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Effects of Tendon Vibration on Force Steadiness and Motor Unit Properties in the Biceps Brachii of Young Men and Women

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By

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ABSTRACT

Muscle compartmentalization in the short (SBB) and long (LBB) heads of the biceps brachii (BB) might occur through spinal connections of 1a afferent feedback. Tendon vibration (TV) was used to quantify the effect of excitatory 1a afferent feedback on motor unit properties in the SBB and LBB. Eight women and 8 men (20-24years) maintained isometric elbow flexion at 15% maximum, and TV was applied (5s) in the middle of a 35s constant effort. Motor unit discharge rates (DR) were higher in men (13.99$\pm$3.12Hz) compared with women (12.81$\pm$3.13Hz) and in the LBB (14.81$\pm$2.81Hz) compared with the SBB (13.82$\pm$2.27Hz), ($p<0.05$). Following TV force steadiness decreased, more motor units were recruited in the SBB compared to LBB, but DR declined more in the LBB. Compartmentalization of SBB and LBB likely occurs through 1a afferent feedback contributing to excitatory post synaptic potentials in SBB motor neurons, but post activation depression predominates in the LBB.

DEDICATION

To all my friends and family who supported me through the highs and lows of completing this degree.

To all of those who could not be here to share in this experience and journey with me, especially Grandma Linda and Nonno Luigi.

Also, to my cat Boots who was a calming presence during all the frustrating times over the last few years. We thought of you not as a pet but as a part of our family. You will be greatly missed.

PUSS N' BOOTS 2005 - 2009

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GLOSSARY

Action Potential (AP) – self-regenerating electrochemical wave used for signal transmission.

Afferent – neurons that relay signals from sensory receptors to the spinal cord.

Agonist - muscle, through which contraction causes specific movement to occur.

Alpha Motor Neuron – large diameter motor neurons located in the brainstem and spinal cord that innervate the extrafusal muscle fibers of skeletal muscle and are responsible for muscle contraction.

Antagonist – muscle that opposes the specific movement created by the agonist.

Compartmentalization – a term for when different portions or heads of the same muscle are found to act independently of each other or display different properties from each other.

Derecruitment – a mechanism to decrease force output by decreasing the number of active motor units.

Discharge Rate – the rate in which consecutive action potentials for a given motor unit are typically measured.

Efferent – neurons that relay signals from spinal cord to effectors (i.e. muscles).

Extensors – muscles responsible for opening joints and increasing the angle between limb components (i.e. triceps brachii contraction).

Extrafusal Fibers – skeletal muscle fibers located external to intrafusal fibers and act to create tension when they contract to produce movement.

Flexors – muscles responsible for closing joints and decreasing the angle between limb components (i.e. biceps brachii contraction).

Force Steadiness – the ability to maintain an isometric force with minimal deviation from a desired value.

Gamma Motor Neurons – small diameter motor neurons located in the brainstem and spinal cord that innervate the intrafusal muscle fibers and are responsible for controlling muscle spindle sensitivity.

Henneman’s Size Principal – states that motor units are activated in an orderly recruitment pattern based on the size of their cell body, with the smaller cells activated before the larger ones.

Ia Afferent – primary sensory afferent where the cell body is located in the dorsal root ganglion and is responsible for detecting change in length and rate of change in length of the muscle spindle.

Ib Afferent – sensory afferent where the cell body is located in the dorsal root ganglion and is responsible for detecting tension changes of golgi tendon organ.

II Afferent – secondary sensory afferent where cell body is located in dorsal root ganglion and is responsible for detecting change in length of the muscle spindle.

Intrafusal Muscle Fibre – skeletal muscle fibers that lie within and parallel to extrafusal fibers to comprise the muscle spindle, detect changes in amount and rate of length and are innervated by gamma motor neurons.

Isometric – contraction generating force without changes in length of the muscle.

Maximum Voluntary Contraction (MVC) – greatest amount of force produced from an isometric muscle contraction.

Motor Unit (MU) – A single aMN and all of the muscle fibers it innervates.

Muscle Spindle – a conglomeration of 3-10 intrafusal fibers (sensory receptors) found within the muscle belly and detects changes in length of the given muscle.

Neutral – wrist position where the palm of the hand is facing medial.

Pronated – wrist position where the palm of the hand is facing downward.

Rate Coding – a mechanism to increase force production by increasing the individual frequency of discharge for active motor units in a motor unit pool.

Recruitment – a mechanism to increase force production by increasing the number of motor units active in the motor unit pool.

Recruitment Threshold – force value for which a given motor unit is activated.

Somatosensory – a diverse sensory system comprised of receptors and processing centers that produce sensory modalities such as touch, proprioception, nociception and temperature perception.

Supinated – wrist position where the palm of the hand is facing upward.

Supraspinal – signals generated above spinal cord in regions of the brain.

LIST OF ABBREVIATIONS

αMN – Alpha Motor Neuron

AP – Action Potential

BB – Biceps Brachii

BRR – Brachioradialis

CNS – Central Nervous System

EMG - Electromyography

EPSP – Excitatory Post-Synaptic Potential

FDI – First Dorsal Interosseous

FS – Force Steadiness

γMN – Gamma Motor Neuron

LBB – Long Head of Biceps Brachii

MU – Motor Unit

MUDR – Motor Unit Discharge Rate

MVC – Maximum Voluntary Contraction

NMJ – Neuromuscular Junction

PAD – Post-Activation Depression

RT – Recruitment Threshold

SBB – Short Head of Biceps Brachii

sEMG – Surface Electromyography

TB – Triceps Brachii

TV – Tendon Vibration

CHAPTER I

REVIEW OF LITERATURE

1.0 Production of Movement

Voluntary movement is more than simply contracting the required muscles to produce a desired outcome. The production of intentional movement is spawned by the central nervous system (CNS) within the brain and through a hierarchical arrangement of the motor system, movement commands are generated in the forebrain and progress to the spinal cord. Control relies on a continuous flow of visual, somatosensory, and postural information between the brain, spinal cord and muscle. Synaptic connections within the CNS are most complex nearer to the forebrain and less complex at the spinal cord. In the peripheral nervous system, motor commands are transmitted to the extrafusal muscle fibres via the alpha motor neuron (αMN) and the sensory signals from those muscle fibres are relayed back to the spinal cord through afferent feedback. Via simple connections, unconscious reflexive movements are organized and emitted. Alternatively, via a series of ascending tracts the brain stem and higher brain areas process and coordinate afferent feedback whereby motor commands are interpreted and relayed back to the efferent organs in skeletal muscle. This series of descending conscious commands coupled with afferent ascending information and reflex processes are responsible for human movement.

A small albeit fundamental component of the motor system is the motor unit (MU). A single α motor neuron (αMN) and all of the muscle fibres innervated

by that motor neuron is termed a motor unit (Ghez & Krakauer, 2000). The αMN consists of the dendrites, soma, axon and the axon terminals. Each αMN may innervate more than one muscle fibre but each muscle fibre is only innervated by one αMN (Masakado, 1994). The motor unit is the final unit of force production. Motor units are more numerous in muscles that produce precise motor movements compared with muscles of gross force production. Muscles with a high number of motor units would include the digits, face and tongue, with fewer motor units dedicated to the gross motor task muscles such as the arms and legs (Amaral, 2000).

Generation of force via motor units involves contraction of the extrafusal muscle fibre in the periphery through activation of the αMN in the central nervous system reaching threshold to generate an action potential (AP). Generation of this signal begins at the junction of the axon hillock. This structure is also known as the triggering zone and is the site where signals from other neurons are incorporated. After integrating all input signals, the output signal of the neuron is generated when all excitatory and inhibitory inputs equal or are greater than threshold (Schwartz & Westbrook, 2000). Propagation of this signal travels from the soma down the axon until it reaches an axon terminal. Axon terminals are the result of the axon splitting into many nerve endings innervating individual muscle fibres (Kandel, 2000). The nerve terminals are filled with many synaptic vesicles containing a neurotransmitter known as acetylcholine. A protein called Synapsin initiates a tethering or clustering of synaptic vesicles during resting periods (Hilfiker et al., 1998). As the AP propagates down the cell membrane of

the nerve terminals, voltage-gated calcium (Ca^{2+}) channels are opened and permit the entry of Ca^{2+} into the terminal. Ca^{2+} binds to a protein called Synaptotagmin which is found within the vesicle membrane and initiates fusion of the vesicles to the plasma membrane of the terminal by means of the SNARE proteins. These proteins include Synaptobrevin found in the vesicle membrane, SNAP 25 and Syntaxin found in the plasma membrane. SNARE proteins cause a tight fusion of the vesicle to the plasma membrane of the terminal, leading to the release of vesicle contents into the synaptic cleft by means of exocytosis (Weber et al., 1998).

The transmission of the AP from the motor neuron of the nervous system to the muscular system occurs at the neuromuscular junction (NMJ) which includes the synaptic cleft, motor endplate and axon terminals. The acetylcholine released into the synaptic cleft binds to acetylcholine receptors embedded in the motor endplate membrane leading to the opening of voltage-gated Na^{+} channels and an inward flow of Na^{+}. This inward current depolarizes the postsynaptic membrane of the muscle fibre and propagation of the AP continues along the muscle membrane. This action potential travels along the sarcolemma and into transverse tubular systems to cause contraction of the muscle fibres. Contraction of many individual muscle fibres is responsible for the gross motor contraction of the muscle (Loeb & Ghez, 2000).

Muscle contraction is sensed by a structure known as the muscle spindle (Figure 1). The muscle spindle is innervated by both sensory and motor axons and has a primary function of sending proprioceptive information about changes

in length of skeletal muscles to the CNS. Muscle spindles are found interspersed among and oriented parallel to extrafusal skeletal muscle fibres. Muscle spindles are composed of 3-10 intrafusal muscle fibres that are embedded between extrafusal muscle fibres. When a muscle is stretched there are two mechanisms of detection. The primary sensory fibres known as Group Ia afferent neurons respond to velocity and degree of stretch and send this information to the spinal cord, while secondary sensory fibres known as Group II afferent neurons relay information about the degree of stretch to the CNS. The information is relayed monosynaptically through synaptic spinal connections to an alpha efferent motor neuron causing the extrafusal fibres to contract and reduce stretch on the muscle. The signal may also be transmitted polysynaptically to other αMN's such as those which prevent antagonist muscles from contracting.

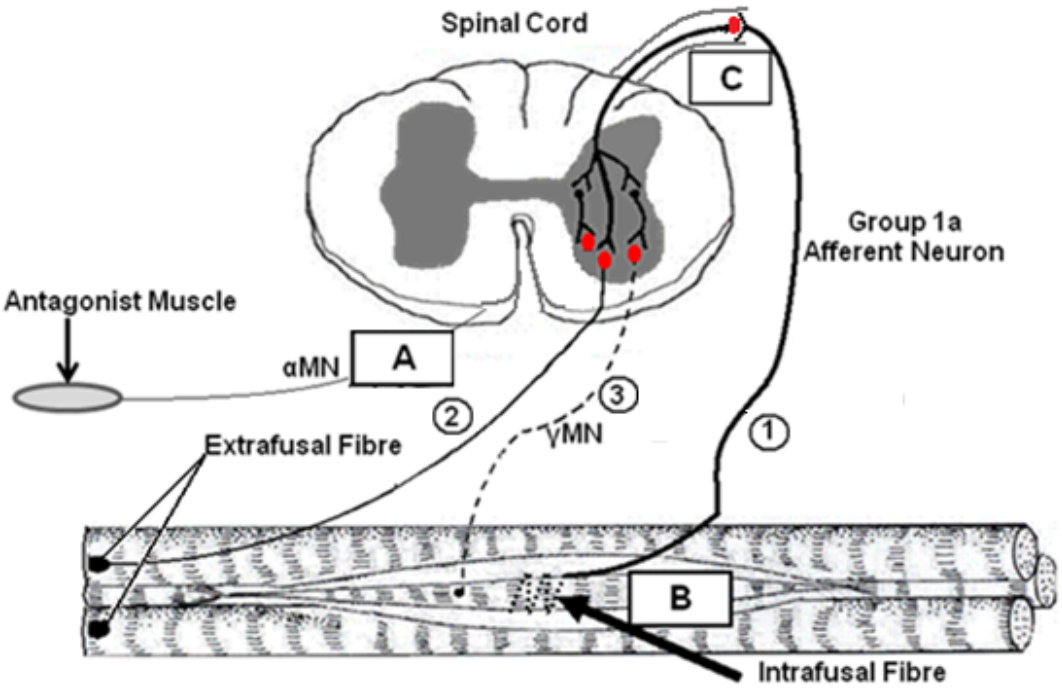

Figure 1: The Muscle Spindle and Spinal Connections. The 1a afferent (1) projects from the muscle spindle of the intrafusal fibres (B) through the dorsal root (C) and onto alpha motor neurons (2), and gamma motor neurons (3) of the homonymous muscle and alpha motor neurons (A) of antagonist muscles.

Gamma motor neurons (γMN) are smaller efferent fibres and are responsible for causing shortening of the polar regions of the intrafusal fibres. This shortening subsequently leads to stretching of the non contractile central region from both ends, increasing the discharge rate of the sensory endings. This mechanism is responsible for maintaining the sensitivity of the muscle spindle during muscle contraction (Pearson & Gordon, 2000). Overall, the net input from supraspinal sources, with excitatory and inhibitory afferent feedback determine whether threshold for an action potential is achieved and whether an action potential is generated (Pearson & Gordon, 2000).

1.1 Force Modulation and Variability

Force modulation via single motor units has been extensively researched (De Luca, 1985; Semmler, 2002). There are two primary means to increase force output at the level of the motor unit (Figure 2). The first is to increase the number of motor units active in the motor neuron pool which is known as "recruitment". The second method is to increase the individual frequency which motor units discharge through a mechanism called "rate coding" (Calancie & Bawa, 1990; Enoka et al., 2003; Masakado 1994). Motor units are activated in an orderly recruitment pattern based on the size of their cell body, with the smaller cells activated before the larger ones (Henneman, Somjen, & Carpenter, 1965). It has also been found that motor units undergo derecruitment in the reverse order of recruitment where larger motor units recruited last become inactive first before the smaller motor units that were recruited first (Clamann,

Gillies, & Henneman 1974, Clamann & Henneman 1976; De Luca, 1985; De Luca & Mambrito, 1987).

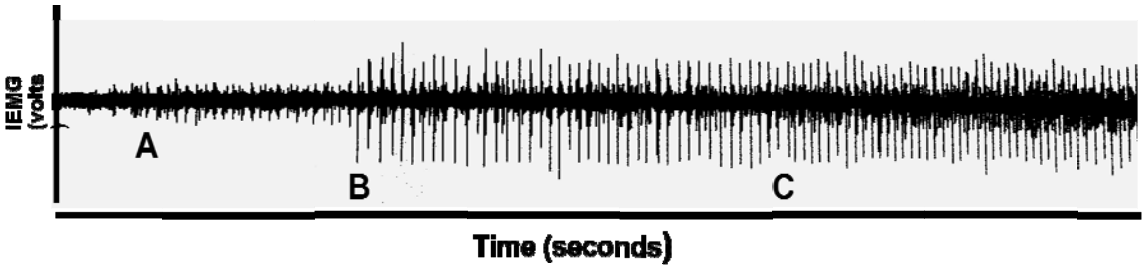

Figure 2: Discharge Rate and Recruitment Threshold. Motor unit (A) is recruited early in the ramp phase of an isometric contraction (15s) and a second motor unit (B) is recruited later in the steady state contraction (21s). As the constant force is maintained, the discharge rate of motor unit B increases (C) (31s).

Force modulation also differs with the size of the muscle group and task of the muscle. Smaller muscles that function in low force precise movements such as the hand have been observed to recruit motor units within a 0-50% Maximum Voluntary Contraction (MVC) level. When a force output greater than 50% MVC is required, the muscle relies solely on an increase in the discharge rate of the motor units to modulate force. For larger muscles such as in the leg or arm which do not require fine force progression and control, motor units are recruited up to ~88% MVC (Kukulka & Clamann, 1981). Motor unit discharge rates in small muscles have been recorded at rates in excess of 60 times per second (Hz), whereas within larger muscles discharge rates of ~35-40 times per second are typically observed (De Luca, 1985; Kukulka & Clamann, 1981; Masakado, 1994). Kukulka and Clamann (1981) studied motor units in the biceps brachii and the adductor pollicis. They found that in the biceps recruitment of motor units occurred up to 88% MVC with discharge rates of 7 to 28 times per second. In the adductor pollicis recruitment only occurred up to 50% MVC and the

discharge rates were slightly higher than in the biceps brachii ranging from 6 to 32 times per second. A study by Seki and Narusawa (1996) compared rate coding strategies between the first dorsal interosseous (FDI) and the biceps brachii (BB) at forces of threshold to 80% MVC. The discharge rate of the FDI (31.1±10.2Hz) increased more than the BB (21.7±7.8Hz) ($p<0.05$) which suggested to the authors that rate coding may be the primary mechanism for force steadiness in the FDI but not in the BB; although steadiness was not directly measured. These studies highlight the synergistic relationship whereby recruitment and rate coding mechanisms work in tandem to control force through the central nervous system and peripheral feedback mechanisms (Erim, De Luca, Mineo, & Aoki, 1996; Farina, Fosci, & Merletti, 2002).

A recent study by Harwood, Edwards, & Jakobi (2009), compared force steadiness in young and old men during a low percentage isometric tracking task using tungsten indwelling microelectrodes in the short (SBB) and long (LBB) heads of the biceps brachii. They found that force steadiness decreased with age and also changed with wrist position. Force steadiness is the ability to maintain an isometric force with minimal deviation from a desired value. The supinated wrist position yielded the greatest force steadiness while a neutral position was the least steady. The pronated wrist position was steadier than the neutral but less steady than the supinated. This was the first study to assess motor unit activity within both heads of the biceps brachii relative to force steadiness in three wrist orientations. It was found that motor unit discharge rate was greater in the neutral position compared to the supinated and pronated

positions. Also, the discharge rate differed between the SBB and LBB in the supinated position but not the neutral or pronated positions. Prior studies have measured force steadiness in one wrist position, typically neutral, and motor unit activity with an indwelling electrode in only one head of the biceps brachii. Often times the location of the microelectrode identified by muscle head is not reported.

1.2 Altering Afferent Feedback

It is well documented that motor unit activity can be influenced by factors such as training, fatigue, and electrical stimulation (Masakado, 1994; Semmler, 2002). Altering the afferent input of the muscle spindles is yet another way that motor unit activity can be changed. The influence of blocking afferent feedback varies between types of muscle contractions; Ia afferent feedback decreases more in shortening compared with lengthening contractions (Nordlund, Thorstensson, & Cresswell, 2002). There are two artificial ways to decrease afferent input to the motor neuron pool. The first is an anaesthetic or ischaemic block and the second is prolonged tendon vibration (Cresswell & Loscher, 2000; Ushiyama, Masani, Kouzaki, Kanehisa, & Fukunaga, 2005). The mechanism of action of the anaesthetic block is to decrease the maximal motor unit sustainable discharge rates through a favoured block of the gamma (γ) motor axons causing reduced facilitation of the alpha motor neurons through muscle spindle afferents (Macefield, Gandevia, Bigland-Ritchie, Gorman, & Burke, 1993). Whereas, the ischaemic block is achieved by using an inflatable cuff over the muscle of choice in order to block the large diameter rather than the small diameter afferents in the selected nerve (Cresswell & Loscher, 2000). Macefield et al. (1993) found that

when an anaesthetic was used to create a block the average discharge rate of the paralyzed muscle was significantly lower than that of the normally innervated muscle. These two blocks are efficient methods of altering the afferent feedback system and in turn changing the motor unit properties of a chosen muscle. This can have a great effect on force steadiness during a simple isometric tracking protocol. Since force is primarily modulated by recruitment and discharge properties of motor units, these two methods would also contribute to force steadiness. Although ischaemic and anaesthetic afferent blocks provide a viable means to alter recruitment threshold and discharge rate, the procedure is often uncomfortable, a physician is required to be present and thus these techniques are not always a practical or available method.

Another means to alter Ia afferents and influence discharge rate of motor units is tendon vibration for short durations (up to 20 seconds) (Roll, Vedel, & Ribot, 1989; Verschueren, Swinnen, Desloovere, & Duysens, 2002). A discharge of impulses along the Ia afferent neurons is created through excitation of the muscle spindles primary endings through application of vibration over a tendon at frequencies of approximately 100Hz (Delwaide, 1973; Grande & Caffarelli, 2003; Verschueren et al., 2002; Verschueren, Swinnen, Desloovere, & Duysens, 2003). With vibration, single motor units are still recruited according to the size principle and derecruitment still occurs in reverse rank order (Desmedt & Godaux, 1978). When subjects are unable to see the vibration being applied to the tendon, the Ia afferent feedback alters proprioception to suggest that the vibrated muscle is lengthening, although the position has not changed (Collins, Refshauge, Todd, &

Gandevia, 2005). This reflex selectively increases muscle activity dependent on the Ia stretch reflex circuit. Tendon vibration is a non-invasive method to alter afferent feedback to assess the role of the muscle spindle in motor unit activity (Verschueren et al., 2003).

Recently, research has shown that the application of vibration over a tendon influences motor unit properties. Grande and Cafarelli (2003) reported a reduction in both recruitment threshold and discharge rates for motor units recorded in the vastus lateralis when vibration was applied to the quadriceps tendon. This change was noted when only short bursts of vibration (2 seconds) were applied but these adaptations in motor unit activity may present difficulties for an individual attempting to perform precise movements at lower levels of activity. If the recruitment threshold is lowered, more motor units are active at lower thresholds which would likely make it more difficult to produce a steady force. A study by Van Deursen, Sanchez, Ulbrecht, and Cavanagh (1998) found that tendon vibration affected the ability to produce accurate force tracking when holding an isometric contraction at a low percentage of maximum force. All individuals were affected but the greatest decline in performance occurred in those individuals who demonstrated better tracking ability; motor unit activity was not recorded in this study. To-date, there has been no attempt to evaluate motor unit responses to tendon vibration relative to force steadiness. Second, the response of women to tendon vibration has yet to be ascertained.

1.3 Sex-Related Neuromuscular Adaptation

Although there is limited literature available with regards to sex differences in motor unit properties, tendon vibration or force steadiness, many studies have shown women to consistently produce less force than men (Frontera, Hughes, Lutz, & Evans, 1991; Kanehisa, Ikegawa, & Fukunaga, 1994; Kanehisa, Okuyama, Ikegawa, & Fukunaga, 1996; Kent-Braun & Ng, 1999; Pincivero, Coelho, & Campy, 2003). Frontera et al. (1991) reported absolute strength in women ranged between 42 and 63% that of men. When they expressed strength per kilogram of muscle mass, the sex differences were smaller or not present at all. This suggests that women may be weaker than men due to a lower percentage of muscle mass. Women have also been found to have a slower force production when maximum torque values were normalized to body weight (Pincivero et al., 2003). It has been inferred that the slower force-time curves in women compared with men, was a consequence of women being unable to fully recruit the available motor unit pool (Eckerson, 2000).

This decrease in maximal force is not due to an inability to produce an MVC. Recent studies in our lab have observed that both young and middle-aged men and women prior to the seventh decade of life were able to maximally activate the dorsi-flexors despite the significant sex-related difference in strength (Scherer, Edwards & Jakobi, 2007), and this similar ability to achieve maximal activation has been reported for elbow flexors and extensors between young men and old men (>80years) (Jakobi & Rice, 2002). More recently when tungsten microelectrodes were inserted into the tibialis anterior or not present

during dorsi-flexion MVC maximum voluntary activation was similar between conditions for both young men and women, albeit force was different between sexes (Brown, Bruce, Kenno, & Jakobi, 2008). In these studies women produced ~35% less force compared to men (Brown et al., 2008; Scherer et al., 2007).

Strength differences have been studied in women during different phases of their menstrual cycle to determine whether hormones affect isometric strength (Janse de Jorge, Boot, Thom, Ruell & Thompson, 2001; Petrofsky, LeDonne, Rinehart & Lind, 1976; Sarwar, Beltran Niclos & Rutherford, 1996). Results from these studies are equivocal. Some have found no isometric strength differences with respect to different phases of the menstrual cycle, therefore concluding that female reproductive hormone levels do not affect skeletal muscle contractile characteristics (Janse de Jorge et al., 2001; Petrofsky et al., 1976). In contrast, it has been found that in women who do not take oral contraceptives, there is a significant increase of about 11% in quadriceps and handgrip strength at mid-cycle compared with both follicular and luteal phases. In addition to strength differences, a slowing of muscle relaxation and an increased fatigability during mid-cycle compared to the other two phases has been reported (Sarwar et al., 1996).

Although sex-related differences in maximal strength and fatigue are well known (Eckerson, 2000; Hunter, Critchlow, Shin, & Enoka, 2004), very few studies have evaluated force steadiness. Sosnoff and Newell (2006b) reported that force steadiness is less with decreased strength which suggests that women, because they are weaker relative to men should demonstrate less

steadiness. Since the biceps brachii is involved in finer motor movements at lighter force levels, and because absolute force is less in this muscle compared with muscles in the thigh, force steadiness is also apt to be less in the upper limbs. Tracy and Enoka (2002) examined force steadiness in young and old men and women in the knee extensors and reported that young men were steadier than women at 2%, 5%, and 10% MVC but no difference was found at 50% MVC.

The inclusion of visual feedback has been shown to positively affect force steadiness of isometric contractions and the exclusion of visual feedback has detrimental effects on force steadiness (Sosnoff & Newell, 2006a, 2006c). When visual feedback has been removed, steadiness decreased by 27% (Tracy, Dinenno, Jorgensen, & Welsh, 2007). These studies suggest that visual feedback is more crucial for elderly than young subjects; however, there is very little data with respect to sex differences on visual feedback (Sosnoff & Newell, 2006a, 2006c; Tracy et al., 2007).

1.4 Summary of Literature

It is known that by altering the afferent feedback to the muscle spindle, motor unit properties can be changed. Tendon vibration is a viable means of altering 1a afferent feedback and in turn effecting motor unit properties. There has been no attempt to determine how 1a afferent feedback influences compartmentalized activity of the biceps. Previous studies have shown that with decreasing muscle strength, force steadiness decreases for low threshold isometric contractions (Sosnoff & Newell, 2006b). Other studies have found that

tendon vibration decreases the ability to produce steady force contractions, and those most steady are affected the greatest (Van Deursen et al., 1998). Since women are weaker than men, it is reasonable to suggest that force steadiness will be less in women compared with men at low force levels. Moreover, if men are more accurate at producing target level forces than women because they are stronger, tendon vibration will likely result in a greater decline in force steadiness in men relative to women. To our knowledge no investigation has compared the effects of tendon vibration on force steadiness between sexes. Furthermore, most tendon vibration studies have focused on locomotor muscles of the lower limbs but very few have studied upper limb muscles.

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CHAPTER II

PURPOSE AND HYPOTHESES

2.0 Purpose

The purpose of this study was to use tendon vibration to assess the contribution of 1a afferents to compartmentalized activation of the BB, and establish whether differences in activation alter force steadiness in men and women.

2.1 Specific Objectives (So)

1. To record MU discharge rates of the long head and short head of the biceps brachii in a supinated wrist position in young men and women.

2. To evaluate force steadiness during an isometric tracking task in young men and women.

3. To evaluate force steadiness during the same isometric tracking task after tendon vibration has been applied relative to the pre-vibration condition.

4. To determine whether MU discharge rates change in young men and women after the application of tendon vibration.

2.2 Research (H_1) and Null (H_0) Hypotheses

Note: Numbers correspond to specific objectives.

1. H_1: Motor unit discharge rates of the long head and short head will differ between men and women.

   H_0: Motor unit discharge rates of the long and short heads of the biceps brachii will not differ between men and women.

2. H_1: Women will be less steady compared with men.

   H_0: No difference will be found between sexes with respect to force steadiness.

3. H_1: Women will be less effected with respect to force steadiness after the application of tendon vibration.

H_0: No difference in force steadiness will be found after the application of tendon vibration with respect to sex.

4. (a) H_1: MU discharge rates will decrease after the application of tendon vibration in both young men and women.

H_0: No difference in MU discharge rates will be found after tendon vibration is applied.

4. (b) H_1: MU discharge rates will decrease more in men compared with women after the application of tendon vibration.

H_0: MU discharge rates will decrease after tendon vibration but there will be no sex-related differences.

CHAPTER III

MANUSCRIPT

3.0 Introduction:

The biceps brachii has traditionally been examined under the assumption that muscle activity is homogeneous between the short (SBB) and long (LBB) heads (Kukulka & Clamann, 1981; Garland, Enoka, Serrano, & Robinson, 1994; Seki & Narusawa, 1996). Compartmentalization between the short and long heads of the biceps brachii has been reported through measures of surface electromyography (Holtermann, Roeleveld, & Karlsson, 2005; Holtermann, Gronlund, Karlsson, & Roeleveld, 2008) and single motor unit (MU) activity (Harwood, Edwards, & Jakobi, 2009; Riley, Baudry, & Enoka, 2008; ter Haar Romeny, Denier van der Gon, & Gielen, 1984). During isometric elbow flexion contractions in young and old men, motor unit activity in the short (SBB) and long (LBB) heads of the biceps brachii (BB) has been shown to change independently as a consequence of forearm rotation (Harwood, Edwards & Jakobi, 2009). The underlying cause of compartmentalized activation between the SBB and LBB remains to be elucidated. Compartmentalized activation between the two heads of the BB might occur as a consequence of differences in synaptic integration from the homonymous 1a afferents to the motor neuron pool of the SBB and LBB. Compartmentalized activation between the SBB and LBB might be dissimilar between men and women, and be an underlying factor of sex- and position-related differences in force steadiness.

Recent investigations have focussed upon spinal connections contributing to compartmentalization (Barry, Pascoe, Carson, Riek & Enoka, 2009; Riley, Baudry, & Enoka, 2008). Studies of synaptic inputs from agonist, antagonist and synergist elbow flexors have indicated that excitatory connections are evident between the wrist flexors and BB, while activation of the brachioradialis inhibits the BB (Naito, Shindo, Miyasaka, Sun, & Morita, 1996). Barry, et al. (2009) reported that a spinal reflex pathway exists between the brachioradialis and BB that slows motor unit discharge rates similarly in the SBB and LBB, and this inhibition can be decreased with practise (Riley et al. 2008). Approximately 12 synaptic connections (Naito, 2004) have been identified in the BB, where historically the most common assumed input is activity of the 1a afferent contributing to homonymous muscle activity. The role of the 1a afferent in compartmentalized activity is unknown.

Tendon vibration is a non-invasive and viable means to artificially increase the activation of the 1a afferents by enhancing muscle spindle activity through the application of short bursts (<20s) of high frequency (approximately 100Hz) vibration. Subsequent to tendon vibration, motor unit discharge rates and recruitment thresholds decrease in lower limb muscles (Delwaide, 1973; Grande & Cafarelli, 2003; Verschueren, Swinnen, Desloovere, & Duysens, 2002; Verschueren, Swinnen, Desloovere, & Duysens, 2003) and isometric force steadiness declines in lower limb muscles (Van Deursen, Sanchez, Ulbrecht & Cavanaugh, 1998). In the elbow flexors force steadiness increases between neutral to pronated and neutral to supinated positions (Harwood et al., 2009),

thus tendon vibration provides a means whereby to determine the role of the 1a afferent in contributing to compartmentalized activation of the BB, and how this might influence force steadiness in men and women.

Force steadiness is influenced by muscle strength, motor unit discharge rates and variability (Enoka et al., 2003). It is likely that men should maintain steadier contractions compared with women because they are stronger (Frontera, Hughes, Lutz, & Evans, 1991; Kanehisa, Ikegawa, & Fukunaga, 1994; Kanehisa, Okuyama, Ikegawa, & Fukunaga, 1996; Kent-Braun & Ng, 1999; Eckerson, 2000; Pincivero, Coelho, & Campy, 2003) and force steadiness increases with strength (Enoka et al. 2003, Moritz, Barry, Pascoe & Enoka, 2005; Sosnoff & Newell, 2006), yet how compartmentalized activation influences force steadiness in unknown. Compartmentalized activation between the short and long head of the BB is likely to influence force steadiness because motor unit discharge rates and variability change with forearm rotation (Harwood et al., 2009). The purpose of this study was to use tendon vibration to assess the contribution of 1a afferents to compartmentalized activation of the biceps, and establish whether differences in activation alter force steadiness in men and women. Some of these data have been presented in abstract form (Edwards, Brown, Kenno & Jakobi, 2008; Brown, Edwards, Kenno & Jakobi, 2009)

3.1 Methods:

Subjects

Force steadiness and muscle activity were recorded from 8 young women (21.5±1.3 years; 20-23 years) and 8 young men (21±1.4 years; 20-24 years), in the LBB and SBB of the biceps brachii. The men were taller (178.1±4.2cm) and

heavier (79.9±10.8kg) compared with the women (164.3±6.0cm; 61.2±8.7kg, $p<0.002$) and all were free of neurological disorders and right hand dominant. All physiological and mechanical force measures were performed on the non-dominant (left) arm. Exclusion criteria consisted of participation in a planned exercise training regimen of more than 3 sessions per week, and those trained in fine motor control tasks (i.e. Musicians). Young women who were taking oral contraceptives for greater than one year were tested during the luteal phase of the menstrual cycle when differences in contractile function are smallest between men and women relative to other periods of the cycle (Sarwar, Beltran Niclos, & Rutherford, 1996). All volunteers signed an informed written consent (Appendix A) before participating in this study. The Research Ethics Board at the University of Windsor approved this study (Appendix B) and all procedures were in accordance with the declaration of Helsinki.

3.2 Experimental Protocol:

Experimental Setup

Subjects were seated in a custom-designed chair (Figure 3) that was adjusted for individual limb and body frame, i.e.) arm and forearm length, back height, and leg length. The subject was seated in the firm high back chair with knees positioned at 90°, and the non-dominant elbow was flexed to 100°, and the arm placed at 15° forward flexion at the shoulder and abducted 20°. The supporting plate for the forearm was attached to and directly above a linear calibrated force transducer (Transducer Techniques, Temecula, CA, USA) to measure application of upward and downward forces. The forearm apparatus

was designed to support the elbow in direct line with the wrist. A handle was grasped and the wrist supinated (palm facing upwards) (Figure 3). Force was recorded at the wrist with a MLP-150 linear calibrated force transducer (68kg) (Transducer Techniques, Temecula, CA, USA) with a sensitivity of 32.5N/mV located beneath the handle. The transducer beneath the elbow was monitored on-line to ensure elbow flexion was not due to shoulder depression. The chair was grounded through the Coulbourn Instruments Hardware Modular equipment (Whitehall, PA) by an A/C coupling capacitor of 0.033μF.

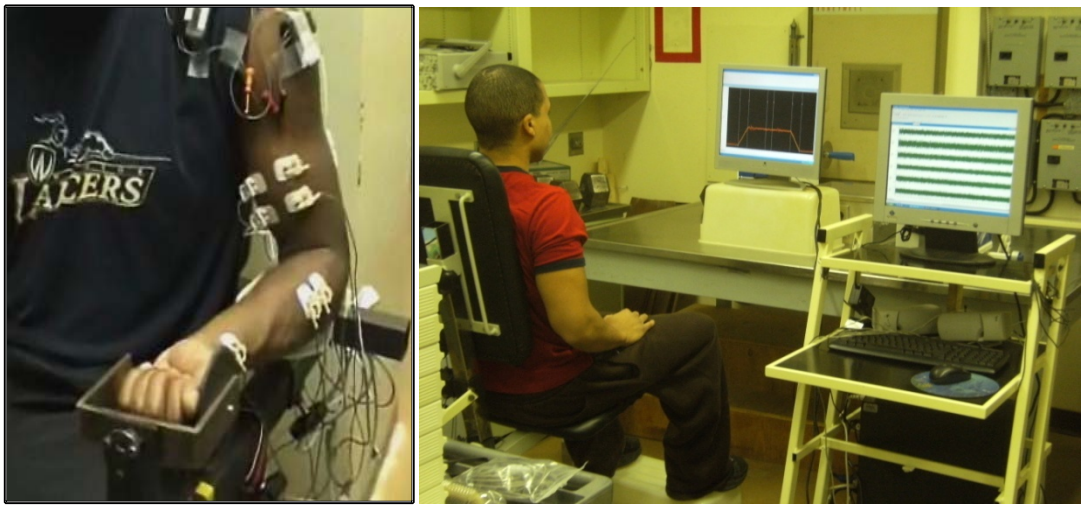

Figure 3: Custom Designed Adjustable Chair. Right Panel: The chair was adjustable for back height, leg length, arm length, forearm length, and shoulder abduction. Visual feedback was provided approximately 1m from the subject. Left Panel: An enlarged view of the forearm support as well as the rotational wrist apparatus. Transducers are located at the wrist and under the elbow support.

Experimental Procedures

Maximum voluntary contractions (MVC) were performed for the long (LBB) and short (SBB) heads of the biceps brachii (BB), triceps brachii (TB), and the brachioradialis (BRR). Three – four attempts at MVC were provided and each contraction was sustained for 3 – 4 sec and attempts were separated with a two minute rest period. The highest MVC recorded for the BB was used for the

determination of the 15% isometric tracking task. Subsequent to assessment of MVC and determination of the target force the tracking task was initiated. From baseline force was increased from the resting position in a ramp fashion over 7.5 s to ~15%. This 15% isometric force was held for 15s, where vibration was applied for 5s between ~32.5s – 37.5s as the subject maintained the force of contraction until ~52.5s. Relaxation then ensued in a ramp-down fashion for 7.5s (Figure 4). Visual feedback was provided (CED, Cambridge, UK) during the tracking task. A target line was provided and the force output displayed in real time at a rate of 5.5mm/s covering 63.4% of a 19 inch flat screen computer monitor (1280 x 1024 resolution) which was placed 15° below eye level. Force steadiness was measured using coefficient of variation of force, which is the quotient of standard deviation divided by mean force and is measured in arbitrary units (au). Force steadiness was determined during the 15s prior to tendon vibration and 15s following vibration. Delays in time to reach the 15% target line was excluded from the pre-vibration segment and post vibration steadiness was calculated ~0.5s following vibration to allow for the period of steady state to return. Vibration was applied to the biceps tendon of the left arm approximately 1cm below the palpable muscle belly of the BB, with a custom made vibration apparatus (Don Clarke, University of Windsor, ON, Canada) at a frequency of ~100Hz. The vibration apparatus was 25.1cm in total length with a handle 11.8cm long and 6.1cm in diameter for the experimenter to appropriately direct the vibration on the tendon. The vibrating portion of the apparatus was 10.0cm in

length with a diameter of 1.3cm. Subjects performed the tracking task 3-4 times in the supinated wrist position with 10 minutes rest between trials.

Figure 4: Representative recordings of a tracking task for a 24 year old female. Panels A and C show individual motor unit action potential trains for motor units 1 and 4, respectively. Panels B and D are the instantaneous discharge rates for motor units 1 and 4, respectively. Panel E is an overlay of the target force (thin solid line) and the achieved force (thick solid line). Panel F depicts the individual action potential shapes for the 6 different motor units recorded. The motor unit discharge rates are presented for each train under each action potential waveform. Panel G is the interference recording from the indwelling electrode in the SBB.

3.3 Electromyography:

Surface Electromyography

To acquire surface electromyography (EMG), electrode placement sites were prepared by abrading the skin with a coarse pad, then wiping with 70% antiseptic isopropyl alcohol pads (Kendall Canada, Peterborough, ON, Canada) to exfoliate the area. Disposable ECG monitoring electrodes (Tyco Healthcare Group, Mansfield, MA, USA) with inherent hydrogel were used for surface EMG

recordings of the SBB, LBB, TB and BRR. All electrode pairs were separated by an interelectrode distance of 4cm and placed mid-belly on the SBB and LBB. The reference electrode was placed on the acromion process of the scapula. The electrodes for the TB were placed at the mid-point of the humerus and a reference electrode was adhered to the skin above the olecranon process. Electrodes were also placed on the center of the muscle belly of the BRR with a reference electrode placed on the lateral epicondyle of the humerus. Signals were sampled at 1000Hz (1401 plus, CED, Cambridge, UK) amplified (1000x) and band-pass filtered (13Hz-1000Hz) (Coulbourn Electronics, Allentown, PA, USA) and converted from analog to digital format (CED, Cambridge, UK). EMG samples were rectified for the 15s prior to tendon vibration and the 15s after tendon vibration (Spike 2, Version 6, CED, Cambridge, UK). All surface EMG was integrated and normalized to the maximum EMG obtained from the MVC of each muscle.

Intramuscular Electromyography

Intramuscular EMG data was acquired using indwelling bipolar fine wires consisting of three strands of insulated stainless steel wire (50μm diameter) (California Fine Wire, Grover beach, CA, USA). The three wires were fed through the cannula of a 23-gauge hypodermic needle (Precision Glide, Franklin Lakes, NJ, USA) and the recording ends were cut on an angle with scissors and super glued together (Elmer's Products Canada, Scarborough, ON, Canada). Two of the wires were utilized to create a bipolar configuration, and the third provided an alternate recording set-up. The electrode was inserted into the

muscle belly through the skin and superficial fascia to a depth of ~3cm. Once the electrode was placed into the muscle at a desirable depth the skin surface was slightly pinched so that the hypodermic needle could be removed without displacing the fine wires. The insulation at the ends was removed with a butane lighter and the surface further exposed using a 320-grit, extra fine waterproof sandpaper (Mastercraft Canada, Toronto, ON) and inserted into the custom made preamplifier with a built-in gain of 10x (Don Clarke, University of Windsor, ON, Canada). Data were sampled at 10,000Hz and were subsequently amplified (10,000x), and filtered (100Hz – 10,000Hz) (Coulbourn Electronics, Allentown, PA, USA). All indwelling EMG data was converted from analog to digital format by a 16-bit A/D converter (1401 plus, CED, Cambridge, UK) at a rate of 10,000Hz. The reference electrodes were placed on the acromion process of the left clavicle. Upon completion of data collection the fine wires were removed from the muscle and the skin was swabbed with 70% antiseptic isopropyl alcohol pads (Kendall Canada, Peterborough, ON, Canada) followed by 10% Povidone-Iodine Solution pads (PDI, Orangeburg, NY, USA).

3.4 Data Analysis:

A customized software package within Spike 2 Version 6 (CED, Cambridge, UK) was used for all offline analysis. Motor units were analyzed if they had a continuous discharge for a minimum of 6 discharges. Motor unit action potential recordings were analyzed with a template matching algorithm (Spike 2 version 6.0 waveform discrimination, CED, Cambridge, UK) where individual motor unit action potentials were identified by waveform shape by

comparing and overlaying sequential action potentials based upon the temporal and spatial characteristics of each waveform. Visual inspection was employed to determine if a single motor unit action potential belonged within a train of potentials. Criterion for inclusion of motor unit trains in the analysis of pre and post vibration comparisons was a continuous discharge throughout the time frame being analyzed i.e.) pre or post vibration. Once individual discrimination of all single motor unit action potentials was complete, calculation of motor unit discharge rate (Hz), motor unit discharge variability (standard deviation of discharge rates), and recruitment thresholds (%) was conducted.

3.5 Statistical Analysis:

A 2x2x2 repeated measures ANOVA was used to examine differences in motor unit properties (Discharge Rate, and Motor Unit Discharge Rate Variability) with respect to sex (men and women), vibration condition (pre and post vibration) and muscle head (SBB, LBB). Force steadiness was evaluated with a 2x2 repeated measures ANOVA between sex and vibration. A 2x2x4 repeated measures ANOVA was used to examine differences in surface EMG values where sex, vibration condition and muscles (SBB, LBB, TB, BRR) were compared. Finally, a 2x2 ANOVA was performed for recruitment threshold to compare sex and muscle. All statistical analysis was completed using Statistical Package for Social Science (SPSS) version 15.0 and Microsoft Excel 2007 Vista. An alpha level of $P \leq 0.05$ was used for statistical significance, and to identify significant interactions independent T-Tests were performed. All data presented within the text including tables are expressed as values $\pm$ standard deviation of

the mean (SD). All figures are displayed as values ± standard error of the mean (SEM).

3.6 Results:

Subjects

Men were (263±47N) stronger compared with women (139±41N), ($p<0.001$). The target force was set at 15%MVC for recording motor units and applying vibration. Women approximated the target at 14.17±0.24%MVC and the men at 14.23±0.83%MVC, ($p=0.73$). A total of 121 single motor units were followed throughout the pre and post vibration conditions; 31 for the LBB in women and 30 for the SBB in women, whereas 30 motor units were recorded in each of the LBB and SBB in men. An additional 40 motor units were recruited during vibration and were analyzed for the post vibration condition (Table 1). In women, 21 motor units were recruited as a result of vibration (9 LBB, 12 SBB), and in men 19 additional units were recruited as a result of vibration (8 LBB, 11 SBB) (Table 1).

Table 1: Classification of Motor Units.

		Pre DR of Tracked MU (Hz)	Number of MU Tracked	Post DR of Tracked MU (Hz)	MU DR difference (pre-post) (Hz)	Number of MU Recruited	DR of MU Recruited (Hz)
Women	**SBB**	13.72 ± 1.89	30	12.16 ± 2.34	1.56	12	11.51 ± 1.77
	LBB	13.88 ± 2.20	31	11.49 ± 2.45	2.39	9	11.98 ± 3.52
Men	**SBB**	13.91 ± 2.63	30	12.97 ± 2.25	0.94	11	12.76 ± 2.20
	LBB	15.77 ± 3.08	30	13.30 ± 2.30	3.41	8	13.73 ± 2.60

Motor units that were analyzed pre and post vibration are classified as "tracked" while motor units only present post vibration are classified as "recruited". SBB, short head of the biceps brachii; LBB, long head of the biceps brachii; DR, discharge rate; MU, motor unit; ± plus or minus. Discharge rates are the mean discharge rates for the duration of the condition averaged across all motor units in that condition. Hz, hertz

Discharge Rate

The 3-way (sex x muscle x condition) interaction for the dependent variable of motor unit discharge rate was non-significant (p=0.32). Of the three 2-way interactions sex x condition (p=0.44) and sex x muscle (p=0.09) were non-significant. The interaction of condition x muscle was significant (p=0.001) (Figure 5).

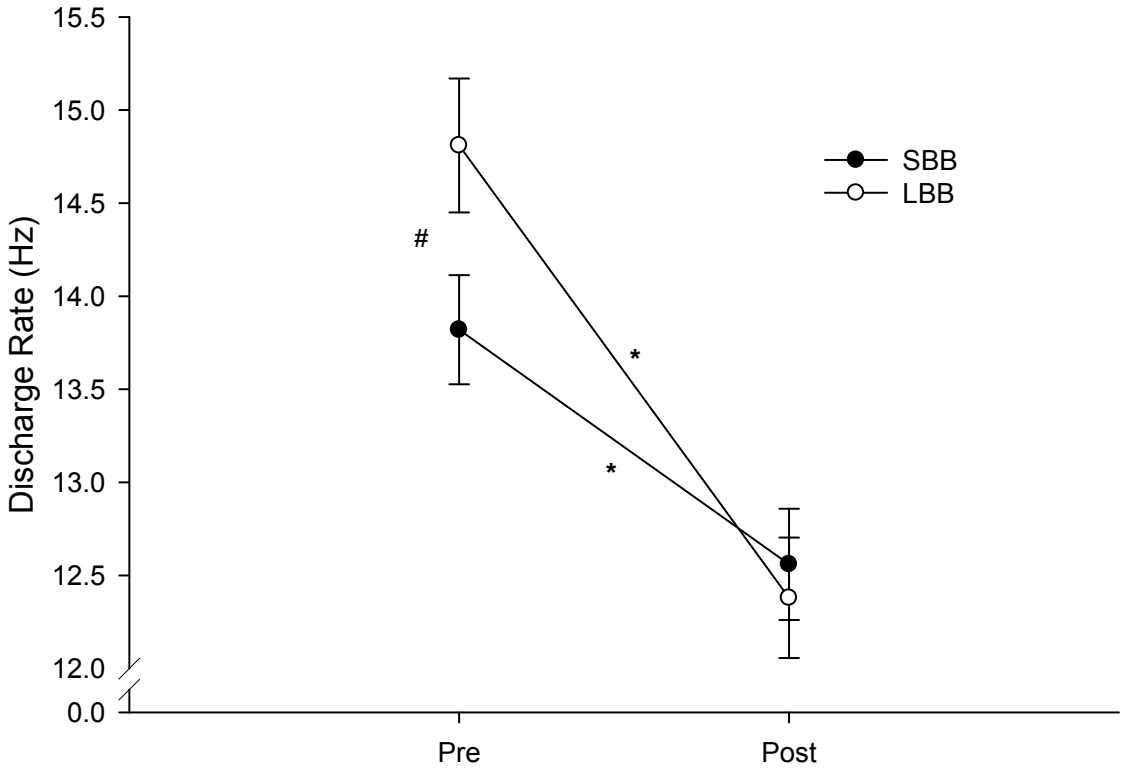

Figure 5: Motor unit discharge rates for the SBB and LBB during the pre and post tendon vibration conditions. Motor unit discharge rates differed between the SBB and LBB prior to vibration and both decreased after vibration was applied (p<0.001). Data are shown as means ± standard error. *represents a significant difference (p<0.05) pre to post vibration and # indicates a significant difference (p<0.05) between the SBB and LBB.

Motor unit discharge rates for the LBB (14.81±2.81Hz) were higher compared with the SBB (13.82±2.27Hz) prior to vibration (p=0.04). Following tendon vibration, motor unit discharge rates declined significantly in the LBB

(p<0.001) and the SBB (p<0.001). Following vibration motor unit discharge rates were similar between the SBB and LBB (Figure 5). Tendon vibration induces a greater decrease in motor unit discharge rates in the LBB (-16.4%Δ) compared with the SBB (-9.1%Δ). There were main effects for sex (p=0.004) and condition (p<0.001), but not for muscle (p=0.30) for motor unit discharge rates. In men motor unit discharge rates (13.99±3.12Hz) were significantly higher compared with women (12.81±3.13Hz) (Figure 6), and post vibration there was a significant decrease (-12.9%Δ) in motor unit discharge rate irrespective of sex (Figure 7).

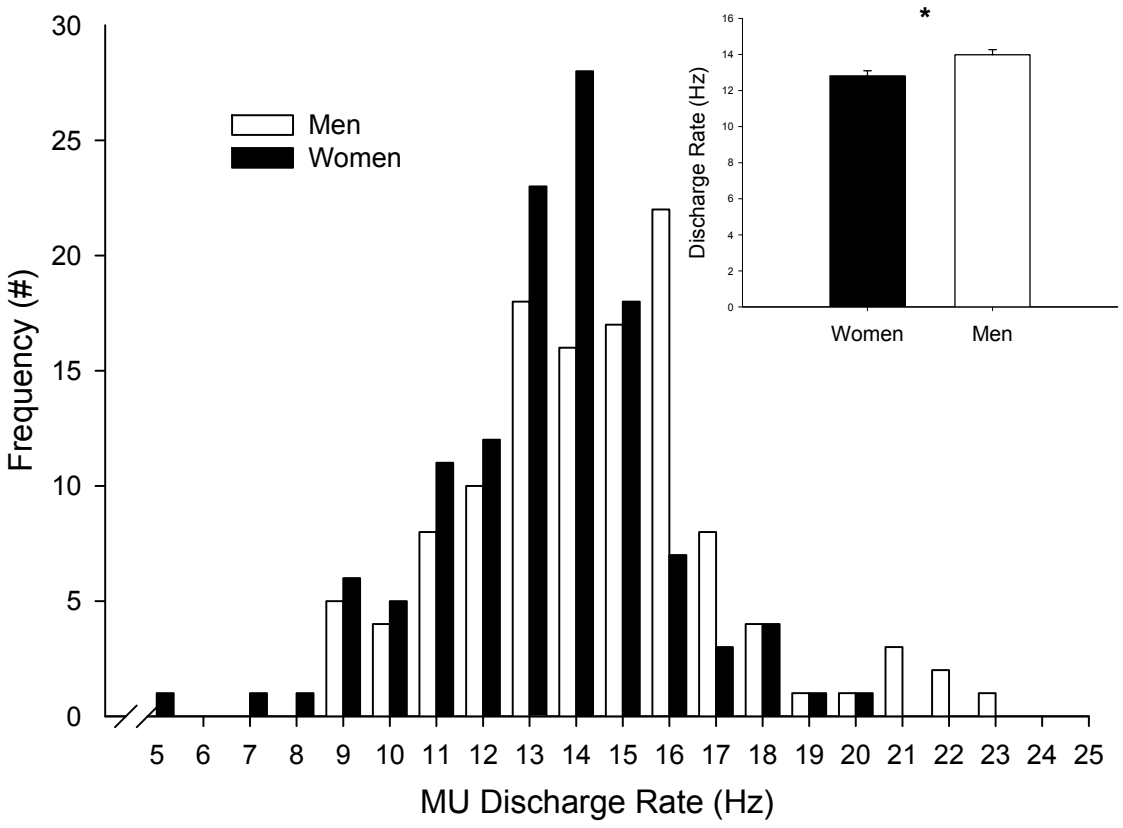

Figure 6: A frequency histogram of motor unit discharge rate where solid bars and open bars are used to represent women and men, respectively. A shift to the left for the solid bars illustrates the tendency for discharge rates to be lower in women compared with men (p=0.004) across the range of recorded motor units. Inset: Average motor unit discharge rates were significantly lower in women compared with men. MU, motor unit; Hz, hertz; #, number. Data are shown mean + standard error. * represents a significant difference (p<0.05) between men and women.

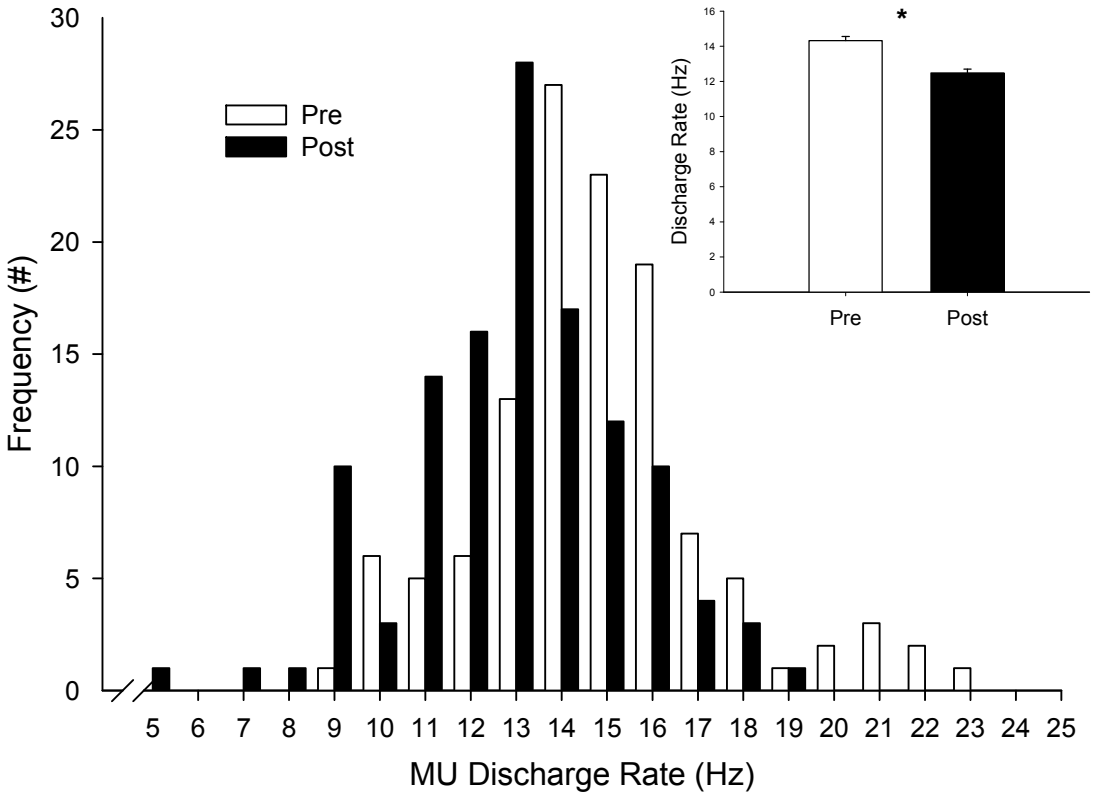

Figure 7: A frequency histogram of motor unit discharge rates where open and solid bars represent pre and post vibration conditions, respectively. The density of the solid bars to the left of the open bars suggest that discharge rates were lower after vibration compared with before vibration (p<0.001). Inset: Average motor Unit discharge rates were significantly lower after vibration was applied. MU, motor unit; Hz, hertz; #, number. Data are shown as mean + standard error. *represents a significant difference (p<0.05) pre to post vibration.

The 3-way (sex x muscle x condition) interaction was non-significant for discharge rate variability (p=0.66). The interaction for sex x condition (p=0.27), sex x muscle (p=0.45), and condition x muscle (p=0.68) with respect to discharge rate variability were also non-significant. There were no main effects of condition (p=0.08) or muscle (p=0.47), but discharge rate variability was higher in men (0.10±0.01u) compared with women (0.06±.01u), (p=0.001).

Recruitment Threshold

A significant sex x muscle interaction (p=0.02) was evident for motor unit recruitment thresholds (Figure 8). The average recruitment threshold for the LBB was similar between men (8.61±5.54%MVC) and women (9.95±4.46%MVC) (p=0.30), but in the SBB the recruitment thresholds were significantly higher in the men (12.63±4.63%MVC) compared with women (10.01±4.34%MVC), (p=0.003). In men, recruitment thresholds were significantly higher in the SBB compared with the LBB (p=0.003) but in women there were no differences between muscles (p=0.96).

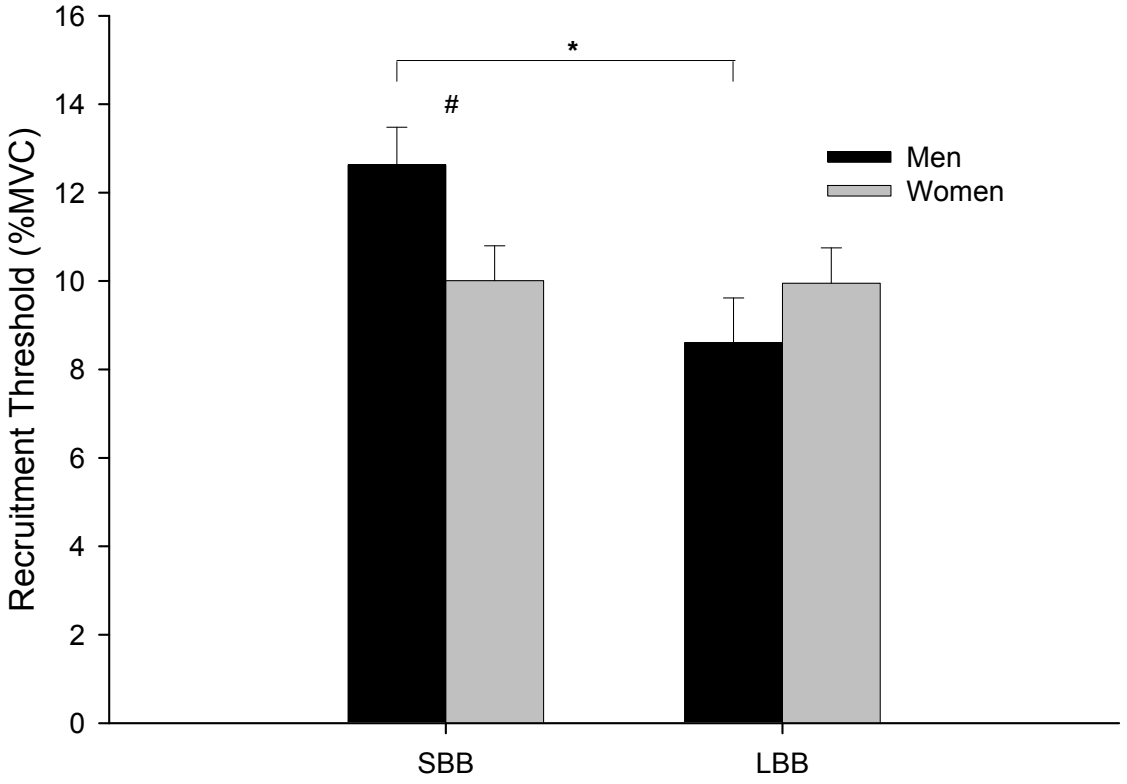

Figure 8. Motor Unit recruitment thresholds of the SBB and LBB in men and women. The recruitment threshold of the SBB in men was significantly greater than the LBB in men and the SBB and LBB in women (p<0.003). SBB, short head biceps brachii; LBB, long head biceps brachii; MVC%, percent of maximum voluntary contraction. Data are shown as mean ± standard error. *represents a significant difference between the SBB and LBB of men (p<0.05) and # indicates a significant difference (p<0.05) between SBB of men and women.

This suggests that the interaction occurs as a consequence of higher recruitment thresholds in the SBB of men relative to the LBB and women. There was a significant main effect for sex ($p=0.02$); recruitment thresholds in men (10.62 ± 5.45%MVC) were significantly higher compared with women (9.98 ± 4.36%MVC).

Force Steadiness

Force steadiness was quantified as the coefficient of variance (CoV) of force and measured in percent error. The CoV is inversely related to force steadiness such that an increased CoV represents a decrease in steadiness. There was a non-significant sex x condition interaction for CoV ($p=0.65$), but main effects of sex ($p=0.001$) and condition ($p<0.001$). Men (1.57 ± 0.43%) were steadier throughout the experiment compared with women (2.00 ± 0.42%). When the data was plotted as MVC versus CoV, a negative linear relationship exists such that as muscle strength increases, CoV decreases. This finding suggests that the stronger the subject, the steadier the isometric elbow flexion force output (Figure 9). The application of vibration caused a 43% decrease in steadiness from 1.48 ± 0.46% for the 15s period before tendon vibration to 2.10 ± 0.75% for the 15s period of time following vibration ($p<0.001$) (Figure 10).

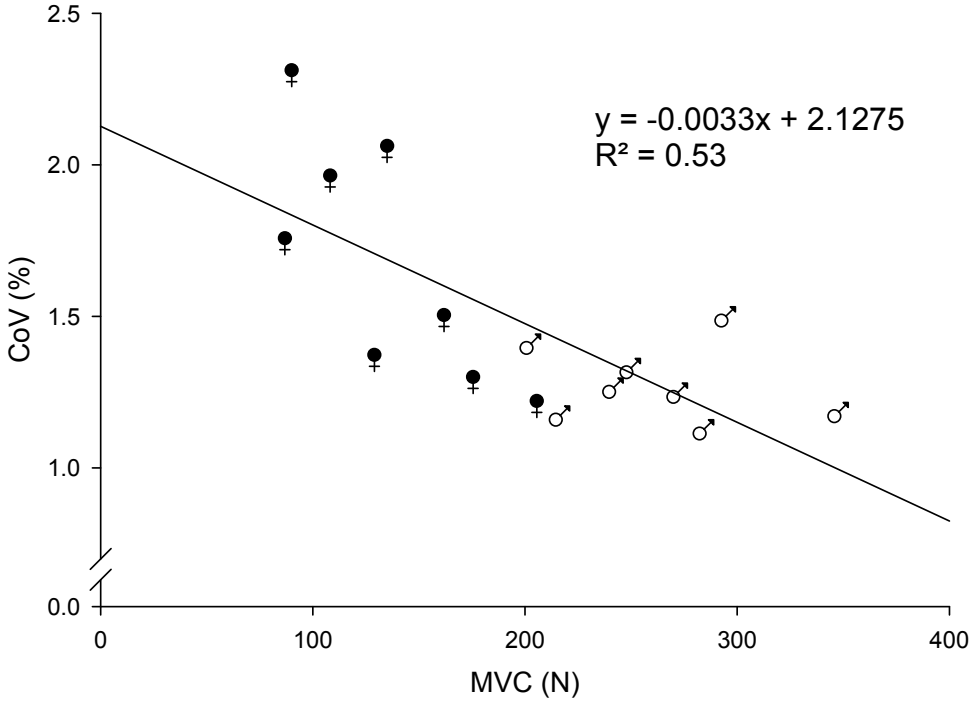

Figure 9. Force steadiness increased as strength increased. Isometric elbow flexion force was higher in men, and the men were steadier relative to the women. Force steadiness is quantified with CoV which is the quotient of standard deviation divided by mean force and is measured as a percent error; CoV, coefficient of variation of force; MVC, Maximum voluntary contraction; N, Newton; %, per cent

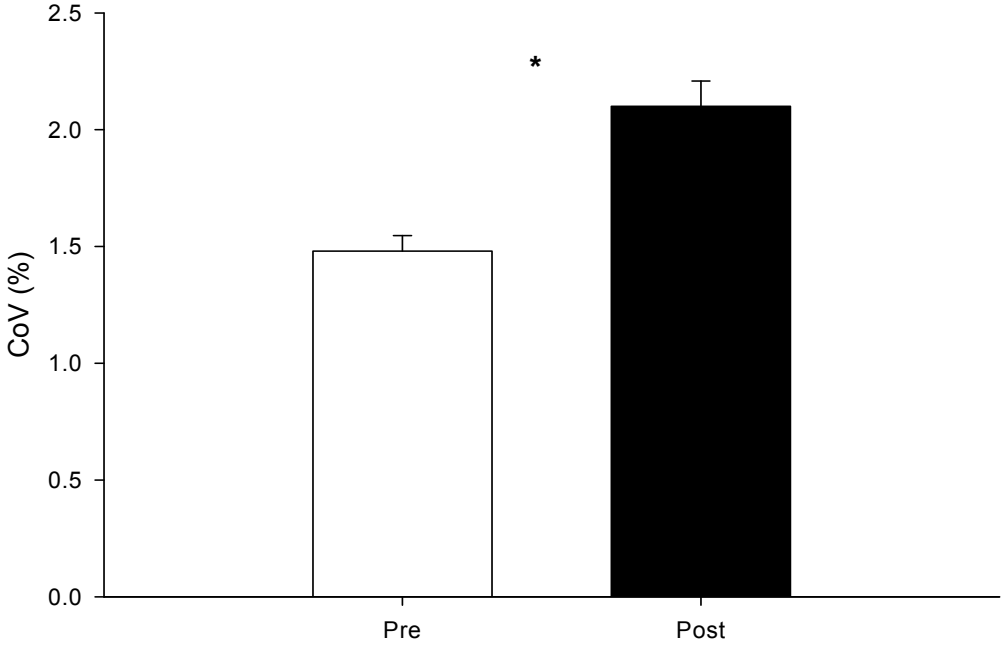

Figure 10. Force steadiness decreased after tendon vibration was applied. CoV, coefficient of variation of force. Data are shown as mean + standard error. *represents a significant difference (P<0.001) pre to post vibration.

Surface Electromyography

The three way repeated measures ANOVA of condition, muscle, and sex ($p=0.64$), and the two way interactions of sex x muscle ($p=0.65$) and condition x sex ($p=0.76$) were non-significant; however, there was a two way interaction observed between condition and muscle ($p<0.001$) (Figure 11).

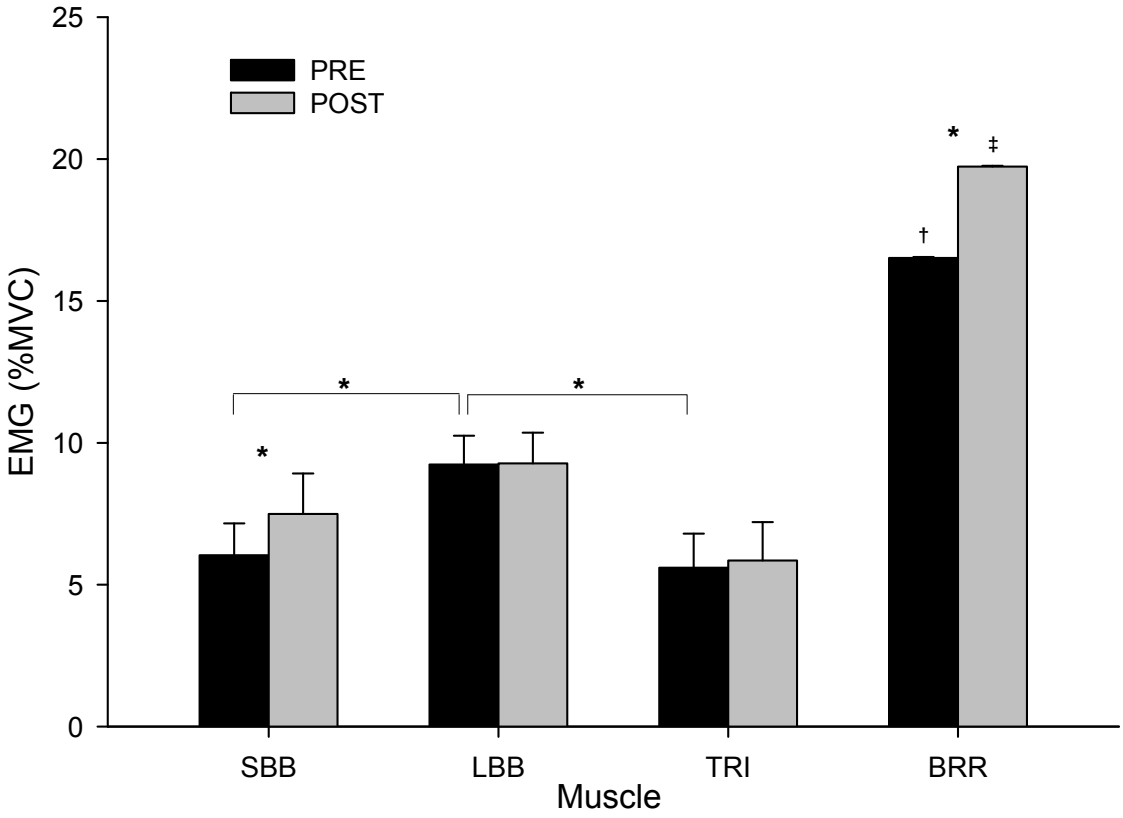

Figure 11. The condition x muscle interaction for EMG indicates a significant difference pre to post vibration for the SBB and BRR. Higher EMG was observed in the brachioradialis prior to† and following‡ vibration relative to the three other muscles. Prior to vibration, muscle activity in the LBB was higher compared with the SBB and TRI. No differences existed between LBB, SBB and TRI following vibration. SBB, short head of the biceps brachii; LBB, long head of the biceps brachii; TRI, triceps brachii; BRR, brachioradialis. Data is shown as mean + standard error. *p<0.05; †p<0.05; ‡p<0.01.

The EMG for the SBB and BRR increased from pre vibration to post vibration (24.0%Δ, $p=0.009$; 19.5%Δ, $p<0.001$; respectively). The EMG in the

LBB ($p=0.92$) and TRI ($p=0.23$) were similar prior to and following vibration. Prior to and following vibration muscle activity in the BRR was significantly higher compared with the SBB, LBB and the TRI ($p<0.001$). The LBB was significantly greater than both the SBB ($p=0.04$) and the TRI ($p=0.03$) before vibration but did not differ post vibration ($p=0.33$ and $p=0.06$, respectively). There was a non-significant main effect for sex ($p=0.13$). There was a significant main effect of condition where following tendon vibration EMG increased 13.3% ($p<0.001$). The main effect of muscle was a consequence of EMG in the brachioradialis (18.1%MVC) being higher than the SBB (6.8%, $p<0.001$), LBB (9.3%, $p<0.001$), and the TRI (5.7%, $p<0.001$).

3.7 Discussion

Compartmentalization is evident through differences in surface EMG and single motor units of the short and long head of the biceps in men (Harwood et al., 2009; Holtermann et al., 2005; Holtermann et al., 2008; Riley et al., 2008; ter Haar Romeny et al., 1984). Compartmentalized activation between the two heads of the BB might occur as a consequence of differences in synaptic integration from the homonymous 1a afferents to the motor neuron pool of the SBB and LBB. Compartmentalized activation between the SBB and LBB might be dissimilar between men and women, and be an underlying factor of sex- and position-related differences in force steadiness. The aim of this study was to determine whether 1a afferents contributes to compartmentalized activation of the SBB and LBB by employing short duration tendon vibration. The functional consequence of alterations in motor unit activity between the SBB and LBB might

be a change in force steadiness. Women were less steady than men, but the decrease in steadiness following tendon vibration was similar. This study is the first to determine that although motor unit discharge rates were 8% lower in women compared to men, 1a afferent feedback results in similar sex-related decline in MU discharge rates and increase in the number of active motor units (Table 1). Although the change in motor unit activity was similar between men and women it was dissimilar between the short and long head of the BB. This difference in motor unit activity suggests compartmentalization is evident, and that tendon vibration induces unique changes between the SBB and LBB that may explain the decrease in force steadiness in men and women post vibration.

Ia Afferent Feedback

Spinal connections which modulate BB activity are slowly being understood with respect to synergist and antagonist control of forearm flexion. The BB and brachioradialis, along with triceps brachii, and pronator teres receive inhibition from each other, whereas excitatory inputs to the BB arise from the extensor carpi radialis and flexor carpi radialis (Naito, Shindo, Miyasaka, Sun & Morita 1996). Ironically, self-regulating feedback for example from homonymous 1a afferents of the BB has been overlooked. Yet, 1a afferent feedback from the brachioradialis decreases motor unit discharge rates of the BB during isometric contractions, and the strength of this inhibitory reflex is position dependent with greater inhibition in neutral compared with supinated (Barry et al., 2009). The position dependent selective behaviour prolongs time to fatigue with practice through greater reductions in motor unit activity in the short head compared to

the long head of the biceps brachii (Riley et al., 2008). Following excitation of 1a afferents of the BB with tendon vibration, a greater decline in motor unit discharge rates in the LBB occurred relative to the SBB of the biceps brachii; however, the number of motor units recruited was greater in the SBB. These data illustrate that 1a afferent feedback is configured beyond common monosynaptic connections and that within the BB, compartmentalized activation occurs through spinal reflexes.

In the supinated forearm position, compartmentalized activation was evident as motor unit discharge rates were higher in the LBB compared to the SBB. Following short duration (5s) tendon vibration there was a greater decline in motor unit discharge rates in the LBB relative to the SBB, but more motor units were recruited in the SBB compared with the LBB. This compartmentalized change in motor unit activity following tendon vibration was similar between sexes, despite motor unit discharge rates being lower in women than men prior to and following tendon vibration. The similar effect of tendon vibration on motor unit activity in men and women, when baseline motor unit discharge rates differed substantially, indicates that spinal connections to the 1a afferent are similar between men and women, but these connections are distributed in a unique manner to the SBB and LBB. Compartmentalized activation via 1a afferents decreases motor unit discharge rates more in the LBB, likely through predominance of post activation depression, whereas in the SBB excitatory post synaptic potentials are more prevalent and this results in a reduction in recruitment thresholds.

Tendon vibration decreases both motor unit discharge rates and recruitment thresholds (Grande & Cafarelli, 2003), and this study of the elbow flexors illustrates that the decline differs between muscle compartments. Excitatory connections to the alpha motor neuron would result in a decrease in the recruitment threshold of motor units, which was evident in both heads of the BB, but relatively greater in the SBB compared to the LBB. The differential effect of tendon vibration on motor unit recruitment between the SBB and LBB might occur as a consequence of relatively greater excitatory post synaptic potentials arising in motor units that regulate the SBB. Excitatory postsynaptic potentials alter membrane potentials and decrease recruitment thresholds of motor units following vibration in lower limb muscles (Romaiguere, Vedel, Pagni, 1993). The decrease in motor unit discharge rates which were greater in the LBB relative to the SBB indicate that inhibition in the LBB, possibly through post activation depression was greater relative to the SBB. Similarly, muscle vibration decreases excitation of the motor neuron pool due to post activation depression (Abbruzzese, Minatel, Faga, Favale, 1997). Tendon vibration induced decreases in motor unit discharge rate would lead to a decrease in the ability to produce a steady force.

Force steadiness decreased in both men and women as a result of tendon vibration. One of the primary factors found to affect force steadiness is motor unit discharge rate variability. As variability increases, force steadiness decreases (Moritz et al., 2005), and in both the SBB and LBB of men and women motor unit discharge variability increased. Potential causes for the change in

motor unit discharge rate variability was the decrease in motor unit discharge rate or the change in recruitment with tendon vibration. The tendon vibration induced decline in motor unit discharge rates indirectly affects motor unit discharge rate variability because as motor unit discharge rates decreases motor unit variability increases (Moritz et al., 2005). Prolonged tendon vibration (>20s) in the medial and lateral gastrocnemius and the soleus, has an inhibitory effect on 1a afferent input and results in an increase in force steadiness (Yoshitake, Shinohara, Kouzaki, & Fukunaga, 2004). This suggests that steady force production is easier to maintain when a rate coding strategy is used rather than recruitment strategies. When vibration was applied in bursts for less than 20s to the patellar tendon, a decrease in motor unit discharge rates and recruitment thresholds were present (Grande & Cafarelli, 2003). In this study short bursts of tendon vibration resulted in a decrease in motor unit discharge rates and recruitment thresholds in both the SBB and LBB which induced an increase in motor unit discharge variability, and the functional consequence of these changes in motor unit activity was a decrease in force steadiness.

Length Differences

Compartmentalized activation of the BB was previously demonstrated through greater muscle activity in the LBB compared to the SBB in a supinated forearm position (Holtermann et al., 2005; Holtermann et al., 2008), and that single motor unit discharge rates respond independently in each muscle head as a consequence of forearm rotation between neutral, pronated and supinated in young and old men (Harwood et al., 2009). In the tibialis anterior recruitment

thresholds are sensitive to muscle length (Pasquet, Carpentier, & Duchateau, 2005). The muscle spindle is the primary sensory receptor that detects changes in muscle length and through 1a afferent feedback the efferent alpha motor neuron activity is regulated. Through the use of tendon vibration in this study to alter 1a afferent feedback the differential change in motor unit activity between heads indicates that the length dependent phenomenon is activated through 1a afferent spinal connections. The differential connectivity within the spinal cord might be governed through the rate at which the 1a afferent sends feedback to the spinal cord. Unlike the tibialis anterior which is a multipennate muscle with a singular origin and insertion the BB is a fusiform muscle that has two unique heads with independent origin and insertion points. The SBB and LBB originate on the coracoid process and supraglenoid tubercle of the scapula, respectively. Recent cadaveric studies of the BB have shown that the SBB and LBB also have unique insertion points on the distal radial tuberosity and proximal radial tuberosity, respectively, and that the tendons are covered by a common aponeurosis at the distal insertions (Athwal, Steinmann, & Rispoli, 2007; Eames, Bain, Fogg, & van Riet, 2007). This anatomical configuration would result in unique changes in length between the SBB and LBB as forearm rotation occurs. Tendon vibration in this study was applied to the center of the biceps tendon, and due to distinct insertions on the radius the tendon vibration might augment 1a afferent feedback less in the SBB because in the supinated position it is shorter relative to the LBB, thus the unequal length between muscles would result in less

excitation of the 1a through fusimotor drive in the SBB because the muscle spindles are unloaded.

Differences in muscle length might also contribute to the sex-related difference in baseline motor unit activity. Motor unit discharge rate, discharge rate variability and recruitment thresholds were greater in men compared with women. In men, the discharge rates reported in this study were in the range of previous work in the BB (Kukulka & Clamann, 1981; Garland et al., 1994), and the sex-related difference where motor unit discharge rates were higher in men relative to women may be attributed to muscle length. The men were significantly taller than the women and had longer arms. Although fibre fascicle lengths have not been compared between men and women, a longer muscle in dynamic movement has higher discharge rates (Dimitriou & Edin, 2008).

Strength Differences

Higher motor unit discharge rates in men might be due to a greater absolute force being produced during the tracking task in relation to the force exerted by women. Target force for the tracking task was set to 15% for both men and women; however, men exerted approximately 263N whereas the women approximately 139N. This would equate to a target force of approximately 40N for men and 21N for women, thus the 15% target force was approximately twice as high in the men. It is well known that in order to increase force, motor unit activity must increase through recruitment or rate coding strategies (Calancie & Bawa 1990; Masakado, 1994; Enoka et al., 2003) and that performance of precise movements relies more upon rate coding strategies for

force modulation rather than recruitment (Kukulka & Clamann, 1981). Since the men show higher discharge rates and a greater reliance on rate coding strategies, this also could account for the steadier force production relative to women.

Extensive literature shows that men are stronger than women (Frontera, Hughes, Lutz, & Evans, 1991; Frontera et al., 2000; Kanehisa, Ikegawa, & Fukunaga, 1994; Kanehisa, Okuyama, Ikegawa, & Fukunaga, 1996; Kent-Braun & Ng, 1999; Pincivero, Coelho, & Campy, 2003) and that force steadiness increases with strength (Moritz et al., 2005). Men were steadier compared with women prior to and after tendon vibration was applied. Past research has compared force steadiness in the elbow flexors during isometric contractions in young and old men (Graves, Kornatz, & Enoka, 2000; Harwood et al., 2009; Tracy & Enoka 2002) and found the young were steadier compared with the old. This is consistent with the positive linear relationship between strength and force steadiness (Figure 9) observed in men and women. Sosnoff & Newell (2006) studied force steadiness as a function of muscle strength in men and also found a positive linear relationship between force and steadiness. This is the first study to compare force steadiness as a function of maximal strength between men and women; the sex-related differences in force steadiness found in this study can likely be attributed to muscle strength.

3.8 Conclusions

In conclusion, there are significant sex-related differences in motor unit properties and force steadiness between young men and women in the elbow

flexors. The sex differences found in this study may be a result of differences in muscle length or strength between men and women. Tendon vibration decreases motor unit discharge rates in both the LBB and SBB; however, discharge rates decreased more in the LBB compared with the SBB. Tendon vibration also lowered the recruitment threshold in the BB, yet more motor units are recruited in the SBB than the LBB. The decrease in motor unit discharge rates and increased variability following tendon vibration results in a decline in force steadiness. The independent changes established after tendon vibration between the LBB and SBB suggest that there is a variation in synaptic input to the two muscle compartments of the BB. The increase in Ia afferent excitation causes a decrease in motor unit discharge rates which is predominant in the LBB and likely arises as a result of post activation depression, whereas the decrease in recruitment thresholds which are greatest in the SBB is typical of excitatory post synaptic potentials.

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CHAPTER IV

CONCLUSION AND RECOMMENDATIONS

4.0 Conclusion

Past studies have looked at the effects of tendon vibration in the muscles of the lower limbs including the rectus femoris, biceps femoris, vastus lateralis, soleus, quadriceps femoris and tibialis anterior (Cresswell & Loscher, 2000; Grande & Cafarelli, 2003; Ushiyama et al., 2005; Van Deursen et al., 1998; Verschueren et al., 2002; Verschueren et al., 2003) but no study has used tendon vibration to determine the effects of 1a afferent feedback on motor unit activity and subsequently force steadiness in the biceps brachii of young men and women. This study confirmed a prior report from lower limb muscles (Grande & Caffarelli, 2003) that tendon vibration decreases motor unit discharge rates; however, this study looked at an upper limb muscle with two distinct heads. Motor unit discharge rates in the long head of the biceps brachii were higher in men compared with women. Irrespective of sex, discharge rates were higher in the LBB and declined more with tendon vibration compared to the SBB, yet more motor units were recruited in the SBB relative to the LBB following tendon vibration. Differences following tendon vibration between the short and long head indicate that excitatory post synaptic potentials from the 1a afferent neuron lower recruitment thresholds more in the SBB relative to the LBB, but the discharge rates decline more in the LBB compared to SBB because post activation depression is greater in this pool of motor units. Force steadiness decreased with tendon vibration. Declines in steadiness likely occur because

force is maintained through less reliance on rate coding and more on recruitment following tendon vibration.

4.1 Summary of Specific Objectives (So)

1. To record MU discharge rates of the long head and short head of the biceps brachii in a supinated wrist position in young men and women.

   Achieved: MU discharge rates were recorded in the long and short heads of the biceps brachii for men and women in a supinated position.

2. To evaluate force steadiness during an isometric tracking task in young men and women.

   Achieved: Force steadiness was quantified in both men and women during a 15% MVC tracking task.

3. To evaluate force steadiness during the same isometric tracking task after tendon vibration has been applied relative to the pre-vibration condition.

   Achieved: Force steadiness was quantified in both young men and women for durations of approximately 15s before and 15s after tendon vibration was applied at 100Hz for 5s.

4. To determine whether MU discharge rates change in young men and women after the application of tendon vibration.

   Achieved: Motor unit discharge rates were found to be higher in men compared with women pre and post tendon vibration. Tendon vibration decreases motor unit discharge rates.

4.2 Summary of Research (H_1) and Null (H_0) Hypotheses

Note: Numbers correspond to specific objectives.

1. H_1: Motor unit discharge rates of the long head and short head will differ between men and women.

   Accepted

   H_0: Motor unit discharge rates of the long and short heads of the biceps brachii will not differ between men and women.

Rejected: Motor unit discharge rates were higher in the LBB of men compared to the LBB in women. No differences were found in the SBB with respect to sex.

2. H_1: Women will be less steady compared with men.

Accepted

H_0: No difference will be found between sexes with respect to force steadiness.

Rejected: Men were steadier compared with women in both the pre and post vibration conditions.

3. H_1: Women will be less effected with respect to force steadiness after the application of tendon vibration.

Rejected: Although men were steadier than women initially and both decreased post vibration, there was no condition by sex interaction present with respect to force steadiness.

H_0: No difference in force steadiness will be found after the application of tendon vibration with respect to sex.

Accepted

4. (a) H_1: MU discharge rates will decrease after the application of tendon vibration in both young men and women.

Accepted

H_0: No difference in MU discharge rates will be found after tendon vibration is applied.

Rejected: The discharge rates were higher in the pre vibration condition compared with the post vibration period.

4. (b) H_1: MU discharge rates will decrease more in men compared with women after the application of tendon vibration.

Rejected: Although discharge rates in men and women decreased with the application of tendon vibration, there was no significant condition by sex interaction with respect to discharge rate.

H_0: MU discharge rates will decrease after tendon vibration but there will be no sex-related differences.

Accepted

4.3 Limitations and Recommendations

The major limitation in this study is consistent to all motor unit investigations (Harwood et al., 2009; Riley, Baudry & Enoka, 2008; ter Haar Romeny, Denier van der Gon & Gielen, 1984), where the sample population of motor units recorded from both heads of the biceps is assumed to be representative of the entire population within the LBB and SBB. An improvement in this study was the stability of recordings of motor units through use of the California fine wire microelectrodes compared with tungsten microelectrodes used previously in the lab. The fine wires have been shown to improve clarity and stability of recordings. The small hook created at the end of the wires acts as a small anchor to maintain position once inserted into the muscle. Also, the reference electrode is located in the muscle rather than superficially on the skin as in tungsten recordings.

The hypothesis that the LBB was longer compared with the SBB as were muscles of men compared with women is a major assumption and also limitation to our results. Future work should include the use of ultrasound or other diagnostic imaging devices to clarify length differences within the muscle and between men and women. A study looking at these differences could greatly aid in further research of compartmentalization theories based upon differences in muscle fascicle length.

Another area in need of further development is the difference in motor unit properties with respect to sex. Studies should compare motor unit number, size and fiber type between men and women to determine if there are sex differences with respect to fiber type composition and motor unit populations within the biceps brachii. It is also necessary to investigate fiber type composition and motor unit number and size between the short and long heads of the biceps brachii to determine any muscular differences within the biceps brachii. These electrophysiological and histochemical studies could provide great insight into mechanisms and reasons for differences in motor unit behavior in the LBB and SBB.

This study expanded on compartmentalization studies conducted at low forces to moderate forces, but no investigation has been conducted on higher forces. This should be examined in the future to determine whether compartmentalized motor unit modulation is similar across all force levels. A more detailed investigation of higher forces may contribute insight into mechanisms in which the short and long heads of the biceps brachii modulate force and maintain position across forces.

APPENDIX A

UNIVERSITY OF WINDSOR

CONSENT TO PARTICIPATE IN RESEARCH

Title of Study: **Effects of Tendon Vibration on Force Steadiness in Young Men and Women**

You are asked to participate in a research study conducted by **a student investigator: Darl Edwards and advisor: Dr. Jennifer Jakobi**, from the **Department of Kinesiology, Faculty of Human Kinetics (x2473)** at the University of Windsor**.** The results of this study will contribute to Darl Edwards's thesis project to complete the candidacy for a Masters of Human Kinetics degree.

If you have any questions or concerns about the research, please feel to contact the student investigator:
Darl Edwards, BHK
Department of Kinesiology, Faculty of Human Kinetics
Neuromuscular Physiology Laboratory, rm 231
University of Windsor
Windsor, Ontario N9B 3P4
Tel. (519) 253-3000 ext. 4049
E-mail: edwar13@uwindsor.ca

PURPOSE OF THE STUDY

The present study aims to identify any differences in force steadiness with and without tendon vibration in young men and women.

PROCEDURES

If you volunteer to participate in this study, we would ask you to do the following things:
-Volunteer approximately two hours of your time in over 1-4 visits separated by 2 - 5 days.
-Allow the application/insertion of electrodes to your forearm and upper arm area while seated in a chair. Fine wire microelectrodes are approximately the diameter of a horse hair and feel like a pin prick upon insertion. The sensation is similar to acupuncture.
- Allow the application of tendon vibration on the biceps tendon.
- Perform both strong and weak contractions of the forearm.

POTENTIAL RISKS AND DISCOMFORTS

A possible risk associated with the use of fine wire microelectrodes is infection. It is recommended to seek the advice of a physician or family doctor if an infection does occur. This risk will be reduced by the creation of a sterile environment and by following experimental precautions regarding data collection. To-date, no incidents of infection have been reported in a laboratory utilizing this technique.

POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

You will not receive monetary gain from participation. Participants will benefit from exposure to neurophysiological techniques and gain a greater understanding of controlling force, as well as how and why it changes with gender and vibration.

PAYMENT FOR PARTICIPATION

Participants will not receive payment for this study.

CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. All data from participants will be collected and coded for anonymity at the beginning of each study session.

PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you participate in this study, you may withdraw at any time without consequences of any kind. The investigator may choose to withdraw you from his research if circumstances arise which warrant doing so. Any persons with musculoskeletal disorders, injury, other neurological disorders or painful neuropathy, myopathy, severe cardiovascular disease, have a pacemaker, recovering from surgery, alcoholism, pregnancy, or extreme physical activity patterns will not be considered suitable for this study and will be excluded.

FEEDBACK OF THE RESULTS OF THIS STUDY TO THE SUBJECTS

Following data collection, contact information will be recorded for later notification. Results from the study will be available on Dr. Jennifer Jakobi's web site http://uwindsor.ca/jjakobi, or by mail. If you would prefer a copy of the manuscript be mailed to you, please provide mailing information.

SUBSEQUENT USE OF DATA

This data will be used in subsequent studies.
Do you give consent for the subsequent use of the data from this study? ☐ Yes ☐ No

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. If you have questions regarding your rights as a research subject, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: ethics@uwindsor.ca

SIGNATURE OF RESEARCH SUBJECT/LEGAL REPRESENTATIVE

I understand the information provided for the study **Effects of Tendon Vibration on Force Steadiness in Young Men and Women " the University of Windsor** as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

_____
Name of Subject

_____ _____
Signature of Subject Date

SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

_____ _____
Signature of Investigator Date

APPENDIX B

Office of the Research Ethics Board

University of Windsor
thinking forward

Today's Date:	March 14, 2008
Principal Investigator:	Mr. Darl Edwards
Department/School:	Kinesiology
REB Number:	07-199
Research Project Title:	Effects of Tendon Vibration on Force Steadiness in Young Men and Women
Clearance Date:	November 9, 2007
Project End Date:	November 9, 2008
Progress Report Due:	
Final Report Due:	November 9, 2008

This is to inform you that the University of Windsor Research Ethics Board (REB), which is organized and operated according to the *Tri-Council Policy Statement* and the University of Windsor *Guidelines for Research Involving Human Subjects*, has granted approval to your research project on the date noted above. This approval is valid only until the Project End Date.

A Progress Report or Final Report is due by the date noted above. The REB may ask for monitoring information at some time during the project's approval period.

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 REB. Minor change(s) in ongoing studies will be considered when submitted on the Request to Revise form.

Investigators must also report promptly to the REB:
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.

Forms for submissions, notifications, or changes are available on the REB website: www.uwindsor.ca/reb. If your data is going to be used for another project, it is necessary to submit another application to the REB.

We wish you every success in your research.

Dr. Maureen Muldoon

Maureen Muldoon, Ph.D.
Chair, Research Ethics Board

cc: Dr. Jennifer Jakobi, Kinesiology
Mark Curran, Research Ethics Coordinator

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

401 Sunset Avenue, Windsor, Ontario, Canada N9B 3P4 . tel: 519.253.3000 ext. 3948 . web: www.uwindsor.ca/reb

VITA AUCTORIS

DARL EDWARDS

78 Woodlawn Cres., Kingsville, Ontario
Darl.Edwards@hotmail.com

EDUCATION

University of Windsor, Windsor, ON
M.H.K. Applied Human Performance **June 2009**
Thesis: "Effects of tendon vibration on force steadiness in young men and women"

University of Windsor, Windsor, ON
B.H.K. Honors Human Kinetics with Minor in Biochemistry **June 2007**
Areas of Concentration: Exercise Physiology, Biochemistry
Independent Study Project: Burst and gap analysis in young & old adults.

PUBLICATIONS

Articles published/submitted to refereed journals:

Jakobi, J.M., **Edwards, D.,** Connely, D.M. (2008). Utility of Portable Electromyography for Quantifying Muscle Activity during Daily Use. Gerontology, 54: 324-331.

Harwood, B.J., **Edwards, D.**, Jakobi, J.M. (2008). Age and Sex related differences in muscle activation for a discrete functional task. European Journal of Applied Physiology, 103(6): 677-686.

Harwood, B.J., **Edwards, D.**, Jakobi, J.M. (2009). Motor unit activity and force steadiness; Influence of Age and Wrist Position. Medicine and Science in Sports Exercise. (Submitted, 47 pages).

Other refereed contributions:

Edwards, D., Brown, R.E., Kenno, K.A., Jakobi, J.M. (2009). Effect of Tendon Vibration on Elbow Flexor Force Steadiness and Motor Unit Activity in Men and Women. *Medicine and Science in Sports Exercise, 41*(S5), (In Press).

Edwards, D., Brown, R.E., Kenno, K.A., Jakobi, J.M. (2008). Influence of tendon vibration on motor unit properties and force steadiness in women. *Applied Physiology Nutrition and Metabolism, 33*(S1), S31.

Brown, R.E., **Edwards, D.**, Kenno, K.A., Jakobi, J.M. (2008). Force steadiness differs between wrist position in young men and women. *Applied Physiology Nutrition and Metabolism, 33*(S1), S13.

Edwards, D., Kenno, K.A., Jakobi, J.M. (2008). EMG Burst and Gap Comparisons in Muscles of the Upper and Lower Limbs. *Medicine and Science in Sports Exercise, 40*(S5), S448.

Harwood, B.J., **Edwards, D.**, Jakobi, J.M. (2007). Differential derecruitment thresholds of the long and short heads of the biceps brachii in young and old men. *Medicine and Science in Sports Exercise, 40*(S5), S446.

Edwards, D., Kenno, K.A., Jakobi, J.M. (2007). Comparison of Daily Muscle Activity in Men and Women through EMG Burst and Gap Analysis. *Applied Physiology Nutrition and Metabolism, 32*(S1), S27.

Harwood, B.J., **Edwards D.**, Jakobi, J.M. (2007). Task-Dependent Motor Unit Activity in Young and Old Adults. *Applied Physiology Nutrition and Metabolism, 32*(S1), S43.

Edwards D., Jakobi JM. (2007). Characterization of Muscular Rest Periods (gaps) in Long-term EMG of Older Men & Women. *Medicine and Science in Sports Exercise*, *39*(5), S269.

Harwood B.J., **Edwards D.**, Jakobi JM. (2007). Quantifying Muscular Activation And Rest In A Discrete Functional Task Of Older Men And Women. *Medicine and Science in Sports Exercise*, *39*(5), S267.

Scherer J., **Edwards D.**, Jakobi JM. (2007). How many Maximum Voluntary Contractions are Really Necessary in Young and Old Adults? *Medicine and Science in Sports Exercise*, *39*(5), S270

Edwards D, Jakobi JM. (2006). Comparison of Daily Muscle Activity with Electromyography in Young and Old Men. *Applied Physiology Nutrition and Metabolism, 31*(S1), S22.

PRESENTATIONS

ACSM Annual General Meeting, Seattle, WA
Effect of Tendon Vibration on Elbow Flexor Force Steadiness and Motor Unit Activity in Men and Women: B-17: Wednesday May 27, 2009 2:15pm **2009**
Medicine and Science in Sports and Exercise, 41(S5).
Edwards, D.L., Brown, R.E., Kenno, K.A., Jakobi, J.M.

CSEP Annual General Meeting, Banff, AB
Influence of Tendon Vibration on Motor Unit Properties and Force Steadiness in women: October, 2008 1:30pm **2008**
Applied Physiology Nutrition and Metabolism, 33(S1), S31.
Edwards, D.L., Brown, R.E., Kenno, K.A., Jakobi, J.M.

ACSM Annual General Meeting, Indianapolis, IN
EMG Burst and Gap Comparisons in Muscles of the Upper and Lower Limbs: 2390: Board #170, May 30, 2:00pm **2008**
Medicine and Science in Sports and Exercise, 41(S5).
Edwards, D.L., Kenno, K.A., Jakobi, J.M.

CSEP Annual General Meeting, London, ON
Comparison of Daily Muscle Activity in Men and Women through EMG Burst and Gap Analysis: October, 2007 9:30am **2007**
Applied Physiology Nutrition and Metabolism, 32(S1), S27.
Edwards, D.L., Kenno, K.A., Jakobi, J.M.

ACSM Annual General Meeting, New Orleans, LO
Characterization of Muscular Rest Periods (gaps) in Long-Term EMG of Older Men and Women: 1673: Board #163, May 30, 2:00pm **2007**
Medicine and Science in Sports and Exercise, 39(S5), S269.
Edwards, D.L., Jakobi, J.M.

CSEP Annual General Meeting, Halifax, NS
Comparison of Daily Muscle Activity with Electromyography in Young and Old Men: November, 2006 9:30am **2006**
Applied Physiology Nutrition and Metabolism, 31(S1), S22.
Edwards, D.L., Jakobi, J.M.

AWARDS

- Human Kinetics Graduate Alumni Award – AHP **2008-2009**
- Human Kinetics Outstanding Graduate Research Award – AHP **2008-2009**
- Graduate Research Excellence Award **2008-2009**
- NSERC Post Graduate Scholarship (awarded twice) **2007-2009**
- University of Windsor Post-Graduate Tuition Waiver **2007-2009**
- CP Crowley Presidents Excellence Award **2007-2008**
- Blue and Gold Scholarship **2007-2008**
- Ontario Graduate Student Award **(declined)**
- NSERC Undergraduate Research Studentship Award **(declined)**
- CIHR Summer Studentship Award **2006-2006**
- 2-Time William Hunter Jr. Memorial Scholarship Winner **2004,2006**
- NSERC Undergraduate Research Studentship Award **2005-2005**
- HK Publisher Award Recipient **2005-2006**
- Deans Outstanding Scholars Award **2003-2007**
- Governors General Medal of Achievement **2002-2003**
- Ontario Junior Citizen of the Year Nominee **2002-2003**

TEACHING EXPERIENCE

University of Windsor, Windsor, ON
Graduate Assistant – Cardiovascular Physiology 95-460 **2008-2009**
Office hours, marking, proctoring, conducted dissection labs.

University of Windsor, Windsor, ON
Graduate Assistant – Physiology of Fitness 95-260 **2007-2008**
Office hours, marking, proctoring, guest lecture/tutorial.

RELATED EXPERIENCE

Hotel Dieu Grace Hospital, Windsor, ON
Student Volunteer **2007-2009**
Patient and family care in the OR recovery room.

University of Windsor Neuromuscular Lab, Windsor, ON
Research Assistant **2006-2007**
Conducted a study during undergraduate degree, assisted grad students with their Thesis projects and other various duties in the lab.

MEMBERSHIPS AND EXTRACURRICULAR

Canadian Society for Exercise Physiology
Graduate Student Member **2008-present**

Baseball Ontario Registered Umpire
Umpire baseball for ages 24 and under in Windsor Essex County **2008-present**

University of Windsor Lancers Men's Track and Field Team
National bronze medalist, 2x provincial champion, 2x prov. bronze medalist **2003-2008**
Member of 2 national championship teams & 5 provincial championship teams
5 time Academic All-Canadian

3rd Degree Member of Knights of Columbus: Council # 8233
Volunteer within catholic community, parish breakfast, picnics, dinners, etc. **2005-present**

Kingsville Optimist Club
Local fundraisers for school scholarships, community projects, etc. **2002-present**