the EMG signal characterization during sports movement (especially during arm wrestling and cricket ball delivery).

iv) Inadequate studies have been performed to measure the muscle activity and signal variability in terms of anthropometric and performance parameters. A major contribution to the EMG response involves the direct stimulation of muscle fibres, type and size depends