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Effect of Shoulder Angle on the Activation Pattern of the Elbow Extensors During a Submaximal Isometric Fatiguing Contraction

(Spine Title: Effect of Shoulder Angle on Elbow Extensor EMG Activity)

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By

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ABSTRACT

PURPOSE: The aim of the current study was to examine the effect of shoulder angle on the electromyographic (EMG) activation pattern of the elbow extensors during a fatiguing contraction. **METHODS:** Ten young men (23.5 ± 1.7) were tested on two occasions with the shoulder at either 0° or 90° of flexion. Baseline isometric maximum voluntary contraction torque and the EMG-torque relationship were determined prior to a sustained isometric contraction at 20% of MVC. **RESULTS:** EMG activity of the long head during the final 10% of the fatiguing contraction exhibited a significantly greater increase when at 90° versus 0° with no effect of shoulder angle on any other portion of the elbow extensors. **CONCLUSION:** Measures from one muscle portion of the elbow extensors are not representative of the whole group under isometric fatiguing contractions, and at longer length the activation of the long head was greater than at the short length.

Keywords: Triceps Brachii, Elbow Extensors, Fatigue, EMG, Anconeus, Shoulder Angle

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LIST OF ABBREVIATIONS

ANC – Anconeus

ANOVA – Analysis of variance

EMG – Electromyography

FT- Fast twitch

LAT – Lateral head of triceps brachii

LG – Lateral gastrocnemius

LONG – Long head of triceps brachii

MED – Medial head of triceps brachii

MG – Medial gastrocnemius

MMG – Mechanomyography

MVC – Maximum voluntary contraction

NIRS – Near infrared spectroscopy

PCSA – Physiological cross sectional area

RF – Rectus femoris

RMS – Root mean square

SD – Standard deviation

SEM – Standard error of the mean

SOL - Soleus

VI – Vastus intermedialis

VL – Vastus lateralis

VM – Vastus medialis

CHAPTER 1: BACKGROUND REVIEW

1.1 Anatomy of Elbow Extensors

The elbow extensors are composed of anconeus (ANC) and the medial (MED), lateral (LAT), and long (LONG) heads of the triceps brachii. Even though the three heads of the triceps brachii are considered one muscle with a common insertion on the olecranon process of the ulna, each head has a distinctive origin (Fig 1). Furthermore, although it was once believed that all portions had a common innervation by the radial nerve, recent literature has shown innervation to each head is unique (Bekler et al., 2009; de Sèze et al., 2004).

The MED originates from the posterior aspect of the humerus, inferior to the radial groove and although receiving a motor branch from the radial nerve, the MED is also innervated by a branch from the ulnar nerve trunk (Bekler et al., 2009). Bekler et al. (2009) were unable to determine if the branch was a motor or sensory branch, but they speculated it was likely a motor branch as previous reports of complete radial denervation does not completely inhibit triceps brachii function. The LAT originates from the posterior aspect of the humerus, superior to the radial grove and is innervated by the radial nerve (Stanescu et al., 1996). The LONG is unique in that it originates from the infraglenoid tubercle of the scapula and therefore acts across the shoulder and elbow joints whereas the MED and LAT only act across the elbow. The shoulder joint possesses the greatest range of motion of any joint within the human body; therefore, the length of the LONG can be influenced greatly by the position of the arm about the shoulder. In a cadaveric and surgical study of the innervation of the LONG, in all subjects the motor branch originated from the axillary nerve rather than the radial nerve (de Sèze et al., 2004).

The ANC originates from the lateral epicondyle of the humerus and inserts onto the lateral surface of the olecranon and the superior lateral surface of the ulna. The nerve supply to the ANC is a branch of the radial nerve. The ANC is involved in elbow extension, abduction of the ulna during pronation and is a stabilizer of the elbow joint (Gleason et al., 1985; Pauly et al., 1977; Zhang & Nuber, 2000).

Of the three heads, the LONG has the largest physiological cross-sectional area (PCSA) at approximately 6.7 cm^2, the MED has the next largest PSCA at 6.1 cm^2 followed by the LAT with a PSCA 6.0 cm^2 (An et al., 1981). The ANC has the smallest PSCA at 2.5 cm^2 (An et al., 1981). An appreciation of the PSCA is significant as it determines the maximum force generating capacity of the muscle which, in turn, may influence the recruitment strategy among synergistic muscles (Kouzaki et al., 2003).

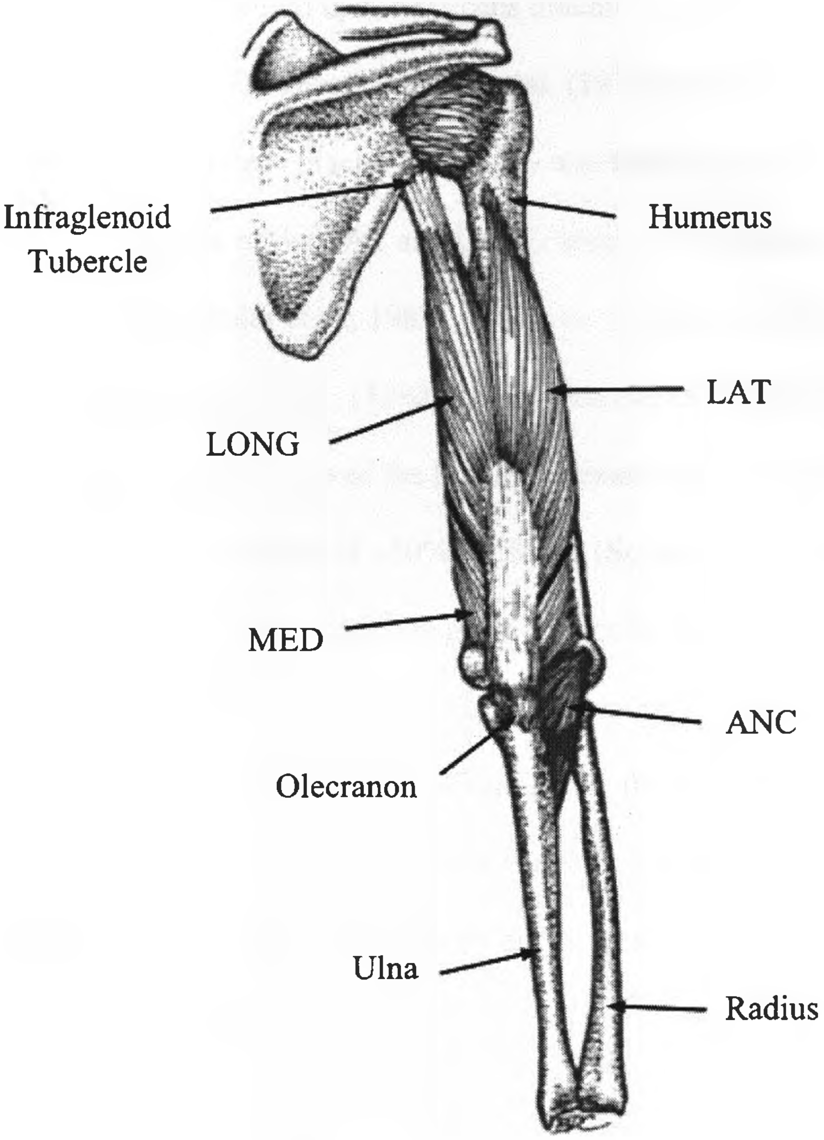

Fig. 1 Posterior view of the right upper limb showing the main bones and the three heads of the triceps brachii and the ANC. Adapted from Travell & Simons (1999).

1.2 Elbow Extensors Composition

In the first study to look at the fibre type distribution in the triceps brachii, Johnson et al. (1973) reported that the triceps brachii is composed of approximately 68% fast twitch (FT) fibres. However, Johnson et al. (1973) did not report from which muscular head of the triceps brachii the biopsy was taken. In a more recent study that examined the fibre type of the LAT and LONG heads, a very similar composition of ~60% FT was found (Elder et al., 1982). Le Bozec & Maton (1987) confirmed the previous findings of Elder et al., (1982) as they determined the LAT to be composed of ~64% FT fibres. The fibre type of the MED was examined in 18 young healthy subjects and was found to be composed of ~50% FT fibres (Schantz et al., 1983). Although the earlier study of Johnson et al. (1973) negated to specify the site of the biopsy, these more recent studies support the contention of the homogenous FT fibre type in the three heads the triceps brachii. In the only study to examine the fibre type distribution in the ANC found a composition of only 37% FT fibres (Le Bozec & Maton, 1987). Overall, the triceps brachii is composed of primarily FT fibres while the ANC is composed of primarily slow twitch fibres.

1.3 EMG Studies of the Elbow Extensors

Bouisset (1973) proposed that within a group of synergistic muscles acting across a joint the electrical activity associated with voluntary activation as recorded by electromyography (EMG) of the group can be reduced to one amongst them. When the elbow extensors are examined using EMG, frequently one head of the triceps brachii is taken as a representative of the whole muscle group under the concept of a ‘muscle equivalent’ (Bouisset, 1973). However, even before development of the ‘muscle equivalent’ concept there was evidence to suggest that the application of this equivalency to the triceps brachii may not be valid.

The first study to utilize EMG to examine the inter-relationships between the three heads of the triceps brachii and ANC found they can be activated independently of one another (Travill, 1962). EMG was recorded from the three heads and ANC during slow dynamic extension of the forearm during a no load and a loaded trial while also repeating the trials with varying shoulder abduction. EMG activity was quantified as either ‘silent’, ‘negligible’, ‘slight’, ‘moderate’ or ‘marked’. Regardless of load or shoulder position the MED and ANC were always active demonstrating ‘slight’ activity at no loads and progressing to ‘moderate’ and ‘marked’ as the load was increased (Travill, 1962). The LONG and to a lesser extent, the LAT were demonstrated to act as reinforcing auxiliaries to the actions of the MED as the load increased (Travill, 1962). Only when the LONG was stretched by abducting the arm by 90° was the activity comparable to the MED under resisted movement. At all other shoulder angles where the LONG would be relatively slack, the MED always demonstrated higher activity than the LONG (Travill, 1962). Travill (1962) concluded that the MED is the prime mover of the elbow whereas the LAT and LONG only assist the MED during resistive movement.

Further studies have examined the elbow extensors in more detail. A study examining all muscles that cross the elbow, (flexors and extensors), found similar finding to that of Travill (1962), in that the ANC and MED were first to exhibit EMG activity followed by the LAT and finally the LONG as the resistance was increased in dynamic contractions (Pauly et al., 1967). Pauly et al. (1967) also concluded that the ANC is a muscle of fine control, stabilization, and extension and under certain movements the ANC alone was sufficient to perform extension of the elbow. Another study examining the EMG/force relationship during isometric contractions found that all heads increased in a linear fashion as the force increased, however the LONG always had lower intergrated EMG values relative to the MED and LAT at higher force levels (Le Bozec et al., 1980b). The effect of shoulder angle was also investigated and although the investigators found no effect, the authors acknowledge that the length change was likely negligible in their protocol (Le Bozec et al., 1980b).

One study examining the role of the three heads of triceps brachii in isotonic versus isometric contractions found that during isometric contractions there was a preference to use mono-articular muscles while during isotonic tasks there was a transfer of force to the bi-articular muscles (van Groeningen & Erkelens, 1994). The authors measured recruitment thresholds in the three heads and showed during the movement task that recruitment thresholds were lower in the LONG while at same time higher in the MED and vice-versa in the isometric task. There was no apparent change in recruitment thresholds for the LAT (van Groeningen & Erkelens, 1994). The transfer of force from the LONG to the MED during an isometric task may be due, in part, to improved accuracy of afferent information from mono-articular muscles than input from bi-articular muscles in isometric contractions (Smeets, 1994).

The findings of van Groeningen & Erkelens (1994) are in agreement with a study by Zhang & Nuber (2000) that examined the load sharing among the three heads and

ANC during isometric contractions. The EMG from the three heads and ANC obtained during submaximal isometric contractions were normalized to the peak M-wave to determine the moment distribution among the heads. Under isometric conditions the MED and LAT contributed approximately 70%-90% of the total extension moment (Zhang & Nuber, 2000). At lower force levels the ANC was shown to contribute up to 15% of the extension moment (Zhang & Nuber, 2000). As the extension moment increased the contribution from the MED and LAT tended to remain the same while an increase was only observed in the LONG (Zhang & Nuber, 2000). However, the authors acknowledge that in their protocol the position of the arm kept the LONG relatively shortened which may have affected its contribution to elbow extension.

1.4 Synergistic Fatigue and EMG

When a sustained submaximal isometric contraction is held until exhaustion there are changes observed within the nervous system that are reflected in the pattern of EMG. There is a subsequent rise in the EMG of the contracting muscle which is believed to represent recruitment of additional motor units and some modulation of the discharge rate (Carpentier et al., 2001; Garland et al., 1994). It has been proposed that recruitment of additional motor units is more efficient for the continuation of the contraction rather than to enhance the rate of fatigued motor units (Kouzaki, 2005). It follows that within a group of synergists, it would be natural that fatigue of one synergistic muscle would facilitate recruitment of other synergists to compensate for the impaired motor capability of the fatigued muscle. This has been observed in the quadriceps femoris muscle group where upon selective muscle fatigue of the vastus lateralis (VL) through electrical stimulation showed a subsequent increased recruitment of vastus medialis (VM) and rectus femoris (RF) (Akima et al., 2002). The possible mechanism for increased recruitment of motor units of synergistic muscles is believed to be facilitated by group III and IV afferents that are sensitive to metabolites associated with fatigue. Duchateau and Hainaut (1993) proposed that the group III and IV afferents inhibit the α-motoneurons of the fatigued muscle while resulting in a reflex compensation of increased supraspinal drive that spreads to neighbouring non-fatigued muscles. The increased excitability of the neighbouring non-fatigued muscles would be in line with the concept that recruitment of non-fatigued motor units is more efficient than increasing the rate to the fatigued muscle.

During a sustained submaximal isometric contraction, despite maximal effort, a common feature is the failure of the EMG to reach maximal values obtained during a pre-maximum voluntary contraction (MVC). The failure to reach maximum EMG values likely involves the interplay of many factors that despite increased supraspinal drive compete to lower EMG. These may include: increased inhibitory feedback from group III and IV afferents, an increase in recurrent inhibition and impairment of neuromuscular propagation (Fuglevand et al., 1993). Although there is increased supraspinal drive to the motoneuron pool, the combination of many inhibitory inputs results in a reduced output at the end of a sustained contraction.

1.5 Muscle Synergy in Other Muscle Groups

1.5.1 Quadriceps Femoris

The quadriceps femoris muscle group is composed of three mono-articular muscles, vastus intermedialis (VI), VL, and VM and one bi-articular muscle, RF. The quadriceps femoris provide a reasonable model for comparison to the triceps brachii as both groups have a common insertion for their respective muscle group and both are composed of three mono-articular muscles and one bi-articular muscle. However, there are some noteworthy differences between the two muscles groups. The fibre type varies widely among the muscles in the quadriceps femoris as the RF is composed of 58% FT fibres, the VL is composed of 53% FT fibres and the VM is only composed of 38% FT fibres (Johnson et al., 1973). Furthermore, in the elbow extensors the bi-articular LONG has the largest PCSA, however, in the quadriceps femoris, the bi-articular RF has the smallest PSCA of the muscle group (Farahmand et al., 1998). Finally, the quadriceps femoris is an anti-gravity muscle group and therefore is frequently used and under relatively large loads whereas the triceps brachii is a gravity-assisted muscle subject to relatively less use then the quadriceps femoris and lighter loads.

Numerous studies have investigated the activation pattern of the quadriceps femoris muscle group during submaximal isometric fatigue. One study examining the EMG patterns during a fatiguing isometric knee extension at 30% of MVC found that the EMG of the RF only slightly increased over the fatigue task whereas VL and VM showed a greater rise in the EMG (Ebenbichler et al., 1998). However, the authors did not state the starting levels of EMG at the beginning of the fatigue task nor whether the RF exhibited higher or lower relative EMG compared to the VL and VM (Ebenbichler et al., 1998). A similar pattern of activation has been observed for the QF during an isometric fatiguing contraction of slightly lower intensity. During a sustained isometric contraction at 20% of MVC until fatigue, the RF only showed a slight increase of 15% in EMG levels whereas the VL and VM increased by approximately 27% (Rochette et al., 2003). The lower increase in RF can be attributed to the relative EMG being approximately 12% higher at the beginning of the contraction compared to VL and VM (Rochette et al., 2003). The authors also changed the hip angle to alter the length of the RF and although there was no difference in the pattern of activation of the individual muscles, the RF started at a slightly higher relative EMG level in the supine (lengthened) position (Rochette et al., 2003). In contrast to the previous findings, when the activation of the quadriceps femoris was assessed in a shortened and lengthened position using the interpolated twitch technique along with EMG, the shortened position demonstrated a higher level of activation and EMG compared to the lengthened position; although M-wave amplitude was reduced in the shortened position (Babault et al., 2003; Maffiuletti & Lepers, 2003; Suter & Herzog, 1997). The observed increase in neural activation at the short muscle length may be compensating for neuromuscular transmission-propagation impairment as evident in the decreased M-wave amplitude (Maffiuletti & Lepers, 2003).

Although there are some discrepancies regarding the activation pattern of the quadriceps femoris, the bi-articular RF definitely exhibits a pattern of activation unique from that of the mono-articular VL and VM. Although measurement of the VI is rarely included in studies of the quadriceps femoris due to the deep position of the muscle, it likely plays a significant role in knee extension as it has been shown it can contribute up to 40% of the extension moment at the knee (Zhang et al., 2003).

1.5.2 Triceps Surae

The triceps surae is comprised of one mono-articular muscle, soleus (SOL), and two bi-articular muscles, medial (MG) and lateral (LG) gastrocnemius. The MG and LG are composed of approximately 50% FT fibres while the SOL contains approximately 10% FT fibres (Johnson et al., 1973). Like other muscle groups, the activation pattern can be affected by the length of the respective muscles by changing the ankle or knee angle. In contrast to the findings in the QF where a shortened RF resulted in higher EMG values, when the MG and LG were lengthened by extension of the knee, neural activation as measured by EMG, was higher compared to when the MG and LG were shortened by flexion of the knee (Signorile et al., 2002; Cresswell et al., 1995). The higher EMG of the MG and LG in a lengthened position was in accordance with the finding that during full extension of the knee the MG and LG can contribute up to 40% of the total torque, and with increasing knee flexion the contribution is significantly reduced (Cresswell et al., 1995). Although EMG of the MG and LG is the opposite of what is observed in the QF, M-wave amplitude shows a similar relationship in that as the muscle is shortened there is a resulting decrease in M-wave amplitude (Cresswell et al., 1995). A change in knee angle, as expected, has no effect on the EMG or M-wave amplitude of the SOL (Signorile et al., 2002; Cresswell et al., 1995).

The activation pattern of the triceps surae during fatigue has been the focus of a few studies although the majority of them are conducted with the knee in full extension so as to achieve a greater contribution of the MG and LG in the contraction. A submaximal contraction at 30% of MVC with the knee in full extension resulted in a higher contribution of the MG and LG compared to the SOL (Löscher et al., 1994). The root mean square (RMS) EMG normalized to the MVC of the MG and LG was approximately 38% at the beginning of the fatiguing contraction while the RMS EMG of the SOL was approximately 28% (Löscher et al., 1994). At the end of the fatiguing contraction all muscles exhibited RMS EMG values of approximately 70% (Löscher et al., 1994, 1996). In the only study to examine the effect of knee angle on the EMG pattern of the triceps surae during a submaximal fatiguing isometric contraction, it was found that changing the knee angle did indeed affect the activation pattern (Sirin & Patla, 1987). Sirin & Patla (1987) quantified the EMG of the three muscles as either coactivation, in which neural input to pairs of muscles (MG+LG, LG+SOL, MG+LG) were observed to increase, or a trade-off, in which neural input to a pair was observed to increase in one muscle but decrease in another. In the knee extended position there was a greater occurrence of "trade-off" activation, while in the knee flexed position there was a greater occurrence of coactivation (Sirin & Patla, 1987). The greater occurrence of trade-off activation in the knee extended position is result of all three muscles being near their optimal length and as a result the three muscles can more evenly distribute the load. On the other hand, in the knee flexed position, the MG and LG contribution to plantar flexor torque is lower requiring the SOL to maintain most of the load, and therefore coactivation is the only option to alleviate some of the load on SOL (Sirin & Patla, 1987).

1.6 Summary

Although there is discrepancy among the different muscle groups as to the effect of changing the length of the bi-articular muscle(s) on the activation pattern of synergists, bi-articular muscle length does appear to influence the activation pattern of synergists. A consistent finding among different muscle groups is the observation that shortening the bi-articular muscle results in a decreased M-wave amplitude that is hypothesized to represent an impairment of neuromuscular transmission-propagation (Maffiuletti & Lepers, 2003; Cresswell et al., 1995). The force-length relationship also appears to be an important factor as significant deviations from the optimal length in the MG and LG resulted in a decrease in EMG (Cresswell et al., 1995). Furthermore, fibre type differences between synergists also can influence the activation pattern because muscles composed of a greater proportion of type I fibres have been observed to exhibit preferential activation within a group of synergistic muscles (Kuo & Clamann 1981). It is likely that multiple factors influence the activation pattern of a group synergistic muscles therefore it would be beneficial to study bi-articular muscle length change in a muscle group where fibre type differences between muscles are minimal and changes in muscles length do not deviate significantly from the optimal length in the force length relationship. The elbow extensors provide a unique model to examine this question because the different heads of the triceps brachii are composed of a similar fibre type (Johnson et al., 1973) and the LONG possibly operates over a board range of the force-length relationship as observed with length changes induced about the elbow (Murray et al., 2000).

CHAPTER 2: INTRODUCTION

When multiple muscles act across a joint, they are classified as a synergistic group if they provide an additive contribution to a particular function during a contraction (Basmajian & DeLuca, 1985). As such, MED, LAT, and LONG of the triceps brachii and the ANC are classified as a synergistic group as they all contribute to the function of elbow extension. However, the LONG is a bi-articular muscle that crosses the elbow and shoulder joints, whereas the others are mono-articular muscles only crossing the elbow joint. Frequently, when the function of the elbow extensors is examined, one head of the triceps brachii is assumed to represent the whole group under the concept of a 'muscle equivalent' (Bouisset, 1973). Although originally proposed for the elbow flexors (Bouisset, 1973), the muscle equivalent concept has been applied to the elbow extensors arguing that measuring one head of the triceps brachii, usually LAT, can be taken as representative of the entire group (Le Bozec et al., 1980a, 1980b). However, this concept has been challenged as being too simplistic to explain or to recognize important differences that likely exist among the different muscles during functional movements (Kouzaki, 2005).

Not surprising therefore, in other synergistic muscle groups, the application of the muscle equivalent concept has been contradicted as EMG measures from one muscle did not specifically correlate to the other synergists (Buchanan et al., 1989; Miaki et al., 1999; Rochette et al., 2003). Particularly, within a synergistic group composed of both mono- and bi-articular muscles, lengthening of the bi-articular muscle(s) while maintaining the length of the mono-articular muscle(s) resulted in changes in EMG activity that were dependent on the muscle group tested. This has been observed in the lower limb synergistic groups of the quadriceps femoris (Rochette et al., 2003) and triceps surae (Signorile et al., 2002; Sirin & Patla, 1987). Increases in muscle length have also resulted in improved voluntary activation and greater fatigability perhaps because of greater recruitment of motor units during fatiguing contractions (Becker & Awiszus 2001; Weir et al., 2000). Greater monosynaptic input from group Ia afferent fibres to the motoneuron pool along with the possibility of improved neuromuscular transmission propagation are thought to promote enhanced voluntary activation and greater recruitment of motor units at longer muscle lengths (Becker & Awiszus 2001; Kubo et al., 2004).

In the limited number of studies that have examined sustained submaximal isometric contractions of the elbow extensors, EMG activity was only obtained from one head of the triceps brachii, either the LAT or MED (Griffin et al., 2001b; Krogh-Lund & Jorgensen, 1991). There are few studies that have explored task-related differences in EMG activation of the muscle portions included in the elbow extensor muscle group. For example, although sustained submaximal isometric contractions held until task failure of the elbow extensors have been previously examined in a few studies, the EMG activation patterns of all muscle portions have not been reported. More importantly, the influence of shoulder angle which will affect the length of only the LONG has not been evaluated during any fatiguing tasks. Although increases ranging between 78% - 350% in EMG activity were observed at the end of the fatiguing contraction for the MED or LAT, this index was not the primary outcome measure (Griffin et al., 2001b; Krogh-Lund & Jorgensen, 1991). Thus, the EMG activation pattern of the four muscle portions during fatigue and the effect of bi-articular length change has not been the focus of a comprehensive study.

The elbow extensors provide a novel model to examine the influence of length change of the bi-articular muscle within a synergistic muscle group on the EMG activation pattern of synergists during submaximal and fatiguing contractions. Kuo & Clamann (1981) determined that within a synergistic muscle group, muscles composed of a greater proportion of type I fibres will exhibit a greater preferential activation. The similar composition of the three heads of the triceps brachii at ~65% type II fibres (Johnson et al., 1973) allows for the influence of differences in fibre type on the EMG activation pattern of synergists to be minimized. Although the ANC fibre type composition is significantly different from that of the three heads of the triceps brachii at ~35% type II fibres (Le Bozec & Maton, 1987), the influence on the EMG activation pattern is likely minimal as it has been demonstrated to contribute up to ~15% of the extension moment at low torque levels (Zhang & Nuber, 2000). As noted above, the elbow extensors are composed of three mono-articular muscles (MED, LAT, and ANC) and one bi-articular muscle (LONG). The length of the LONG is affected by the elbow and shoulder angle whereas the mono-articular muscles are affected only by elbow angle changes. With increasing shoulder flexion, the length of the LONG becomes greater (Kapandji, 1982). The purpose of this study was to examine the effect of changing the shoulder angle and therefore the length of the bi-articular LONG on the EMG activity of the four components of the elbow extensors during various contraction intensities, and during a sustained isometric fatiguing contraction at 20% of MVC. It is hypothesized, that due to the increased excitatory drive resulting from possibly improved neuromuscular transmission propagation and greater monosynaptic input from Ia afferents that there would be greater recruitment of motor units in a lengthened position. As a result, the EMG activity of the LONG during fatigue will show a greater increase in the flexed shoulder position.

CHAPTER 3: METHODS

3.1 Subjects

Ten healthy recreational-active young men (23.5 [SD 1.7 y], 179.9 [5.3 cm], 81.5 [7.1 kg]) were recruited from the university environment. Subjects were informed to refrain from caffeine consumption on the day of testing. Informed oral and written consent was obtained from all subjects prior to testing. The local university ethics board approved the study (Appendix C).

3.2 Experimental Setup

All testing was performed on a Biodex System 3 dynamometer (Shirley, New York, USA) which was used to record isometric elbow extension torque (Fig. 2). Subjects were seated comfortably in an upright position with the hip angle at 85°, elbow maintained at 90° of flexion (0° = full extension), and depending on the testing session, the shoulder was maintained at either 0° or 90° of flexion in the sagittal plane. The forearm was maintained in a neutral position and the wrist rested on a custom designed aluminum plate. A goniometer was used to determine the elbow and shoulder angles. All testing was conducted on the non-dominant arm. To stabilize the shoulder during testing and minimize any extraneous movements, the shoulder was firmly secured with two straps placed around the upper torso. The axis of rotation of the dynamometer was aligned with the lateral epicondyle of the humerus.

EMG activity was sampled from the three heads of the triceps brachii and ANC by means of intramuscular electrodes made from 100 μm formvar insulated stainless steel wire (California Fine Wire Co., Grover City, CA) with ~5 mm of the insulation removed at the recording tip. After cleaning the area with 70% isopropyl alcohol, two wires were inserted independently into each muscle portion separated by 20 mm using 27.5-gauge 12 mm sterilized hypodermic needles. The needles were inserted into the: (1) LAT, 6 cm distal to the posterior border of the deltoid; (2) LONG, 6cm distal to the axilla on the medial side of the arm; (3) MED, 4 cm proximal to the medial epicondyle of the humerus and (4) ANC, 2 cm lateral to the inferior border of the olecranon (Pauly et al., 1967). Ground reference electrodes were placed on the styloid process of the radius and ulna at the wrist. The intramuscular recording of gross EMG signals using this technique minimized the potential of recording cross-talk between the muscle portions.

3.3 Experimental Procedure

Except for changing the shoulder angle, subjects performed the same experimental protocol during the two testing sessions separated by at least 3 days. Initially the subjects performed three MVCs separated by 3 min of rest. The subjects were encouraged verbally during each MVC and were provided visual feedback of extensor torque on a monitor placed ~1 m in front of the subjects. If the three MVC attempts were not within 5%, additional MVCs were performed with additional rest as needed. The greatest torque achieved by the subject was taken as the MVC and used subsequently to calculate the submaximal target torques. Following 3 min of rest, subjects performed 5 s contractions, in order, at 20%, 40%, 60%, and 80% of MVC, each separated by 1 min of rest. Following 5 min of rest, a sustained 20% MVC isometric fatiguing contraction of the elbow extensors was performed until the torque fell 10% below the target despite strong verbal encouragement from the investigator. Approximately 10 s after the termination of the fatiguing contraction, subjects performed a MVC to determine the amount of fatigue induced.

3.4 Equipment

All torque data obtained from the Biodex were sampled at 100 Hz using a 12-bit A/D converter (CED Model 1401 Plus; Science Park, Cambridge, UK) online using Spike2 software (Version 6, CED, Cambridge, UK). Spike2 was used for offline analysis of isometric torque values.

Intramuscular EMG signals from the four muscle portions were amplified (x1000) (Neurolog NL824; Hertfordshire, UK), filtered (10Hz-10kHz) (Neurolog Bioamplifier; Hertfordshire, UK), and sampled at 5 kHz using a 12-bit A/D converter (CED Model 1401 Plus; Science Park, Cambridge, UK). Spike2 was used for online inspection and offline analysis of intramuscular EMG signals.

3.5 Signal Analysis

During the MVC trial that had the highest torque value, the RMS amplitude of the EMG signals was calculated as the average amplitude from a 1.5 s window centered about the peak torque. The average RMS amplitude obtained during the MVC was subsequently used to normalize the EMG activity obtained during submaximal contractions.

For submaximal contractions of 20%, 40%, 60%, and 80% of MVC the RMS amplitude was calculated as the average of a 1.5 s window in the latter half of the contraction to allow for the subject to achieve the target torque. The RMS amplitude of the EMG signals was normalized to the RMS amplitude of the EMG signals obtained during the MVC.

For the fatiguing contraction, the RMS amplitude of the EMG signals was calculated as the average of a 1.5 s window for consecutive 10% intervals for the duration of the fatigue task. The RMS of the EMG signals during fatigue was normalized to the RMS amplitude of the EMG signals obtained during the MVC. To account for each muscle portion starting at different percentages of the RMS at the onset of the fatiguing contraction, the RMS amplitude was also calculated for a 1.5 s window corresponding to the initial 5% time point of the fatiguing contraction. Subsequently, values obtained at the 10% intervals were normalized to the initial 5% to obtain a percentage increase in RMS amplitude relative to the beginning of the fatiguing contraction.

3.6 Statistics

All data were analyzed using SPSS software (version 16; SPSS Inc, Chicago, IL). MVC torque and endurance times were analyzed using a dependent t-test to compare the two shoulder angles. A three-factor ANOVA (intensity x muscle x angle) with repeated measures was used to compare the EMG-torque relationship at the submaximal isometric contractions of 20%, 40%, 60%, and 80% of MVC. A three-factor ANOVA (time x muscle x angle) with repeated measures was used to compare the normalized RMS of the EMG signals of the muscle portions at every 10% of the fatigue task. If a significant main effect or an interaction was present, a Tukey's HSD post hoc test was performed. The significance level was set at $p < 0.05$. Data are reported as means ± standard deviations (SD) within the text and displayed as means ± standard error of the mean (SEM) in the figures.

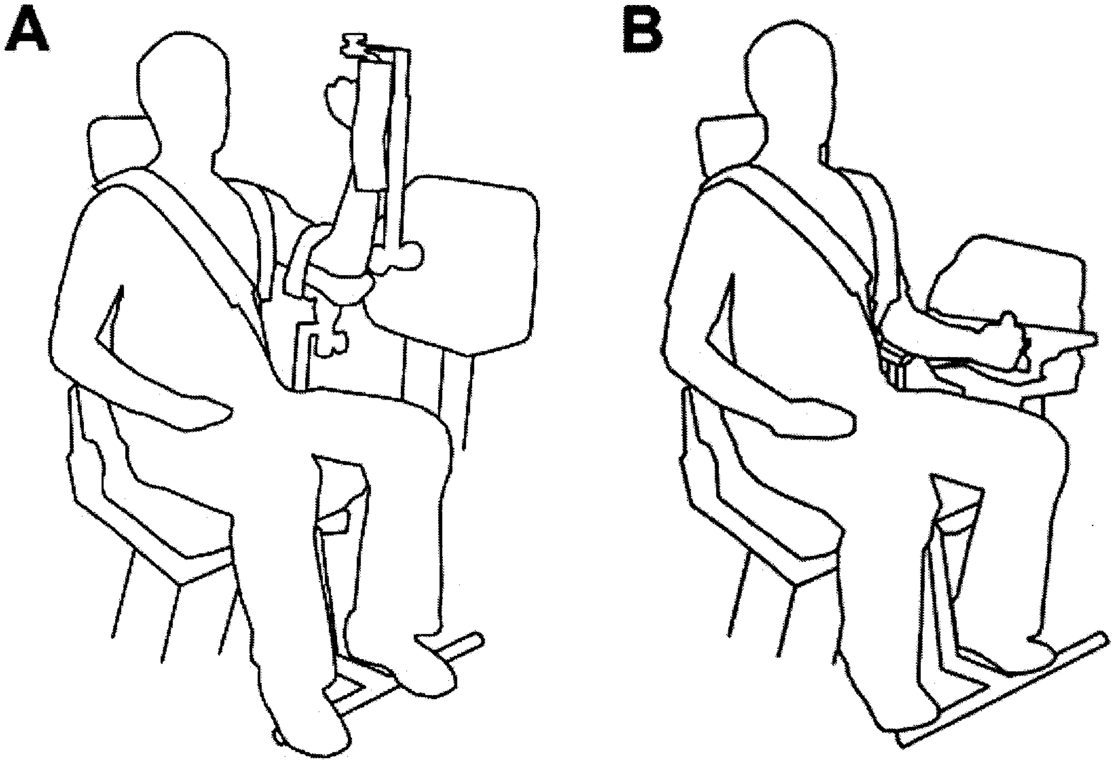

Fig. 2. Experimental setup. Shoulder was placed at either 90° of forward flexion (A) or 0° of forward flexion (B).

CHAPTER 4: RESULTS

4.1 Torque and Endurance Measures

Torque and endurance measures can be found in Table 1. Baseline MVC torque did not differ between 90° (long length) (71.0 [11.3 Nm]) and 0° (short length) (67.2 [19.2 Nm]) of forward shoulder flexion. The endurance time of the fatiguing contraction was not significantly different between long and short lengths (234.8 [67.9 s] and 314.8 [113.9 s], respectively). At the long length, the MVC following the fatiguing contraction exhibited a significantly greater decrease in peak torque (42.6 [12.5%]) compared with short length (28.7 [10.3%]).

4.2 EMG-Torque Relation

There was no difference among muscles for the average amplitude of the RMS of the EMG normalized to the MVC values recorded during brief isometric contractions at 20%, 40%, 60%, and 80% of MVC torque (Fig. 3). Normalized RMS EMG increased linearly for all muscle portions. There was no interaction for angle and intensity indicating that the increase in RMS EMG was similar between the two shoulder angles.

4.3 RMS EMG Activity During the Fatiguing Contraction

The RMS normalized to the initial 5% time point of the fatiguing contraction showed a significant increase for the MED, LAT and LONG over the fatiguing contraction at both shoulder angles. The ANC did not exhibit a significant increase in RMS amplitude at any interval in the fatiguing contraction at either shoulder angle. When comparing each muscle portion between the two angles, at 90° LONG exhibited a significantly greater increase in normalized RMS at 90% and 100% of the fatiguing contraction versus 0° (Fig. 4C). All other muscle portions did not exhibit any significant differences between the two shoulder angles (Fig. 4A, B, D) ($p > 0.05$).

Table 1. Subject Characteristics & Performance Values (n=10)

Measure	Mean	SD
Age (y)	23.5	1.7
Height (cm)	179.9	5.3
Mass (kg)	81.5	7.1
PRE MVC Torque (Nm)		
Shoulder at 0°	67.2	19.2
Shoulder at 90°	71.0	11.3
Decrease in MVC (%)		
Shoulder at 0°	28.7	10.3
Shoulder at 90°	42.6 *	12.5
Time To Task Failure (s)		
Shoulder at 0°	314.8	113.9
Shoulder at 90°	234.8	67.9

(*) denotes a significant difference between shoulder angles ($p<0.05$)

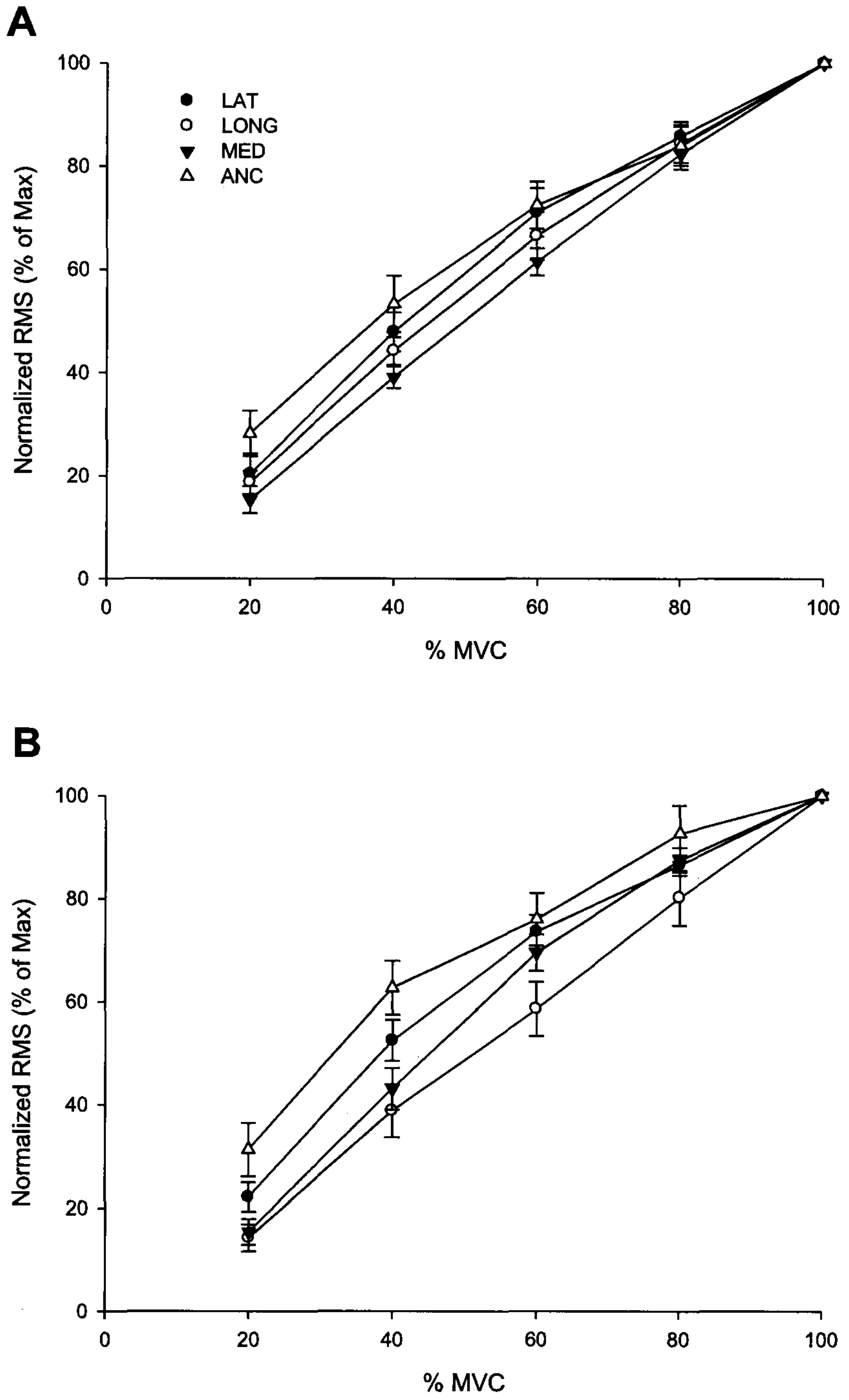

Fig. 3 Relation of normalized RMS EMG and relative torque for the elbow extensor muscles at 0° of forward flexion (A) and 90° of forward flexion (B). Normalized RMS EMG increased with increasing torque although no significant differences existed among muscles and between shoulder angles ($p > 0.05$).

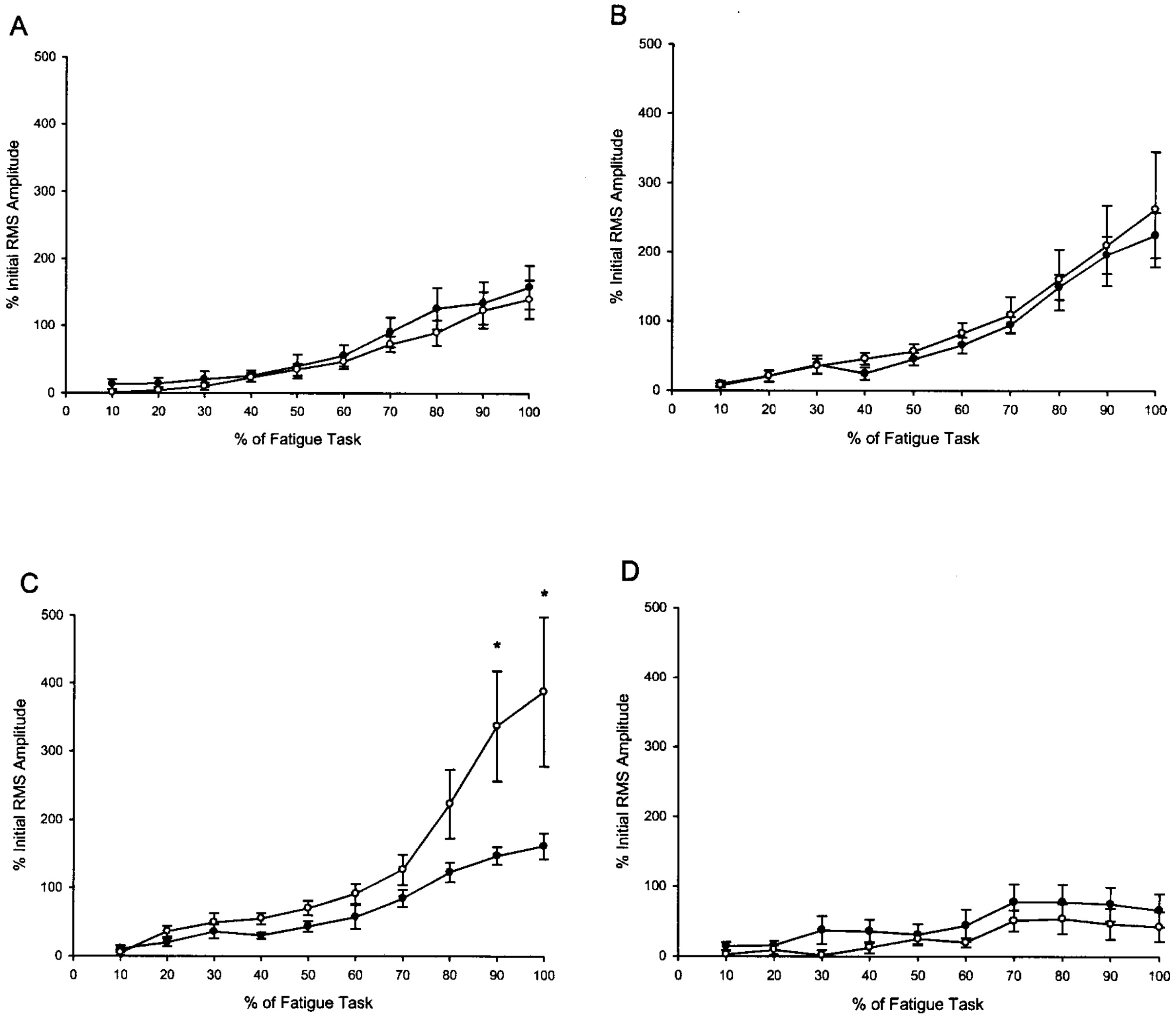

Fig. 4 Percent increase in RMS amplitude for the fatiguing task for LAT (A), MED (B), LONG (C), and ANC (D) at 0° of forward flexion (●) and 90° of forward flexion (○). A, B, D: There were no significant differences between the two angles at any time point in the fatigue task ($p > 0.05$). C: At 90% and 100% of the fatigue task, LONG exhibited a greater rise in RMS amplitude at 90° versus 0° of forward shoulder flexion ($^{*}p < 0.05$).

CHAPTER 5: DISCUSSION

5.1 Purpose

This study examined the effect of shoulder angle and therefore the effect of length change of the LONG on the EMG activation pattern of the elbow extensors during incremental submaximal contractions and during a sustained submaximal isometric contraction maintained until task failure. Few studies have examined the task related differences in the four muscular components of the elbow extensors during submaximal contractions and no previous investigation has been conducted on the EMG activation pattern during a submaximal fatiguing contraction. Furthermore, as the LONG is a bi-articular muscle crossing the shoulder and elbow joints, the effect of changing the length of only the LONG on the EMG activation pattern of the elbow extensors has not been the focus of a comprehensive study. Thus, the purpose of this study was to comprehensively record EMG activity from all four muscular portions of the elbow extensors during incremental submaximal contractions and during a sustained fatiguing submaximal contraction maintained until task failure. The protocol was repeated twice on two separate days with the only difference being the shoulder was either at 0° or 90° of shoulder flexion to examine the effect of length change of the bi-articular muscle. The main outcome measures were changes in isometric PRE MVC torque at each shoulder angle, EMG activity recorded from each muscular portion, endurance time, and the decrease in isometric torque of the POST MVC.

5.2 Major Findings

Our results demonstrate that 1) shoulder angle did not affect the overall MVC torque of the elbow extensors, and confirm the EMG-torque relationship of any of the four muscle components is not affected by shoulder angle; 2) during a sustained isometric contraction at 20% MVC until task failure, the increased EMG activity of the LONG was significantly greater at the final 10% of the fatigue task when the shoulder angle was at 90° (long length) versus 0° (short length), with no observed effect of shoulder angle on the MED, LAT, and ANC; 3) when the shoulder was at 90°, the decline in torque for the elbow extensors following fatigue was greater than at 0°, and 4) all components exhibited a significant increase in EMG activity over the fatiguing contraction except for the ANC which showed no significant increase in EMG activity.

5.3 Baseline Measures

In the current study, the change in shoulder angle did not significantly affect MVC torque. Although other muscle groups have exhibited significant differences in peak torque depending on the joint angle, this has been attributed to deviations from the optimal length in the force-length relationship (Becker & Awiszus, 2001; Leedham & Dowling, 1995). Murray et al. (2000) determined that the LONG operates over a narrow range of the isometric torque-length relationship with regard to length change induced by changing elbow angle, indicating length change will have minimal effect on the torque generating capacity of the LONG. Although the torque-length relationship of the LONG is not known with respect to changes in shoulder angle, in the current study the similar peak torque observed at each shoulder angle suggests that changes in LONG muscle length over the range of motion do not induce length changes that deviate from the narrow range of the torque-length relationship observed at varying elbow angles.

The similar linear intensity-related increase in the EMG-torque relationship for all four components of the elbow extensors is in agreement with the only other study to examine quantitatively this relationship during non-fatiguing contractions (Le Bozec et al., 1980b). We further confirm the findings of Le Bozec et al. (1980b) that demonstrated shoulder angle had no effect on the EMG-torque relationship. No effect of joint angle on the EMG-torque relationship has been reported for other muscles with portions that span two joints such as the biceps brachii (Leedham & Dowling, 1995) and rectus femoris (Rochette et al., 2003). However, a significant decline in the EMG-torque relationship of the bi-articular gastrocnemii has been observed when the knee is flexed, but this seems to be more of a biomechanical effect causing a significant reduction in the muscle's ability to contribute to plantar flexion torque (Hof & Van Den Berg, 1977). It is likely that the change in shoulder angle did not significantly affect the ability of the LONG to contribute to elbow extension torque as evident by the similar peak torques achieved during the baseline MVCs at each shoulder angle.

5.4 Fatigue Measures

When a submaximal isometric contraction is maintained umtil the target force can no longer be maintained, the EMG activity will progressively increase during the contraction (Fuglevand et al., 1993). Classically, the increase in EMG activity has been attributed to an increase in descending drive resulting in the recruitment of unfatigued motor units and an increase in motor unit firing rates (Fuglevand et al., 1993). Previous studies examining sustained submaximal isometric fatigue of the elbow extensors at similar contraction intensities have only recorded EMG activity from one muscle portion (Griffin et al., 2001b; Krogh-Lund & Jorgensen, 1991). At 20% of MVC the EMG activity of the LAT increased ~78% after 282 s (Griffin et al., 2001b) and at 25% MVC there was an increase of ~350% for the MED after 198 s (Krogh-Lund & Jorgensen, 1991). In the present study we recorded from all four portions and found a wide range of increases in EMG activity among the muscle portions after ~270 s of fatigue. For the LONG, the greatest increase in EMG activity was 388% at 90° compared to 161% at 0°. Shoulder angle had no effect on the EMG activity of the other portions although differences in the increases in EMG activity were observed among the portions. The MED increased up to 262%, the LAT up to 158%, and the ANC up to 66% at the end of the fatiguing contraction. Thus it is clear that the relative activation among the portions of the elbow extensors is not equal during fatigue, and indeed although the LONG showed a greater increase when lengthened, this did not affect the relative EMG activity of the other muscle portions.

In forward flexion, the change in shoulder angle had no affect on the EMG activation pattern during the fatiguing contraction for all muscle portions of the elbow extensors except for the LONG. When the LONG was lengthened, there was a significantly greater increase in EMG activity during the final 10% of fatigue compared to a shortened position. The significant increase in EMG activity at the end of the fatiguing contraction is likely attributable to increased recruitment of unfatigued motor units. This suggestion is supported by the findings of a study of the LAT (Griffin et al., 2001b) and another of the biceps brachii (Garland et al., 1994) both, using similar fatiguing protocols, measured a decrease in motor unit firing rates during fatigue. Although motor unit firing rates of the LAT may not directly correlate to the LONG, observations from other muscles such as the biceps brachii that firing rates decline during sustained submaximal isometric contractions support the suggestion of increased recruitment during the fatiguing contraction (Garland et al., 1994). Thus, it is reasonable to suggest that increased recruitment accounts for increased EMG activity in spite of decreased firing rates observed during fatigue.

Indeed, motor unit recruitment is enhanced at long versus short muscle lengths during fatigue (Weir et al., 2000). Weir et al. (2000) determined that at long muscle lengths in the tibialis anterior, greater increases in EMG amplitude during a sustained submaximal isometric fatiguing contraction relative to short muscle lengths were correlated with larger increases in mechanomyography (MMG) amplitude. It has been suggested that increases in MMG amplitude likely reflect increased motor unit recruitment (Orizio et al., 1992). This finding has also been observed in the upper limb of the bi-articular biceps brachii using MMG (Mamaghani et al., 2002). Over varying elbow and shoulder angles, when the elbow and shoulder were extended thereby inducing the greatest length of the biceps brachii, the increase in EMG and MMG amplitude was observed to be the greatest relative to all other elbow and shoulder angles tested during a 20% MVC sustained isometric contraction until fatigue. Becker & Awiszus (2001) demonstrated that in the quadriceps femoris muscle, as length was progressively shortened, voluntary activation as assessed through the interpolated twitch technique was increasingly impaired with shorter muscle lengths. Weir et al. (2000) highlight that the greater increase in EMG activity at the longer muscle lengths is a result of a greater percentage of the motor unit pool is available for recruitment due to the enhancement of voluntary activation. The observations from previous studies in other muscle groups and that of the current study suggest that when the LONG was lengthened in the 90° of flexion, there was greater recruitment of unfatigued motor units as the fatiguing contraction progressed possibly due to less inhibition of motor units in the long length. Increased recruitment of unfatigued motor units is also supported by the observation of a greater reduction in the MVC following the fatiguing contraction when the shoulder angle was at 90° compared to 0°. The recruitment of a greater population of the motoneuron pool would lead to a greater reduction in torque producing capacity of the muscle following the fatiguing contraction due to contractile failure of the fatigued motor units.

5.5 Anconeus

An interesting finding of the current study was that although the MED, LAT and LONG demonstrated a significant increase in EMG activity over the fatiguing contraction regardless of shoulder angle, ANC did not exhibit any significant increase in EMG activity. The only other study examining fatigue of the ANC observed during intermittent isometric contractions at 50% of MVC, an ~ 40% increase in ANC EMG activity although the time to fatigue of 84 s was significantly shorter than in the current study (Le Bozec & Rougier, 1991). Although this is a similar increase in EMG as that observed in the present study (43% - 66% depending on shoulder angle) our increase was statistically non-significant. The unique nature of the ANC muscle compared to the other components of the elbow extensors is likely responsible for the observed differences. The fibre type of the ANC (~35% type II fibres) is significantly different from that of the triceps brachii (~65% type II fibres) (Le Bozec & Maton, 1987), and it has been determined previously that muscles within a synergistic group composed of a greater proportion of type I fibres will be recruited first (Kuo & Clamann,1981). As a consequence a smaller proportion of the ANC motor unit pool is available for recruitment as fatigue progresses. Furthermore, as the ANC is composed of a greater proportion of type I fibres, the time of the fatiguing contraction was likely insufficient to induce a significant amount of fatigue in the ANC that would result in a compensatory increase in motor unit recruitment which is evident in the non-significant increase in EMG activity.

5.6 Summary and Conclusions

Increased shoulder angle, and thus increased length of LONG, resulted in greater fatigability of the elbow extensors and a greater increase in EMG activity of the LONG with no effect of shoulder angle on the MED, LAT, and ANC. The findings of the present study have implications when examining the previous and future studies of the elbow extensors. Due to the unique nature of the LONG being a bi-articular muscle crossing the shoulder and elbow joints, under submaximal isometric fatiguing contractions, measures from one component of the elbow extensors cannot be considered representative of the whole elbow extensors muscle group. Furthermore, shoulder angle must also be considered as it has significant implications on the fatigability of the elbow extensor muscle group.

CHAPTER 6: LIMITATIONS AND FUTURE DIRECTIONS

The results from this study concluded that increased length of the bi-articular LONG resulted in greater neural activation in the final 10% of the fatiguing task and a greater decline in torque following the fatiguing task. In the current study the shoulder angle was only changed by 90°, however, the shoulder joint is unique in that it is the joint that possesses the greatest range of motion within the human body. Therefore, the length change induced by increasing the shoulder flexion angle by 90° represents only a moderate length change compared to that of the length change that would occur at more extreme shoulder flexion angles (e.g. 180°). Furthermore, in the current study length change of the LONG was achieved by flexing the arm in the sagittal plane. However, due to the great mobility of the shoulder joint, it is also possible to induce a length change of the LONG by moving the arm in the frontal plane by increasing the abduction angle. It would be interesting to examine the effect of even greater changes in the length of the LONG along with movements in other anatomical planes and the resulting effect on the EMG activation pattern of the elbow extensors.

Another limitation of the current study is that although it is known that increasing shoulder flexion will increase the length of the LONG, it is not known precisely how much length change actually occurred. Future studies would benefit from the use of ultrasound to measure the amount of length change that occurs in the LONG with a change in shoulder angle. An accurate measurement of the length change would allow for a comparison of the results to other muscle groups where the amount of length change that occurs is known.

The elbow extensors receive blood flow from profunda brachii artery that is a branch of the brachial artery. Griffin et al. (2001a) determined that during a sustained isometric contraction at 20% MVC, blood flow did not change in the profunda brachii artery at any point in the fatiguing contraction as measured by ultrasound. However, blood flow was only measured at one shoulder angle of 90° of flexion. It is not known if shoulder angle would have any effect on blood flow in the profunda brachii possibly due to differences in intramuscular pressure or a physical impairment of the artery. Furthermore, although blow flow may not be impaired at the level of the profunda brachii artery, impairments in blood flow at higher order arterioles or at the level of the capillary bed may be a possibility. The use of near-infrared spectroscopy (NIRS) would allow for the direct measurement of oxygenation at the level of the muscle and may provide insight to differences in oxygenation among different portions of the elbow extensors. Future studies should examine the possibility of changes in blood flow with changes in shoulder angle along with using NIRS to examine any relationship blood flow and oxygenation has on the fatigue response of the elbow extensors.

Although the subjects were well practiced at maximal elbow extension contractions, were provided with visual feedback of the torque signal, and were encouraged during the MVC, it was not possible to determine the level of activation during the MVCs. As the experimental setup required eight intramuscular wires inserted into the elbow extensors, the setup did not allow for the use of surface stimulation to assess activation during the MCVs with the interpolated twitch technique. It is possible that changing the shoulder angle affected the ability of the subjects to maximally activate their elbow extensors during the MVCs. Future studies would benefit from the use of stimulation to assess any changes in activation of the elbow extensors with a change in shoulder angle. Furthermore, previous studies have examined the M-wave amplitude to assess any impairment in neuromuscular transmission-propagation with a change in joint angle. Although the assessment of M-wave amplitude would be a beneficial addition, recording of M-wave amplitude changes in the components of the elbow extensors is unfeasible due to the unique innervation supply to each component. Whole muscle stimulation would also have provided some insights into changes in muscle contractile properties.

As a fatiguing contraction was maintained until task failure, there was greater activation of the long head when lengthened with no effect on the mono-articular portions. Elbow position was maintained at a constant angle of 90° so as to maintain the length of the medial head, lateral head, and the anconeus. Future studies should examine the effect of changing elbow angle on the EMG activation pattern of the components of the elbow extensors. Furthermore, changing the elbow angle would not only allow the examination of changes in muscle length of the mono-articular muscles on the EMG activation pattern, but would also determine if the long head is affected to a lesser or greater extent by length changes about the elbow relative to that at the shoulder.

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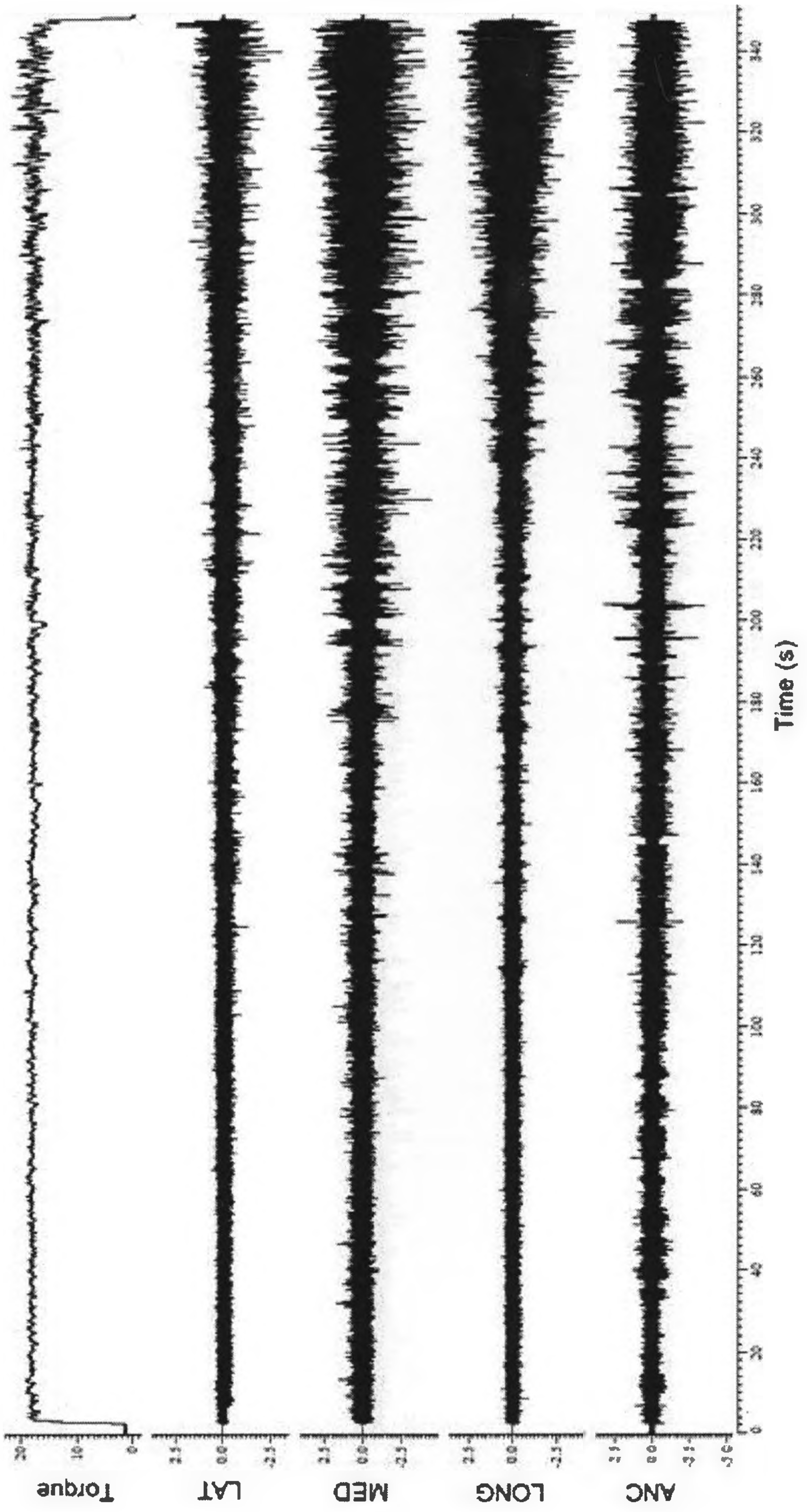
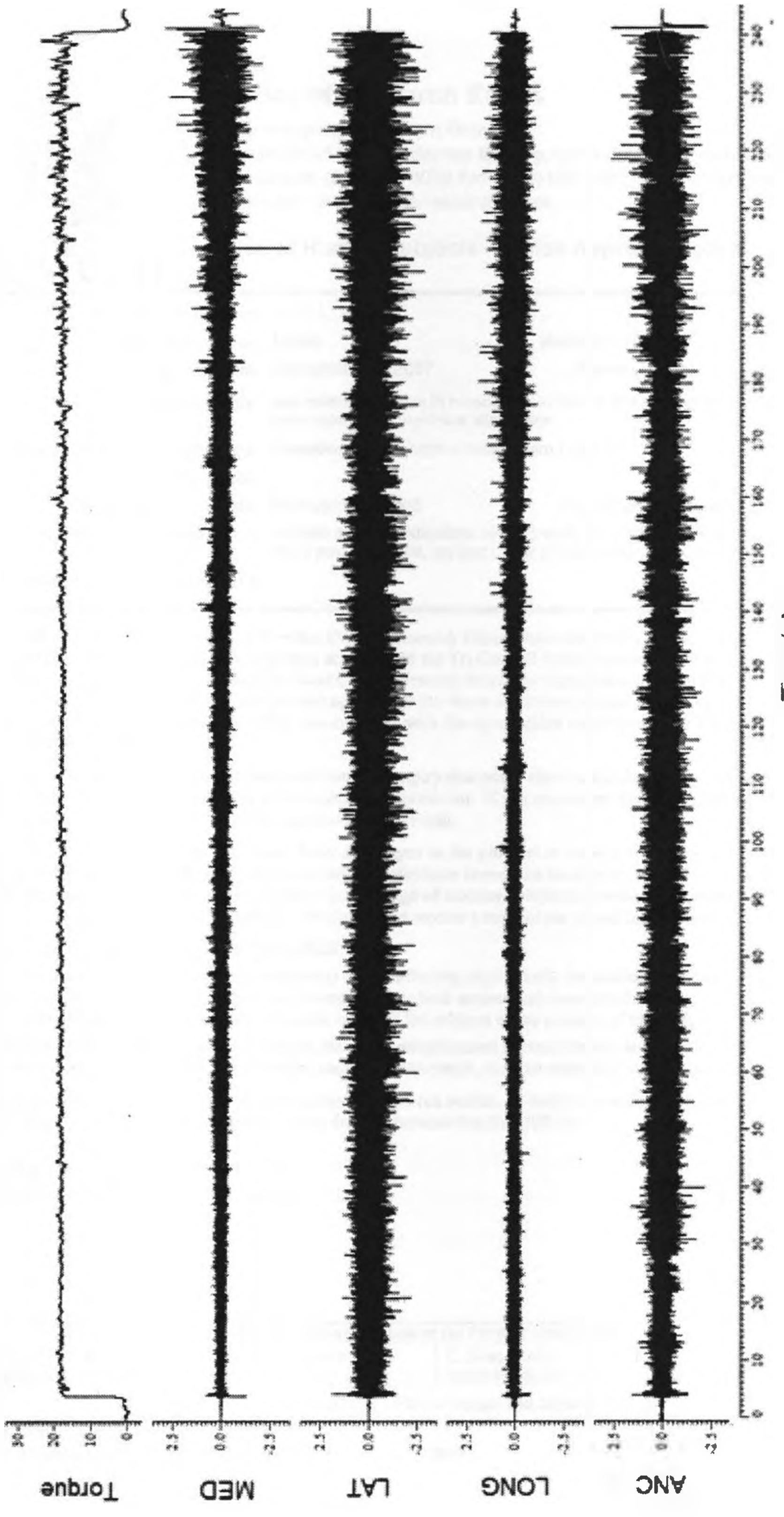
APPENDIX A



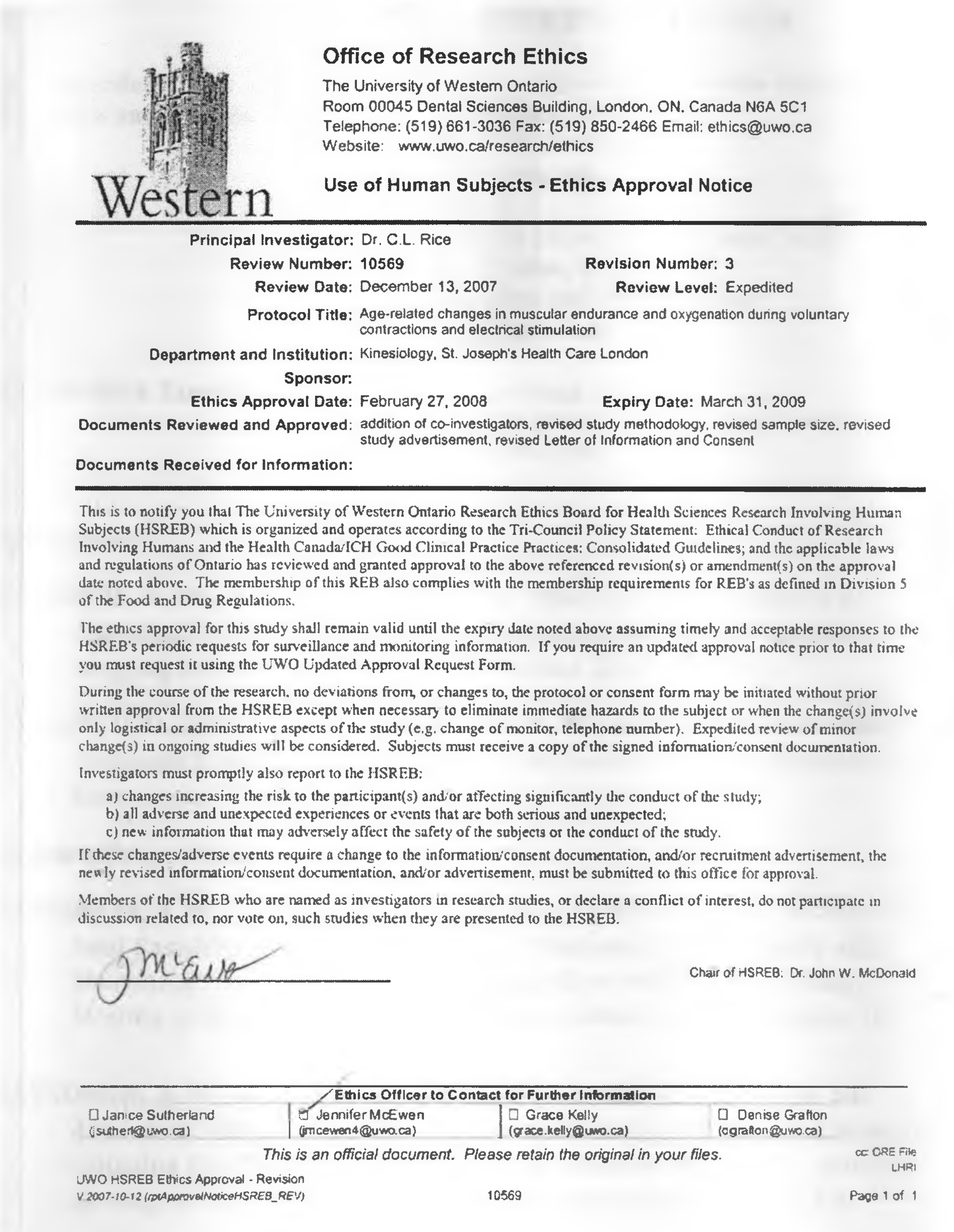
Raw EMG and torque signal of a representative subject with the shoulder at 90°.

APPENDIX B



Raw EMG and torque signal of a representative subject with the shoulder at 0°.

APPENDIX C



Office of Research Ethics

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Website: www.uwo.ca/research/ethics

Use of Human Subjects - Ethics Approval Notice

Principal Investigator: Dr. C.L. Rice
Review Number: 10569 **Revision Number:** 3
Review Date: December 13, 2007 **Review Level:** Expedited
Protocol Title: Age-related changes in muscular endurance and oxygenation during voluntary contractions and electrical stimulation
Department and Institution: Kinesiology, St. Joseph's Health Care London
Sponsor:
Ethics Approval Date: February 27, 2008 **Expiry Date:** March 31, 2009
Documents Reviewed and Approved: addition of co-investigators, revised study methodology, revised sample size, revised study advertisement, revised Letter of Information and Consent
Documents Received for Information:

This is to notify you that The University of Western Ontario Research Ethics Board for Health Sciences Research Involving Human Subjects (HSREB) which is organized and operates according to the Tri-Council Policy Statement: Ethical Conduct of Research Involving Humans and the Health Canada/ICH Good Clinical Practice Practices: Consolidated Guidelines; and the applicable laws and regulations of Ontario has reviewed and granted approval to the above referenced revision(s) or amendment(s) on the approval date noted above. The membership of this REB also complies with the membership requirements for REB's as defined in Division 5 of the Food and Drug Regulations.

The ethics approval for this study shall remain valid until the expiry date noted above assuming timely and acceptable responses to the HSREB's periodic requests for surveillance and monitoring information. If you require an updated approval notice prior to that time you must request it using the UWO Updated Approval Request Form.

During the course of the research, no deviations from, or changes to, the protocol or consent form may be initiated without prior written approval from the HSREB except when necessary to eliminate immediate hazards to the subject or when the change(s) involve only logistical or administrative aspects of the study (e.g. change of monitor, telephone number). Expedited review of minor change(s) in ongoing studies will be considered. Subjects must receive a copy of the signed information/consent documentation.

Investigators must promptly also report to the HSREB:

a) changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
b) all adverse and unexpected experiences or events that are both serious and unexpected;
c) new information that may adversely affect the safety of the subjects or the conduct of the study.

If these changes/adverse events require a change to the information/consent documentation, and/or recruitment advertisement, the newly revised information/consent documentation, and/or advertisement, must be submitted to this office for approval.

Members of the HSREB who are named as investigators in research studies, or declare a conflict of interest, do not participate in discussion related to, nor vote on, such studies when they are presented to the HSREB.

Chair of HSREB: Dr. John W. McDonald

Ethics Officer to Contact for Further Information

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This is an official document. Please retain the original in your files.

cc: ORE File
LHRI

UWO HSREB Ethics Approval - Revision
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