EMG changes of the forearm extensors at different forearm postures.

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Abstract:

Lateral epicondylitis is caused by repetitive and forceful movements of the forearm over long durations without sufficient rest in between. This study aimed to compare muscle length change in directions at different forearm postures. Fifteen healthy participants performed wrist extension against a force transducer at forearm pronation, supination, and neutral at 75±1% of their maximum voluntary contraction. Surface electromyography was used to record muscle activity of the extensor carpi radialis brevis, extensor digitorum communis, and extensor carpi ulnaris. There was a significant interaction between forearm posture and muscles analyzed. This study suggests that there is an opposite length change of the extensor carpi radialis brevis compared to the extensor digitorum communis and extensor carpi ulnaris, strengthening the link between pronation and supination and the development of pain at the lateral epicondyle.

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Table of Contents

List of Tables

List of Figures

Table of Abbreviations:

Abbreviation	Definition
CET	Common Extensor Tendon
ECRB	Extensor Carpi Radialis Brevis
ECU	Extensor Carpi Ulnaris
EDC	Extensor Digitorum Communis
EMG	Electromyography
LE	Lateral Epicondylitis
MVC	Maximum Voluntary Contraction
NIOSH	National Institute of Occupational Safety and Health
PEC	Parallel Elastic Component
SEC	Series Elastic Component
WRMSD	Work Related Musculoskeletal Disorders

Chapter 1:

1.1 Introduction:

Disorders to the musculoskeletal system caused by occupational tasks are referred to as Work Related Musculoskeletal Disorders (WRMSDs). They affect tissues such as tendons, cartilage, nerves, and muscles. They are often caused by tasks that involve force, awkward postures, and repetition, such as assembly line work and many office jobs. The National Institute of Occupational Safety and Health (NIOSH) reported that in 2004, 34% of all nonfatal occupational illnesses in the United States were WRMSDs. The annual cost of WRMSDs ranges from $13 to $20 billion USD (Aptel et al., 2002). One of the WRMSDs of the upper limb is tennis elbow, also known as lateral epicondylitis (LE). The prevalence rates are discussed later on in the chapter.

Tennis elbow was first described in 1883 as a condition that causes pain at the lateral side of the elbow in tennis players. More specifically, it is denoted as pain where the common extensor tendon (CET) attaches to the lateral epicondyle. Although the most common term used today is still tennis elbow, it may be misleading to the general population since it gives the impression that it occurs solely while playing tennis. In response, there have been several terms developed to describe this condition. One is lateral epicondylitis, which denotes that swelling occurs at the lateral epicondyle (Whaley & Baker, 2004). Nirschl suggested the term angiofibroblastic tendinosis in 1992. This is a more accurate name as it has been shown that inflammation is only present during the very early stages of the condition and that it dissipates soon after (Whaley & Baker, 2004). Nirschl's reasoning for modifying the term was that the tissue was characterized by disorganized and immature collagen formation with immature fibroblastic and vascular elements. Currently, no study has found why there is a buildup of immature collagen. The consensus is that it is a degenerative process rather than an inflammatory one, since swelling is present only during the initial phases of the condition (Tosti et al., 2013). Despite this, LE continues to be the term adapted in clinical and epidemiological literature and will be the term used here.

The prevalence of lateral epicondylitis is 1-3% in the general population and 2-15% in the working population (Shiri et al., 2006). It was reported by Fan et al. (2009) that in 2006, the direct cost for Washington State to provide compensation for the 263 workdays lost by employees suffering from lateral epicondylitis was twelve million dollars ($12M). They also stated that the incidence rate was 4.7 per 10,000 employees. Therefore, understanding the causes of this condition and how to prevent its occurrence is not only important for health related reasons, but also from an economic point of view.

A review from NIOSH concluded that there is strong evidence of an association between LE and exposure to the combined risk factors of force, posture, and repetition (Anderson, et al., 1997). Performing an unchanging repetitive work task at least half of the time, working with the hands bent or twisted during precision demanding tasks, or working with the hands lifted in front of the body was found to increase the risk of developing LE (Harr & Andersen, 2003). There is a significant association between frequency of forceful exertion and lateral epicondylitis, even after adjusting for the personal and work-related psychosocial factors such as smoking, weight, and BMI. Additionally, forceful lifting and forearm supination greater than 45° were found to be associated with LE. When these two factors were combined, it resulted in a greater chance of developing LE compared to each factor alone (Fan et al., 2009). Jobs that require driving screws repeatedly, a task known to include forceful pronation and supination, and tightening with force were shown to be strong predictors of LE (Leclerc et al., 2001). These tasks are particularly common in repetitive work such as the assembly lines at automotive plants, the clothing and shoe, food, and packaging industries. Despite the fact that the causative factors in the workplace are becoming clearer, the mechanisms of injury are not so clear. Some of the proposed mechanisms will be discussed in the following paragraphs.

As stated earlier, the initial stage of LE involves inflammation at the lateral epicondyle. There are a few studies that use Magnetic Resonance Imaging (MRI) to obtain a deeper understanding and visualization of the symptoms of LE. One such study performed by Mackay et al. (2003) reported a thickening of the common extensor tendon (CET) in MRI images that is consistent with LE. The CET is the site of attachment for the extensor carpi radialis brevis (ECRB), extensor digitorum communis (EDC), and extensor carpi ulnaris (ECU) on the lateral epicondyle of the humerus. They were not able to localize the individual tendons that attach to the CET in the images, suggesting that they are located very close to one another and that alternative imaging techniques are required to localize the tendons.

The tendon of the ECRB lies deep and superior to the tendons of the EDC and ECU. This places the ECRB adjacent to the capitulum and covered by the tendon of the EDC, which indicates that there is very little space between the three individual tendons of the ECRB, EDC, and ECU (Bunata et al., 2007). In such a confined space, changes in force, length, or angle of pull may cause friction between the individual tendons and be one of the potential mechanisms of injury.

Moore (2002) outlined two biomechanical theories of LE proposed by various researchers. The first theory by Nirschl and co-authors focused on the role of eccentric tensile loading on the ECRB (Nirschl & Pettrone, 1979; Kraushaar & Nirschl, 1999). They stated that tendon tearing occurs when the tensile forces caused by eccentric movements exceed the tolerable rate of elongation of the tissue fibres, thus causing an injury that initiates a repair response. This process is sometimes disorganized or incomplete, and results in the disruption of the normally ordered tendon fibres by invasion of fibroblasts and atypical granulation tissue, which ultimately leads to the development of LE. The second theory proposed by Bosworth (1965) examined radial head compression. It stated that the main cause of LE was due to the compression between the underside of the ECRB aponeurosis and the annular ligament and radial head during elbow extension combined with tensile loading of the ECRB while the radial head rotated with either pronation or supination. This compression causes fraying of the ECRB tendon and the repair response leads to lateral epicondylitis. Although there are a few proposed theories of LE, Moore (2002) concludes that there is little information upon which to develop a definitive biomechanical theory for LE.

A tendon is a fibrous connective tissue that attaches a muscle to a bone. During a submaximal muscle contraction, the muscle shortens and pulls on the tendon, causing the bone to which the tendon is attached to move (McKinley and O'Loughlin, 2006). During an isometric contraction, muscle fibres shorten and all the stretch occurs in the tendons (Griffiths, 1991). Length changes in muscle have been shown to modify the EMG-force relationship (Hof, 1984). Surface EMG and force have a positive relationship during isometric contractions, which can be quantitatively understood through analysis of the EMG recordings (Robertson et al., 2009). Therefore, if force is held constant, then changes in EMG levels may reflect changes in muscle length.

In summary, the results obtained by Mackay et al. (2003) and Bunata et al. (2007) help in understanding the proximity of the tendons of the ECRB, EDC, and ECU. They cannot be easily isolated due to the fact that they lie very close to one another. Consequently, there may be an interaction between their tendons during forceful exertions that can lead to the development of LE. Tendons are stretched as the muscles they are attached to shorten during contractions. Therefore, if the muscles change length differently from one another, the tendons will also be stretched by different amounts. If all three tendons do not experience a similar length change, this may suggest that there is friction between them, which could be a potential cause of LE.

1.2 Goals:

The purpose of our study was to compare potential changes in relative muscle length at different forearm postures in order to see whether or not the change is uniform across the different postures. We focused on the muscles of the ECRB, EDC, and ECU using electromyography (EMG) to monitor muscle activation.

This is not a direct method of measuring potential changes in relative muscle length at different forearm postures, but it will infer whether or not these changes occur. We can assume tendon length changes from potential changes in muscle length.

Chapter 2: Literature Review:

2.1: Work related upper extremity musculoskeletal disorders

Upper limb WRMSDs are an umbrella term for a range of specific disorders to the upper limb, such as carpal tunnel syndrome, tendinitis, or lateral epicondylitis with common work-related risk factors such as repetition, forceful exertion, and awkward postures. Jobs that are highly repetitive, where more than 50% of the time is spent performing the same type of fundamental task, have a 2.8 odds ratio of injury compared to low repetitive jobs (Silverstein et al., 1986). Additionally, if the tasks required in a job are highly repetitive (cycle time less than 30 seconds or more than 50% of the cycle time involved in the same fundamental cycle) and require high force (average hand force requirement of more than 4kg), the odds ratio increases to 30.3 (Silverstein et al., 1986). In a cross-sectional study performed by Ranney et al. (1995), they found evidence of work-related musculoskeletal disorders in 54% of the 146 female workers with highly repetitive jobs (cycle time less than 30 seconds or more than 50% of the cycle time involved in the same fundamental cycle).

WRMSDs cost industry 20 billion USD per year (Aptel et al., 2012). In particular, the direct compensation cost of LE for the 263 lost workdays in Washington State alone was 12 million USD in 2006, with a prevalence rate of 4.7 for every 10,000 employees.

2.1.1: Lateral Epicondylitis

LE is a specific WRMSD. Symptoms include pain around the lateral side of the elbow, attenuated forearm extension forces, and pain while grasping or wrist dorsiflexion when performing regular activities of daily living (Smedt et al., 2007). The prevalence of

LE increases with age, and is highest in individuals between 40-60 years old. It is also more common in the dominant elbow than the non-dominant elbow, indicating that physical load factors play a role in the development of LE (Shiri &Viikari, 2011).

Lateral Epicondylitis causes functional disability and has high costs due to loss in productivity and increase in health-care use. The length of sick leave due to this condition is around 1-2 weeks, with 10-30% of individuals having a prolonged duration of sick leave up to 11-12 weeks. In rare cases, work disability extends up to 1 year or over, and can cause job changing in strenuous jobs (Shiri & Viikari, 2011).

In a meta analysis of 20 LE papers performed by Andersen et al. (1997), it was concluded that there is strong evidence of an association between LE and exposure to repetitive forceful movements that include but are not limited to repeated flexion of the wrist in addition to pronation and supination of the forearm. Performing highly repetitive tasks at least half of the time and working with the hands lifted in front of the body have also been found to increase the risk of developing LE (Harr & Andersen, 2003). While it is not explicitly stated, it is inferred that the hands were in the anterior-posterior plane of movement. Additionally, even after adjusting for the personal and work-related psychosocial factors, a significant association has been found between the frequency of forceful exertion and lateral epicondylitis (Fan et al., 2009).

In summary, upper extremity WRMSDs in general and LE specifically represent a large financial and health cost in industry, supporting the importance of continued research in this area.

2.2: Anatomy of the elbow

The upper arm consists of the humerus followed by the radius and ulna that make up the forearm. The medial and lateral epicondyles are located on the distal end of the humerus and reflect the axis of rotation of the forearm with respect to the upper arm at the elbow. They also provide insertion points for the forearm muscles, including the ECRB, EDC, and ECU. It is important to note that in some texts the EDC is split into two muscles that have similar origins but have insertions into different digits. We will refer to it as one muscle. Figure 1 displays the skeletal anatomy of the arm. The tendons of all three muscles (ECRB, EDC & ECU) originate from a common extensor tendon (CET), which is attached to the lateral epicondyle of the humerus. Figure 2 shows the muscular anatomy of the forearm (McKinley and O'Loughlin, 2006). The ECRB is primarily a wrist extensor and radial deviator, but it is also an elbow flexor and forearm pronator while the EDC and ECU are elbow extensors and forearm supinators, along with their primary role as finger extensor (EDC), wrist extensor (EDC & ECU), and ulnar deviator (ECU) (Ramsay et al., 2009). Other structures to note include the radial head, which passes below the ECRB, and anconeus, which originates and inserts deep to the ECRB. Primarily the anconeus is a forearm extensor (McKinley and O'Loughlin, 2006).

It is hypothesized that the injury caused by lateral epicondylitis takes place on a microscopic level (Faro & Wolf, 2007). The common extensor tendon origin is where the microtears are thought to occur. As noted, it is comprised of three tendons that all attach at the lateral epicondyle.

Ramsay et al. (2009) developed a geometric musculoskeletal forearm-hand model across the elbow and wrist for 16 muscles using Software for Interactive Musculoskeletal Modeling. They used literature to estimate the origin and insertion points of each muscle as well as their physiological cross-sectional area. Additionally, they provided the polynomial equations and values for the respective inputs in the equations in order to calculate each muscle's moment arm. Table 1 shows the maximum moment arm values calculated by Ramsay (2009) for Elbow Flexion Extension (EFE) and Pronation Supination (PS) of the forearm. They do not state what posture the elbow and forearm were at during these calculations. Table 2 shows the values of the moment arms calculated with the elbow fixed at 90° and the forearm at pronated at 60° from neutral, supinated at 90° from neutral, and at a neutral posture. The values for Table 2 were determined from the equations provided by Ramsay (2009).

Table 1: The maximum moment arm values for the ECRB, EDC, and ECU for Elbow Flexion Extension (EFE) and forearm Pronation Supination (PS) as calculated by Ramsay (2009). A positive value denotes pronation and elbow flexion.

	Posture	
	EFE	PS
Muscle	Moment Arm (mm)	
ECRB	14.75	4.96
EDC	-18.08	-4.76
ECU	-10.2	-4

Table 2: The moment arm values (mm) for the ECRB with the elbow fixed at 90° while the forearm was at neutral, pronated 60° from neutral, and supinated 90° from neutral. EFE-PS denotes the elbow as a primary joint and the forearm as a secondary joint. PS-EFE denotes the forearm as a primary joint and the elbow as a secondary joint. EFE= Elbow Flexion Extension; PS= Pronation Supination; Positive value=pronation and elbow flexion

			Elbow 90			
	Pro=60		Neutral		Sup=90	
	EFE-PS	PS-EFE	EFE-PS	PS-EFE	EFE-PS	PS-EFE
ECRB	10.00	3.06	10.64	-0.05	11.60	-4.71

An et al. (1981) performed a study on four frozen cadavers in order to determine the length, physiological cross-sectional area, and moment arms of the muscles that cross the elbow joint. The specimens were hung in order to minimize the effects of gravity or localized pressure that would distort the normal anatomy. They were then embedded in wooden boxes and rigidly fixed. Table 3 displays their results. The moment arms are for the ECRB, EDC, and ECU at full elbow extension and forearm supinated, neutral, and pronated, respectively.

Table 3: The length, physiological cross-sectional area, and moment arm values for the ECRB, EDC, and ECU. Data from An et al. (1981). The moment arm values are for elbow extension with forearm fully supinated, neutral, and fully pronated respectively. Negative=flexion, Positive=extension

Muscle	Length (cm)	Physiological Cross-sectional Area (cm^2)	Flexion-Extension Moment arm (cm)
ECRB	5.3	2.9	-1.162, -1.205, -1.531
EDC	6.9	0.9	-0.321, -0.019, -0.133
ECU	4.5	3.4	0.907, 0.488, 1.513

The moment arm data derived in table 2 show that the ECRB acts as a supinator rather than a pronator at forearm neutral and supination at 90°. Additionally from the moment arm values in table 3, the EDC is also shown to act as an elbow flexor rather than an elbow extensor. These data suggest that the function of these muscles depends on the posture of the elbow and forearm. The radius and ulna rotate with respect to the humerus as the posture of the elbow and forearm changes. This causes a change in orientation of the ECRB and EDC, altering their function.

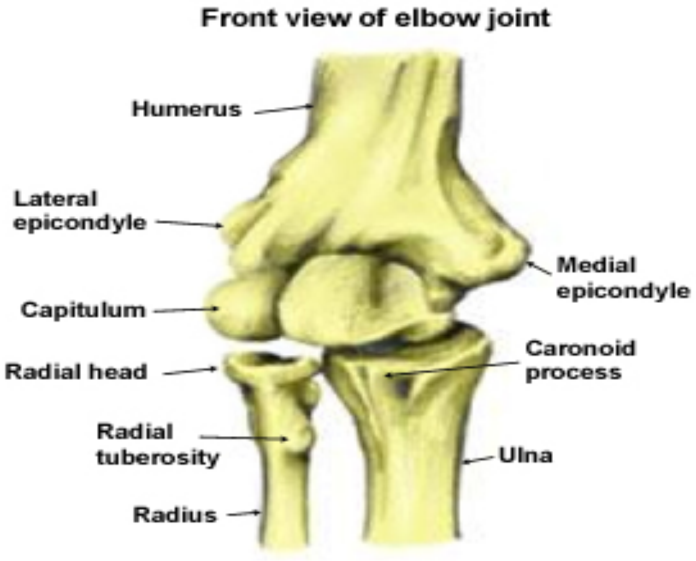


Figure 1: The skeletal anatomy of the elbow. Copyright permission obtained from SportsInjuryClinic.net.

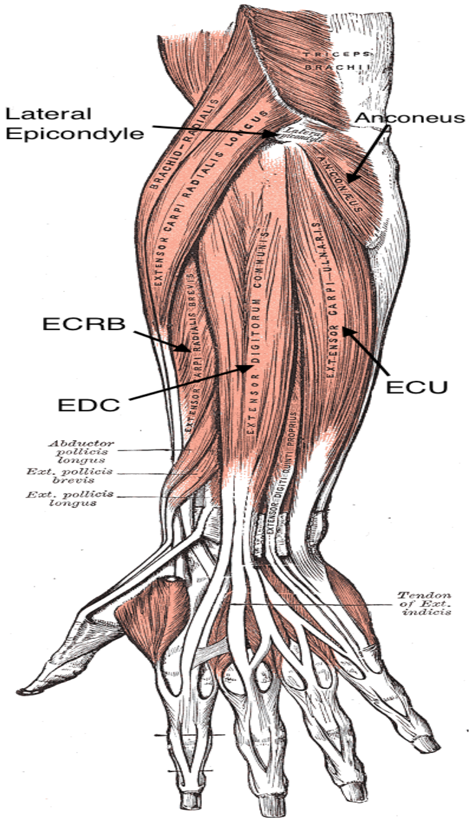


Figure 2: The muscular anatomy of the forearm from the posterior. Adapted from Boundless.com. Copyright permission obtained from Boundless.com.

2.3: Etiology and risk factors of Lateral Epicondylitis:

In a meta analysis performed by Shiri and Viikari (2011), they found that high force exertion of the hands (average force more than 3kg) combined with high repetition (cycle time less than 30 seconds) is associated with lateral epicondylitis. In one of the studies that supported this finding, they were able to observe and measure the biomechanical movements of 207 workers in eight fish-processing factories to come to the conclusion mentioned above. Shiri et al. (2006) conducted interviews and surveyed a population sample of 4,698 men and women residing in Finland to estimate the prevalence of lateral epicondylitis. A dose-response relation was found between repetitive movements of the hands or wrists and manual handling of loads heavier than 20kg at least 10 times a day (manual lifting, carrying, pushing, or pulling items), with risk being higher for longer durations (Shiri et al., 2006). These data were gathered through self-reported questionnaires from the sample. Leclerc et al. (2001) examined a sample of 598 workers using self-administered questionnaires that gathered information about work conditions and upper limb disorders. They found that tasks that involve forceful pronation and supination such as repeatedly driving screws were strong predictors of developing LE (Leclerc et al., 2001). These tasks are especially common in repetitive work such as assembly lines in the automotive, food, and packaging industries. Fan et al. (2009) collected data on 733 workers in the manufacturing and health care sectors in Washington State from 2001 to 2004. A workplace assessment was performed by ergonomists. The data on the workers were collected from structured interviews. Fan et al. (2009) found a significant association between forceful lifting (object weights or push/pull forces $\geq$44.1N) with the forearms supinated greater than 45° and LE. When these two factors were combined, there was a greater chance of developing LE compared to each factor alone.

Briggs and Elliott (1985) noted that pain generally associated with LE was reproduced when the forearm was pronated and a force causing wrist flexion was applied to an extended wrist. They also note that if the forearm is fully pronated, the wrist flexed and the elbow extended, pain was present during the last 20° of elbow extension. A posture of a flexed wrist, extended elbow and pronated forearm should produce passive forces that pull on the ECRB origin and cause pain in the patient. Therefore another mechanism that may be responsible for increased pain is pronation. Although these postures do not act to lengthen the tendon of the ECRB, they are useful in determining whether or not a person is suffering from LE. These postures cause the tendon of the ECRB to change orientation with respect to the radial head and cause shearing of the tendon. While inherently this does not make sense given the function of the ECRB as a pronator, Briggs and Elliot (1985) noted after studying cadavers that full elbow extension coupled with forearm pronation caused shearing to occur at the origin of the ECRB with the radial head during the last 15 to 20° of elbow extension as the radial head undergoes anterior movement against the undersurface of the muscle. Additionally, at full elbow extension, the ECRB becomes a supinator rather than maintaining its role as a pronator (Ramsay, 2009), which could explain the production of passive forces that pull on the ECRB at forearm pronation with full elbow extension, causing pain in the patient.

Snijders et al. (1989) performed their study on cadavers and focused on the origin of the ECRB. The bony region of the ECRB is small compared to that of the ECRL and ECU. As a result, there is more stress on the ECRB tendon insertion compared to the

ECU for the same amount of force. Consequently, the ECRB is at a higher risk of being damaged compared to the ECU. Forces on the ECRB tendon and its bony origin are caused when it is contracting for any of its roles such as wrist extension, radial deviation, forearm pronation or elbow flexion (An et al., 1981). Postures that act to lengthen the ECRB are forearm supination, elbow extension, ulnar deviation and wrist flexion.

Tanaka et al. (2011) investigated the effect of elbow and forearm position on the contact pressure of the common extensor tendon origin. They hypothesized that contact pressure between the bone and tendon would increase at the lateral side of the capitulum with elbow extension, forearm pronation, and varus stress under tension of the tendons. The forearm was mounted horizontally from the humerus to a wooden pole with the lateral epicondyle facing up. The varus stress load was either from the effect of gravity on the forearm or the summation of gravity and a 1.96Nm torque produced by placing a 9.8N weight 20cm distal from the tip of the olecranon on the forearm. To verify this hypothesis, they measured the contact pressure between the origin of the common extensor tendon and the lateral side of the capitulum using a small pressure sensor and compared it quantitatively during different elbow flexion angles, forearm rotation positions, and varus stress loads. They found that contact pressure was greatest at 0° or 30° of elbow flexion, forearm pronation, and positive varus stress loads on the bone. In addition, they performed a three-way ANOVA that showed that contact pressures were significantly affected by elbow flexion angle, forearm rotation position, and degree of varus stress load. Contact pressure was greater when the ECRB was loaded compared to when the EDC was loaded. This led them to the conclusion that ECRB muscle contraction, rather than EDC contraction, mainly causes the bone to tendon contact that inevitably leads to LE.

Bosworth suggested another theory in 1965, where the focus was on radial head compression. He claimed that the compression produced between the underside of the ECRB aponeurosis and the annular ligament and radial head during elbow extension combined with tensile loading of the ECRB while the radial head rotated with either pronation or supination was the main cause of LE. This compression causes fraying of the ECRB tendon and the repair response leads to lateral epicondylitis.

A biomechanical model proposed by various researchers outlined by Moore (2002) focused on the role of tensile loading of the ECRB (Nirschl and Pettrone, 1979; Kraushaar and Nirschl, 1999). Kraushaar and Nirschl (1999) state that tendon tearing occurs when tensile forces caused by eccentric movements produce a net increase of more than 8 percent of the total tendon length. This causes an injury that triggers a repair response. However, the repair process is sometimes disorganized or incomplete, and results in the disruption of the normally ordered tendon fibres by invasion of fibroblasts and atypical granulation tissue. Moore (2002) also discusses another theory proposed by Bosworth (1965), which is discussed above this paragraph. He concludes that there is not enough information upon which to develop a definitive biomechanical theory of LE.

Coel et al. (1993) reported that the anconeus muscle had the most intense MRI signal in the seven subjects with LE. This triangular muscle is located below and behind the elbow. It originates from a tendon at the outer condyle of the humerus and inserts into the side of the olecranon and upper fourth of the posterior surface of the shaft of the ulna. Its function is still a matter of controversy, but it is thought to be an elbow extensor and abductor of the ulna at the elbow. This may explain how this muscle may be involved in chronic LE. The changes may be associated with abnormal motion or compensation brought on by pain from inflammation of the ECRB tendon, but further clarification is needed.

Rojas et al. (2007) compared muscle activation using EMG of the ECRB, ECRL, ECU, and EDC in subjects with LE and subjects who did not suffer from LE. They found that those suffering from lateral epicondylitis had higher motor unit recruitment than the healthy subjects due to higher decreases in conduction velocity in the patients compared to the control, signifying the presence of fatigue.

In summary, it has been shown that LE can develop as a result of repetitive force exertion at different forearm postures. The ECRB tendon has the smallest cross-sectional area and experiences the largest stress in any posture that loads its tendon. Additionally, when the elbow is extended during pronation or supination, the compression of the radial head against the tendon of the ECRB may cause fraying of the tissue. The EDC and ECU change length in an opposite direction to the ECRB during pronation and supination. They shorten going from neutral to supination, while the ECRB lengthens. On the other hand, the ECRB shortens from neutral to pronation, while the EDC and ECU lengthen. Therefore, length changes during supination and pronation may result in friction between the three tendons that make up the CET. Although several mechanisms have been suggested, no definitive etiology has been proven.

2.4: Force-length relationship of muscles:

The muscle consists of an active element called the contractile component, and passive connective tissue. At the optimal length of a muscle, there are a maximum number of cross-bridges formed between the actin and myosin filaments of the contractile component, therefore making maximum active tension production possible. As the muscle lengthens, the filaments are pulled apart, which decreases the number of cross-bridges formed and reduces the tension produced. The parallel elastic component (PEC), which is the passive connective tissue that surrounds the contractile element of a muscle, acts similar to an elastic band in producing tension. At or below the optimal length of the muscle, the PEC is in a state of slack and does not produce tension. However, as the muscle lengthens beyond its optimal length, tension buildup starts to occur as the PEC is stretched (Winter, 2009).

When an activated muscle is stretched with contraction, it is able to produce greater tension than in the absence of the stretch, due to the PEC contribution. Unlike the contractile component, the PEC of the muscle cannot be voluntarily activated or shut off. Additionally, the tension produced by the active element of the muscle diminishes, thus relying more on the PEC for tension production at lengths greater than its optimal length (Hall, 2009).

Gordon et al. (1965) performed a study to measure tension development in a highly stretched muscle. They dissected twitch fibres with pieces of tendon at either end from the dorsal part of the semitendinosus muscle of frogs. The muscle fibre was then isolated at a controlled length using a servomotor so that there was no overlap of thick and thin filaments, in order to imitate an isometric condition. A series of shocks was delivered to the muscle and a tension transducer was used to measure the tension produced by the passive component of the muscle at a fixed length. They found that a considerable amount of tension was produced, which demonstrates that beyond the optimal length of a muscle, the PEC is able to contribute to force generation.

Griffiths (1991) directly measured the length changes of muscle fibres in vivo during isometric and stretch contractions of the medial gastrocnemius of seven cats using ultrasound. He found that at lengths longer than the optimal length of the muscle, isometric contractions caused creep (slow rise in tension) as the tendons were stretched while the muscle fibres slowly shortened. This study showed that the major component of the series elastic compliance exists in tendons and that muscle fibres shorten by 18-28% during supramaximal isometric contractions.

Figure 3 demonstrates the relationship of active tension due to cross-bridge formation and passive tension due to the PEC as a function of muscle length. The overall tension produced by a muscle is the sum of the active and passive tensions.

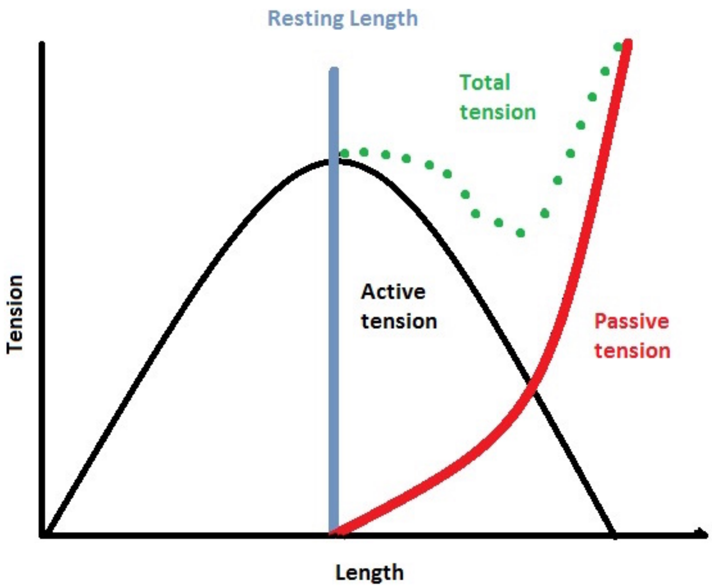


Figure 3: The length-tension curve of a muscle broken down into the active and passive tension contributions as length varies.

In summary, beyond its optimal length, the motor control system relies on the involuntary tension produced by the parallel elastic component in addition to the voluntary tension contribution of the active element for tension generation.

2.5: Measuring muscle activity using EMG:

Surface electromyography (EMG) is commonly used in biomechanics as an indication of the initiation and magnitude of muscle activation. There is also a relationship between the EMG signal and the force produced by a muscle (De Luca, 1997). When the signal is rectified and smoothed, the amplitude of the signal is qualitatively related to the amount of force produced and an accurate quantitative relationship can only be deduced for certain muscles. There are many factors that influence an EMG signal that include but are not limited to the influence of electrode location on the signal amplitude and frequency, crosstalk from nearby muscles that may contaminate the recording, and the motor unit firing rate. Thus, for practical reasons it is best to take EMG recordings during isometric contractions since the muscles do not change in length and the electrodes are least likely to move around on the skin (De Luca, 1997).

Under isometric conditions, the relationship between EMG and muscle force can be linear. These linear increases in EMG amplitude with incremental changes in force are presumably produced by a combination of motor unit recruitment and increases in motor unit firing rate (Robertson et al., 2004). Specifically during submaximal isometric contractions, the initial increase in EMG amplitude is due to the increase in the number of motor units needed to sustain the contraction and the increase in firing rate of the most recently recruited motor units (Robertson et al. 2004). In dynamic non-isometric contractions, the relationship between force and EMG has been shown to be linear with length changes associated with fixed movement patterns, such as bicycling at a constant speed (Hof, 1984).

Lippold (1952) performed an EMG study on 30 gastrocnemius-soleus muscle groups of the right leg performing plantar-flexion. The forces were measured with a dynamometer that consisted of a rigid wooden framework into which the leg was clamped from the knee to the heel. Isometric muscle activity was recorded at different strengths ranging from 4.5 to 45kg for a period of five seconds. All of the subjects were capable of exerting the maximum force of 45kg. Lippold (1952) concluded that there is a linear relation between the EMG and force produced by a voluntary isometric contraction.

Milner-Brown and Stein (1975) studied 137 single motor units from the first dorsal interosseus muscles in the hands of seven normal participants in order to study the relationship between rectified surface EMG and force. The subjects had visual and auditory feedback from an oscilloscope as they were asked to maintain a motor unit discharge of 5-10 impulses/second for a period of 3-5 minutes. The tension was isometric and a force transducer was used to measure the force generated. The EMG signal was full-wave rectified and averaged as a function of time. They observed a linear relation between the rectified surface EMG and force up to maximum voluntary contractions.

Olney and Winter (1985) performed a study to develop and validate a biologically based deterministic model for calculating ankle and knee moments of normal subjects during normal walking. They used EMG and kinematic variables and had available the total instantaneous joint moments for deriving certain model parameters. The joint angle and angular velocity were assumed to be proportional to muscle length and linear velocity, respectively. The tibialis anterior and soleus were used for the prediction of ankle moment. The rectus femoris and vastus lateralis were used for knee extensor moment, while the medial hamstrings and medial gastrocnemius were used for knee flexor moment. They found that in order to be able to predict changes in joint moment from EMG, the force-length relationship of the muscle should be considered.

Length changes in muscle have been shown to modify the EMG-force relationship. Surface EMG and force have a positive relationship during isometric contractions, which can be quantitatively understood through analysis of the EMG recordings. Therefore, if force is held constant, then changes in EMG levels may reflect changes in muscle length.

2.6: Hypothesis

We hypothesized that when the forearm is supinated, the fibres of the ECRB will lengthen compared to the fibres of the ECU and EDC, which would lead to friction between their tendons and become a potential cause of lateral epicondylitis. If the EMG recordings of the three muscles do not increase or decrease collectively in the same direction when changing from pronation to supination under constant force, it would signify that the fibres of the three muscles do not change in length uniformly. This would be reflected as an interaction between EMG and muscle. No other study to date has ventured into this method of understanding the mechanisms of lateral epicondylitis.

Chapter 3: Methodology

3.1: Participants and Task:

Sixteen right-hand dominant participants (8 male, 8 female) were recruited by word of mouth from the York community. A questionnaire (Appendix A) was used to screen the participants in order to determine eligibility. Exclusion criteria included a history of tennis elbow or any injury to the dominant arm within the past year. Participants were seated on a chair and rested their dominant upper arm on a table whose height was adjusted until the upper arm was parallel to the table. Their elbows were flexed at 90° and the wrist kept at a constant neutral posture (Figure 4). Their wrist was taped onto the attachment of the force transducer in order to ensure maximum interaction between the wrist and the transducer and consistent neutral wrist posture. Their forearm was strapped close to the elbow onto a wooden board attached to the custom structure built for this collection in order to prevent any movement. The participants were asked to push the dorsal side of their hand against a force transducer as hard as they were able to for a period of three seconds with their forearm at neutral while keeping the wrist neutral at all times (e.g. isometric wrist extensor activation at 0° wrist extension and 0° ulnar deviation). The maximum reading at the neutral forearm posture was recorded as their maximum force at 100% MVC.

The recording began when the recorder verbally instructed the subject to begin extending their wrist against the force transducer. The subjects were able to see the ramp up of force visually on a monitor and were told to stop after they were able to exert a constant force within 75±1% of their MVC for a sum of five seconds, not necessarily consecutively. Each trial was repeated three times for each forearm posture (supination, pronation, and neutral) and subjects were given a five minute rest period in between to prevent muscle fatigue during which they were allowed to rest their arm on the table.

The clamped force transducer did not move during force exertion. It was shifted between trials to the maximum comfortable supination and pronation angles for each of the subjects.

If the subjects were not able to maintain 75±1% of their MVC consecutively for five seconds, their recordings were windowed post-collection by removing the sections of data that were not in the 74-76%MVC range to include only the five seconds of data at 75±1% of their MVC.

Participants provided informed consent to all experimental procedures and associated risks, as approved by the York University Office of Research Ethics, prior to the experimental session.

The angle of forearm pronation and supination from forearm neutral was calculated for each subject using a protractor.

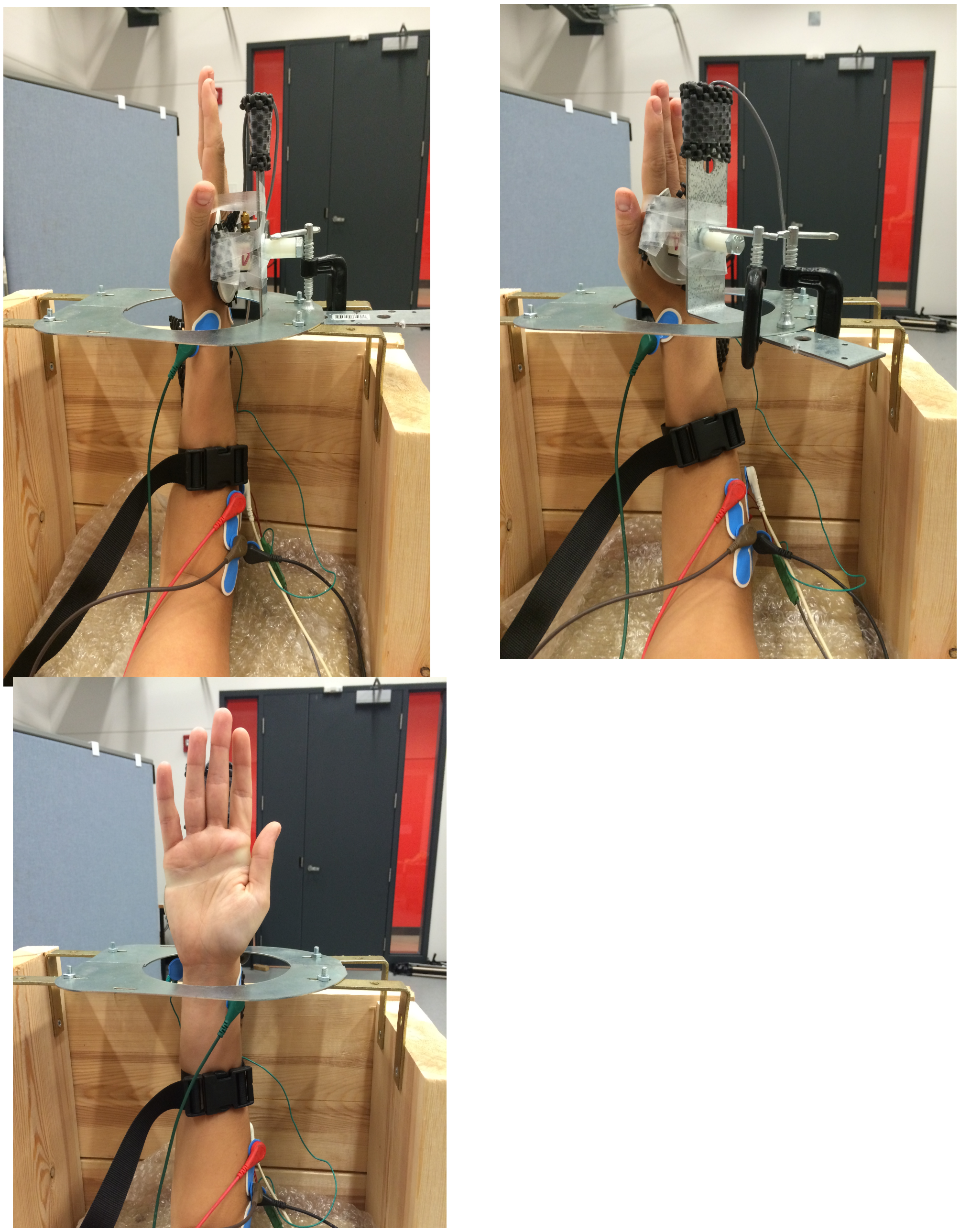


Figure 4: The setup of the collection at the three different forearm postures of neutral (top left), pronation (top right), and supination (bottom left) respectively.

3.2: Equipment:

A data acquisition unit (PowerLab v5.1.1, ADInstruments ML865, Dunedin, New Zealand) was used to collect raw EMG at 2000Hz with a gain of 1000 from the ECRB, EDC, and ECU simultaneously. The PowerLab system has a common mode rejection ratio >95dB (normally 110dB) at 100Hz and an input impedance of $>10^6$ Ohms.

Single use Al/AgCl Ambu BlueSensor N adhesive gel electrodes with a diameter of 22mm were used. They were placed on the bellies of the 3 muscles of interest, parallel to the fibres of the ECRB, EDC, and ECU while the participant had their elbow flexed at 90° and palm facing down, as outlined by Zipp (1982). The electrodes for the ECRB were placed close to the lateral epicondyle of the humerus and a third of the distance distal to the elbow, following the midline of the radius and ulna. The EDC electrodes were placed close to the lateral epicondyle and the midpoint between the styloid processes of the ulna and raidus. The electrodes for the ECU were placed on the midpoint between the lateral epicondyle and the olecranon and the styloid process of the ulna (Zipp, 1982). The skin was cleaned with alcohol wipes and shaved prior to electrode placement. The interelectrode distance was 2cm in order to limit crosstalk as recommended by Hermens et al. (2000). A load cell (Transducer Techniques MLP-500-C0, Temecula, California) was used to measure force during wrist extension and was connected to the ADInstruments unit in order to obtain a synchronized recording of force and EMG in time.

3.3: Statistical Analysis:

Prior to data collection, participants were instructed to relax their arm on the table in order to obtain a baseline EMG reading of their muscles and remove the bias from the rest of the recordings. The EMG recordings were full wave rectified and low pass filtered at 3Hz. They were then normalized to the 100%MVC obtained at the neutral forearm posture. The mean linear envelope was calculated during the portion of the signal where the force was observed to be at a steady state.

A 3-way ANOVA was performed on the normalized EMG comparing sex to forearm posture (supination, pronation) and muscle (ECRB, EDC, ECU). Force was also averaged over the same time period and a repeated measures ANOVA (forearm posture: supination, neutral, pronation) was performed. Data processing was accomplished using custom-written MATLAB codes (v. 8.1.0.604, The Mathworks Inc., Natick, MA, USA). All statistical analyses were performed used SPSS (version 22).

Chapter 4: Results:

All of the subjects were healthy individuals with no pain or history of LE to their dominant arm. The mean height and weight of the subjects were 1.70±0.10m and 69.44±13.67kg, respectively. The average age was 24 years, with a range of 21-30 years old. Fifteen of the sixteen participants were included in the analysis. Results for one of the participants were dropped due to quality of the recordings. The average angles of forearm pronation and supination from forearm neutral were 60° and 90°, respectively. A 3-way repeated measures ANOVA using a Bonferroni post-hoc correction, with sphericity assumed, showed a significant interaction between the posture of the forearm and the muscles that were analyzed (p=0.039, $F(2,26)$=3.651). The ECRB experienced a positive change in mean normalized EMG from supination to pronation, while the EDC and ECU had negative differences of their means from supination to pronation (Figure 5).

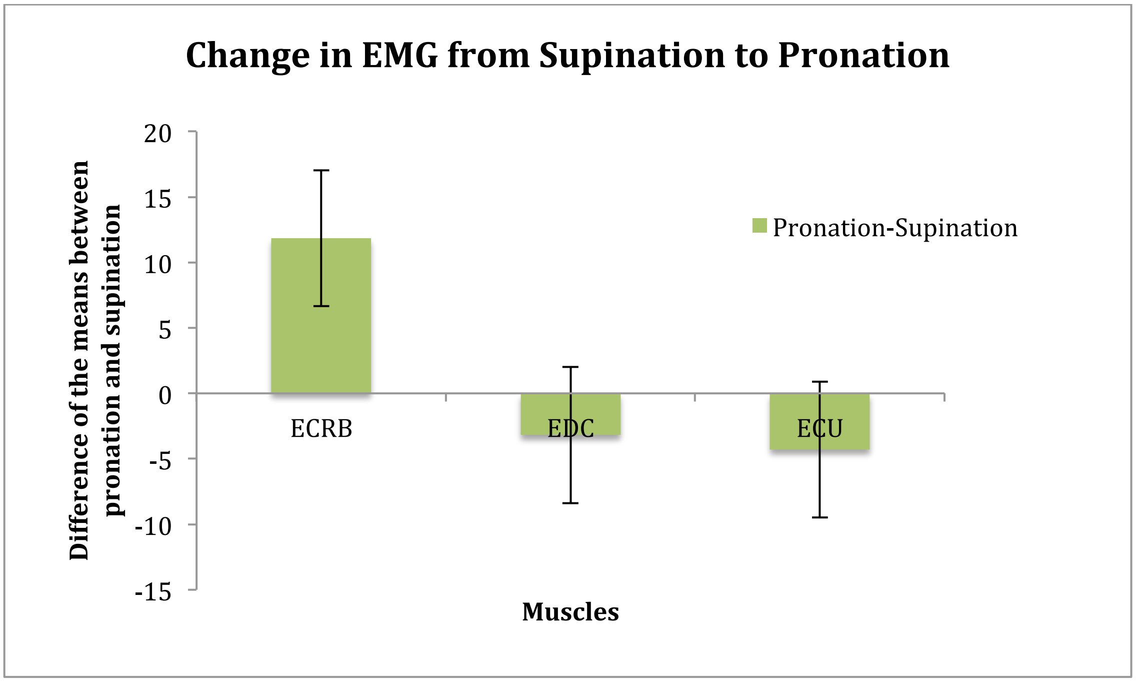


Figure 5: The difference of the means of the normalized EMG of the 3 muscles from supination to pronation (p=0.039, $F(2,26)$=3.651).

There was no significant main effect of muscle or posture alone. There was no main effect or interaction associated with sex. Table 4 shows descriptive statistics of the muscles at the different postures.

Table 3: The means and standard deviations of the normalized EMG of the muscles at different forearm postures. N=15. (*p*=0.039, *F (2,26)*=3.651)

	Neutral	Supination	Pronation
ECRB	100	69.02±21.58	80.87±20.83
EDC	100	81.05±26.29	77.87±19.38
ECU	100	74.98±21.16	70.70±23.29

Table 5 shows the mean forces exerted at the different postures. These forces were normalized to the maximum force exerted at forearm neutral. There was no significant main effect between the forces at the three different postures (*p*=0.986, *F (2,42)*=0.014). There was no significant difference between sex and posture or muscle (*p*=0.475, *F (2,26)*=2.572).

Table 4: The mean of the forces exerted at the different postures alongside the standard deviation.

	Neutral	Supination	Pronation
Force (%)	75.01±0.82	74.99±0.82	74.98±0.81

Chapter 5: Discussion

5.1: Implications:

The goal of this thesis was to study potential muscle length changes of the ECRB, EDC, and ECU at different forearm postures (supination, pronation, and neutral). We hypothesized that when the forearm is supinated, the fibres of the ECRB will lengthen compared to the fibres of the ECU and EDC, which would lead to friction between their tendons and become a potential cause of lateral epicondylitis. The primary function of the ECRB, EDC, and ECU is wrist extension, but they also have secondary purposes (Ramsay et al., 2009). The ECRB is a forearm pronator, so it is expected to be shortest in length during pronation given a fixed wrist and elbow posture compared to the EDC and ECU, which are both forearm supinators (Ramsay et al., 2009). Given a constant external load, a divergence in muscle length between the 3 muscles as a function of pronation/supination will be reflected as an opposite directional change in the magnitude of the EMG of the ECRB compared to the change in the magnitude of the EMG of the EDC and ECU, which was found. As the length of a muscle decreases below its optimal length, passive forces within the muscle are no longer present and the active force produced per motor unit will be reduced (Winter, 2009). As a result, more motor units will need to be activated to achieve a certain force and a higher EMG recording will be acquired due to the increased recruitment of motor units (Winter, 2009). A higher EMG recording of the ECRB was found for the same force during pronation compared to the EDC and ECU. We also observed higher EMG levels in supination for the EDC and ECU compared to the ECRB. Our results support the hypothesis that the fibres of the ECRB will lengthen during forearm supination compared to the EDC and ECU.

The tendons that diverge from the CET, namely the tendons of the ECRB, EDC and ECU, cannot easily be isolated in MRI images (Mackay et al., 2003). This signifies their close proximity to one another and a potential for interaction between one another during uneven muscle length changes. By maintaining a constant moment at the wrist (the hand was vertical and force was constant) and a constant wrist posture, the extensor muscle forces required to exert the isometric force are expected to be constant. If the extensor muscle forces required to exert the isometric force were in fact constant, then changes in EMG would reflect a length change in the muscle.

The fact that there was no significant difference between the forces exerted at supination and pronation indicates that the methods used to maintain constant force output were successful. In order to be certain that the force exerted would be consistent, the following steps were taken. First, the wrist was held in the same posture throughout the collection period by taping it onto the stand the force transducer was attached to. Second, the effect of gravity was taken into account by ensuring that the forearm and hand were held vertical at all times during collection. Third, subjects were able to see a display of the force exerted and used it as a guide to maintain their exertion at 75% MVC.

It should be noted that while length change is one reason for a change in EMG levels, there are several other possibilities. First, no other muscles were monitored, so there could be increased co-contraction. However, it would be expected that the effect of increased co-contraction would affect the three muscles in the same direction since the wrist extensors would collectively have to exert more force to counteract the force produced by the wrist flexors in order to maintain a neutral wrist posture. For example, increased wrist flexor activity caused by activation of the flexor carpi ulnaris or the flexor carpi radialis would be expected to increase the activity of all wrist extensors, since the wrist extensors will all have to resist the flexor moment produced by the activation of the wrist flexors.

The results presented assume that the moment arms of the three muscles crossing the wrist are not significantly affected by pronation and supination. Further advanced imaging data will be required to fully test this assumption. The moment arm data presented by Ramsay et al. (2009) (Table 2) suggest that pronation and supination do not affect the moment arms of the muscles at the wrist, just at the elbow. This shows that the ECRB maintains its secondary role as a pronator, and is consistent with the postures used in our study. However, even if pronation and supination were significantly affected, it would result in a change in the direction of force produced rather than a change in muscle length. This is due to the fact that the cross sectional area of the ECRB tendon has been noted to be smaller (Bosworth, 1965), therefore the uneven strain would be expected with a change in force. This would have the same outcome in the CET. It is potentially a combination of both.

5.2: Limitations:

The fluctuations in force exertion would affect the frequency and intensity of muscle activation, which in turn would compromise the validity of the EMG recording. In order to account for that, the trials were windowed to five seconds of recordings sustained at 75±1%MVC.

The subjects may have experienced fatigue in between the trials. To account for this issue, they were given rest periods in between each exertion. This may not have been enough, since muscle fatigue might still have been present during the trials, which would cause variations in EMG output (Hakkinen and Komi, 1986).

Electrode movement is always possible for electrodes that are attached on the surface of the skin (De Luca, 1997). The ECRB electrodes are close to the elbow so a little movement is expected. Additionally, movement of the electrodes on the EDC and ECU should be expected more during supination. A significant effect of electrode movement would lead to results that are different than the ones we obtained. The positioning of the electrodes was observed by a volunteer to ensure that they did not move during collection. It was reported that there was no observable movement during any of the trials.

An assumption of this study was that tendon length change occurred at the proximal side, even though it could be present at either the proximal or distal side. Additionally, it was assumed that tendon length changes could be inferred from potential changes in muscle length.

5.3: Future Research:

Coupling these results with ultrasound or advanced imaging techniques of the wrist and elbow will allow better discernment of the change in path of the three muscles in question and add in other potential mechanisms of injury such as friction between the radial head and the ECRB. Based on the results of this research, future studies on LE should be performed on a microscopic level in order to better understand the tendon length changes. Future EMG studies could include more muscles or small changes in angle can be tested to see if there is a limit to significant changes.

5.4: Conclusion:

In conclusion, it was found that the fibres of the ECRB lengthened during forearm supination compared to the EDC and ECU, which shortened. Therefore, there may be friction between the tendons of these muscles during pronation and supination, which could be one of the mechanisms of injury of lateral epicondylitis.

Understanding the underlying cause of lateral epicondylitis is important in preventing work-related musculoskeletal injuries to the forearms. It is also crucial from an economic perspective, as the cost of compensation for such injuries is very high. Acquiring thorough knowledge regarding this matter may help in designing safer workplaces and improved safety guidelines for work that includes high repetition over a long period of time.

References

An, K. N., Hui, F. C., Morrey, B. F., Linscheid, R. L., & Chao, E. Y. (1981). Muscles across the elbow joint; a biomechanical analysis. *Journal of Biomechanics , 14* (10), 659-669.

Anderson, V. P., Bernard, B., Burt, S., Cole, L., Fairfield-Estill, C., Fine, L., et al. (1997). *Musculoskeletal Disorders and Workplace Factors.* Cincinnati: NIOSH.

Aptel, M., Cuvelier, A., & Cnockaert, J. (2002). Work-related musculoskeletal disorders of the upper limb . *Joint Bone Spine , 69*, 546-555.

Bosworth, D. M. (1965). Surgical Treatment of Tennis Elbow;a follow-up study. *Journal of Bone and Joint Surgery , 47* (8), 1533-1536.

Bunata, R., Brown, D., & Capelo, R. (2007). Anatomic Factors Related to the Cause of Tennis Elbow . *Journal of Bone and Joint Surgery , 89*, 1955-1963.

Coel, M., Yamada, C., & Ko, J. (1993). MR Imaging of Patients with Lateral Epicondylitis of the Elbow (Tennis Elbow): Importance of Increased Signal of the Anconeus Muscle . *American Roentgan Ray Society* , 1019-1021.

De Luca, C. J. (1997). The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics , 13*, 135-163.

Elliott, B. G., & Briggs, C. A. (1985). Lateral epicondylitis: a review of structures associated with tennis elbow. *Anatomia Clinica , 7*, 149-153.

Fan, J. Z., Silverstein, B. A., Bao, S., Bonauto, D. K., Howard, N. L., Spielholz, P. O., et al. (2009). Quantitative exposure-response relations between physcial workload and prevalence of lateral epicondylitis in a working population. *American Journal of Industrial Medicine , 52*, 479-490.

Gordon, A., Huxley, A., & Julian, F. (1965). Tension development in highly stretched vertebrate muscle fibres . *Journal of Physiology* , 143-169.

Griffiths, R. (1991). Shortening of muscle fibres during stretch of the active cat medial gastrocnemius muscle: the role of tendon compliance. *Journal of Physiology* , 219-236.

Hakkinen, K., & Komi, P. (1986). Effects of fatigue and recovery on electromyographic and isometric force and relaxation time characteristics of human skeletal muscle . *European Journal of Applied Physiology* , 588-596.

Hall. (2009). *Introduction to Biomechanical Analysis of Human Movement.* Toronto: McGraw-Hill.

Harr, J., & Andersen, J. (2003). Physical and psychosocial risk factors for lateral epicondylitis: a population based case-referent study . *Biomechanical Journal* , 322-329.

Hermens, H., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures . *Journal of Electromyography and Kinesiology* , 361-374.

Herquelot, E., Bodin, J., Roquelaure, Y., Ha, C., Leclerc, A., Goldberg, M., et al. (2013). Work-related risk factors for lateral epicondylitis and other cause of elbow pain in the working population. *American Journal of Industrial Medicine , 56*, 400-409.

Hof, A. (1984). EMG and muscle force: an introduction. *Human Movement Science* , 119-153.

Kraushaar, B., & Nirschl, R. (1999). Tendinosis of the elbow (tennis elbow). . *The Journal of Bone and Joint Surgery* , 259-278.

Leclerc, A., Landre, M., Chastang, J., Niedhammer, I., & Roquelaure, Y. (2001). Upper-limb disorders in repetitive work . *Scandinavian Journal of Work, Environment, & Health , 27* (4), 268-278.

Lippold, O. (1952). The relation between integrated action potentials in a human muscle and its isometric tension . *Journal of Physiology* , 492-499.

Mackay, D., Rangan, A., G., H., Hughes, T., & Latimer, J. (2003). The objective diagnosis of early tennis elbow by magnetic resonance imaging . *Occupational Medicine , 53* (5), 309-312.

McKinley, M., & O'Loughin, V. D. (2006). *Human Anatomy.* New York: McGraw-Hill .

Milner-Brown, H., & Stein, R. (1975). The relation between the surface electromyogram and muscular force. *Journal of Physiology* , 549-569.

Moore, S. J. (2002). Biomechanical Models for the Pathogenesis of Specific Distal Upper Extremity Disorders. *American Journal of Industrial Medicine , 41*, 353-369.

Nirschl, R. P. (1992). Elbow Tendinosis/Tennis Elbow. *Clinics In Sports Medecine , 11* (4), 851-870.

Olney, S., & Winter, D. (1985). Predictions of knee and ankle moments of force in walking from EMG and kinematic data. *18*, 9-20.

Ramsay, J. W., Hunter, B. V., & Gonzalez, R. V. (2009). Muscle moment arm and normalized moment contributions as reference data for musculoskeletal elbow and wrist joint models . *Journal of Biomechanics* , 463-473.

Ranney, D., Wells, R., & Moore, A. (1995). Upper limb musculoskeletal disorders in highly repetitive industries: precise anatomical physical findings . *Ergonomics , 38* (7), 1408-1423.

Robertson, G., Caldwell, G., Hamill, J., Kamen, G., & Whittlesey, S. (2004). *Research Methods in Biomechanics.* Champaign, Illinois: Human Kinetics.

Rojas , M., Mananas, M. A., Muller, B., & Chaler, J. (2007). Activation of Forearm Muscles for Wrist Extension in Patients Affected by Lateral Epicondylitis. *Conference of the IEEE EMBS* (pp. 4858-4861). Lyon: Cite Internationale.

Shiri, R., & Viikari-Juntara, E. (2011). Lateral and medial epicondylitis: role of occupational factors. *Best practice and Research Clinical Rheumatology , 25*, 43-57.

Shiri, R., Viikari-Juntura, E., Varonen, H., & Heliovaara, M. (2006). Prevalence and Determinants of Lateral and Medial Epicondylitis: A Population Study. *American Journal of Epideiomology , 164* (11), 1065-1074.

Silverstein, B. A., Fine, L. J., & Armstrong, T. J. (1986). Hand wrist cumulative truama disorders in industry. *British Journal of Industrial Medicine , 43*, 779-784.

Smedt, T., Jong, A., Van Leemput, W., Lieven, D., & Van Glabbeek, F. (2007). Lateral epicondylitis in tennis: update on aetiology, biomechanics and treatment . *Journal of Sports Medicine , 41*, 816-819.

Snijders, C. J., Stoeckart, R., & Vleeming, A. (1989). Anatomy of the extensor carpi radialis brevis muscle related to tennis elbow. *Clinical Biomechanics , 4* (4), 210-212.

Tanaka, Y., Mitsuhiro, A., Izumi, T., Wada, T., Fujimiya, M., & Yamashita, T. (2011). Effect of Elbow and Forearm Position on Contact Pressure Between the Extensor Origin and the Lateral Side of the Capitellum . *Journal of hand surgery , 36A*, 81-88.

Tosti, R., Jennings, J., & Sewards, M. J. (2013). Lateral Epicondylitis of the Elbow. *The American Journal of Medicine , 126* (4), 357.e1-357.e6.

Whaley, A. L., & Baker, C. L. (2004). Lateral epicondylitis. *Clinics in sports medicine , 23*, 677-691.

Winter, D. A. (2009). *Biomechanics and Motor Control of Human Movement.* Hoboken: John Wiley & Sons.

Wolf, J. M., & Faro, F. (2007). Lateral Epicondylitis: Review and Current Concepts. *Journal of Hand Surgery , 32* (8), 1271-1279.

Zipp, P. (1982). Recommendations for the Standardization of Lead Positions in Surface Electromyography . *European Journal of Applied Physiology and Occupational Physiology* , 41-54.

Appendix A: Initial Questionnaire

Initial Questionnaire **Date**: -

____

Participant #: __________

Demographic Information

1. Date of Birth (mm/d/yr): ______________________________________
2. Sex: Female ☐ Male ☐
3. Handedness: ______________________________________
4. Height: _________m __________cm or __________ft ___________in
5. Weight: ______________Kg or __________Lb

Health and Injury Information

1. Do you currently have any health condition that could potentially be aggravated with physical activity (i.e. cardiovascular problems, high blood pressure, joint problems, ☐tc.)? Y ☐ N

   If yes, please explain: ____

2. Have you ever been diagnosed with neurological disorders (i.e. carpal tunnel syndrome, pronator teres syndr☐me)? Y☐ N

   ☐ If yes, please explain: ____ ____ ______

3. Have you ever received treatment for any of the following, please specify:

   ☐ Fractures - body part: ____

   ☐ Dislocations –body part: ____

   ☐ Muscle Strains or sprains - ____

☐ Upper Back pain - ____

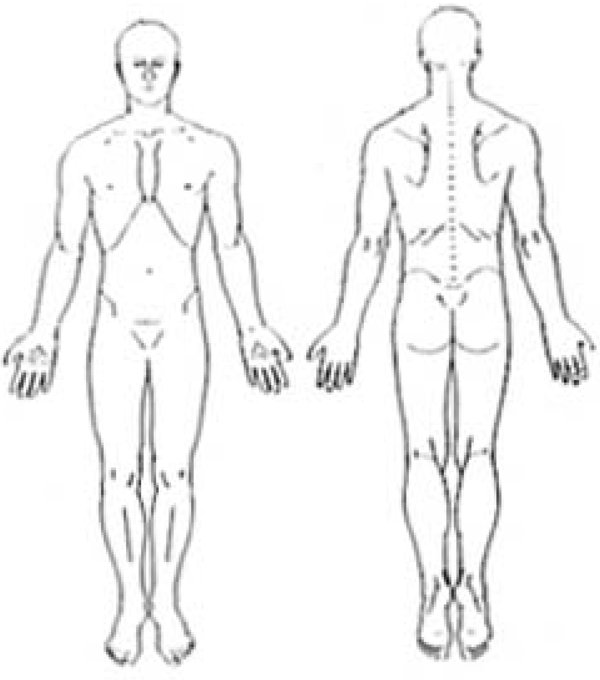
☐ Lower back pain - ____

☐ Tendonitis/tenosynovitis - ____

☐ Other musculoskeletal disorder - ___________________________________

4. In the past year, have you had treatment for any musculoskeletal injury or disorder? Please specify: ____

5. Do you currently have any physical discomfort/pain? Y☐ N ☐
   If yes, please indicate in the figure where you feel the discomfort/pain



Appendix B: Informed Consent Form

INFORMED CONSENT FORM

School of Kinesiology and Health Science, York University

Study Title: EMG changes of the forearm extensors at different forearm postures.

Conducted By: Student: Mani Sadeghzadeh

Faculty Member: Dr. Anne Moore

The purpose of our study is to compare muscle length change in directions at different forearm postures. We will focus on the muscles of the ECRB, EDC, and ECU using electromyography (EMG) to monitor muscle activation. A series of static grasping contractions will be performed with a constant force, constant hand orientation with respect to gravity and constant wrist posture. The only variable that will change is the forearm posture, thus causing changes in the length of the muscles and therefore changes in angles of pull. The ECRB is an elbow flexor and forearm pronator while the EDC and ECU are elbow extensors and forearm supinators, respectively. Therefore, we hypothesize that at different forearm postures, the fibres of the ECRB will experience an opposite change in length compared to the fibres of the ECU and EDC. No other study to date has ventured into this method of understanding the mechanisms of tennis elbow.

Prior to the study you will be asked to answer a questionnaire to gather information on height, weight, handedness, and musculoskeletal health. Following, you will be acquainted with the equipment and set up for data collection. The task you will be required to do is first grasping a handgrip dynamometer as hard as you can and next grasping it while matching a level on the computer monitor. You will be asked to repeat this in three postures of your forearm – pronation (hand facing away from you), supination (hand facing towards you) and mid (hand facing to the side).

During the collection trials, you will wear an electrogoniometer on the dorsal side of your dominant hand, as well as electromyographic (EMG) sensors on your forearm, all of which will be taped to your skin. The electrogoniometer will be used to measure postures of your wrist, and the EMG sensors will serve to pick up the electrical activity generated by your muscles. Your movements might be videotaped. Representative postures will be photographed. Postures, hand grip force and muscle activity of the mentioned muscles that you use when you perform the required tasks will be recorded.

Before you begin, you will be asked to do a series of maximal contractions in order to standardize the data. Your estimated participation will take 1-2 hours at the ergonomics and biomechanics lab at the Sherman Health Science Research Centre.

Risks and Benefits

This study has been reviewed and approved by the Human Participants Review Sub-Committee, York University's Ethics Review Board, and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. The risks associated with this study are minimal. There is the possibility of a skin rash as a reaction to the adhesive on the EMG sensors. Should a skin rash occur, it would typically disappear in a few days. It is important that you advise the researcher if any equipment is bothering you in any way, like in the case of straps adjusted excessively tight.

Also, with any physical activity, including repetitive manual work and maximal activity there is the chance of slight muscle soreness following the study. Cardiovascular patients may have an increased risk doing physical activity. Although you will be asked perform the hand grasping task, we request that you do not participate if you have cardiovascular problems or currently receiving treatment for a musculoskeletal injury.

Confidentiality will be protected to the fullest extent possible by law. All information/data derived from the study will be kept confidential to the limit allowed by law by the use of participant code numbers in place of names. Data will be stored electronically with only code numbers attached to the files. Following 10 years, individual data will be erased and only summary data of the overall study retained. All information derived from this study will be used for research and teaching purposes. Photographs and videos will only be used for demonstrations in class or at scientific conferences and your face will be blocked out.

I accept to be photographed and videotaped for the purposes of demonstrations in class or at scientific conferences:

☐ Yes ☐ No

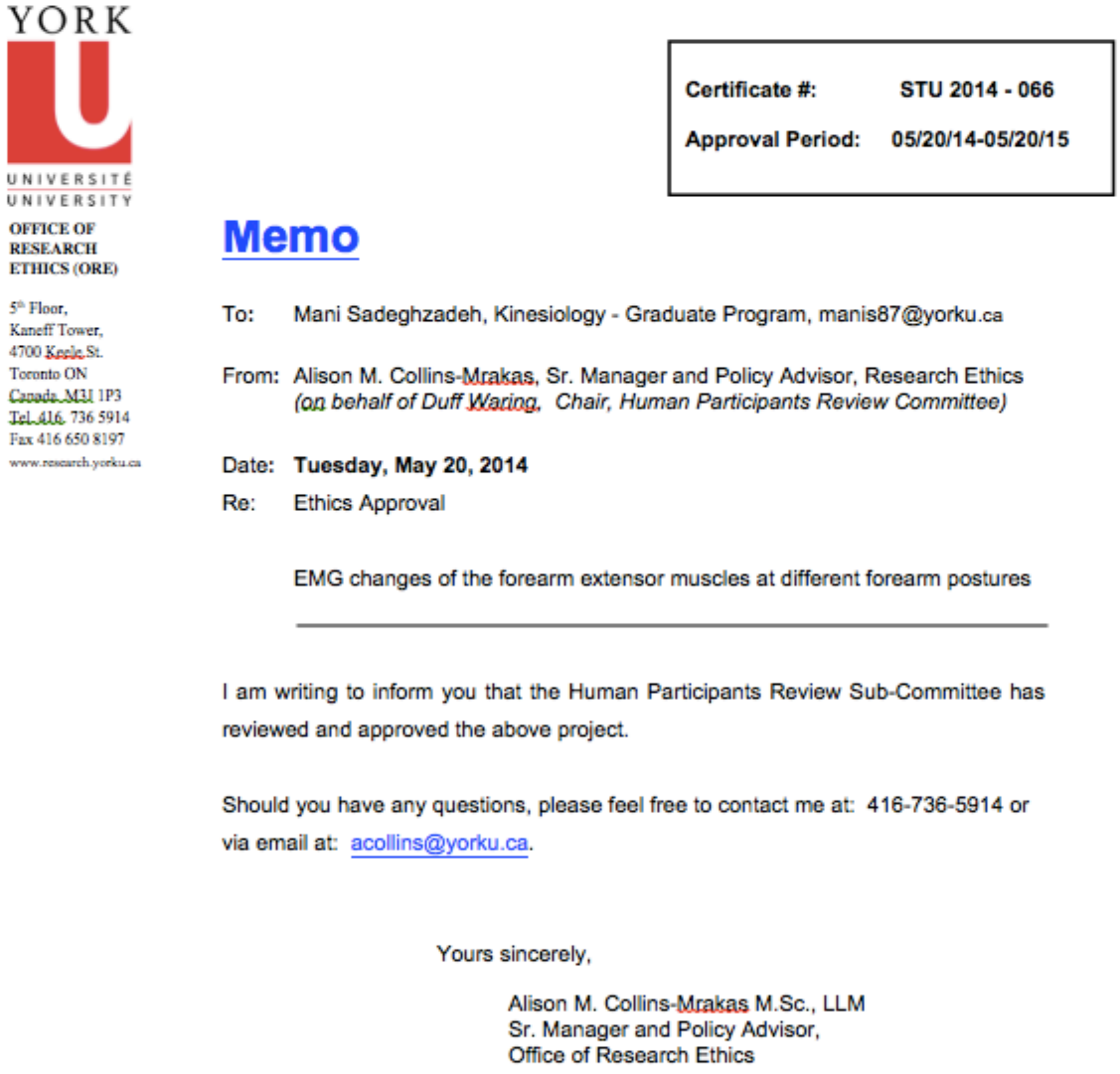
Consent of Participant

I am not waiving any of my legal rights by signing this form. I have read this form about the nature and procedures of the study have received a copy and understand it in full. I agree to serve as a participant in the study. I have been assured that Mani Sadeghzadeh will respond appropriately to any questions that I may have. I understand that participation is entirely voluntary and I can refuse to answer any question, item, etc., and may withdraw my consent at any time by verbal declaration without prejudice to me either now or in the future. I know that if I withdraw my consent any data already obtained will be destroyed. Before giving my consent, I know that there would be no advantages or disadvantages for me depending on my decision and refusal to participate or withdrawal from participation will not jeopardize current or future relationships with the researchers or York University. I know that the university and those conducting this project subscribe to the ethical conduct of research and to the protection at all times to the dignity, rights, interest and safety of its participants.

______________________________	______________________________
Print Name	Signature of Participant

Dated at Toronto, Ontario	Signature of Researcher
Dated at Toronto, Ontario	Witnessed

Appendix C: Certificate of Research Ethics



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Certificate #: **STU 2014 - 066**

Approval Period: **05/20/14-05/20/15**

Memo

To: Mani Sadeghzadeh, Kinesiology - Graduate Program, manis87@yorku.ca

From: Alison M. Collins-Mrakas, Sr. Manager and Policy Advisor, Research Ethics
(on behalf of Duff Waring, Chair, Human Participants Review Committee)

Date: **Tuesday, May 20, 2014**

Re: Ethics Approval

EMG changes of the forearm extensor muscles at different forearm postures

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I am writing to inform you that the Human Participants Review Sub-Committee has reviewed and approved the above project.

Should you have any questions, please feel free to contact me at: 416-736-5914 or via email at: acollins@yorku.ca.

Yours sincerely,

Alison M. Collins-Mrakas M.Sc., LLM
Sr. Manager and Policy Advisor,
Office of Research Ethics