The Effect of Velocity of Contraction on the Repeated Bout Effect

A Thesis Submitted to the College of

Graduate Studies and Research

in Partial Fulfillment of the Requirements

for the Degree of Master of Science

in the College of Kinesiology

University of Saskatchewan

Saskatoon

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Fall 2010

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Abstract

The 'repeated bout effect'(RBE) is an adaptation whereby a single eccentric (ECC) exercise session protects against muscle damage during subsequent ECC exercise bouts and is characterized by faster strength recovery and a reduction in soreness and inflammation. The purpose was to determine if the protective capacity of the RBE is greater when both bouts of ECC exercise are performed at the same compared to a different velocity of contraction as well as at a fast or slow velocity. Thirty-one right handed participants were randomly assigned to perform an initial unilateral bout of either fast (180°/s) or slow (30°/s) maximal isokinetic ECC elbow flexion. Three weeks later 16 participants completed a repeated bout of ECC exercise at the same velocity as the initial bout (SAME)(FAST-FAST[n=8] and SLOW-SLOW[n=8]), while 15 participants completed a bout at the corresponding different velocity (DIFF) (FAST-SLOW[n=8] and SLOW-FAST[n=7]). Elbow flexor function and damage was measured prior to, immediately after, and at 24, 48, and 72 hours post exercise. Dependant variables included maximal voluntary contraction (MVC) isometric strength (Dynamometer), muscle thickness (MT; Ultrasound), delayed onset muscle soreness (DOMS; Visual Analog Scale), biceps and triceps electromyography (EMG), percent activation (Interpolated twitch), and twitch torque. There were no group differences for height, weight, training experience, or total work performed during the ECC bouts ($p>0.05$). After the repeated bout, there was a significant reduction in MVC strength, MT, and DOMS at 24, 48, and 72 hours, pooled across participants ($p<0.05$). After the repeated bout, MVC strength recovered faster only for the SAME group. There were no differences between groups for MT, DOMS, EMG, ITT, and TT. The analysis revealed neither fast nor slow contractions offered greater protection against muscle damage when the repeated bout was not completed at the same velocity. Since a faster recovery of strength is velocity specific this suggests there may be a neural contribution to the repeated bout effect.

Acknowledgements

I would like to acknowledge my supervisor Dr. Jon Farthing for all the time, effort, and guidance he has provided me with throughout my master's studies. He has continually provided me with a challenging learning environment in which he encouraged independent thought while providing much needed guidance and assistance. I would also like to acknowledge my thesis committee members Dr. Phil Chilibeck, Mr. Bart Arnold, and Dr. Saija Kontulainen. Thank you for your input into this thesis and for all of your contributions to my academic career over the years.

Dedication

I dedicate my master's thesis to my parents. Thank-you for always supporting me in my ambitions and for always believing I could achieve my goals. Without your constant love and support I would not be here today. I love you.

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Chapter 1

Scientific Framework

1.1 Introduction

Eccentric resistance training has become a popular topic within the fitness, rehabilitation, and research worlds. Eccentric exercise is ideal for maximizing muscle hypertrophy, strength, and neuromuscular gains due to the greater force and muscle damage it incurs compared to isometric or concentric training (Hortobágyi, Hill, Houmard, Fraser, Lambert & Israel 1996; Farthing & Chilibeck, 2003). After an isometric or concentric exercise, full function of the muscle is restored within two hours of the exercise session (Proske & Allen, 2005). This is not the case with eccentric exercise where the muscle can remain weak for days due to severe soreness, damage, and swelling (Connolly, Reed & McHugh, 2002). The muscle damage inherent after eccentric exercise is caused by overstretching and disrupted sarcomeres, which can cause damage to the sarcoplasmic reticulum, transverse tubules, and sarcolemma (Proske, 2005). According to the overload principle, muscle damage is one of the key reasons adaptation occurs so rapidly with eccentric training.

A prominent adaptation with eccentric training is the repeated bout effect. The repeated bout effect is an adaptation whereby a single eccentric exercise session protects against muscle damage during subsequent eccentric exercise bouts (Nosaka and Clarkson, 1995; McHugh, Connolly, Eston, Kremenic & Gleim, 1999). The second bout of eccentric exercise results in decreased markers of muscle damage; including a decrease in muscle soreness, a faster recovery of strength, and a reduction in inflammation. Many aspects of the repeated bout effect have been explored within the literature. However, the velocity at which a repeated bout of eccentric exercise is completed at is an area which needs to be explored further.

The velocity at which a contraction is performed can also lead to differences in muscle adaptation. Farthing and Chilibeck (2003) found that muscle hypertrophy and strength were maximized under training conditions where the greatest forces were observed during muscle contraction. Fast eccentric contractions (180 °/s) were superior for increasing muscle hypertrophy and strength when compared to concentric and even slow eccentric (30 °/s) contractions. The authors theorized that the greater amount of force combined with muscle lengthening during contraction was a determining factor. This greater amount of force (overload) would theoretically damage the muscle to a greater extent causing the tissue to repair and adapt in a way to resist damage to a similar load. Although the velocity of contraction has been shown to be a factor in the hypertrophic and strength response of muscle, less is known with regards to contraction velocity and the repeated bout effect.

It is unknown whether an initial fast eccentric velocity (e.g., 180 °/s; 3.14 rad/s) would protect against the repeated bout at a slow eccentric velocity (e.g., 30 °/s; 0.52 rad/s) or vice versa. In other words, since faster eccentric exercise is thought to induce more muscle damage, does a single bout of fast eccentric exercise protect you for subsequent bouts of slower eccentric exercise? Or is the repeated bout effect specific to the velocity of eccentric contraction that was performed in the initial bout? This is an important question as it has practical implications for anyone using eccentric training as a mode to improve muscle hypertrophy and strength in rehabilitation or athletic settings. If the repeated bout effect is specific to the velocity of prior bouts it would be beneficial to train at similar velocities you will be working at in the future. Training at high speed eccentric velocities could reduce muscle strains in an athletic population by reducing muscle damage from competition. As well, reversing muscle atrophy or preventing sarcopenia in an elderly population could be maximized through eccentric training. Maximizing hypertrophic stimuli without causing unnecessary repetitive damage to the muscle could be accomplished via the repeated bout effect. Understanding the mechanisms and adaptations that occur with eccentric training will refine interventions for injury prevention, treatment, and strength training.

1.2 Review of Literature

1.2.1 Muscle Damage with Eccentric Exercise

It is well known that eccentric contractions cause significant muscle damage. A significant amount of research in the past decade has looked at the unique ability of eccentric contractions to produce this muscle damage and what applicability it might have in a training or rehabilitation setting. Eccentric contractions, regardless of velocity, preferentially recruit larger fast-twitch motor units which allows for elevated force production (McHugh, Tyler, Greenburg & Glein, 2002). This is opposite to concentric contractions which recruit motor units progressively as needed from slower-twitch motor units to faster-twitch motor units. Eccentric contractions induce a lower motor unit firing rate compared to isometric and concentric contractions (Clarkson & Hubal, 2002). Eccentric contractions may produce more muscle damage due to the high force and low fiber recruitment, which places substantial mechanical stress on the associated structures within each fibre (Enoka, 1996).

The process of muscle damage after eccentric exercise is described nicely in review articles by Clarkson & Hubal (2002), Proske & Allen (2005), and Falvo & Bloomer (2006). The mechanical stress associated with eccentric exercise causes disruption of the sarcomeres and failure within the excitation contraction coupling system (Morgan & Allen, 1999). When a muscle is subjected to a series of eccentric contractions, the degree of damage is determined by the length of the muscle at which the contractions are performed. Myofibrils of a muscle fiber are stretched while contracting which causes some sarcomeres to stretch more than others. Z-line streaming is a common characteristic found with eccentric exercise when sarcomeres are no longer properly aligned. Desmin, which is a protein that links Z-lines together, may be susceptible to exercise induced damage (Clarkson, 2002). Sarcomeres get progressively weaker until there is no overlap between the myofilaments. During repeated eccentric contractions the stronger sarcomeres will also become overstretched which can lead to damage in adjacent myofibrils. After a series of eccentric contractions, there is a rise in whole-muscle passive tension. This is due to the sarcomere disruption and membrane damage of the sarcoplasmic reticulum, transverse tubules, or sarcolemma which stimulates the uncontrolled release of $Ca2^{+}$ into the sarcoplasm. This activates the contractile filaments of actin and myosin within the muscle. Presumably, the contraction will be maintained as long as ATP levels remain high. This process also triggers proteolysis associated with fibre breakdown and repair (Proske & Allen, 2005).

After the damage is induced by eccentric contractions there are a host of biochemical changes occurring within the affected area in order to clear out the damaged proteins (Peake, Nosaka, Suzuki, 2005). The increase in inflammatory cytokines and reactive oxygen species may worsen the injury as neutrophils begin to destroy the necrotic tissue (Stupka, Tarnopolsky, Yardley, Phillips, 2001). Neutrophils release proteolytic enzymes and oxygen radicals that degrade tissue and increase membrane permeability in order to allow enzymes such as creatine kinase into the blood (Clarkson, 2002). There is an invasion of the damaged areas by macrophages and monocytes. Products of the inflammation such as histamine, serotonin, substance P, and prostaglandins act to sensitize muscle nociceptors producing the sensation of soreness. They activate type III and type IV afferent fibers which carry message of pain from the muscle to the central nervous system (Clarkson, 2002). These changes in processing at the level of the spinal cord allow mechanoreceptors, served by large-diameter afferents, to access the pain pathway contributing to the delayed onset muscle soreness (DOMS) experienced with eccentric exercise (Smith, 1991). The inflammation is accompanied by edema, which is responsible for the muscle swelling (Proske, 2005). There is an increase in muscle fiber size and a greater intramuscular pressure (Peake, 2005). Also, after a bout of eccentric exercise a person's proprioception is disturbed. Normally, information about position and force levels relies on the centrally derived sense of effort. However, the sense of force and position in damaged muscles is not providing proper feedback which increases the effort needed to maintain a specified position or force (Paschalis, Nickolaidis, Giakas, Jamurtas, Owolabi & Koutedakis, 2007).

Since measurement of muscle damage in a human population can only be done via muscle biopsy or with imaging techniques, indirect measures are often used to assess muscle damage. There is currently no universal time course of recovery between individuals or muscle groups (Falvo & Bloomer, 2006). Generally speaking, after eccentric exercise there is an immediate reduction in the maximal force production of the specific muscle of approximately 40-60%. If this is measured after repeated eccentric contractions the force decline is likely caused by both metabolic fatigue and damage. After contractions that do not produce muscle damage (e.g. concentric) maximal strength is normally restored in the next few hours. The reduction in strength after eccentric exercise is generally thought to be due to metabolic or neural fatigue (Clarkson, 2002). An important consequence of a series of eccentric contractions is a shift of the optimum length for peak active tension in the direction of longer muscle lengths (McHugh & Tetro, 2003). Inflammation tends to rise within a few hours following damaging eccentric exercise, and tends to peak around 48 hours post exercise (Geronilla et al., 2003). The onset of swelling roughly parallels that for soreness, and is present at 24 h after the exercise. Depending on the severity of the exercise, swelling and soreness typically persist for another 3–4 days. The swelling can often exacerbate the resulting muscle soreness that often peaks 24 to 48 hours following the eccentric exercise. Other common signs and symptoms include a decrease in range of motion, increased creatine kinase (CK) release into circulation, and increased muscle girth due to swelling (Clarkson, 2002). Surprisingly, these indicators of muscle damage can be reduced significantly after only one session of eccentric exercise. This phenomenon is known as the repeated bout effect.

1.2.2 Repeated Bout Effect

The repeated bout effect has been shown consistently in the literature in both rat and human models (Jones, Allen, Talbot, Morgan & Proske, 1997). After a repeated bout of eccentric exercise there will be less muscle damage than after the initial bout of eccentric exercise. It offers a 20-60% protective effect on indexes of muscle damage (Chen, Kazunori & Sacco, 2007). The repeated bout effect has been shown to last several weeks and possibly up to six months after the initial contraction (Nosaka, Clarkson, McGuiggin & Byrne, 1991; Nosaka, Sakamoto, Newton & Sacco, 2001). The magnitude of the repeated bout effect is dependent on the exercise intensity of the initial bout. The higher the intensity of the initial bout of eccentric exercise, the greater protective effect it will offer (Nosaka et al., 2001). Nosaka, Newton, Sacco, Chapman & Lavender (2005) found that eccentric contractions at longer muscle lengths provide a greater stimulus for protection than eccentric contractions at shorter muscle lengths; however, short eccentric contractions still offered approximately half of the protective effect of a prior bout of long muscle length eccentric contractions. Chen, Chen, Lin, Wu & Nosaka (2009) showed that the first bout of eccentric exercise provides the greatest adaptation and protective capacity.

However, further adaptation can be induced to a lesser extent when the eccentric exercise is repeated up to four times.

A number of studies have tried to understand how the protective capacity of the repeated bout effect is altered by the timing and volume of eccentric exercise. Sakamoto, Maruyama, Naito & Sinclair (2009) found a repeated bout effect was still evident even when exhaustive dumbbell training was performed on days 1, 2, 3, and 5 of the recovery period. The high intensity, primarily concentric dumbbell exercise only slightly reduced the protective capacity of the repeated bout effect. Consistent with these findings, general resistance training after an eccentric bout of exercise does not interfere with the onset of recovery (Nosaka & Newton, 2002). Further, Chen & Nosaka (2006) concluded that recovery from eccentric exercise is not affected by a second bout of eccentric exercise performed 3 days later, regardless of the number of eccentric contractions. A greater number of eccentric contractions performed at the initial bout does not increase the protective effect against subsequent bouts of eccentric exercise. Brown, Child, Day & Donnelly (1997) showed no difference in the protective capacity of 10, 30, or 50 contractions on a standard second bout of eccentric exercise (50 repetitions). Nosaka, Sakamoto, Newton & Sacco (2001), found as few as 2 maximal eccentric contractions can still provide a repeated bout effect. These results show that the protective capacity of a prior bout of eccentric exercise has clinical significance in small volumes and is robust against outside influences such as resistance training.

The repeated bout effect is specific to the exercised muscle but not specific to the mode of exercise, and does not appear to be influenced by age. Connelly, (2002) measured markers of muscle damage in the quadriceps, and found eccentric contractions during the initial bout decreased the damage to the muscle during a subsequent downhill run compared to a control group who only completed the downhill run. The repeated bout effect appears to be similar in young and old individuals (Chapman, Newton, McGuigan & Nosaka, 2008). Marginson, Rowlands, Gleeson & Eston, (2005) compared adolescent boys to middle-age men and found that both groups responded similarly in the protective effect offered by the initial contractions. There appears to be a greater protective capacity of the repeated bout effect in an untrained population (Chen, Nosaka & Sacco, 2007). Falvo, Schilling, Bloomer, Smith & Creasy (2007), found a very limited protective capacity of a prior bout of eccentric bench press in a trained population. Through these studies, researchers have been able to develop a profile of the repeated bout effect. Understanding the influences and factors which can impact the magnitude of the protective effect will allow researchers and clinicians to apply eccentric exercise in the appropriate manner.

1.2.3 Mechanisms of the Repeated Bout Effect

The exact mechanism of the repeated bout effect is yet to be determined. The current literature suggests that the effect is controlled by multiple mechanisms at both a systems level as well as at a cellular or molecular level. McHugh (2003) described three main theories explaining the possible mechanisms of the repeated bout effect.

Neural Theory

The first theory is based on neural adaptation whereby the central nervous system would adapt its activation patterns in response to the initial bout of exercise to reduce the damage of the repeated bout. Eccentric contractions produce far greater amounts of force than concentric contractions; however, they require fewer active motor units for a given muscle force. There may be a much greater stress placed on substantially fewer activated fibres which might cause the relative increase in muscle damage compared to concentric contractions (McHugh, 1999). If a change in the recruitment pattern spreads the force out over a greater number of fibres by recruiting more motor units then this could reduce the myofibrilar disruption which occurs with training. With training, the median frequency decreases during the repeated bout which is an indirect indication that a larger number of type I muscle fibres are being recruited (Warren, Ingalls, Lowe & Armstrong, 2002). As well, an increased electromyography/torque ratio after the initial eccentric bout signifies activation of a larger motor unit pool (Hortobágyi et al., 1996). Possibly the most convincing evidence of neural adaptation is the detection of cross-education of the repeated bout effect. With one maximal unilateral training session, Howatson, Van Someren & Hortobágyi, (2007) showed a decrease in muscle damage during a repeated bout to the contralateral homologous limb which had not been exposed to any prior training. This result would indicate a higher order adaptation such as an improved motor plan or increased activation from the motor cortex which could improve the untrained limb's activation patterns decreasing the damage during any further training bouts (Howatson et al., 2007).

In contradiction to the neural adaptation theory a recent study by Aldayel, Jubeau, McGuigan & Nosaka (2010), showed a reduction in muscle damage marker response after a second bout of electrical muscle stimulation. Black & McCully (2008) provided similar evidence as they found electrically stimulated contractions provided a similar protective capacity to voluntary contractions. Since electrically stimulated contractions do not require any neural drive and the magnitude of effect was similar between groups they concluded that the primary mechanism for the reduction in muscle injury is not related to changes in muscle recruitment.

Mechanical Adaptation Theory

The second possible mechanism is a mechanical adaptation theory in which the non-contractile elements of the musculoskeletal system would acclimatize in response to the initial bout. Pousson, Hoecke & Goubel (1990) have shown increased dynamic muscle stiffness after eccentric exercise. Dynamic muscle stiffness is the elastic properties or extensibility of active muscles. The increase in dynamic stiffness is thought to be due to either an increase in tendon stiffness or in cross-bridge stiffness. Eccentric training disrupts the sarcomere alignment and more specifically the desmin and titan content which are responsible for maintaining the structure of the sarcomere. After an eccentric training session desmin content is increased during the repair of the muscle in order to reinforce the sarcomere (Barash, Peters, Friden, Lutz & Lieber, 2002). This increased structural content could limit the damage to sarcomeres during subsequent contractions.

Another possible mechanical adaptation is increased passive muscle stiffness with an increase in the intramuscular connective tissue providing the protective effect (Reich, Lindstedt, Lastayo & Pierotti, 2000). An increase in the connective tissue during the repair process following maximal eccentric contractions would dissipate the forces placed on the muscle over a greater area and possibly cause less damage to specific fibres (Lapier, Burton, Almon & Cerny, 1995).

Cellular Adaptation Theory

The third proposed mechanism is a cellular adaptation theory where changes within the contractile tissue and sarcomere would reduce the damage. There is a rightward shift in the length tension curve for a given length of the muscle after the initial bout of eccentric exercise (McHugh & Tetro, 2003). This causes the optimal angle of force production to occur at a longer muscle length than prior to the eccentric bout. Since contractions performed at longer muscle lengths result in greater symptoms of muscle damage (Morgan, 1990), a longitudinal addition of sarcomeres in series could reduce the strain imposed by the stretch of eccentric contractions, limiting the myofibrilar disruption that occurs (Lynn, Morgan & Talbot, 1998). Butterfield, Leonard and Herzog (2005) also showed an increase in sarcomere number in series at long muscle lengths for downhill eccentrically biased contractions. With a decreased force placed on each sarcomere with the same rate of stretch, a reduction in muscle damage would be likely.

Another possible cellular adaptation is the maintenance of excitation-contraction coupling. Warren (2001) reported that 50–70% of the initial strength loss seen with eccentric training can be explained by impaired excitation-contraction coupling. This refers to the entire series of events from the time acetylcholine is released into to the neuromuscular junction to when calcium is released from the sarcoplasmic reticulum. An adaptation to excitation-contraction coupling would explain the reduction in strength loss after the initial bout of eccentric exercise. However, direct evidence is lacking in support of this theory.

Recent publications indicate an adaptation to the inflammatory response with eccentric exercise would reduce the long term damage caused to the muscle. The initial injury triggers an inflammatory response which worsens the damage prior to the start of recovery. This is known as primary and secondary damage. Neutrophil and monocyte activation induce muscle damage as they enter the fiber, and activation of neutrophils and monocytes is reduced after the repeated bout of exercise (Pizza, Davis & Hendrickson, 1996). In more recent research a blunted inflammatory response was noted in response to a repeated bout of eccentric exercise after either passive stretching, isometric, or eccentric contractions. This was thought to be an adaptation to avoid the proliferated disruption of the myofibrils (Pizza, Koh, McGregor & Brooks, 2002). Currently, it is not possible to determine whether the decrease in inflammation was due to a decrease in actual muscle damage or whether a protective blunted inflammatory response was seen with a similar amount of induced damage.

Another cellular theory is that the repeated bout effect is due to the initial bout causing damage to the weak sarcomeres and muscle fibres. During the repair of the muscle the weak fibres and sarcomeres would be replaced by stronger sarcomeres (McHugh, 2003). Upon repair of the sarcomeres there would be an increased uniformity of sarcomere length during the repeated eccentric bout. Some of the damage seen after eccentric exercise could be due to irreversible damage to weak muscle fibres. It is thought that if weak fibres were destroyed during the initial eccentric bout a second eccentric bout would not elicit the same damage response. Haddad & Adams (2002) reported that one bout of eccentric exercise lead to an increase intracellular signalling (i.e., phosphorylations) and expression of mRNAs for insulin-like growth factor-I system components and myogenic markers. This could indicate an increase in protein synthesis occurring after a single bout of eccentric exercise (Haddad & Adams, 2002). However, this theory is very difficult to test experimentally creating even more challenges for researchers.

There are other recent theories proposed to explain the repeated bout effect. Heat shock proteins play an important role in cell survival after various stresses. HSP27 and HSP70 increase following maximal eccentric exercise (Thompson, Scordilis, Clarkson & Lohrer, 2001). These proteins may serve to protect the tissues from damage with the repeated bout of exercise (Thompson, Clarkson & Sordilis, 2002). In a recent study by Vissing, Bayer, Overgaard, Schjerling, & Raastad (2009) the authors concluded that heat shock protein translocation and expression is attenuated in response to repeated eccentric exercise.

With all of these factors influencing damage to the muscle with eccentric contractions it is unlikely that one unifying theory can explain all of the observations found in the literature on the repeated bout effect. It is possible that the repeated bout effect occurs through the interactions of various neural, connective tissues, and cellular factors that are dependent on the particulars of the eccentric exercise bout and muscle groups involved.

1.2.4 Velocity of Eccentric Contractions

The velocity at which a contraction is performed can lead to differences in muscle damage and adaptation. Chapman, Newton & Nosaka (2005), found no difference in the eccentric torque produced by the biceps at 30°/s, 90°/s, 150°/s, and 210 °/s. However, they showed eccentric torque was approximately 15% higher than isometric torque at each of the four velocities. Farthing & Chilibeck (2003) found fast velocity eccentric contractions (180 °/s) were superior for increasing muscle hypertrophy and strength when compared to concentric and slow eccentric (30 °/s) contractions. The authors theorized that the greater amount of force combined with muscle lengthening during contraction was a determining factor. Paddon-Jones, Keech, Lonergan & Abernethy (2005) compared indirect markers of muscle damage between participants that completed 36 maximal fast or slow velocity isokinetic eccentric contractions. They concluded that the magnitude and time course of markers of muscle damage were differentially influenced by a fast or slow velocity eccentric exercise bout. Peak plasma creatine kinase activity was similar between the fast velocity and slow velocity groups. Both groups experienced a similar decrement in strength but the fast velocity group recovered strength significantly faster. The slow group experienced a greater increase in upper arm girth than the fast group 20 min, and at 24 and 96 hours after exercise. As well, the fast velocity group experienced their peak soreness 48 hours later than the peak soreness of the slow velocity group. Chapman, Newton, Sacco & Nosaka (2006) found that fast velocity eccentric exercise causes greater muscle damage than slow velocity eccentric exercise when done with the same time under tension. When matching for time under tension the fast velocity condition completes a vastly greater number of contractions than the slow velocity condition making comparison difficult. In a follow up study by Chapman, Newton, Sacco & Nosaka (2008) equal contractions were completed for both fast and slow velocity bouts with participants completing either 30 or 210 reps of each velocity. There was no difference in muscle damage between velocities when they completed 30 contractions. However, the fast velocity induced greater muscle damage than the slow velocity when they completed 210 eccentric contractions. They concluded contraction velocity has a substantially greater impact on muscle damage when a greater number of contractions are performed. If greater muscle damage occurs from the fast eccentric training it might provide a greater stimulus for adaptation and cause greater protective effects in future eccentric bouts. Contrary to their hypothesis, Chapman, Newton, McGuigan & Nosaka (2009), found slow velocity eccentric contractions reduced muscle damage induced by fast-velocity exercise. This result would suggest the repeated bout effect occurs for all eccentric contractions regardless of velocity. However, no study has directly compared groups of participants that completed each bout at the same velocity to those who completed each bout at different velocities.

The proposed project aims to determine whether the repeated bout effect is velocity specific. Specificity of the repeated bout effect could indicate a contribution of neural mechanisms - perhaps involving improved motor planning specific to the movement velocity or greater motor unit recruitment. However if it happens that the repeated bout effect is not specific to the velocity of eccentric contraction performed during the initial bout that could indicate a greater contribution of cellular or structural adaptation such as an increase in the number of sarcomeres in series, the destruction and repair of the weak sarcomeres, or an increase in structural proteins.

1.3 Purpose Statement, Research Questions, and Hypothesis

1.3.1 Purpose Statement

The primary purpose is to determine whether the protective capacity of a single bout of eccentric resistance exercise, also known as the repeated bout effect, is specific to the velocity of contraction (i.e. Same vs. Different) performed during the initial eccentric exercise bout. The secondary purpose is to determine if there is a difference in the magnitude of the repeated bout effect depending on whether the initial bout of eccentric exercise was performed at a fast or slow velocity.

1.3.2 Research Questions

1) Is the repeated bout effect specific to the velocity of contraction that was performed during the initial eccentric exercise bout? Is the protective effect of a single bout of eccentric exercise different if the repeated bout is performed at the same velocity versus a faster or slower velocity of contraction?

2) Is there a difference in the magnitude of the repeated bout effect depending on whether the initial bout of eccentric exercise was performed at a fast or slow velocity?

1.3.3 Hypothesis

1) There will be a greater magnitude of the repeated bout effect when the repeated bout is performed at the same velocity compared to when it is performed at a different velocity.

2) There will be a greater magnitude of the repeated bout effect when the initial bout of eccentric training is performed at a fast velocity as compared to a slow velocity (i.e. the fast bout of exercise will show a greater protective effect than the slow exercise).

Chapter 2

Methods

2.1 Study Design

This study employed a between-within factorial mixed design. For the initial bout of eccentric exercise, participants were randomly assigned to either a fast (180˚/s) eccentric (n=16; 7 male, 9 female) or slow (30˚/s) eccentric (n=15; 9 male, 6 female) group. They were also randomly assigned to complete either the same or different velocity of contraction which lead to four distinct groups after the repeated bout of eccentric exercise. Dependant measures of muscle damage and performance included muscle thickness (MT), isometric MVC strength (MVC), electromyography (EMG), interpolated twitch (ITT), twitch torque (TT), and delayed onset muscle soreness (DOMS). After completing baseline measures of muscle damage and performance, participants performed an initial single unilateral exercise bout of either fast or slow isokinetic eccentric elbow flexion. Measures of muscle damage and function were collected prior to eccentric exercise, immediately after eccentric exercise, and at 24, 48, and 72 hours post eccentric exercise. After these measures were taken each participant took a 3 week break and did not perform any training or exercise of the arms. After the 3 week break each participant returned to the lab and completed a repeated bout of either a slow or fast velocity eccentric exercise. A 3 week break was chosen as a consistent timeline in the literature to ensure complete recovery of the muscle after the initial eccentric bout. A substantial repeated bout effect has been shown to occur with approximately 3 weeks between eccentric bouts (Nosaka, Newton & Sacco, 2005; Chen, Chen, Lin, Wu & Nosaka, 2009). Half of the participants from each group completed the same velocity (SAME) eccentric exercise protocol as the initial bout, while the other half of the participants completed a different velocity (DIFF) of contraction. The same protocol was followed as the initial bout with baseline measures of MT, isometric MVC, EMG, ITT, TT, and DOMS. The repeated damaging eccentric bout was then completed and dependent variables were measured in the same way as the initial bout; immediately after, and at 24, 48, and 72 hours post-testing. For the complete study design refer to figure 1.1.

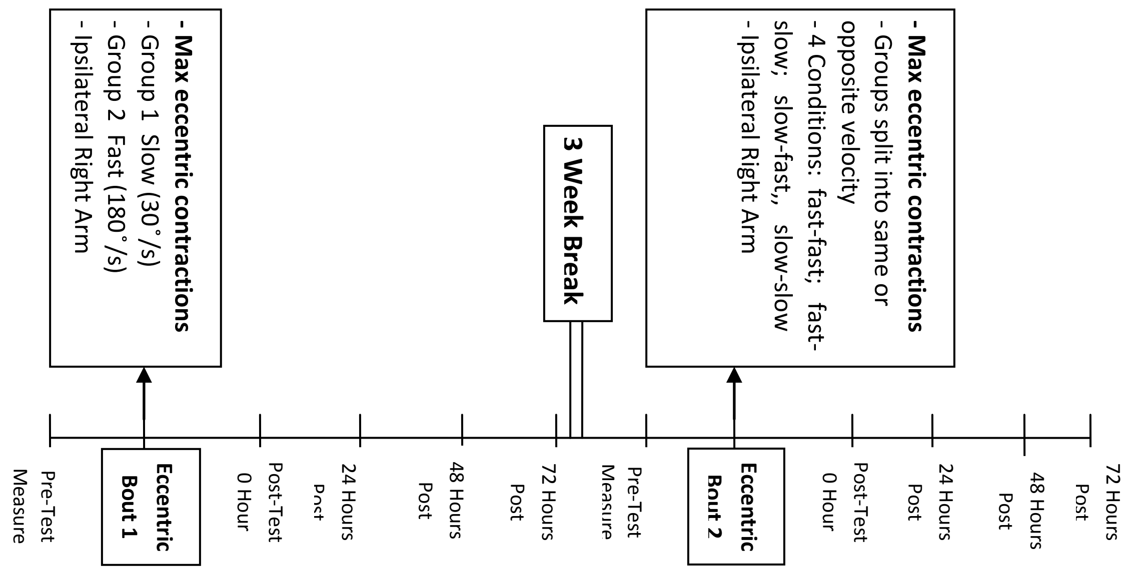

Figure 1.1 – Study Design

**All dependant variables will be collected at each time point*

- Dependant Variables: MVC isometric strength (MVC), electromyography (EMG), twitch torque (TT), interpolated twitch (ITT), muscle thickness (MT), delayed onset muscle soreness (DOMS)

Upon completion of the repeated bout of eccentric exercise all of the participants were pooled (N=31; 16 males, 15 females) in order to determine if the initial bout of eccentric exercise provided a protective effect against muscle damage on the repeated bout of eccentric exercise, regardless of the velocity of contraction executed at the repeated bout. Also, participants were divided into 2 groups based on whether they completed the same velocity (SAME: n=16; 7 males, 9 females) of contraction at the initial and repeated eccentric bouts (fast-fast or slow-slow) or whether they completed each bout at a different velocity (DIFF: n=15; 9 males, 6 females) of contraction (fast-slow, slow-fast). From this, it can be determined if the protective capacity of the repeated bout effect is specific to the contraction velocity. Based on the initial and repeated bout velocity that each participant completed four distinct groups can be compared; slow-slow (n=8, 4 males, 4 females), slow-fast (n=7; 5 males, 2 females), fast-slow (n=8; 4 males, 4 females), fast-fast (n=8; 3 males, 5 females). As best as possible, groups were matched for gender, strength, and handedness. This made it possible to determine if there is a difference in the magnitude of the repeated bout effect depending on whether the initial bout of eccentric exercise was performed at a fast or slow velocity.

2.2 Participants

A sample of 35 participants were initially recruited for the study. After the first week of testing, 4 individuals indicated they would be unable to continue with participation. Two individuals reported conflicts with summer employment and 2 were not comfortable completing the second week of testing. A sample of 31 male (n=16) and female (n=15) participants between the ages of 19 – 33 completed the study protocol. The study was approved by the University of Saskatchewan biomedical review board for research in human subjects, and all subjects gave their written informed consent prior to data collection. (See Appendix A for a copy of the Ethics: Certificate of Approval). Their mean (±SD) age, height, body weight, and handedness score was 24.3 ± 3.1 years, 174.8 ± 8.3 cm, 78.2 ± 15.6 kg, and 17.2 ± 2.1 respectively. All of the participants were strongly right handed in order to control for arm strength asymmetries and the effects of limb dominance. Handedness was determined using a 10-item version of the Waterloo Handedness Questionnaire (WHQ). Scores on the questionnaire can range from -20 to +20 where negative score indicate left-handedness and positive scores indicate right-handedness. Participant's descriptive statistics are shown in Table 2.1. According to a sample size calculation, with alpha level = 0.05 and 80% power, and an estimated medium effect size of partial $\eta^2 = 0.1$, a minimum of 12 participants per group were needed to detect a significant group (4) x bout (2) x time (4) interaction for percent change in MVC strength (primary measure). Effect size was estimated using mean and SD (60 ± 20 Nm) for isometric elbow flexion MVC from previous studies conducted in the lab (Magnus et al., 2010) and estimates of the magnitude of the repeated bout effect (10-15%) for the MVC of the elbow flexors muscle group found in the literature (Howatson et al., 2007; Chen et al., 2009). Sample size estimates were calculated using MorePower, version 5.1 (Campbell and Thompson, 2002). All of the participants were considered relatively untrained and had not performed training with eccentric overload or isokinetic dynamometry in the previous year. One month of resistance training experience was defined as training three days per week for 4 weeks (See Table 2.2 for recent and lifetime training experience of participants). Participants were free from neuromuscular disease and were instructed to not take any anti-inflammatory agents or nutritional supplements during the experimental period. Males and females were recruited so the study would better generalize to the population. Studies have shown no difference in the protective capacity of the repeated bout effect between males and females (Eston, Lemmey, McHugh, Byrne & Walsh, 2000). Participants were asked to limit the strenuous exercise on their upper body for one-week prior to the initial bouts of eccentric exercise and for the remainder of the study. Maintenance of a cardiovascular training program was encouraged. However, no new resistance, cardiovascular, or flexibility program was to be undertaken during the time frame of the study. Each participant completed a handedness, previous training experience, and previous injury questionnaire to ensure they did not fit any of the exclusion criteria. Participants were included if they were right handed with no specific eccentric or isokinetic training within the past year, and were free from prior serious injury to either limb.

Table 2.1 – Participant Characteristics

Data listed as Means ± Standard Deviation.

	Pooled Participants (N=31)			
Age (Years)	24.3 ± 3.1			
Height (cm)	174.8 ± 8.3			
Weight (kg)	78.2 ± 15.6			
Waterloo Handedness Score	17.2 ± 2.1			
	Same Velocity (N=16)		**Difference Velocity (N=15)**	
Age (Years)	24.8 ± 3.8		23.8 ± 2.1	
Height (cm)	174.5 ± 8.6		175.0 ± 8.2	
Weight (kg)	77.9 ± 17.3		78.4 ± 14.2	
Waterloo Handedness Score	16.8 ± 2.1		17.6 ± 2.1	
	Slow-Slow(8)	**Fast-Fast(8)**	**Fast-Slow(8)**	**Slow-Fast (7)**
Age (Years)	24.4 ± 5.1	24.3 ± 3.1	23.8 ± 2.8	23.9 ± 0.9
Height (cm)	174.3 ± 8.6	174.8 ± 9.1	171.9 ± 8.6	178.6 ± 6.6
Weight (kg)	75.8 ± 15.7	80.1 ± 19.6	73.1 ± 12.4	84.4 ± 14.5
Waterloo Handedness Score	16.9 ± 2.0	16.8 ± 2.3	17.5 ± 2.3	17.7 ± 1.9

Table 2.2 – Resistance Training Experience

Data listed as Means ± Standard Deviation.

	Pooled Participants (N=31)			
Resistance Training in Previous Year (Months)	6.1 ± 4.5			
Resistance Training in Lifetime (Months)	43.6 ± 38.1			
	Same Velocity (N=16)		**Difference Velocity (N=15)**	
Resistance Training in Previous Year (Months)	5.8 ± 4.8		6.5 ± 4.3	
Resistance Training in Lifetime (Months)	42.4 ± 42.5		44.9 ± 34.2	
	Slow-Slow(8)	**Fast-Fast(8)**	**Fast-Slow(8)**	**Slow-Fast(7)**
Resistance Training in Previous Year (Months)	2.9 ± 3.5	8.6 ± 4.4	6.5 ± 5.0	6.6 ± 3.9
Resistance Training in Lifetime (Months)	36.3 ± 49.9	48.6 ± 35.9	46.5 ± 39.1	43.1 ± 30.7

2.3 Procedures

2.3.1 Eccentric Bouts

Each maximal voluntary eccentric bout was performed at a velocity of either 30°/s or 180°/s. Participants were familiarized to the eccentric training protocol by completing two 50% eccentric contractions and one maximal eccentric contraction prior to the damaging eccentric protocol. The eccentric bout included 6 sets of 8 maximal eccentric elbow flexion repetitions, completed on the Humac NORM isokinetic dynamometer (Computer Sports Medicine Inc., Stoughton, MA). This volume of work was chosen to ensure adequate muscle damage occurred in order to see the full protective capacity of the repeated bout effect. Approximately 50 repetitions have been shown in the literature to be a strong stimulus to produce the repeated bout effect (Howatson et al., 2007; Skurvydas, Kamandulis & Masiulis, 2010). Participants were placed in a supine position with their feet up on the bench and their opposite arm across their chest to minimize stabilizer muscle activation. During the exercise the participant's trunk was stabilized with a pelvic strap as well as a shoulder strap to minimize involvement of other muscle groups. The range of motion for the eccentric movement was 110°. The end range of motion was determined by having the participant place their arm (elbow) in full extension (0°) at the side of their body where it was most comfortable. The end range for the eccentric contractions was set 10° short of full extension. The total range was set at 120° of flexion from full extension, with the active range of motion at 110°. The exact position was maintained for both the initial and repeated bouts of eccentric exercise. Each participant's initial and repeated bouts of eccentric exercise were matched for total work. This was done to ensure the initial and repeated eccentric exercise sessions produced similar stress for the elbow flexors. The only difference was the velocity of contraction and thus the time under tension. Peak torque and minimum peak torque were also recorded for each set to ensure maximal effort on each repetition, to further validate the consistency of the initial and repeated bouts. Elbow flexion was chosen as it is a common model in the repeated bout effect literature allowing for quality comparisons between studies. It is also a fairly familiar task and produces more consistent and reliable data compared to a less familiar task that involves pronounced learning effects (Nosaka et al., 2001; Chen et al., 2009).

2.3.2 Isometric Strength

Maximal isometric elbow flexion torque (Nm) was completed on the Humac NORM isokinetic dynamometer to assess changes in maximal MVC strength after the maximal eccentric bouts. Use of isokinetic dynamometry allowed precise control of the contraction type and velocity, while accurately measuring torque production. The strength assessment was done in the same supine position as the eccentric bouts with an elbow joint angle of 90°. Participants were secured into the dynamometer with a shoulder and pelvic strap and placed their feet up on the chair with their non-dominant arm across their lap in order to minimize activation of alternate or stabilizer muscle groups. Each maximal attempt was 3 seconds long and was separated by 1 minute of rest. The peak force of contraction out of four was used for comparison. Isometric MVC strength measures were taken prior to, immediately after, and at 24, 48, and 72 hours after the initial and repeated bouts of eccentric exercise. In order to minimize the effect of learning during testing, all participants were familiarized with the lab equipment prior to maximal strength testing by performing a set of 8 contractions on the dynamometer progressively increasing in intensity. Verbal encouragement was given for all testing contractions. Within our lab the CV for strength measures using the dynamometer for various muscle groups ranges from 5–6% (Farthing and Chilibeck, 2003; Farthing et al., 2005; Krentz and Farthing, 2010).

2.3.3 Muscle thickness

Muscle thickness of the elbow flexors was measured via B-mode ultrasound (Aloka SSD-500, Tokyo, Japan) to determine if swelling and edema or changes in muscle thickness occurred in response to the eccentric exercise bout. It was expected that this measure could indicate changes in the elbow flexors relating to inflammatory responses (e.g. edema), based on previous animal (Fujikake et al. 2008) and human studies (Nosaka and Clarkson, 1996). A stringent and reliable land-marking method using overhead transparency film was employed to ensure identical locations were measured at each time point. This technique has demonstrated to be valid and reliable on previous occasions in our lab (Farthing and Chilibeck, 2003; Farthing et al., 2005; Candow and Chilibeck, 2005; Krentz et al., 2007; Farthing et al., 2009). The landmark for the center of the ultrasound probe was placed on the bulk of the biceps brachii while in a lengthened position, approximately two thirds of the way distally down the arm between the acromion process of the shoulder and the olecranon process of the elbow. Four measurements were taken at each time point on each arm with the average of the two closest measurements being used as the thickness value. Additional measurements were taken in the event that any two of the four measurements were not within 1 mm. Muscle thickness measures were taken prior to, immediately after, and at 24, 48, and 72 hours after the initial and repeated bouts of eccentric exercise. Muscle thickness was assessed prior to any strength assessment to avoid any transient hypertrophy. The CV for the muscle ultrasound procedure for the elbow flexors muscle thickness in our lab is 2.1% (Farthing and Chilibeck, 2003).

2.3.4 Electromyography

Maximal isometric muscle activation was assessed by using electromyography (EMG) to determine changes in muscle activation associated with the each maximal eccentric bout. A Delsys EMG system (Bagnoli-4, Delsys, Boston, MA, USA) was used with one surface electrode placed on the biceps brachii muscle to measure agonist activation and a second electrode on the triceps brachii muscle to measure antagonist muscle activation. The biceps and triceps brachii electrodes were placed on the bulk of the muscle when the muscle was in a flexed position. The biceps electrode was located between the anode and cathode of the interpolated twitch electrodes according to the methods of Klein, Rice & Marsh (2001). A reference electrode was placed on the knee cap to serve as a common ground for the EMG signal. Land marking measurements were recorded after the first testing session to ensure correct placement at each testing time point. Raw EMG signal was collected for each of the maximal isometric MVC contractions. EMG measures were taken prior to, immediately after, and at 24, 48, and 72 hours after the initial and repeated bouts of eccentric exercise.

The EMG main amplifier unit included single differential electrodes with a bandwidth of 20 ± 5 Hz to 450 ± 50 Hz, a 12 dB/octave cutoff slope, and a maximum output voltage frequency of ± 5 V. The overall amplification or gain per channel was 1K for the biceps and triceps brachii muscles. The system noise was <1.2 μV (rms). The electrodes were two silver bars (10 mm x 1 mm diameter) that were spaced 10 mm apart, and had a Common Mode Rejection Ratio (CMRR) of 92 dB.

Maximal eccentric muscle activation was also assessed by EMG to determine any changes in muscle activation from the initiation to the conclusion of the eccentric bout. The electrode placements remained the same being placed on the bulk of the biceps and triceps brachii muscles. Raw EMG signal was collected for the 1^{st} and 6^{th} sets of each eccentric bout. Eight maximal eccentric repetitions were performed during each set.

Raw data (volts) was later converted to mean absolute value (MAV) using Matlab (Version 7.3.0) to examine changes in signal amplitude. A 0.3 second window of time immediately prior to the interpolated twitch was used to calculate the MAV. During the testing sessions, the average MAV from the four repetitions was used for comparison. A stringent method for land-marking the electrodes was utilized to ensure accurate placement of the electrodes for each testing occasion (Farthing et al., 2005). The skin surface was shaved and cleaned adequately prior to placing the electrodes. Resting muscle signals were checked for noise, and where appropriate, the skin was cleaned and shaved again, and the electrodes were repositioned. The quality of the skin contact was checked during low level muscle contractions. The CV for biceps brachii EMG within our lab is 15.0%.

2.3.5 Voluntary Muscle Activation

Percent voluntary activation was estimated using the interpolated twitch technique (ITT). A Digitimer Constant Current High Voltage Stimulator (Model DS7AH) was used to supramaximally activate the elbow flexors. The cathode electrode was placed over the proximal muscle belly of the biceps brachii while the anode electrode was placed over the distal tendon of the biceps. Prior to the maximal isometric contractions, a series of resting control twitches were used to determine the maximum current (milliamps - mA) needed to reach maximum resting twitch torque. The amount of current used to deliver the maximum twitch torque was also used for the interpolated twitch technique. Two 4-pulse trains (at 100Hz, 50μs pulse duration) were applied, both during and approximately 5 seconds after the maximal voluntary contraction. The 4-pulse train was manually triggered at the peak of the maximal voluntary contraction. The level of activation was calculated as voluntary activation (%) = (1 – superimposed twitch/estimated resting twitch) x 100 (Shield and Zhou, 2004; Gandevia, Herbert & Leeper, 1998; Allen, McKenzie & Gandevia, 1998).

The magnitude of electrical current applied to the biceps brachii during twitch interpolation ranged from 100 to 150 milliamperes (mA). A very small current level of 50 mA stimulus intensity was progressively increased until no further increase in twitch torque response to stimulation was observed, or when the stimulus was no longer tolerable for the participant. After the current intensity was identified, the identical intensity was used for the superimposed twitch during maximal voluntary contractions, and the subsequent control twitch.

2.3.6 Muscle Soreness

A self perceived scale of muscle soreness was used to assess delayed onset muscle soreness (DOMS) for a period of four days following each eccentric training bout. A visual analog scale of a 100 mm continuous line representing “not sore at all” at 0mm and “Very Very Sore” at 100mm was used. Two sites were monitored to ensure a valid measurement. The muscle belly at the midpoint of the ultrasound probe was the landmark for the first site. For the second site each participant was asked to point out the location on the biceps that was “most sore”.

Participants reported soreness scores with the biceps in an extended position and while constant pressure was being applied using an Algometer. The Algometer ensured the tester pushed with exactly 3 kg of pressure on each site every measurement. A rating of soreness was done prior to, immediately after, and at 24, 48, and 72 hours after the initial and repeated bouts of eccentric exercise.

2.3.7 Data Acquisition

Custom software in Labview (Version 8.6) was used to obtain stimulator pulses, torque, and 2 channels of EMG data simultaneously. All channels were acquired at a sampling rate of 1000 Hz. An analog-to-digital (A to D) converter was used convert the analog signals from each device to digital signals displayed in Labview.

2.4 Statistical Analysis

The data were analyzed three different ways in order to fully answer the two different research questions. Throughout the analysis the raw scores for the MVC strength and muscle thickness data were normalized to the pre-test time point values to control for baseline variability between subjects. Percent change was calculated by subtracting the post-eccentric bout score from the baseline-eccentric bout score, dividing by the baseline-eccentric bout score, and multiplying by 100. Raw scores were used for the DOMS, EMG, ITT, and TT data.

2.4.1 Pooled Participants

In order to determine if the initial bout of eccentric exercise provided a protective effect against muscle damage after the repeated bout of exercise, regardless of contraction velocity, all of the participants were pooled together. For this analysis there are 2 within-subjects factors of *Time* and *Bout*, as well as 6 dependant variables (MVC, MT, DOMS, EMG, and ITT, and TT). Separate 2 (*Bout*; initial, repeated) x 4 (*Time*; 0, 24, 48, 72) repeated measures ANOVAs were conducted for MVC strength and muscle thickness data. For the remainder of the variables, separate 2 (*Bout*; initial, repeated) x 5 (*Time*; pre, 0, 24, 48, 72) repeated measures ANOVAs were conducted.

2.4.2 Velocity Specificity

In order to determine if there was a greater protective effect when participants completed both bouts of eccentric exercise at the same velocity, participants were randomly split into 2 groups. This analysis included 1 between-subjects factor of *Group* (same velocity, different velocity) and 2 within-subjects factors of *Time* and *Bout*, for each dependant variable. Separate 2 (*Bout*; initial, repeated) x 2 (*Group*; SAME, DIFF) x 4 (*Time*; 0, 24, 48, 72) repeated measures ANOVAs were conducted for MVC strength and muscle thickness data. Separate 2 (*Bout*; initial, repeated) x 2 (*Group*; same, different) x 5 (*Time*; pre, 0, 24, 48, 72) repeated measures ANOVAs were conducted for the DOMS, EMG, ITT, and TT data.

2.4.3 Velocity of Contraction

In order to determine if there was a difference in the magnitude of the repeated bout effect depending on whether the initial bout of eccentric exercise was performed at a fast or slow velocity the participants were split into 4 groups. There was 1 between-subjects factor of *Group* (slow-slow, slow-fast, fast-slow, fast-fast) and 2 within-subjects factors of *Time* and *Bout*, for each dependant variable. Separate 2 (*Bout*; initial, repeated) x 4 (*Group*; slow-slow, slow-fast, fast-slow, fast-fast) x 4 (*Time*; 0, 24, 48, 72) repeated measures ANOVAs were conducted for MVC strength and muscle thickness data. Separate 2 (*Bout*; initial, repeated) x 4 (*Group*; slow-slow, slow-fast, fast-slow, slow-slow) x 5 (*Time*; pre, 0, 24, 48, 72) repeated measures ANOVAs were conducted for the DOMS, EMG, ITT, and TT data.

If significant main effects or interactions were detected, simple main effects analysis continued using one-way ANOVA and Tukey's post hoc tests, or multiple comparisons with adjustment were used where appropriate. Significance was accepted at $p < 0.05$. All values are expressed as means ± standard deviation except in the figures where standard error was used for clarity of the display. Analyses were completed using SPSS version 17 (Chicago, IL).

Chapter 3

Results

3.1 Participant Characteristics, Training Experience, and Eccentric Bout Torque and Total Work

No differences between any groups were seen for age, height, weight, or Waterloo handedness score, and there were no differences between groups for resistance training experience in the past year or lifetime. This indicates each sample was similar and should allow for reliable and accurate comparison (Table 2.1 and 2.2).

The initial eccentric bout was compared to the repeated eccentric bout for all groups in order to ensure there was no difference in total work performed between bouts. Peak torque for the highest eccentric rep was recorded in order to ensure maximal effort and drive was the same between the initial and repeated bouts of exercise. Peak torque from the lowest eccentric rep was assessed in order to ensure similar fatigue between the initial and repeated bouts of eccentric exercise.

When all of the participants were pooled, paired t-tests revealed no difference in total work, peak torque, or lowest peak torque between the initial and repeated bouts of eccentric exercise (Table 3.1.1). When the participants were split into the SAME vs. DIFF groups the omnibus ANOVA revealed a significant bout x group interaction, GG $F(1.0, 28.0)=5.289$, $p=0.029$ for highest peak torque achieved during the eccentric bouts. For the SAME group there was a simple main effect of bout, GG $F(1.0, 15.0)=5.881$, $p=0.028$ for peak torque. This indicates for the SAME group the peak torque produced was reduced at the repeated bout of eccentric exercise (Table 3.1.1). There was no difference between the initial and repeated bouts of eccentric exercise in the DIFF group for peak torque. As well there were no differences between the initial and repeated bouts for total work or lowest peak torque for either group.

When participants were split into the four groups model, the omnibus ANOVA revealed a significant bout x group interaction for total work, GG $F(3.0, 27.0)=4.354$, $p=0.013$. However, there were no effects of bout when the data were split into each of the four velocity groups. This indicates the total work that each group performed from the initial to the repeated bout of eccentric exercise was not different. The omnibus ANOVA revealed a significant bout x group interaction for lowest peak torque produced, GG $F(3.0, 27.0)=15.703$, $p=0.001$. There was a simple main effect of bout for the SLOW-FAST, GG $F(1.0, 6.0)=17.120$, $p=0.006$, and FAST-SLOW groups, GG $F(1.0, 7.0)=14.538$, $p=0.007$ for the lowest peak torque produced. For the conditions which repeated the SAME velocity of contraction each time (SLOW-SLOW, FAST-FAST) there was no difference in the lowest peak torque. This would indicate the participants were equally fatigued at both the initial and repeated bouts. However, in the SLOW-FAST and FAST-SLOW conditions the lowest peak torque was significantly lower in the SLOW condition whether it was completed at the initial or repeated bout of exercise. This would indicate the SLOW eccentric bout induced greater muscle fatigue. There was also a bout main effect for highest peak torque produced, GG $F(1.0, 27.0)=4.374$, $p=0.046$. However, there were no differences in the peak torque from the initial to the repeated bout of eccentric exercise for any of the groups individually. Total work, peak torque, and lowest peak torque values are shown in table 3.1.1.

Table 3.1.1 Eccentric bout total work, peak torque, and lowest torque

		Pooled Participants (N=31)			
TOTAL WORK (Nm)	Initial Bout	3208 ± 1228			
	Repeated Bout	3278 ± 1283			
PEAK TORQUE (Nm)	Initial Bout	73.9 ± 22.7			
	Repeated Bout	71.2 ± 21.3			
LOWEST TORQUE (Nm)	Initial Bout	53.4 ± 16.8			
	Repeated Bout	55.5 ± 18.5			
		Same Velocity (N=16)		**Difference Velocity (N=15)**	
TOTAL WORK (Nm)	Initial Bout	3095 ± 1244		3328 ± 1244	
	Repeated Bout	3100 ± 1211		3468 ± 1371	
PEAK TORQUE (Nm)	Initial Bout	74.4 ± 24.5		73.3 ± 21.6	
	Repeated Bout	70.9 ± 23.5*		71.6 ± 19.7	
LOWEST TORQUE (Nm)	Initial Bout	53.8 ± 19.5		53.1 ± 14.2	
	Repeated Bout	53.3 ± 19.7		57.8 ± 17.6	
		Slow-Slow (N=8)	**Fast-Fast (N=8)**	**Fast-Slow (N=8)**	**Slow-Fast (N=7)**
TOTAL WORK (Nm)	Initial Bout	2640 ± 868	3550 ± 1445	3326 ± 1272	3331 ± 1312
	Repeated Bout	2644 ± 872	3558 ± 1381	3292 ± 1268	3670 ± 1557
PEAK TORQUE (Nm)	Initial Bout	66.4 ± 20.3	82.5 ± 26.9	68.9 ± 17.6	78.4 ± 25.8
	Repeated Bout	65.0 ± 21.7	76.8 ± 25.1	64.9 ± 18.7	79.3 ± 19.1
LOWEST TORQUE (Nm)	Initial Bout	44.8 ± 15.1	62.8 ± 19.9	54.4 ± 11.9	51.6 ± 17.3
	Repeated Bout	43.6 ± 12.9	62.9 ± 21.3	48.8 ± 13.3*	68.1 ± 16.7*

Values are mean ± standard deviation
* Initial bout is significantly different than repeated bout (p<0.05)

3.2 Results for Pooled Participants

Recall that the pooled analysis was performed in order to assess if the initial bout of eccentric exercise provided any protection against muscle damage after the repeated bout of eccentric exercise for the six dependant variables.

3.2.1 Isometric Strength

The omnibus ANOVA revealed a significant bout main effect, Greenhouse-Geisser (GG) $F(1.0, 30.0)=5.272$, $p=0.029$. Pooled across time, the repeated bout had a smaller decrease in elbow flexion MVC compared to the initial bout which indicates a repeated bout effect did occur (Figure 3.2.1). There was also a significant time main effect GG $F(1.9, 56.9)=40.884$, $p<0.001$. Pooled across bout, Bonferroni adjusted post-hoc analysis revealed a significant recovery of strength from time 0 to time 24 hours ($p<0.001$) and from time 48 to time 72 hours ($p=0.003$). Refer to appendix E for MVC strength raw data. (Refer to Figure 3.2.1 for a graph of MVC strength differences).

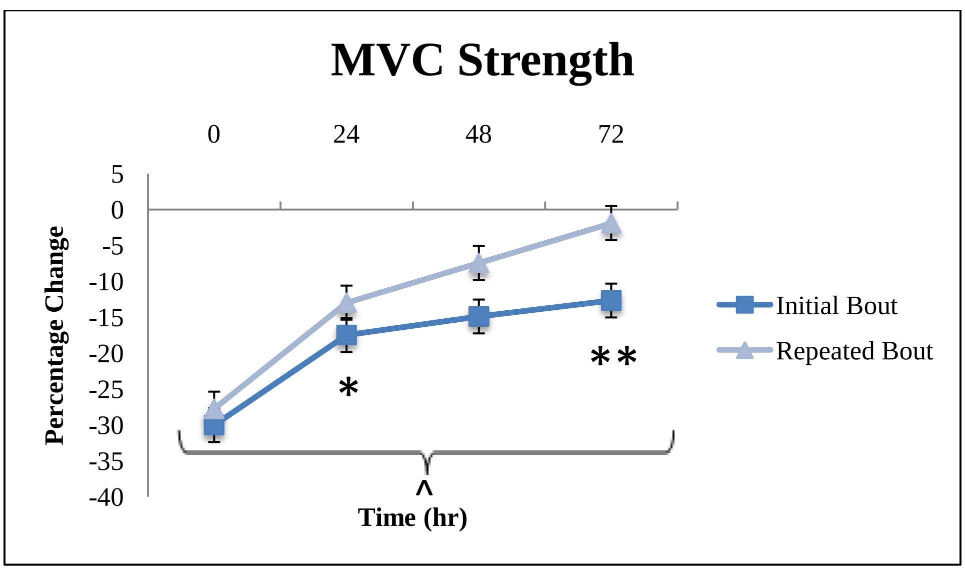

Figure 3.2.1 - MVC strength over time. Values are % change from baseline mean ± SE
^ Initial bout is significantly different than repeated bout pooled across time ($p<0.017$).
* Strength at 24 hours is significantly greater than at time 0 pooled across bout ($p<0.05$).
** Strength at 72 hours is significantly greater than at time 48 pooled across bout ($p<0.05$).

3.2.2 Muscle Thickness

The omnibus ANOVA revealed a significant bout main effect, GG $F(1.0, 30.0)=7.333$, $p=0.011$. Pooled across time, the repeated bout had less increase in muscle thickness compared to the initial bout which indicates a repeated bout effect did occur. There was also a significant time main effect GG $F(2.3, 70.4)=25.206$, $p<0.001$. Pooled across bout, Bonferroni adjusted post-hoc analysis revealed a significant reduction in muscle thickness from time 0 to time 24 hours ($p=0.001$) and from time 48 to time 72 hours ($p=0.027$). Refer to appendix F for muscle thickness raw data. (Refer to Figure 3.2.2 for a graph of muscle thickness differences).

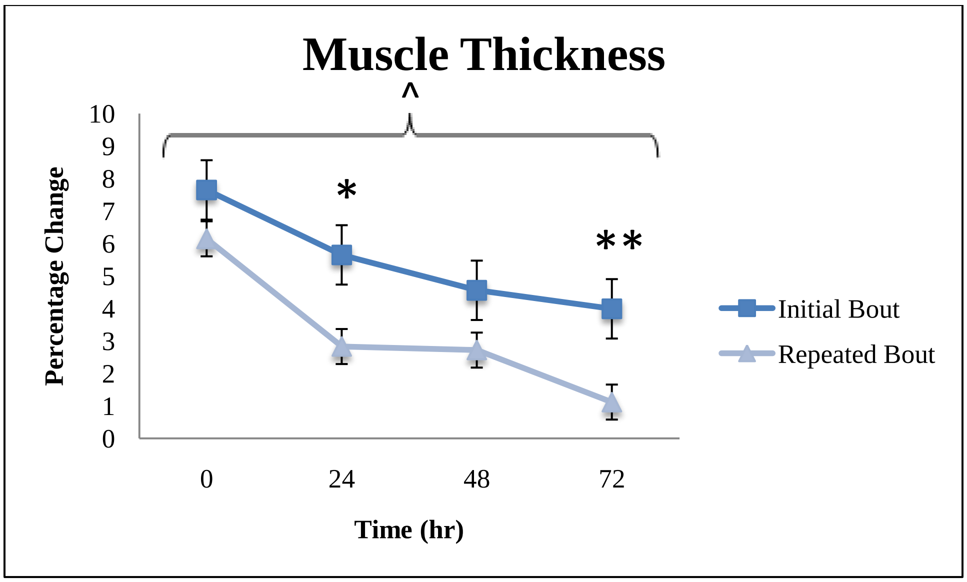

Figure 3.2.2 - Muscle thickness over time. Values are % change from baseline mean ± SE
^ Initial bout is significantly different than repeated bout pooled across time ($p<0.017$).
* Muscle thickness at 24 hours is significantly lower than at time 0 pooled across bout ($p<0.05$).
**Muscle thickness at 72 hours is significantly greater than time 48 pooled across bout ($p<0.05$).

3.2.3 Muscle Soreness

3.2.3.1 Muscle Soreness (Belly)

The omnibus ANOVA revealed a significant bout x time interaction, GG $F(2.3, 68.8)=4.935$, $p=0.007$. Post hoc paired t-tests (Bonferroni Adjustment) revealed a significant difference between bouts at time 48 (Initial Bout: 28.8±17.4 mm to Repeated Bout: 18.8±19.8 mm; *p*=0.004), and 72 hours (Initial Bout: 23.7±20.3 mm to Repeated Bout: 10.8±16.1 mm; *p*=0.009). (Refer to Figure 3.2.3.1 for a graph of muscle belly soreness differences).

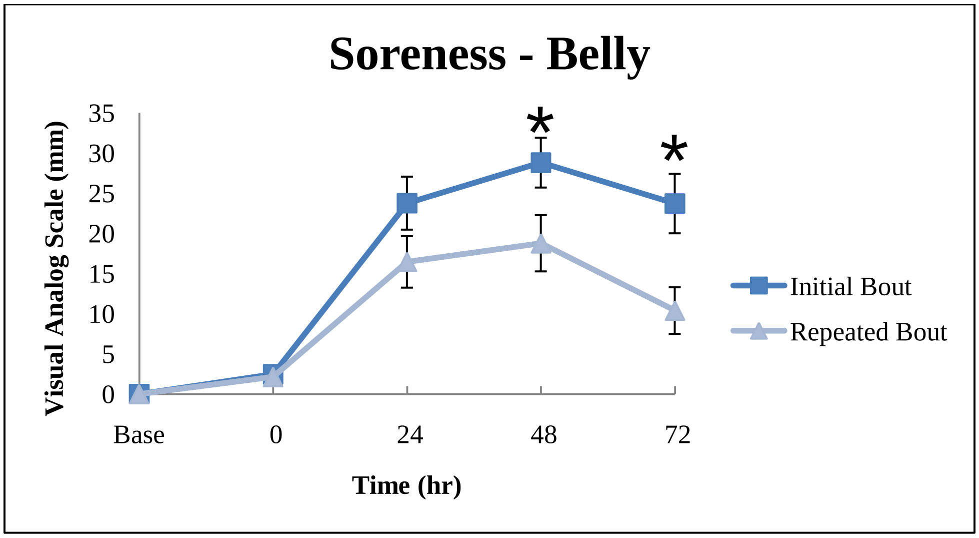

Figure 3.2.3.1 – Muscle soreness over time (Muscle Belly). Values are mean ± SE.
* Repeated bout is significantly different than initial bout (*p*<0.017). Bonferroni Adjusted.

3.2.3.2 Muscle Soreness (Most Sore)

The omnibus ANOVA revealed a significant bout x time interaction, GG $F(2.7, 81.4)=8.111$, $p<0.001$. Post hoc paired t-tests (Bonferroni Adjustment) revealed a significant difference between bouts at time 24 (Initial Bout: 42.3±21.6 mm to Repeated Bout: 29.3±22.3 mm; *p*=0.005), 48 (Initial Bout: 46.2±17.8 mm to Repeated Bout: 28.9±24.9 mm; *p*<0.001), and 72 hours (Initial Bout: 37.1±22.7 mm to Repeated Bout: 21.7±19.4 mm; *p*=0.003). (Refer to Figure 3.2.3.2 for a graph of muscle soreness differences for the most sore location).

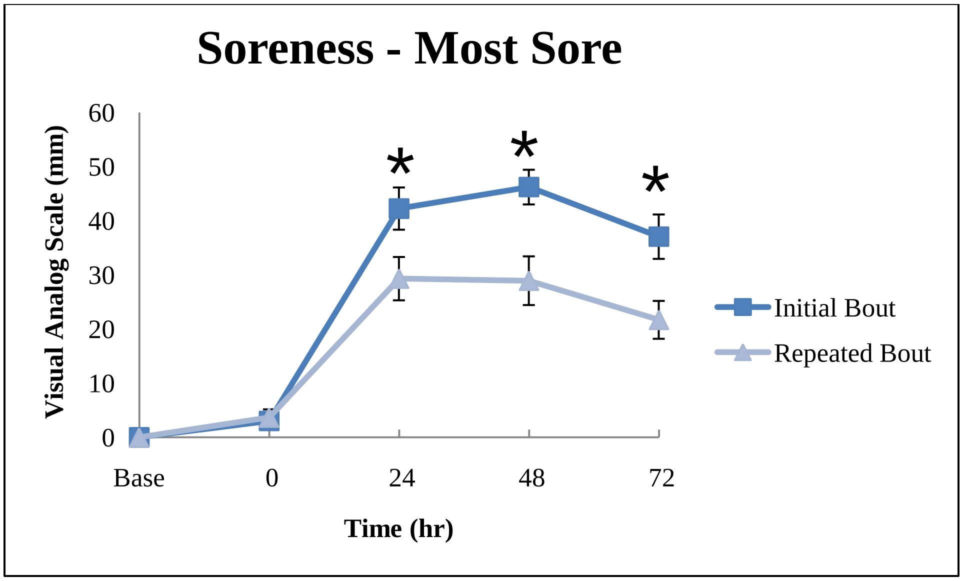

Figure 3.2.3.2 – Muscle soreness over time (Most Sore). Values are mean ± SE.
* Repeated bout is significantly different than initial bout (*p*<0.017). Bonferroni Adjusted.

3.2.4 Electromyography

For biceps EMG, the omnibus ANOVA revealed a significant bout main effect, GG *F*(1.0, 30.0)=4.229, *p*=0.049. Pooled across time, the repeated bout had greater biceps activation compared to the initial bout which indicates a repeated bout effect did occur. There was also a significant time main effect GG *F*(2.4, 70.9)=5.670, *p*<0.003. Pooled across bout, Bonferroni adjusted post-hoc analysis revealed a significant decrease in the EMG activation from baseline to time 0 (*p*=0.005). Biceps EMG activation was not different than baseline at time 24, 48, or 72 hours (*p*>0.05). (Refer to Figure 3.2.4.1 for a graph of triceps EMG differences). Triceps EMG activation did not change over time or between bouts. (Refer to Figure 3.2.4.2 for a graph of triceps EMG differences)

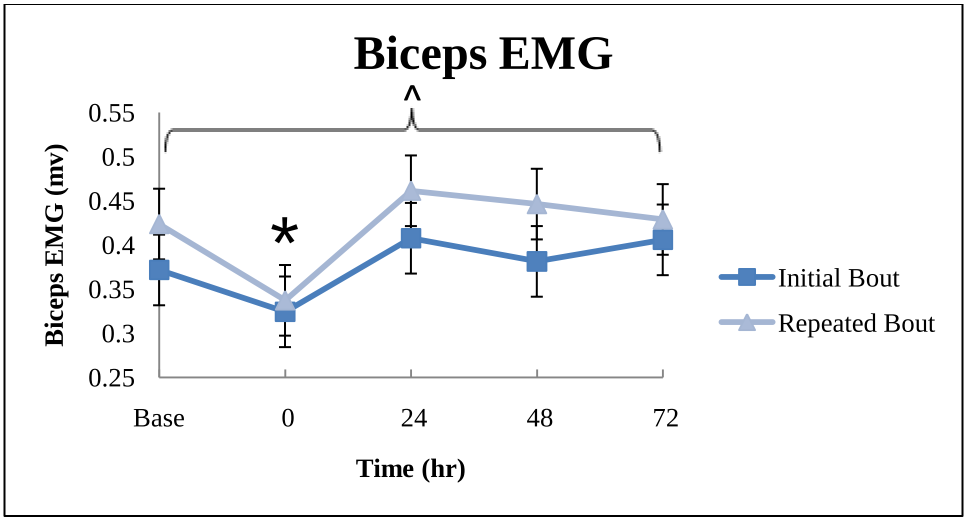

Figure 3.2.4.1 – Biceps electromyography over time. Values are mean ± SE
^ Repeated bout significantly different than initial bout (p<0.05)
* Biceps EMG at time 0 is significantly lower than baseline pooled across bout (p<0.05).

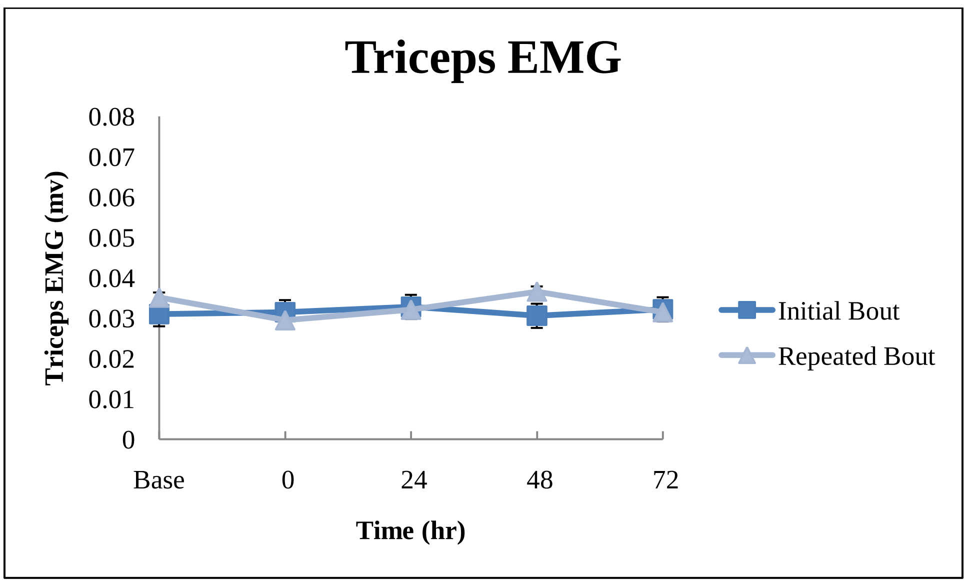

Figure 3.2.4.2 – Triceps electromyography over time. Values are mean ± SE.

3.2.5 Voluntary Muscle Activation

The omnibus ANOVA revealed a significant time main effect, GG F(3.1, 70.9)=11.209, p<0.001. Pooled across bout, Bonferroni adjusted post-hoc analysis revealed a significant decrease in the % activation from baseline at time 0, 24 and 48 hours, (p<0.05) but is recovered to baseline at time 72 hours (*p*=0.411). Without a bout x time interaction or bout main effect it would appear that % muscle activation is changing over time across all participants but is not different between bouts. (Refer to Figure 3.2.5 for a graph of biceps % activation differences).

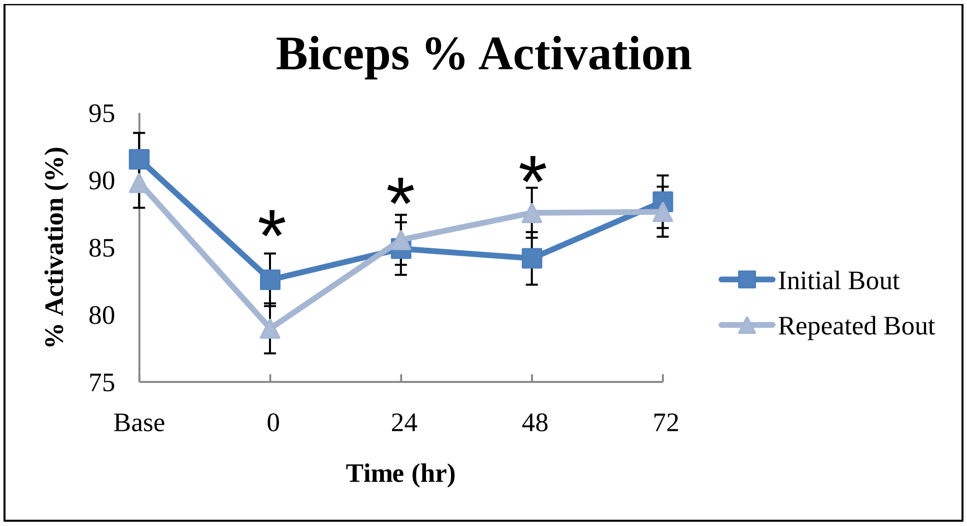

Figure 3.2.5 – Voluntary Muscle Activation over time. Values are mean ± SE
* Biceps % activation is significantly lower than baseline pooled across bout ($p<0.05$).

3.2.6 Twitch Torque

The omnibus ANOVA revealed a significant time main effect, GG $F(2.9, 86.7)=55.807$, $p<0.001$. Pooled across bout, Bonferroni adjusted post-hoc analysis revealed a significant reduction in twitch torque from baseline to time 0, 24, 48 and 72 hours ($p<0.001$). Twitch torque did not recover after 72 hours. Without a bout x time interaction or bout main effect it would appear that twitch torque is changing over time across all participants but is not different between bouts. (Refer to Figure 3.2.6 for a graph of twitch torque differences).

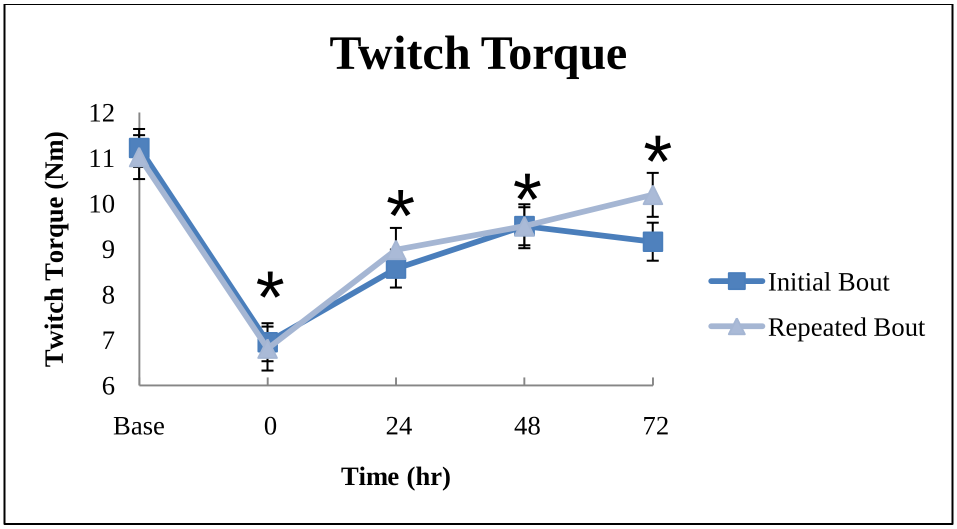

Figure 3.2.6 – Twitch Torque over time. Values are mean ± SE.
* Twitch torque is significantly lower than baseline pooled across bout (*p*<0.05).

3.3 Results for Velocity Specificity

The velocity specificity analysis was conducted in order to determine if the protective effect of a single bout of eccentric exercise is greater when the repeated bout is performed at the same velocity (SAME) of contraction compared to a different velocity (DIFF) of contraction for any of the dependant variables.

3.3.1 Isometric Strength

The omnibus ANOVA revealed a significant bout x time x group interaction, GG adjusted $F(2.4, 83.8)=3.219$, $p=0.038$. For the SAME group, there was a significant bout x time interaction, GG $F(2.1,31.6)=4.513$, $p=0.017$. Post hoc paired t-tests (Bonferroni adjustment) revealed a significant difference between bouts at time 48 hours (Initial Bout: -18.7±17.0 % reduced to Repeated Bout: -2.7±12.8 % reduced; $p=0.004$). Post hoc paired t-tests (No adjustment) also revealed a significant difference between bouts at time 24 hours, (Initial Bout: -18.0±12.4 % reduced to Repeated Bout: -10.2±12.8 % reduced; $p= 0.033$), and time 72 hours (Initial Bout: -15.5±18.0 % reduced to Repeated Bout: -0.6±17.5 % reduced; $p=0.042$). (Refer to

Figure 3.1.1.1 for a graph of MVC strength differences for the SAME velocity group). For the DIFF group there was a significant effect of time, GG $F(1.6,22.6)=35.9$, $p<0.001$. Please refer to Figure 3.1.1.2 for a graph of MVC strength differences for the DIFF velocity group. Also, refer to appendix E for MVC strength raw data.

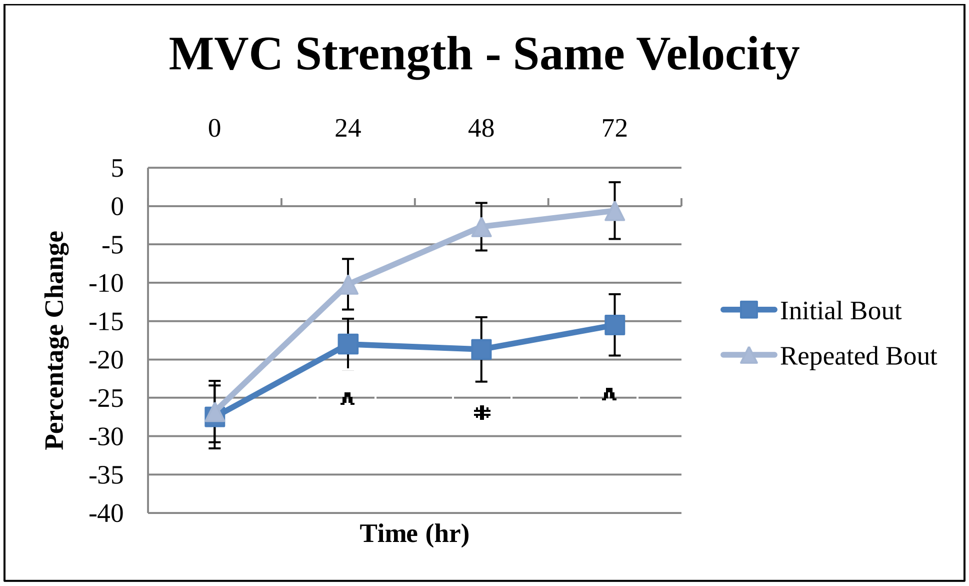

Figure 3.3.1.1 - MVC strength over time. Values are % change mean ± SE
* Initial bout is significantly different than repeated bout ($p<0.017$). Bonferroni adjusted.
^ Indicates significant difference between initial and repeated bout ($p<0.05$) Unadjusted.

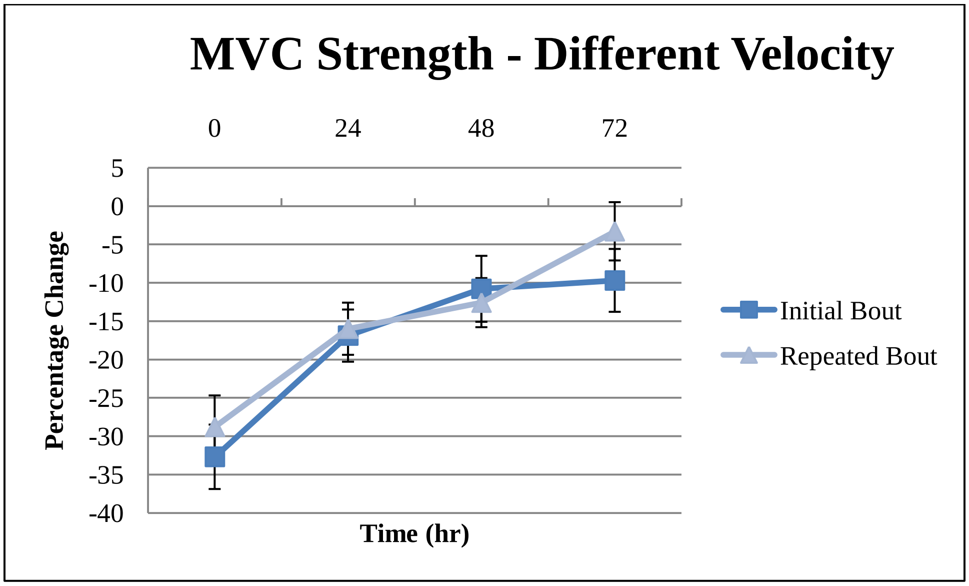

Figure 3.3.1.2 - MVC strength over time. Values are % change mean ± SE

3.3.2 Muscle Thickness

The omnibus ANOVA revealed a significant bout main effect, GG $F(1.0, 29.0)=7.051$, $p=0.013$. With no interaction or group main effect it appears that pooled across participants there is a difference between the initial and repeated bouts with no difference between groups. There was also a significant time main effect GG $F(2.3, 65.5)=24.993$, $p<0.001$. Refer to Figure 3.3.2.1 for a graph of muscle thickness differences for the SAME group. Refer to Figure 3.3.2.2 for a graph of muscle thickness differences for the DIFF group. Also, refer to appendix F for muscle thickness raw data.

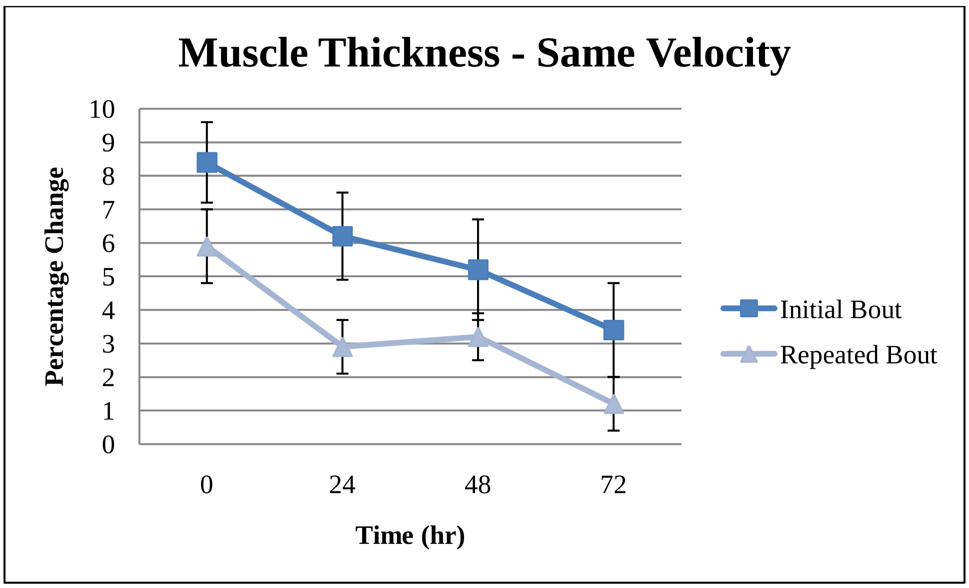

Figure 3.3.2.1 - Muscle thickness over time. Values are % change mean ± SE

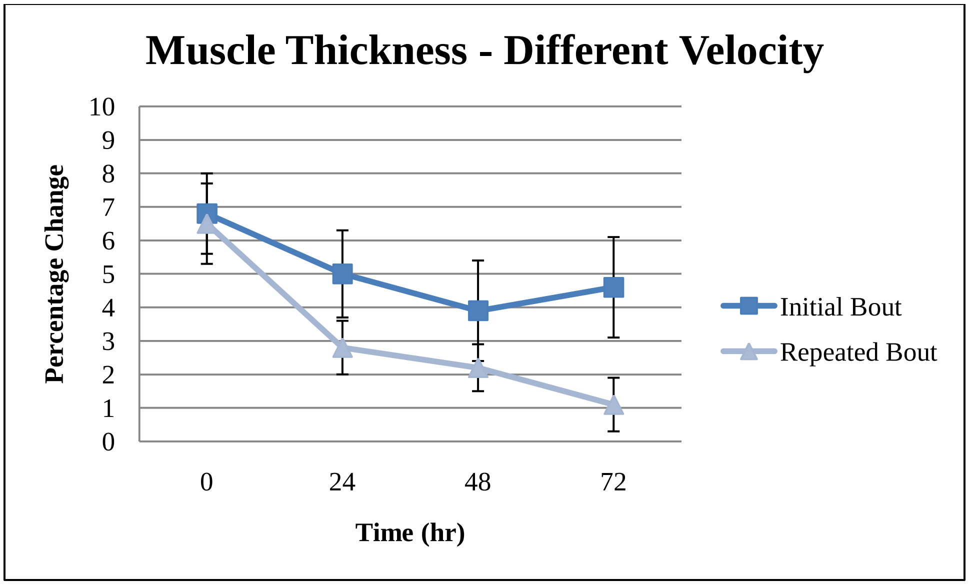

Figure 3.3.2.2 - Muscle thickness over time. Values are % change mean ± SE

3.3.3 Muscle Soreness

Muscle Soreness (Belly)

The omnibus ANOVA revealed a significant bout x time interaction, GG $F(2.3, 67.0)=4.782$, $p=0.008$. This is the same result we have shown previously for the pooled data. There is no difference between the SAME and DIFF velocity groups for muscle soreness. For the initial bout, Bonferroni adjusted post-hoc analysis revealed a significant increase in muscle soreness from baseline at time 0, 24, 48 and 72 hours ($p<0.05$). There was no difference in soreness between 24, 48, and 72 hours (p<0.05). For the repeated bout, Bonferroni adjusted post-hoc analysis revealed a significant increase in muscle soreness from baseline at time 24, 48 and 72 hours ($p<0.05$). There was no difference in soreness between 24, 48, and 72 hours (p<0.05). Refer to Figure 3.3.3.1 for a graph of muscle belly soreness differences for the SAME group. Refer to Figure 3.3.3.2 for graphs of muscle belly soreness differences for the DIFF group.

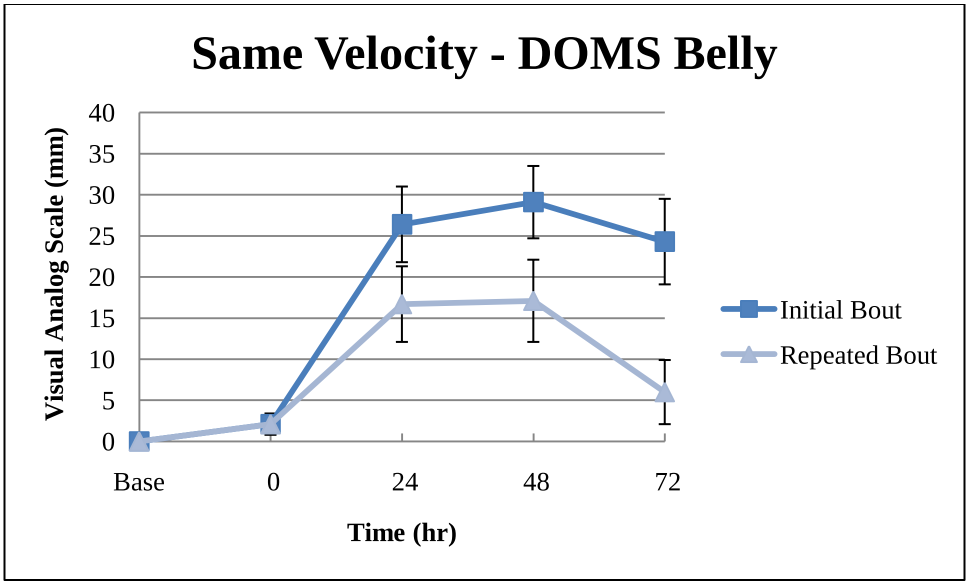

Figure 3.3.3.1 – Muscle soreness over time (Belly). Values are mean ± SE.

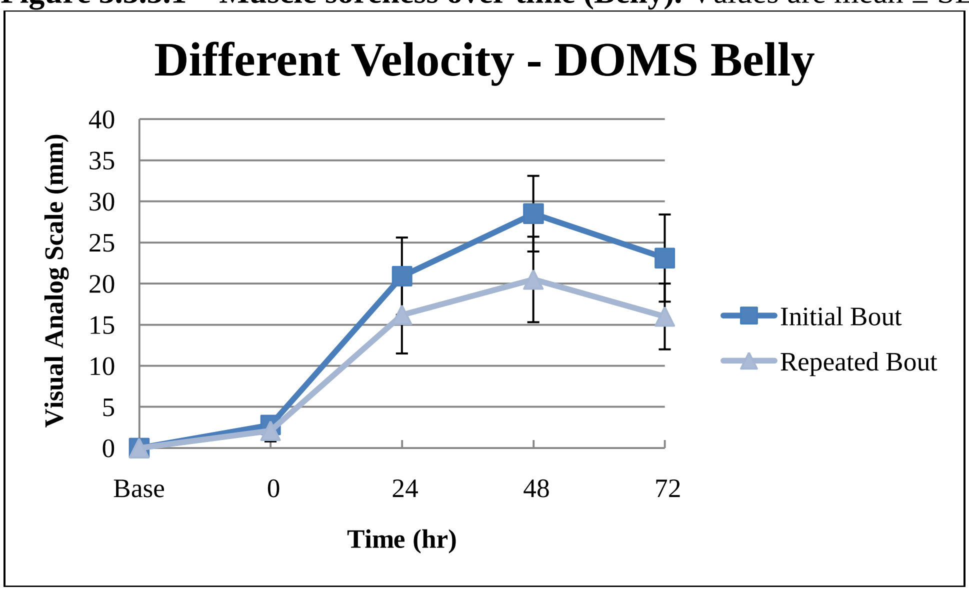

Figure 3.3.3.2 – Muscle soreness over time (Belly). Values are mean ± SE.

Muscle Soreness (Most Sore)

The omnibus ANOVA revealed a significant bout x time interaction, GG $F(2.7, 78.7)=7.888$, $p<0.001$. This is the same result we have shown previously for the pooled data (refer to graph 3.2.3.1). There is no difference between the SAME and DIFF velocity groups for muscle soreness. For the initial bout, Bonferroni adjusted post-hoc analysis revealed a significant increase in muscle soreness from baseline to time 0, 24, 48 and 72 hours ($p<0.05$). There was no difference in soreness between 24, 48, hours ($p<0.05$) but there was a reduction in soreness from 48 to 72 hours ($p<0.05$). For the repeated bout, Bonferroni adjusted post-hoc analysis revealed a significant increase in muscle soreness from baseline at time 24, 48, 72 ($p<0.05$). There was no difference in soreness between 24, 48, and 72 hours (p<0.05) (Refer to Figure 3.3.3.3 for a graph of muscle soreness differences for the SAME group. Refer to figure 3.3.3.4 for a graph of muscle soreness differences the DIFF group.

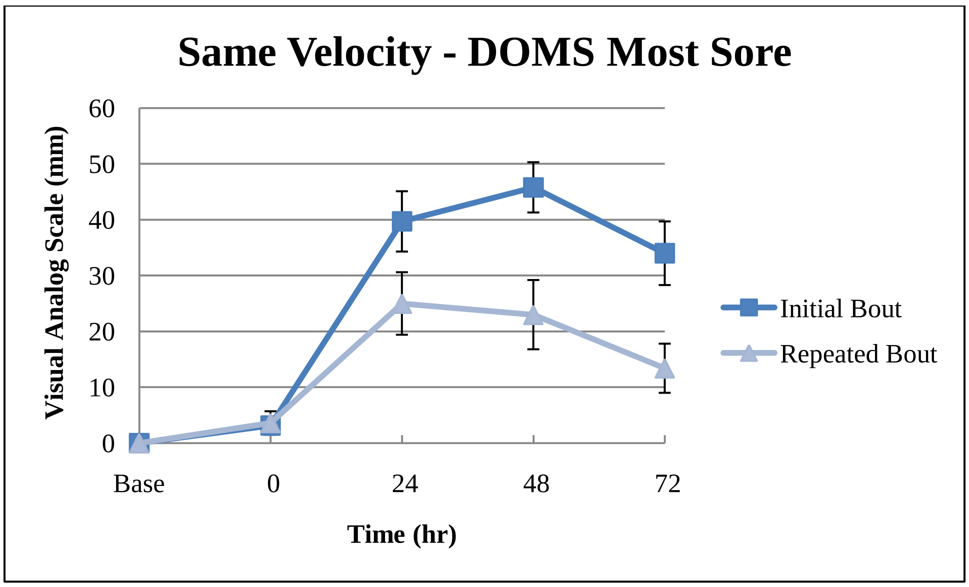

Figure 3.3.3.3 – Muscle soreness over time. Values are mean ± SE.

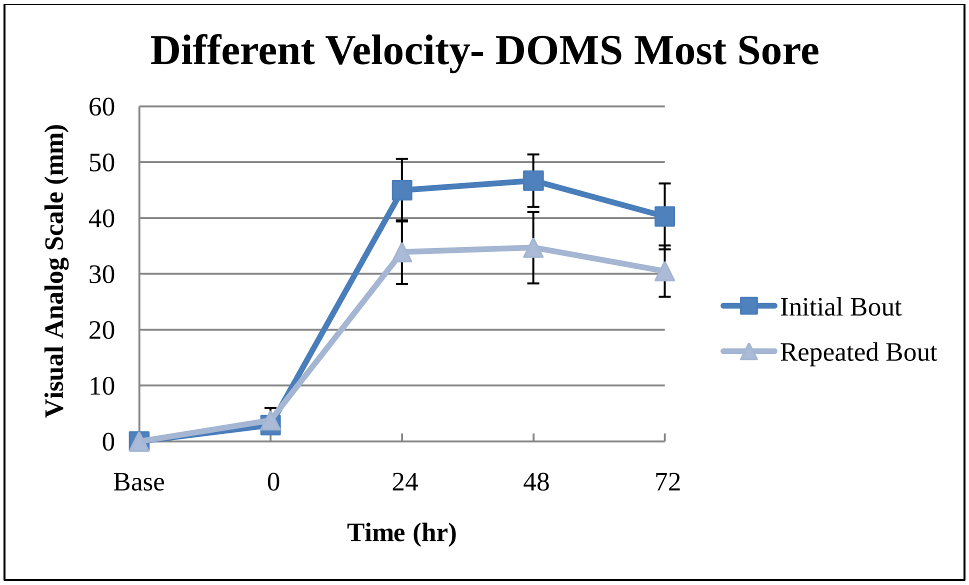

Figure 3.3.3.4 – Muscle soreness over time. Values are mean ± SE.

3.3.4 Electromyography

The omnibus ANOVA revealed a trend towards a bout main effect, GG $F(1.0, 29.0)=4.118$, $p=0.052$. Pooled across participants there is a trend for biceps EMG amplitude (MAV) to increase after the repeated bout of exercise. There was also a significant time main effect GG $F(2.3, 66.1)=5.730$, $p=0.004$. (Refer to Figure 3.3.4.1 and 3.3.4.2 for graphs of Biceps EMG differences for the SAME and DIFF groups respectively). For triceps EMG, there are no interactions, or main effects to report. Triceps EMG activation did not change over time, between bouts, or differ among groups. (Refer to Figure 3.3.4.3 and 3.3.4.4 for graphs of triceps EMG differences)

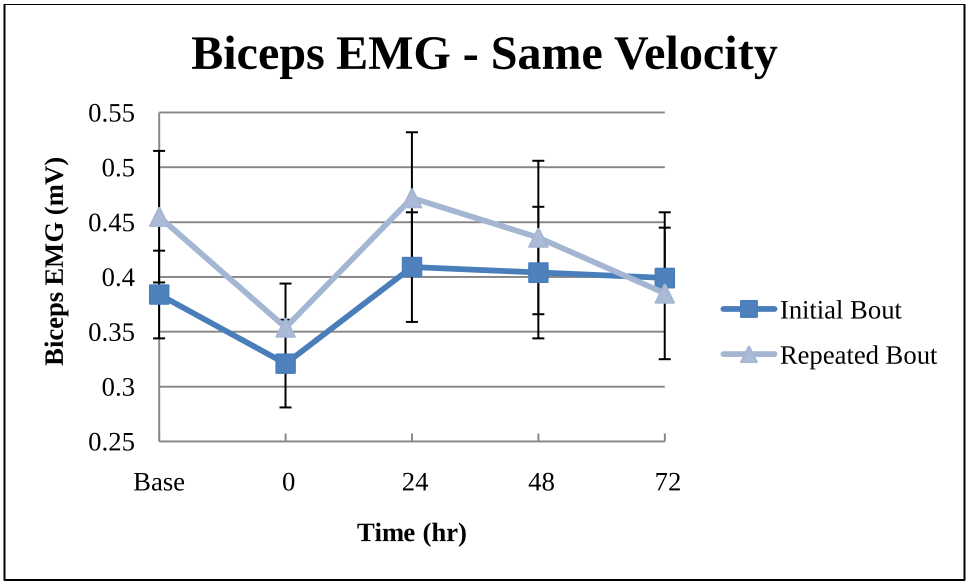

Figure 3.3.4.1 – Biceps electromyography over time. Values are mean ± SE

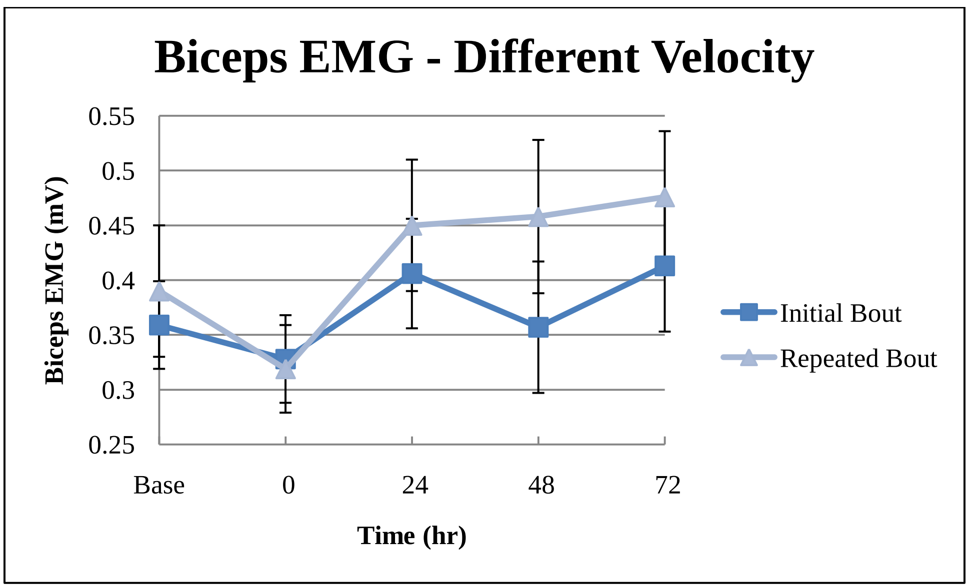

Figure 3.3.4.2 – Biceps electromyography over time. Values are mean ± SE

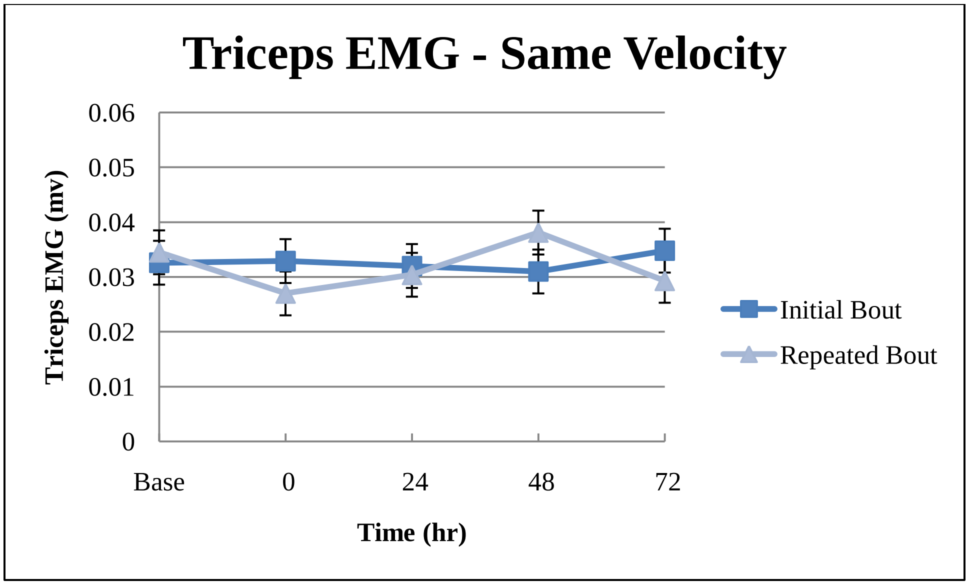

Figure 3.3.4.3 – Triceps electromyography over time. Values are mean ± SE.

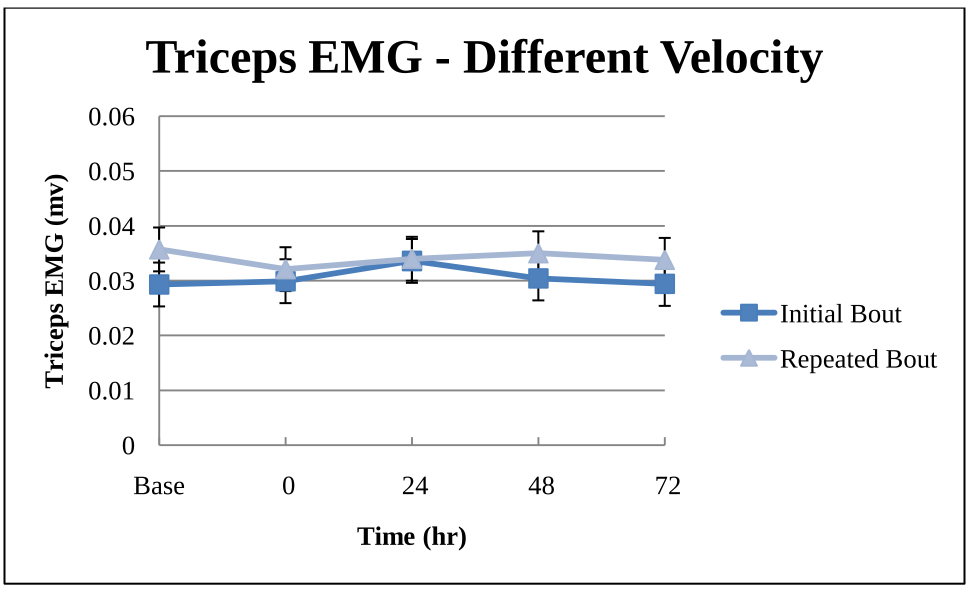

Figure 3.3.4.4 – Triceps electromyography over time. Values are mean ± SE.

3.3.5 Voluntary Muscle Activation

The omnibus ANOVA revealed a significant time main effect, GG $F(3.1, 89.2)=11.025$, $p<0.001$. (Refer to Figures 3.3.5.1 and 3.3.5.2 for graphs of biceps % activation differences for SAME and DIFF velocity groups respectively).

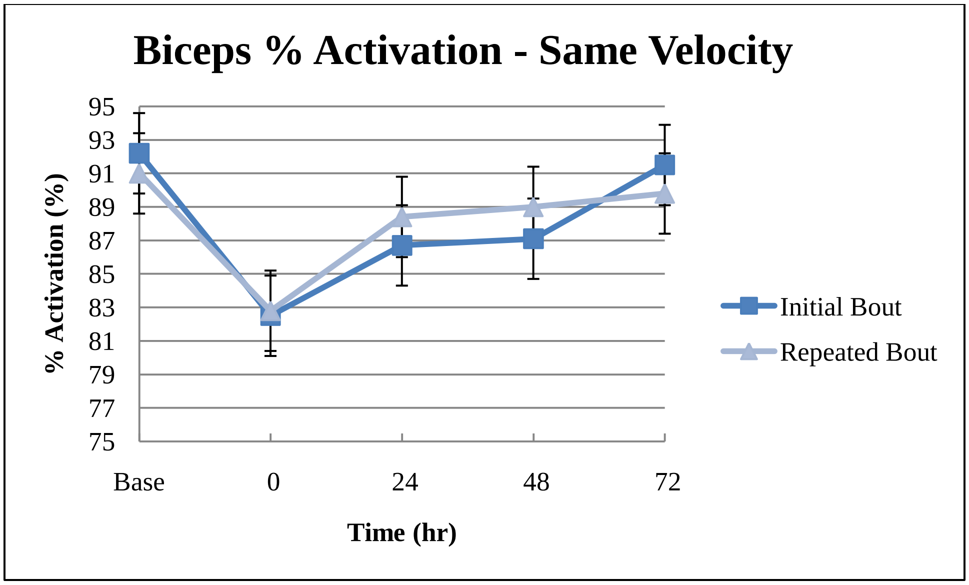

Figure 3.3.5.1 – Voluntary muscle activation over time. Values are mean ± SE

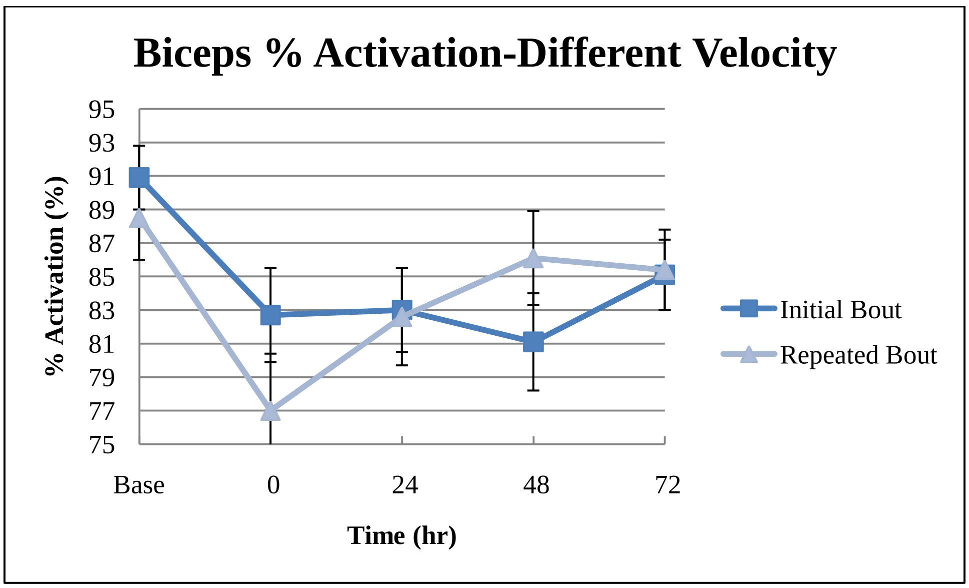

Figure 3.3.5.1 – Voluntary Muscle Activation. Values are mean ± SE

3.3.6 Twitch Torque

The omnibus ANOVA revealed a significant time main effect, GG $F(2.9, 83.4)=54.337$, $p<0.001$. Without an interaction or main effect of bout or group it would appear that twitch torque is changing over time across all participants but is not different between bouts or different between the SAME and DIFF groups. (Refer to Figures 3.3.6.1 and 3.3.6.2 for graphs of muscle soreness differences for SAME and DIFF velocity groups respectively).

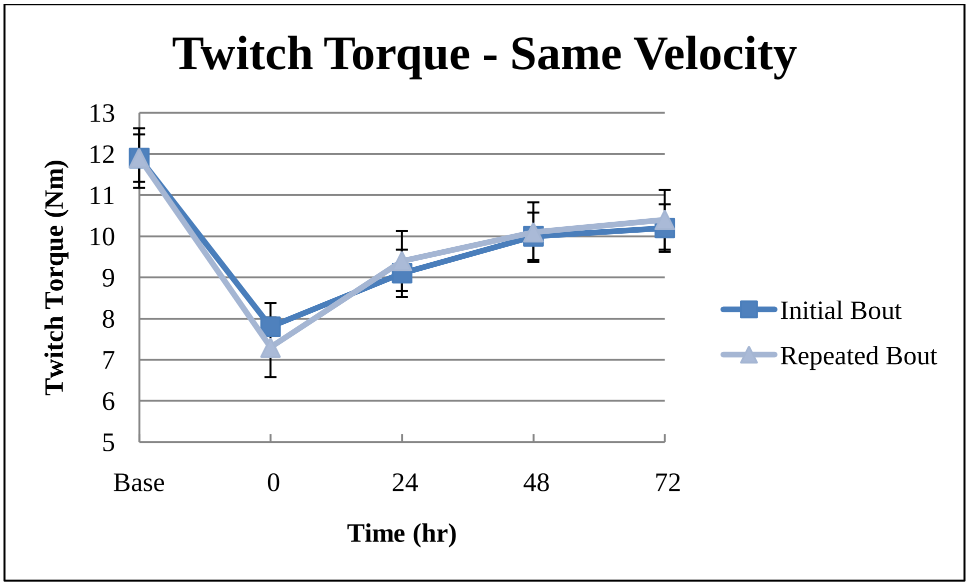

Figure 3.3.6.1 – Twitch torque over time. Values are mean ± SE.

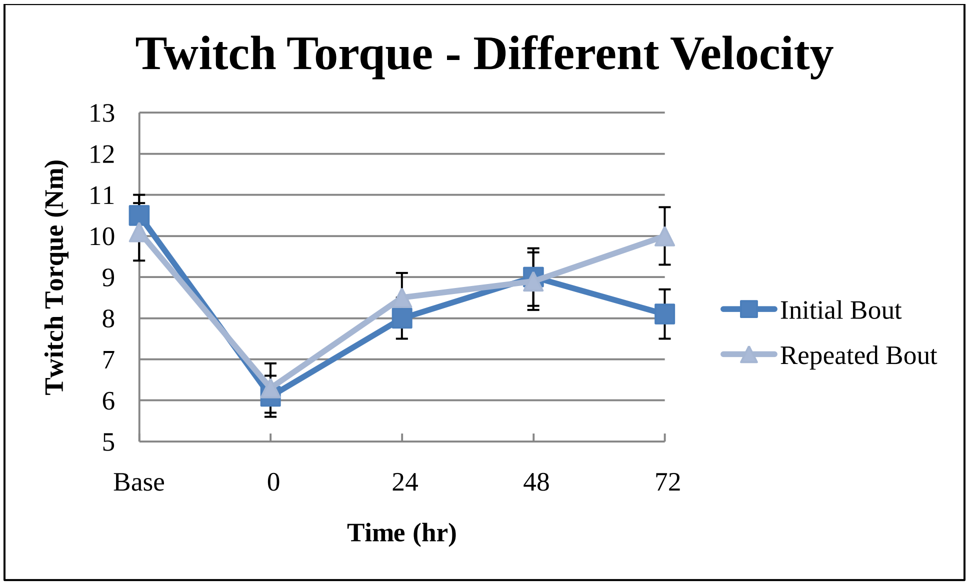

Figure 3.3.6.1 – Twitch torque over time. Values are mean ± SE.

3.4 Results for Velocity of Contraction (Four group model)

The four group analysis was completed in order to determine if there a difference in the magnitude of the repeated bout effect depending on whether the initial bout of eccentric exercise was performed at a fast or slow velocity for any of the dependant variables.

3.4.1 Isometric Strength

The omnibus ANOVA revealed a significant group x time interaction, GG $F(6.0, 54.4)=3.515$, $p=0.005$. Bonferroni adjusted post-hoc analysis revealed a greater reduction in strength for the SLOW-SLOW group compared to the FAST-FAST group at time 0 ($p=0.003$). As well, there was a greater reduction in strength for the FAST-SLOW group compared to the FAST-FAST group at time 0 ($p=0.43$). There was also a significant bout main effect, GG $F(1.0, 27.0)=6.205$, $p=0.019$. Pooled across group and time, the repeated bout had a smaller decrease in torque compared to the initial bout which indicates a repeated bout effect did occur. Refer to Figure 3.4.1.1 for a graph of MVC strength differences for the SLOW-SLOW velocity group. Refer to Figure 3.4.1.2 for a graph of MVC strength differences for the SLOW-FAST velocity group. Refer to Figure 3.4.1.3 for a graph of MVC strength differences for the FAST-SLOW velocity group). Refer to Figure 3.4.1.4 for a graph of MVC strength differences for the FAST-FAST velocity group. Refer to appendix E for MVC strength raw data.

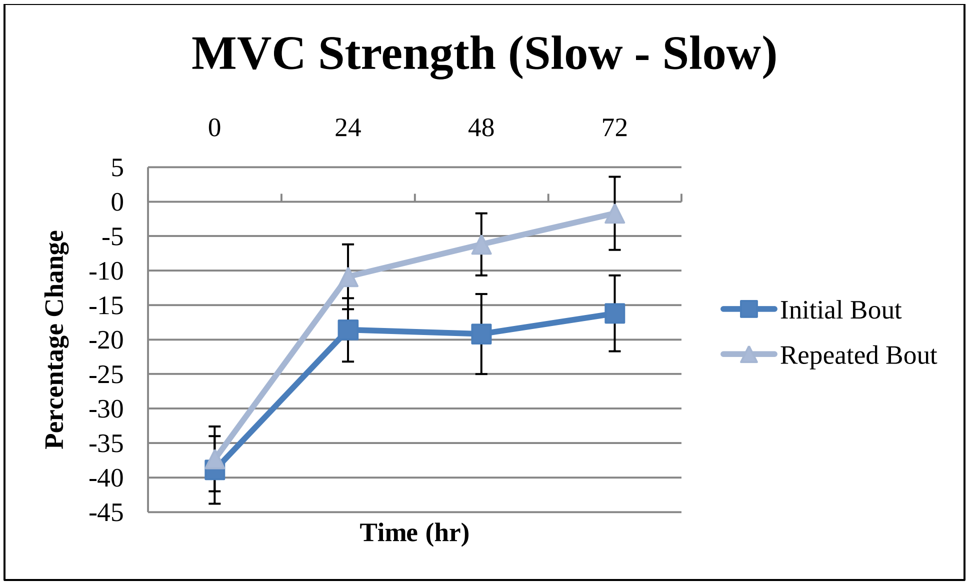

Figure 3.4.1.1 - MVC strength over time. Values are % change mean ± SE

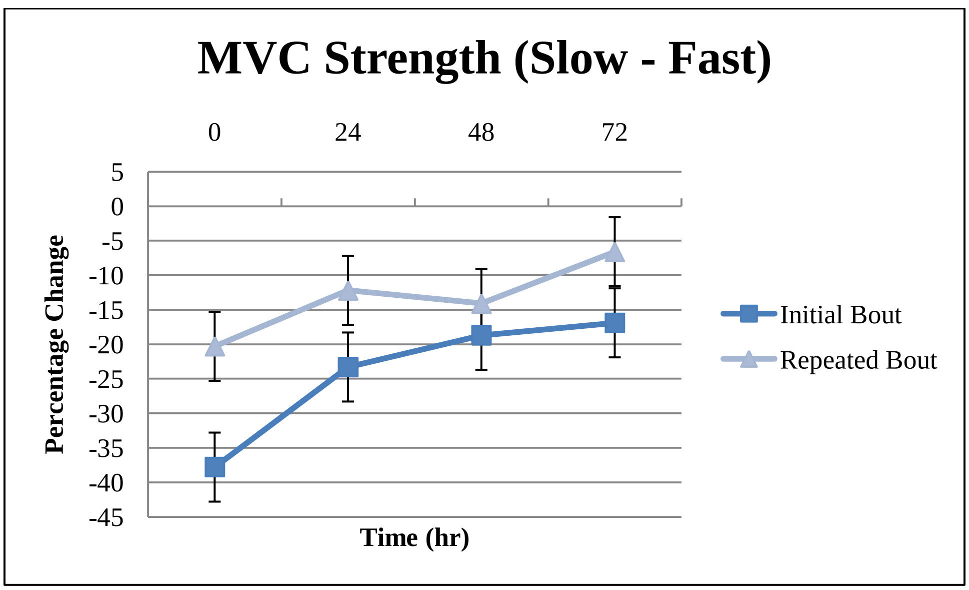

Figure 3.4.1.2 - MVC strength over time. Values are % change mean ± SE

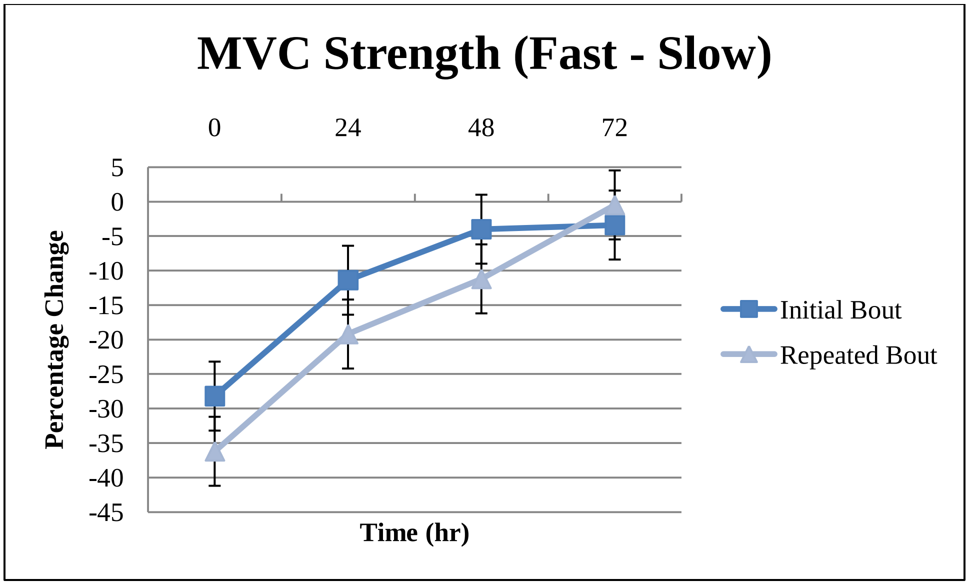

Figure 3.4.1.3 - MVC strength over time. Values are % change mean ± SE

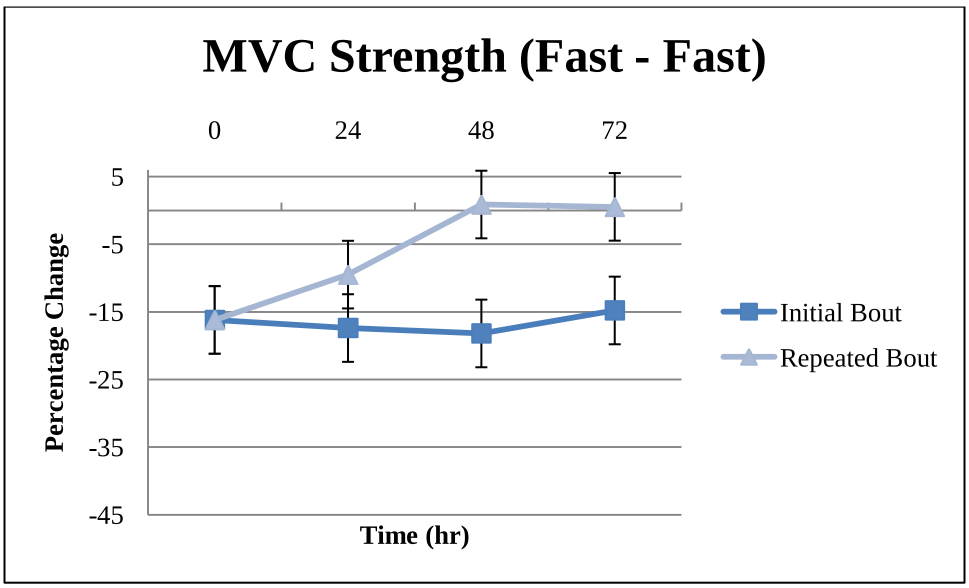

Figure 3.4.1.4 - MVC strength over time. Values are % change mean ± SE

3.4.2 Muscle Thickness

The omnibus ANOVA revealed a significant bout main effect, GG $F(1.0, 27.0)=6.925$, $p=0.014$. Pooled across group and time, the repeated bout had less increase in muscle thickness compared to the initial bout which indicates a repeated bout effect did occur. There was also a significant time main effect GG $F(2.2, 59.1)=24.163$, $p<0.001$. Pooled across bout and group, Bonferroni adjusted post-hoc analysis revealed a significant reduction in muscle thickness from time 0 to time 24 hours ($p=0.002$) and from time 48 to time 72 hours ($p=0.007$). (Refer to Figure 3.4.2.1 and 3.4.2.2, 3.4.2.3, and 3.4.2.4 for graphs of muscle thickness differences for the SLOW-SLOW, SLOW-FAST, FAST-SLOW, and FAST-FAST velocity groups respectively). Refer to appendix F for muscle thickness raw data.

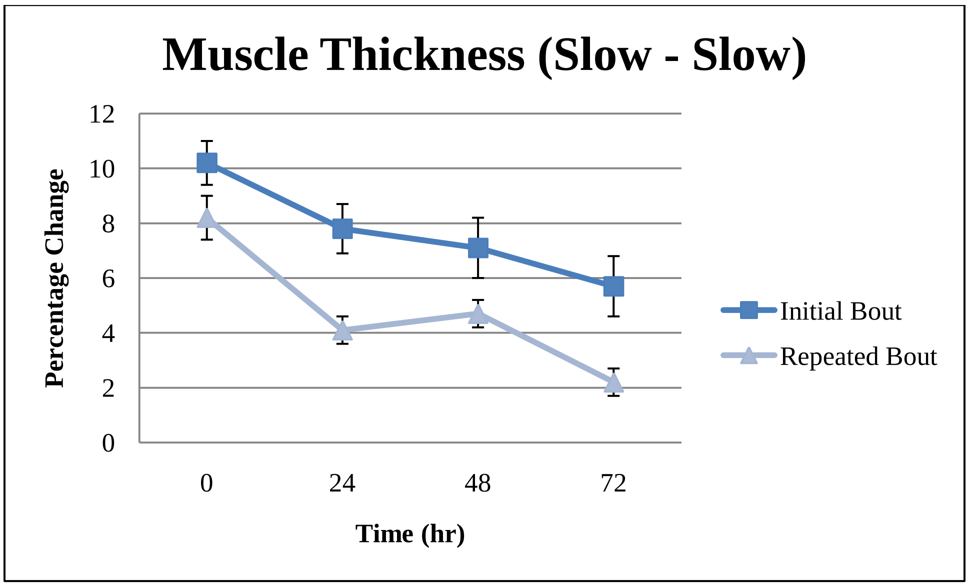

Figure 3.4.2.1 - Muscle thickness over time. Values are % change mean ± SE

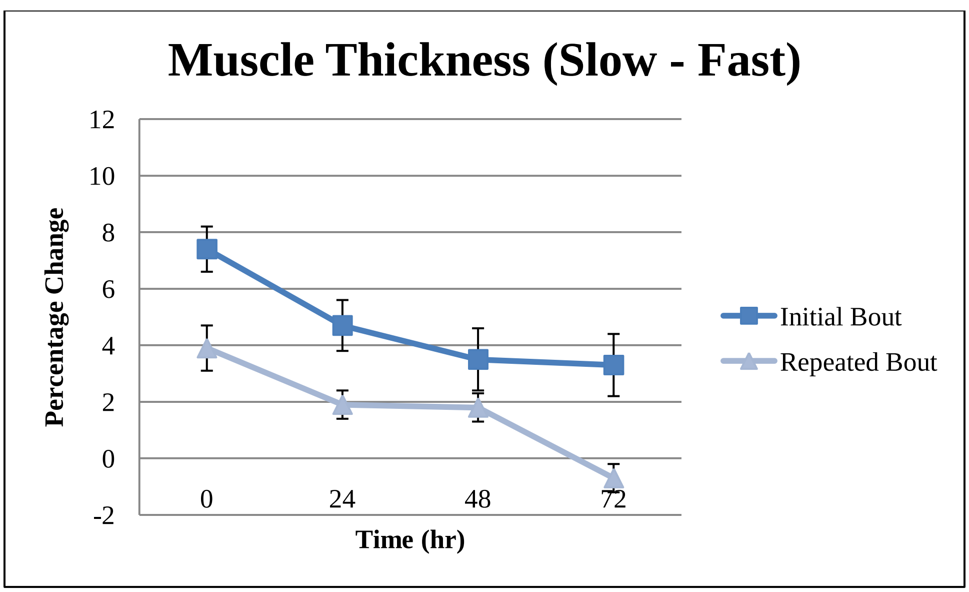

Figure 3.4.2.2 - Muscle thickness over time. Values are % change mean ± SE

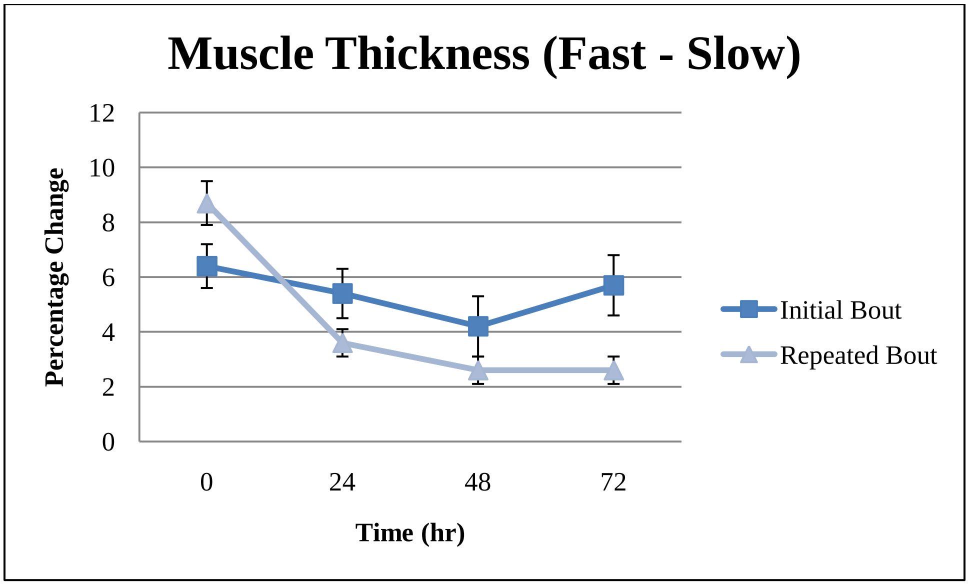

Figure 3.4.2.3 - Muscle thickness over time. Values are % change mean ± SE

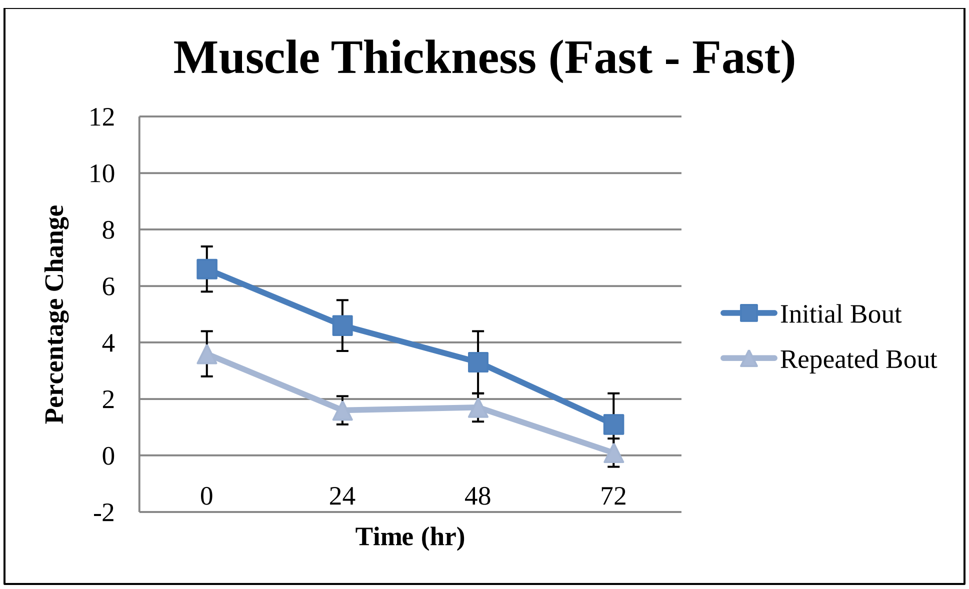

Figure 3.4.2.4 - Muscle thickness over time. Values are % change mean ± SE

3.4.3 Muscle Soreness

Muscle Soreness (Belly)

The omnibus ANOVA revealed a significant bout x time interaction, GG $F(2.3, 61.2)=4.707$, $p=0.01$. The four groups did not change differently across bouts or time points for muscle soreness (Refer to Figures 3.4.3.1, 3.4.3.2, 3.4.3.3, and 3.4.3.4 for graphs of muscle belly soreness differences for SLOW-SLOW, SLOW-FAST, FAST-SLOW, SLOW-SLOW velocity groups respectively).

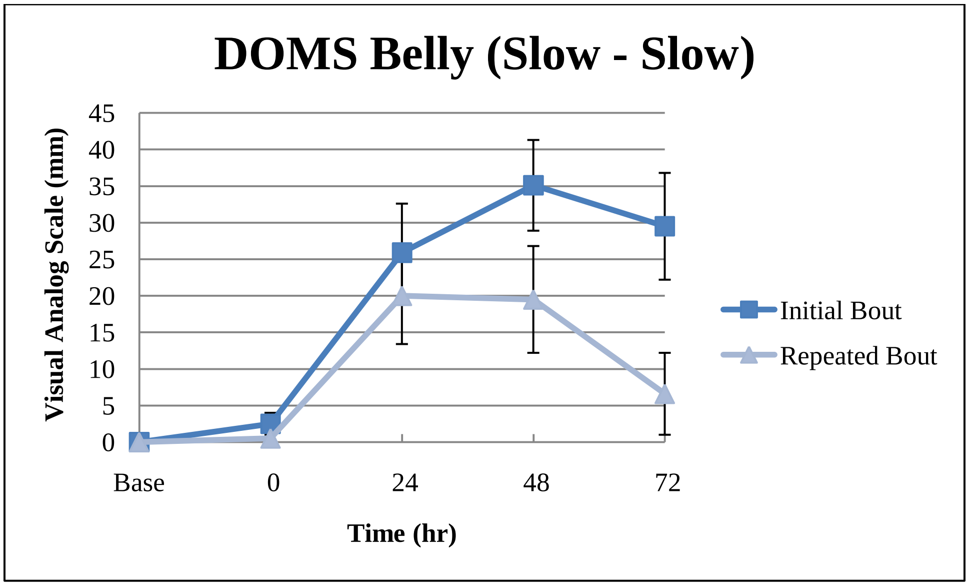

Figure 3.4.3.1 – Muscle soreness over time. Values are mean ± SE.

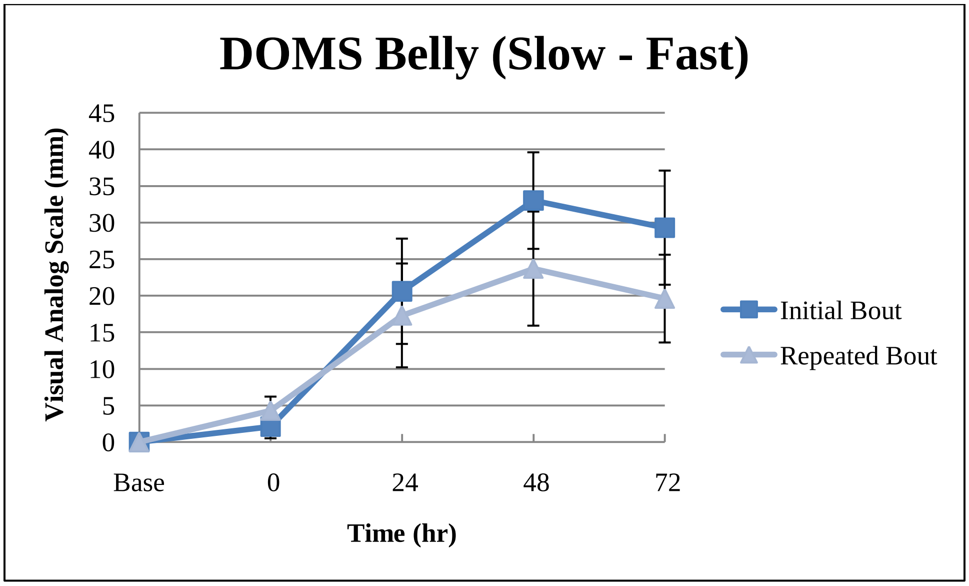

Figure 3.4.3.2 – Muscle soreness over time. Values are mean ± SE.

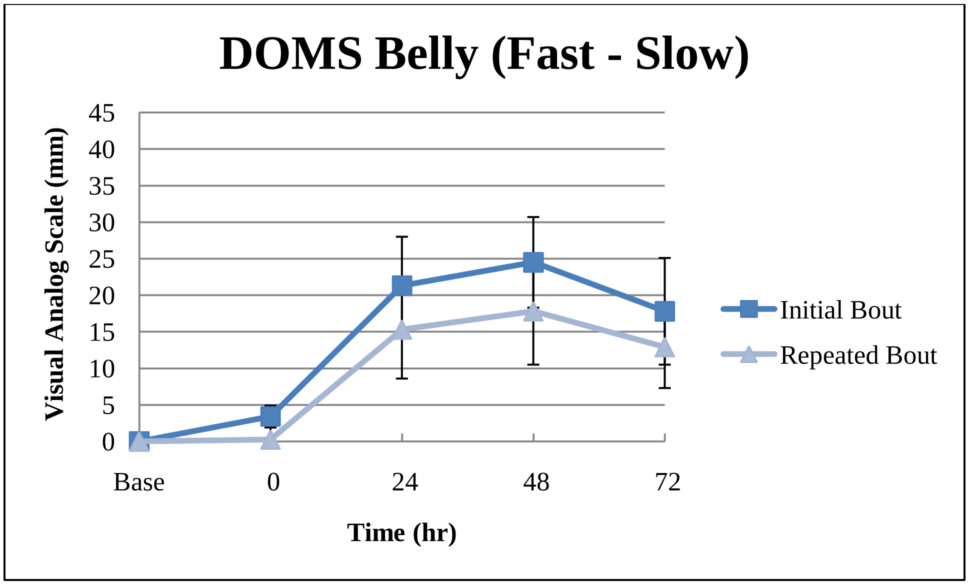

Figure 3.4.3.3 – Muscle soreness over time. Values are mean ± SE.

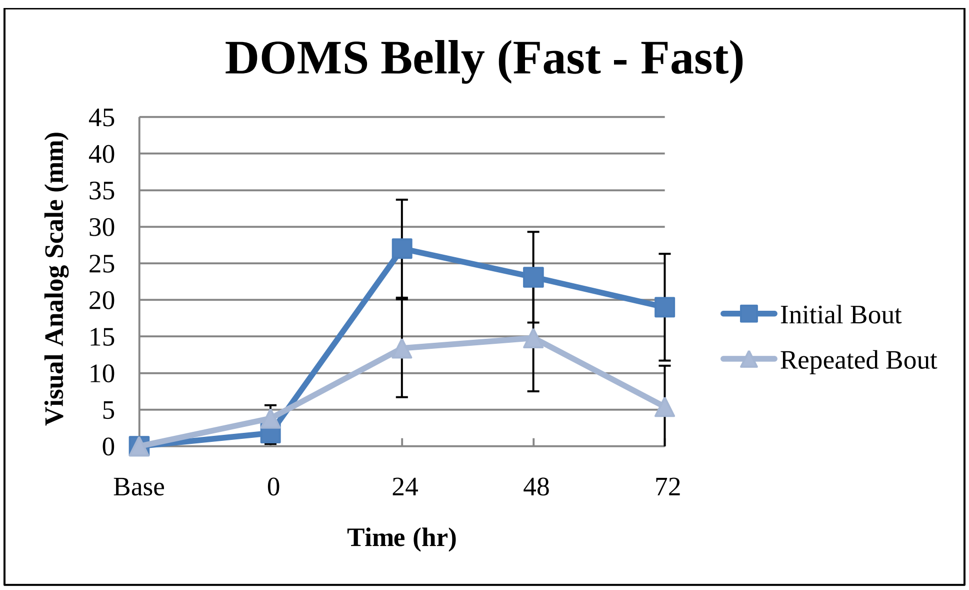

Figure 3.4.3.4 – Muscle soreness over time. Values are mean ± SE.

Muscle Soreness (Most Sore)

The omnibus ANOVA revealed a significant bout x time interaction, GG $F(2.7, 72.1)=7.854$, $p<0.001$. The groups did not change differently across bouts or time points for muscle soreness. (Refer to Figures 3.4.3.5, 3.4.3.6, 3.4.3.7, and 3.4.3.8 for graphs of muscle belly soreness differences for SLOW-SLOW, SLOW-FAST, FAST-SLOW, SLOW-SLOW velocity groups respectively).

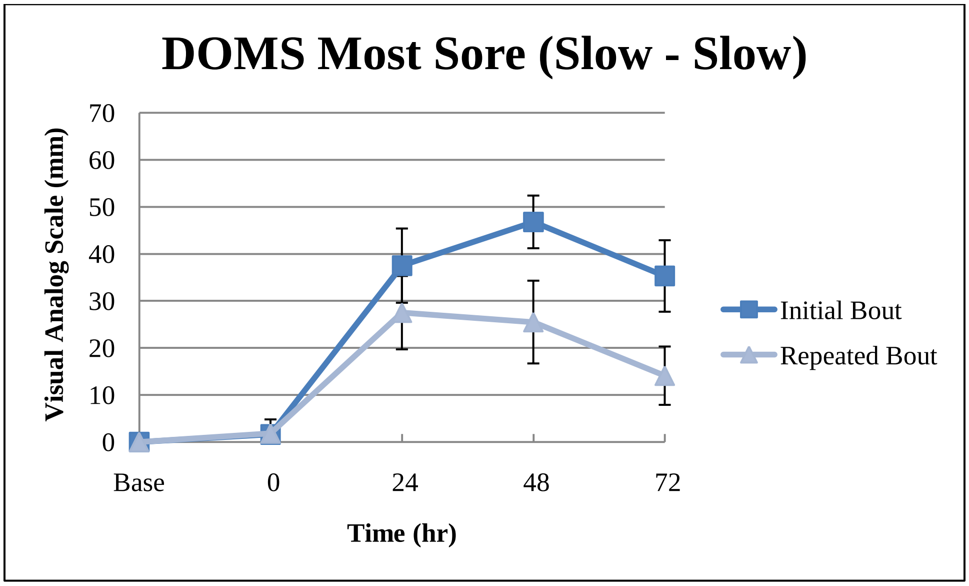

Figure 3.4.3.5 – Muscle soreness over time. Values are mean ± SE.

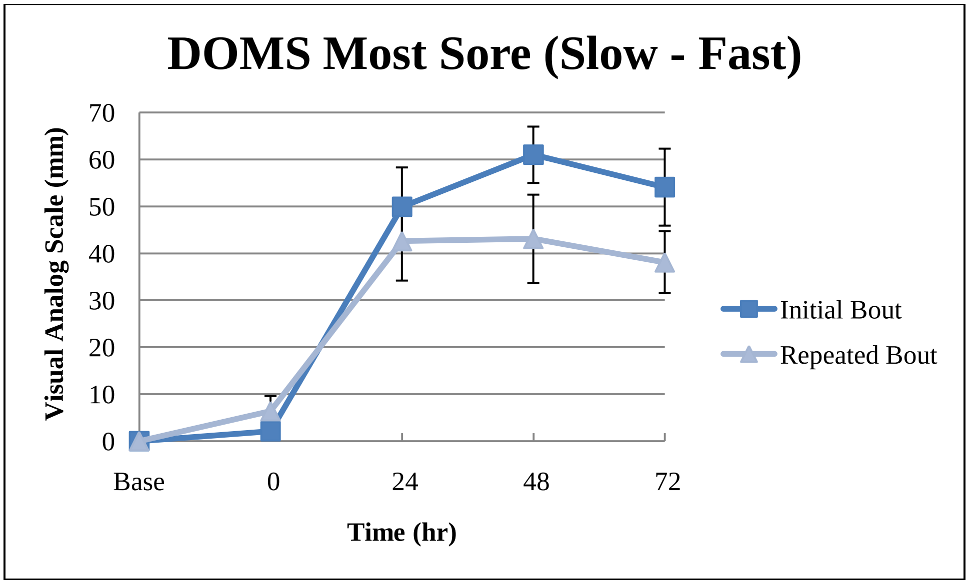

Figure 3.4.3.6 – Muscle soreness over time. Values are mean ± SE.

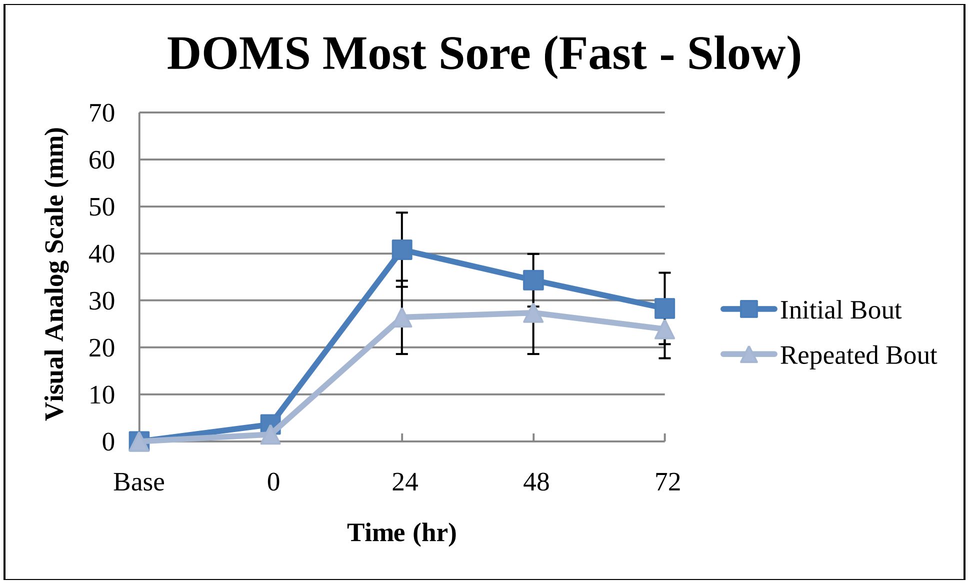

Figure 3.4.3.7 – Muscle soreness over time. Values are mean ± SE.

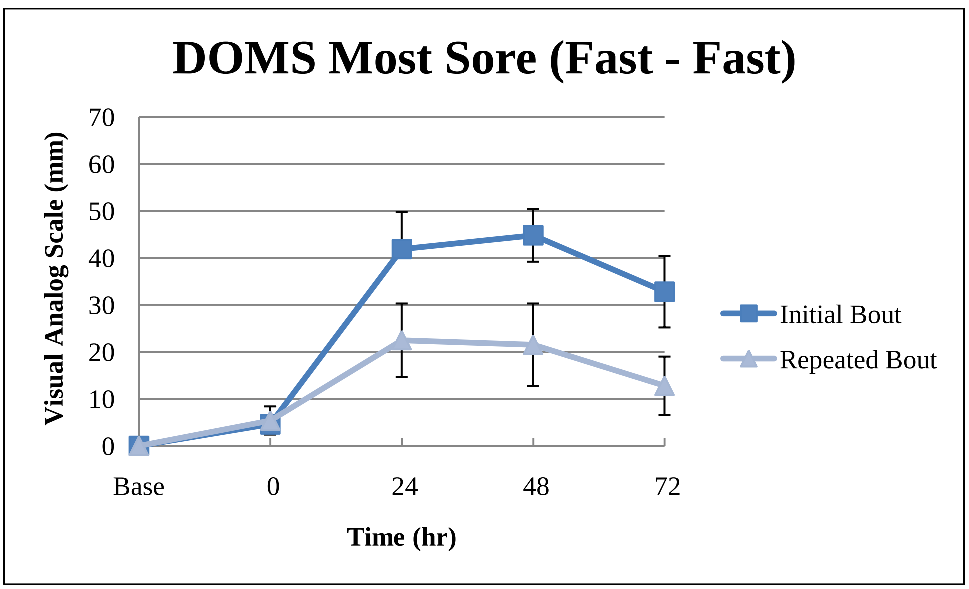

Figure 3.4.3.8 – Muscle soreness over time. Values are mean ± SE.

3.4.4 Electromyography

The omnibus ANOVA revealed a significant time main effect, GG $F(2.3, 60.8)=5.482$, $p=0.005$. Biceps EMG changed over time across all participants but did not differ between bouts or different between any of the groups. (Refer to Figure 3.4.4.1, 3.4.4.2, 3.4.4.3 and 3.4.4.4 for graphs of triceps EMG differences for SLOW-SLOW, SLOW-FAST, FAST-SLOW, FAST-FAST velocity groups). For triceps EMG, there are no interactions, or main effects to report. Triceps EMG activation did not change over time, between bouts, or differ among groups. (Refer to Figure 3.4.4.5, 3.4.4.6, 3.4.4.7 and 3.4.4.8 for graphs of triceps EMG differences for SLOW-SLOW, SLOW-FAST, FAST-SLOW, FAST-FAST velocity groups)

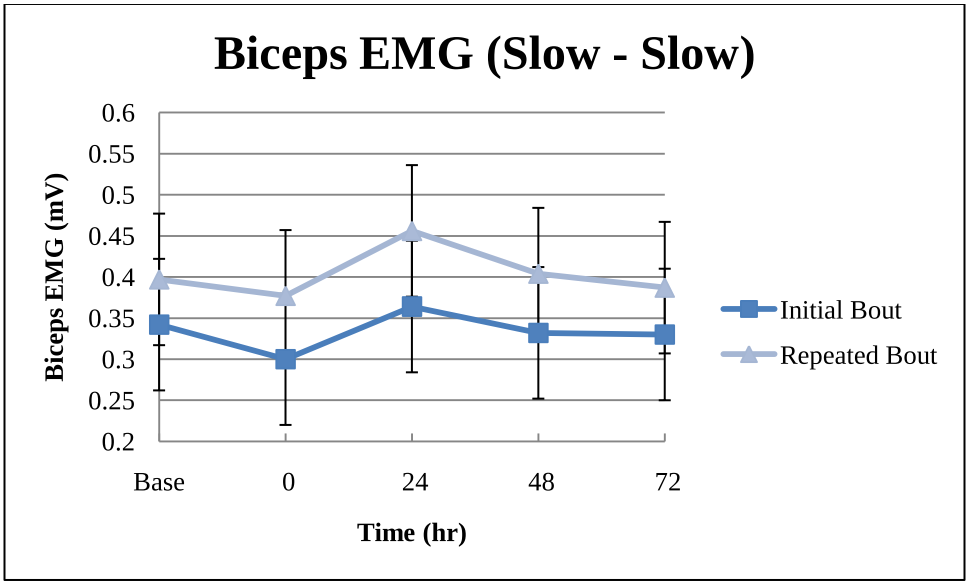

Figure 3.4.4.1 – Biceps electromyography over time. Values are mean ± SE

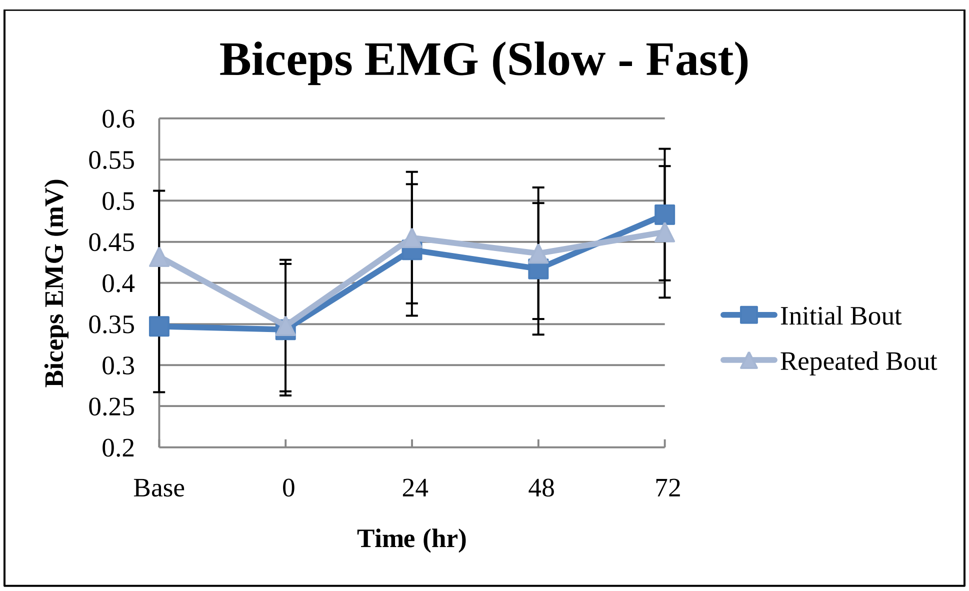

Figure 3.4.4.2 – Biceps electromyography over time. Values are mean ± SE

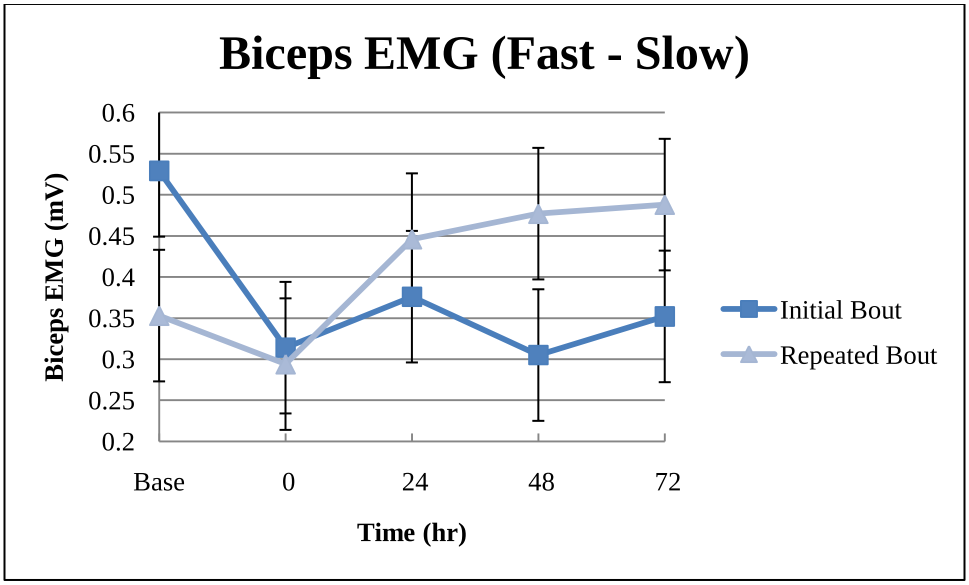

Figure 3.4.4.3 – Biceps electromyography over time. Values are mean ± SE

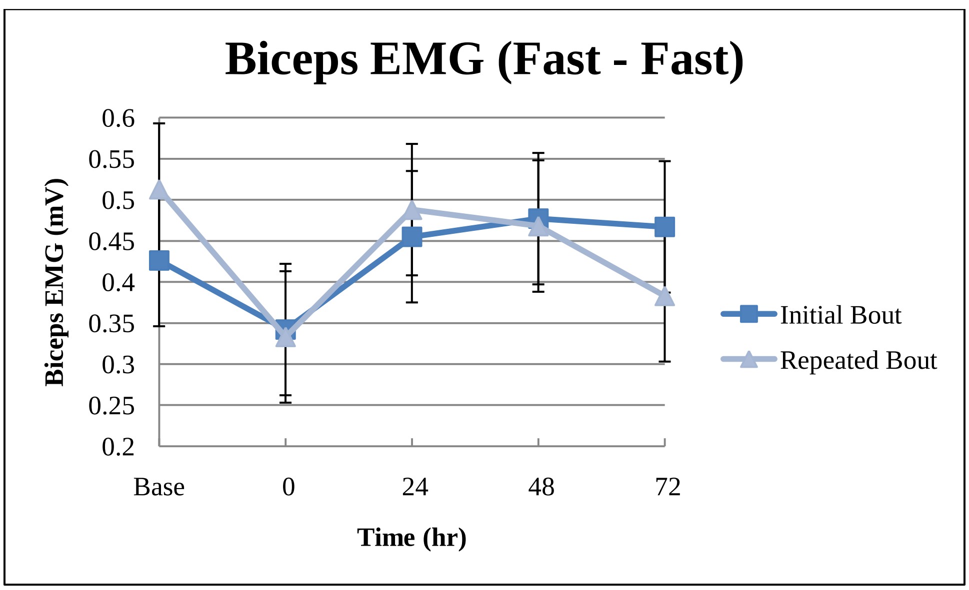

Figure 3.4.4.4 – Biceps electromyography over time. Values are mean ± SE

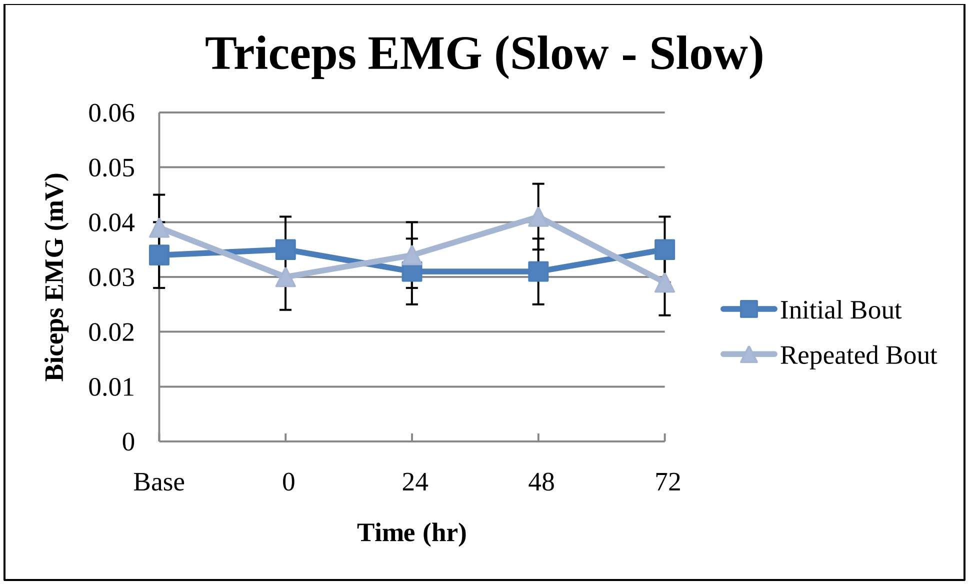

Figure 3.4.4.5 – Triceps electromyography over time. Values are mean ± SE.

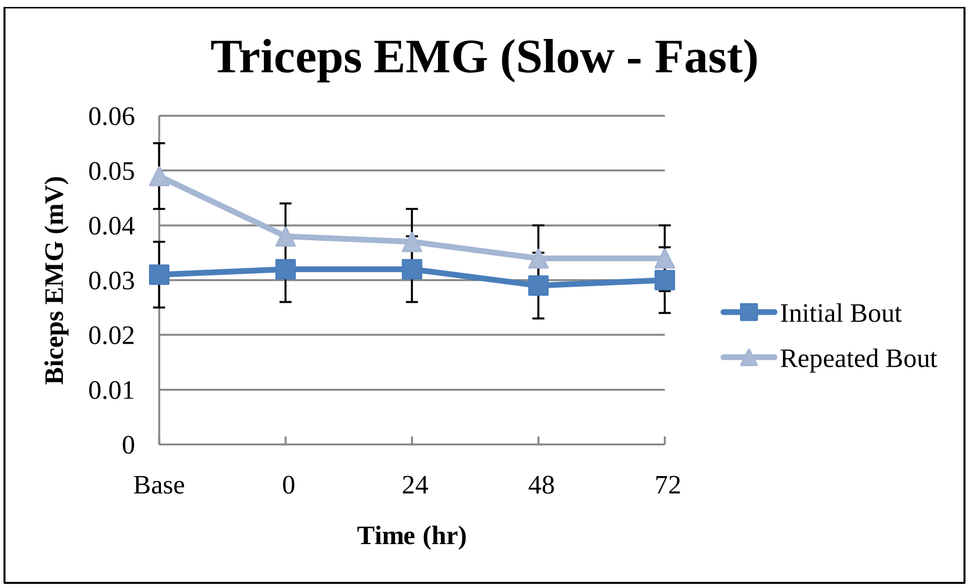

Figure 3.4.4.6 – Triceps electromyography over time. Values are mean ± SE.

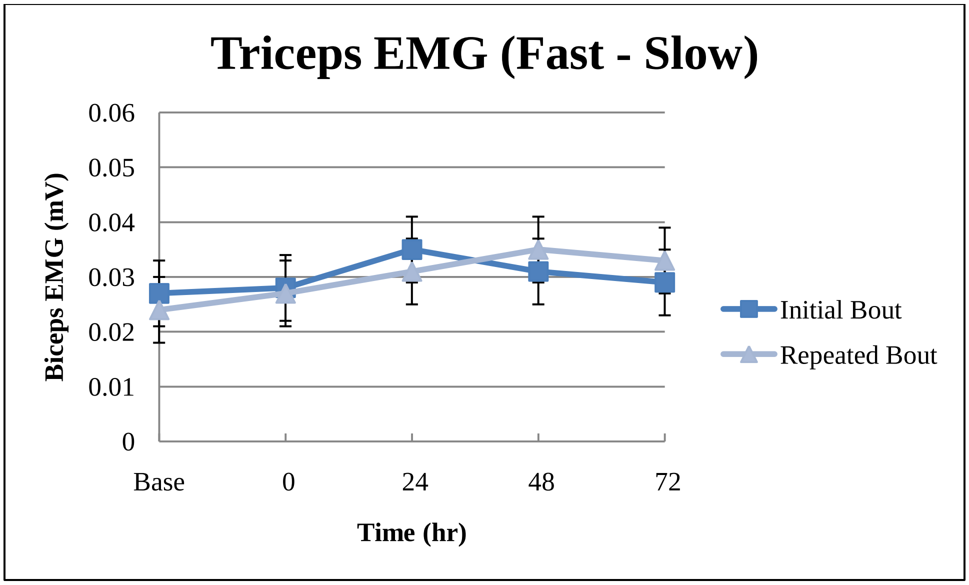

Figure 3.4.4.7 – Triceps electromyography over time. Values are mean ± SE.

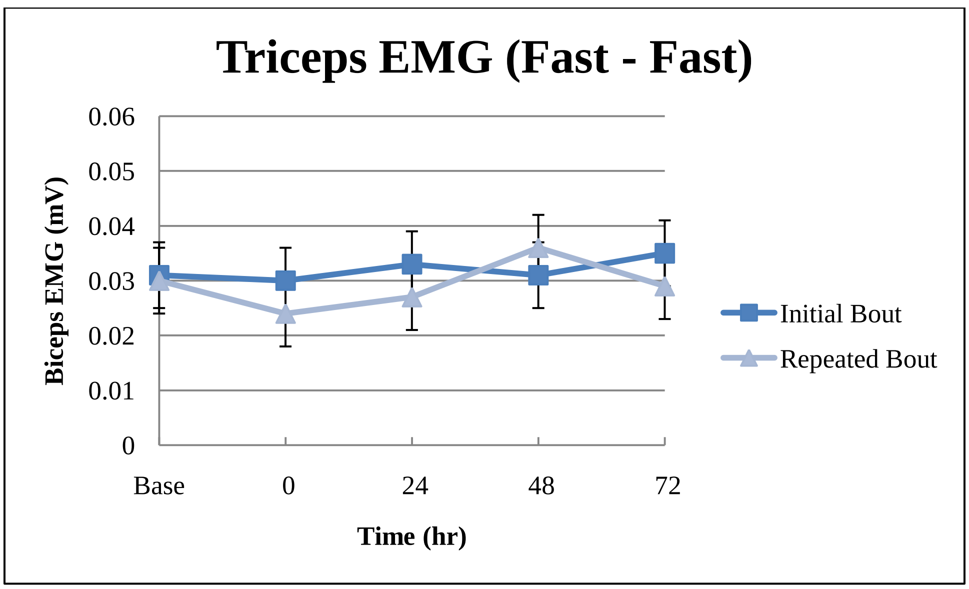

Figure 3.4.4.8 – Triceps electromyography over time. Values are mean ± SE.

3.4.5 Voluntary Muscle Activation

The omnibus ANOVA revealed a group x bout interaction, GG $F(3.0,27.0)=4.158$, $p=0.015$, and a significant time main effect, GG $F(2.9, 79.0)=10.749$, $p<0.001$. After the initial bout, pooled across time there were no differences in % activation between groups ($p>0.05$).

After the repeated bout, pooled across time FAST-FAST group had significantly higher % activation than the FAST-SLOW group. (Refer to Figures 3.4.5.1, 3.4.5.2, 3.4.5.3, and 3.4.5.4 for graphs of biceps % activation differences for SLOW-SLOW, SLOW-FAST, FAST-SLOW, SLOW-SLOW velocity groups respectively).

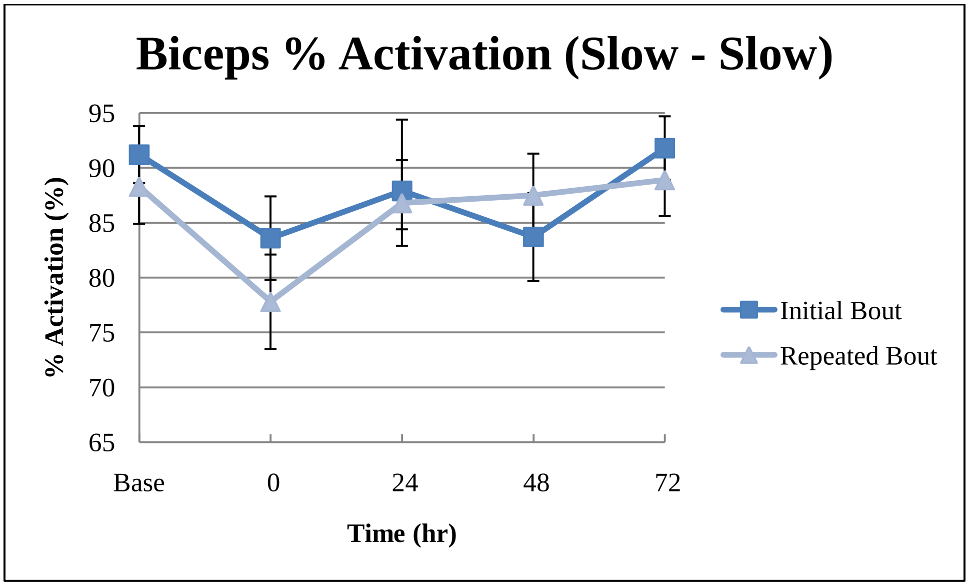

Figure 3.4.5.1 – Voluntary muscle activation over time. Values are mean ± SE

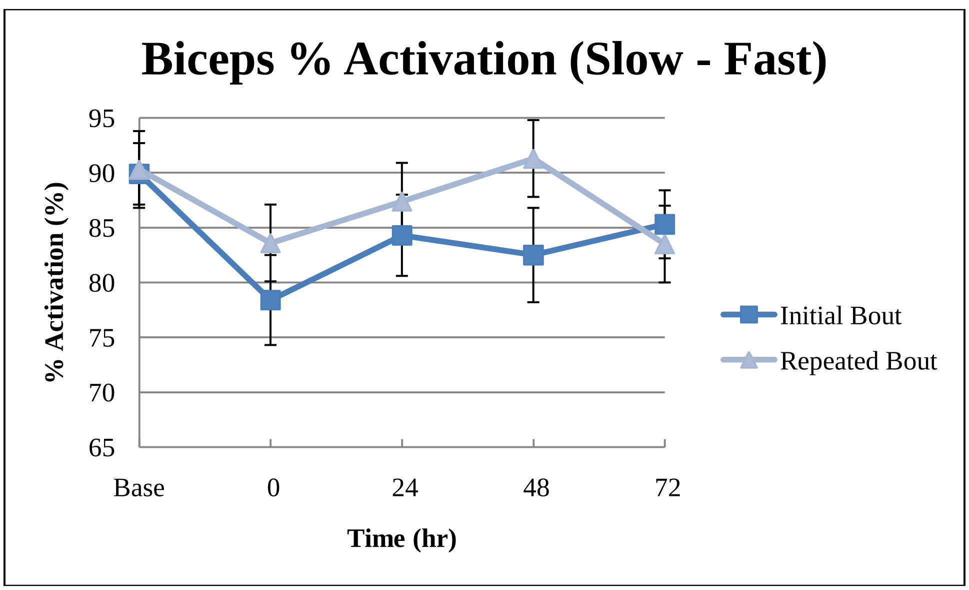

Figure 3.4.5.2 – Voluntary muscle activation over time. Values are mean ± SE

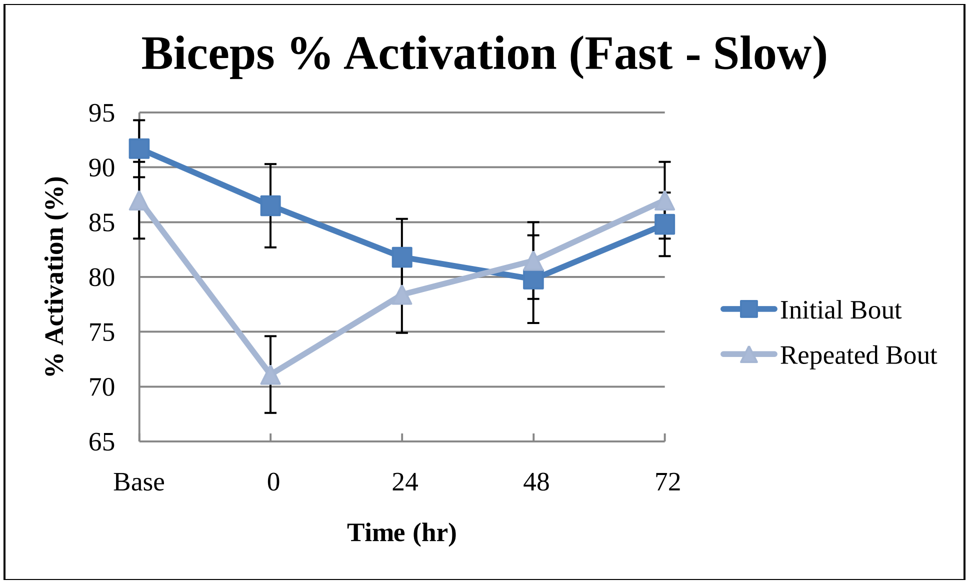

Figure 3.4.5.3 – Voluntary muscle activation over time. Values are mean ± SE

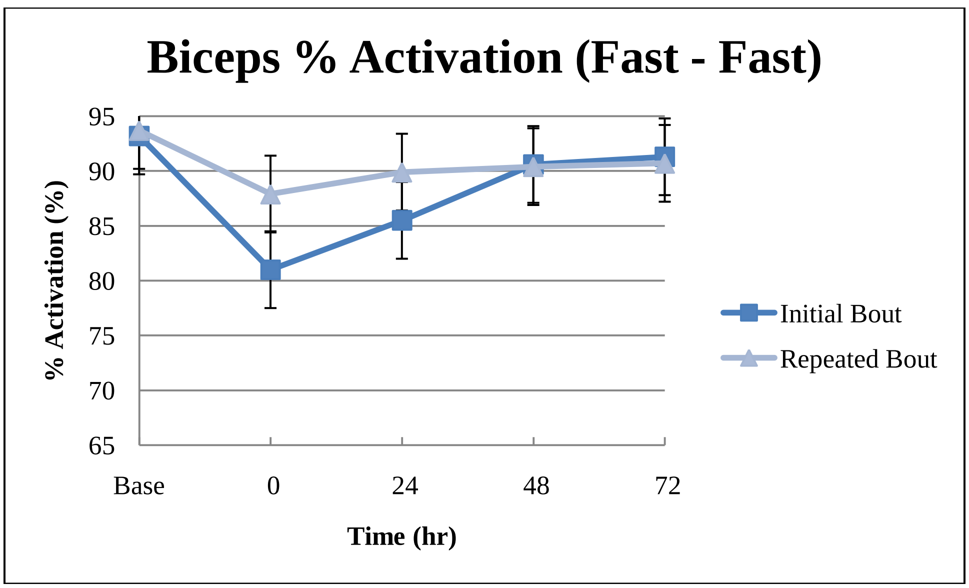

Figure 3.4.5.4 – Voluntary muscle activation over time. Values are mean ± SE

3.4.6 Twitch Torque

The omnibus ANOVA revealed a significant time main effect, GG $F(3.0, 80.4)=56.525$, $p<0.001$. Without a bout x time x group interaction or any combination thereof, twitch torque is changing over time across all participants but is not different between bouts or between any of the groups. (Refer to Figures 3.4.6.1, 3.4.6.2, 3.4.6.3, and 3.4.6.4 for graphs of twitch torque differences for SLOW-SLOW, SLOW-FAST, FAST-SLOW, SLOW-SLOW velocity groups respectively).

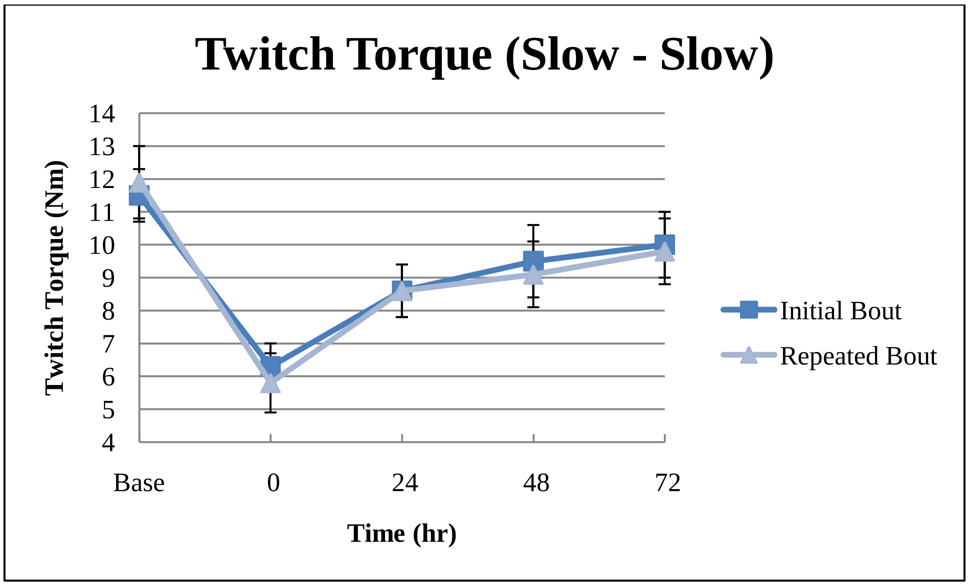

Figure 3.4.6.1 – Twitch torque over time. Values are mean ± SE.

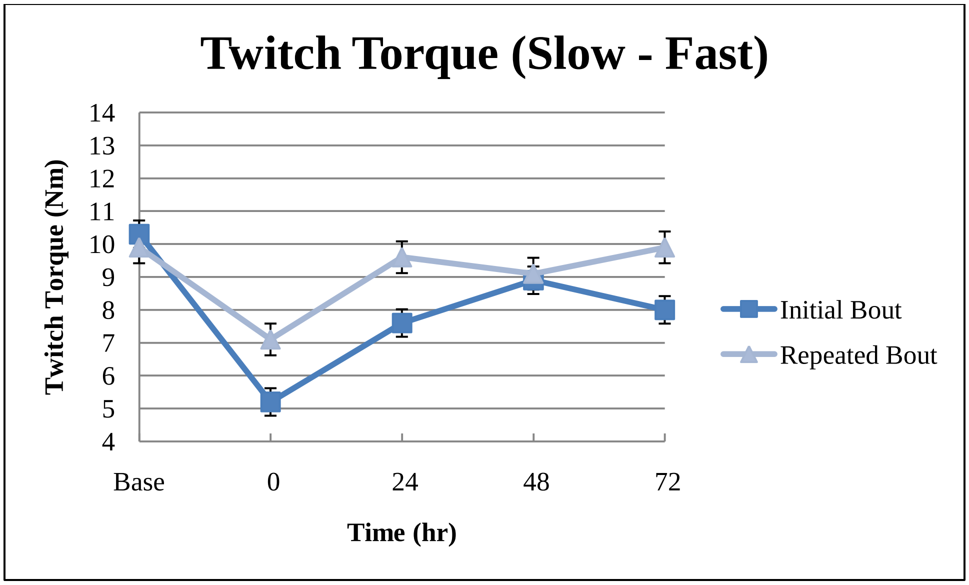

Figure 3.4.6.2 – Twitch torque over time. Values are mean ± SE.

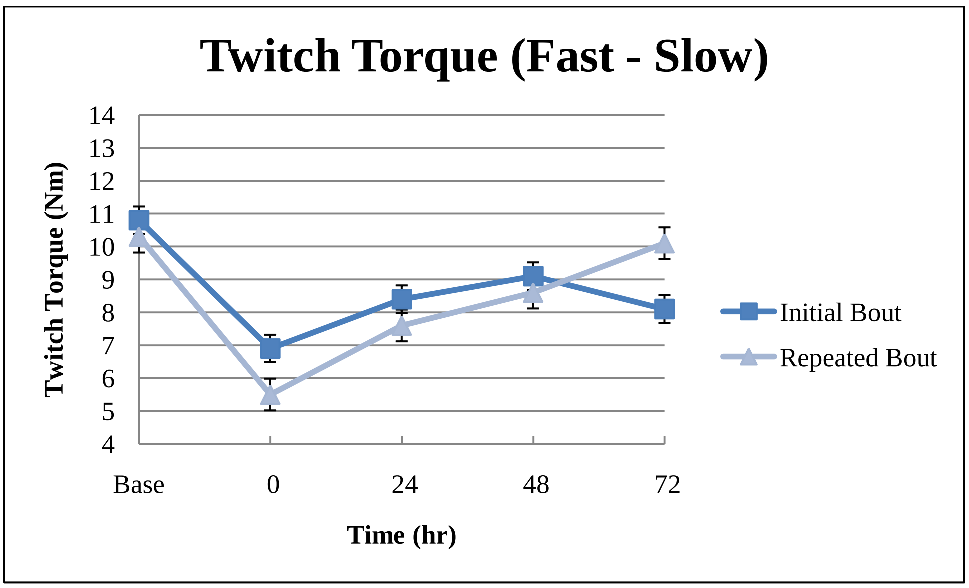

Figure 3.4.6.3 – Twitch torque over time. Values are mean ± SE.

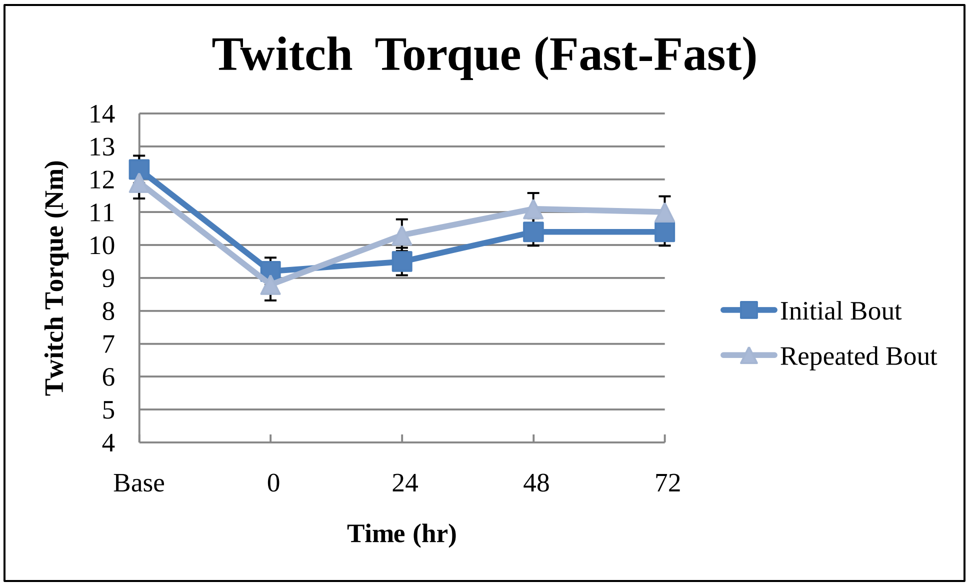

Figure 3.4.6.4 – Twitch torque over time. Values are mean ± SE.

Chapter 4

Discussion

The main finding of the current investigation is that the protective capacity of the repeated bout effect for the elbow flexion MVC strength is specific to the velocity of the initial bout. This is the first study to my knowledge, which has shown that when a repeated bout of eccentric exercise is completed at the same velocity as the initial bout there is a greater protective capacity for strength recovery than when the bouts are completed at different velocities.

The results of this study confirm previous repeated bout effect literature and provide new insights into its possible mechanisms and applications. As expected, the first analysis confirmed the presence of the repeated bout effect within our pooled sample. There was a faster recovery of strength, a reduction in muscle thickness, a reduction in soreness (both the muscle belly and most-sore), as well as an increase in amplitude of biceps EMG activity after the repeated bout of eccentric exercise. This result is a confirmation of the literature which has shown that a single eccentric exercise session protects against muscle damage during subsequent eccentric exercise bouts for many types and intensities of eccentric exercise across gender and age (McHugh et al., 1999; McHugh, 2003).

4.1 Velocity of Contraction

There were two main hypotheses that this study aimed to test. The first hypothesis was there would be a greater magnitude of the repeated bout effect when the repeated bout is performed at the same velocity compared to when it is performed at a different velocity. Barroso et al. (2010) found no difference in the repeated bout effect between those that trained at a fast velocity at each bout compared to a slow velocity. The results confirmed this finding as similar trends in the protective capacity of both the SLOW-SLOW and FAST-FAST groups who trained at the same velocity at each bout. Showing a similar protective effect for each velocity made it appropriate for us to combine them into a single group. Those who completed each bout at the same velocity (SAME) were then compared to those who completed the eccentric bouts at different velocities (DIFF). The first hypothesis was supported in that only the SAME group saw a faster recovery of strength after the second bout. To my knowledge this is the first study that has looked at the specificity of the repeated bout effect. However, others have compared muscle damage following either fast or slow velocity eccentric contractions. Paddon-Jones et al. (2005) suggested greater muscle damage occurred after 36 slow velocity contractions as compared to fast velocity contractions. Strength recovery was significantly reduced in the slow velocity group. They also showed a greater increase in upper arm girth and a faster onset of peak soreness which indicates greater muscle damage occurred. Studies by Chapman et al. in 2006 and 2008 compared muscle damage after eccentric exercise bouts between fast velocity and slow velocity contractions. In both studies the authors concluded that fast velocity eccentric contractions induced more damage than slow velocity contractions. Within their study design they matched for either time under tension or the number of contractions performed but did not match for total work. Thus the 210 fast velocity eccentric contractions that were performed in each study applied greater forces through the elbow flexors than the slow velocity contractions leading to greater damage. Chapman, Newton, McGuigan & Nosaka (2009) found that a slow velocity (30°/s) bout of eccentric exercise reduced muscle damage induced by a 2nd bout of fast velocity eccentric (210°/s) exercise. The authors noted that the magnitude of the protective effect was reduced compared to previous results in their lab. More recently, researchers have compared the magnitude of the repeated bout effect after either fast or slow velocity contractions. Borroso et al. (2010) found no difference in the protective capacity of fast or slow velocity eccentric contractions of the biceps. In this study the bouts were performed only at a fast or slow velocity, which only answers the question of effect of velocity. Therefore, there was a need for the current study design, which allowed the unique ability to assess both specificity and the effect of velocity of contraction on the repeated bout effect. The finding that the repeated bout effect showed specificity of velocity for MVC strength is a unique aspect of this study, and has important implications for both research and application.

The second hypothesis within this study was that there would be a greater protective capacity of the repeated bout effect when the initial bout of eccentric training was performed at a fast velocity compared to a slow velocity. This hypothesis was based on previous studies that showed the higher the intensity of the initial bout of eccentric exercise, the greater protective effect for a repeated bout of eccentric exercise (Nosaka et al., 2001). Therefore, if greater muscle damage occurs from the fast eccentric training, it was predicted that it might provide a greater stimulus for adaptation and cause greater protective effects in future eccentric bouts. This hypothesis was not supported as a fast velocity eccentric bout did not offer a greater protective effect than a slow velocity bout. There was no difference between groups for the repeated bout effect shown in the four group analysis. A study by Chapman et al. (2006) showed that when matched for time under tension fast velocity eccentric contractions induced greater muscle damage than slow velocity eccentric contractions. However, matching for time under tension meant those in the fast velocity group performed six times the number of contractions compared to the slow velocity group. The potential shortcoming of this approach is that the total work performed by the fast velocity group was significantly greater than the slow velocity group, which likely led to greater muscle damage. A follow up study by Chapman et al. (2008) which matched for the number of repetitions showed no difference in muscle damage when performing

30 fast or slow velocity eccentric contractions. However, when they increased the number of contractions to 210 they once again saw greater muscle damage in the fast velocity contractions. Once again when 210 contractions were performed the total work done was significantly higher in the fast velocity condition which may contribute to the greater effect of damage. From these results Chapman et al. (2009) hypothesized that an initial bout of slow velocity (30°/s) eccentric exercise would not affect muscle damage in a subsequent bout consisting of fast velocity (210°/s) eccentric contractions. The results were contrary to their hypothesis as a repeated bout effect was shown after the second bout of fast velocity eccentric exercise. However, the reduction in symptoms of muscle damage was not large within this study which supports the results shown in the current study. Within the current study it is difficult to differentiate the effect of velocity of contraction on the repeated bout effect due to our limited number of participants in our 4 group analysis. With a larger sample size the trends in the data suggest the results may have been similar to what was shown by Chapman et al. (2009). Barraso et al. (2010) further explored the comparison between fast and slow velocity contractions and the repeated bout effect when they had participants complete the same eccentric contraction velocity at both the initial and repeated bout at a velocity of either 60°/s (slow) or 180°/s (fast). In this study total work was similar for all of the bouts for the groups. This indicates that each group had similar stress being placed on their elbow flexors, and the eccentric bouts were the same from the initial bout to the repeated bout. Barraso et al. confirmed that less muscle damage occurred after the repeated bout of eccentric exercise, corresponding with the literature. However, there was no difference in the protective capacity of the initial bout of exercise between fast or slow contractions. They concluded that eccentric contraction velocity had little effect on muscle damage or the repeated bout effect. This conclusion was supported in the current study as a bout

of fast velocity eccentric exercise provided a similar protective capacity as a bout of slow velocity eccentric exercise when both bouts were performed at the same velocity. Our results did not confirm our hypothesis that fast velocity eccentric contractions would provide a greater protective effect than slow velocity contractions. Fast velocity eccentric contractions did not appear to provide any greater protection against muscle damage for a slow velocity eccentric bout. The specificity effect would indicate there may be a greater adaptation when each bout is completed at the same velocity of contraction but our analysis does not provide evidence of one velocity protecting to a greater extent than the other. The four group design allowed us to assess differences between the fast and slow velocities as well as assess which velocity may offer a greater protective effect against muscle damage. Within the current study it appeared that both slow and fast velocity contractions offer similar protective effects against muscle damage when bouts are completed at the same velocity. It would also appear that, contrary to our hypothesis, neither fast or slow contractions protect more effectively against muscle damage when the repeated bout is not completed at the same velocity. However, these findings are difficult to interpret due to the four group analysis being less powered than the other analyses. With a larger sample size we may have been able to detect if there was a difference in the repeated bout effect for the SLOW-FAST and FAST-SLOW groups.

4.2 Eccentric bouts

Both the initial and repeated bouts of eccentric exercise for each participant were completed under the same conditions with the only difference being the velocity of contraction performed. Within each participant the total work for the initial and repeated bouts of eccentric exercise was matched to ensure a consistent amount of force was being placed on the elbow flexors at each bout in order to allow for standardized comparison. For reasons of applicability it was decided that 6 sets of 8 repetitions would be done for each bout no matter the velocity of contraction. Previous studies have chosen to match for time under tension. However, when comparing different velocities of contraction as in the case of this study, it would mean completing several times the number of fast velocity contractions than slow velocity contractions. Chapman et al. (2006) used this protocol to assess differences in muscle damage with different velocities of eccentric exercise and found the greater number of fast velocity eccentric contractions produced more muscle damage when matched for time under tension. In the case of the current study if 48 contractions were completed for the slow velocity condition, then 288 contractions would be completed for the fast velocity to match for time under tension. This is unrealistic for anyone training in a weight room and limits the applicability of the findings. The style of workout in our design is similar to a hypertrophy workout someone would use in a weight room setting (Ratamess et al., 2009). There is generally support that fast velocity eccentric contractions produce higher forces than slow velocity eccentric contractions (Hortobágyi and Katch, 1990; Farthing and Chilibeck, 2003; Chapman, Newton, & Nosaka, 2005). However, Chapman et al. (2005) found no difference in the eccentric torque produced by the biceps at 30°/s, 90°/s, 150°/s, and 210 °/s. Since total work is the force over a given distance there could potentially be more force placed on the elbow flexors in the fast velocity condition if 6 sets of 8 contractions were completed at each bout. Chapman et al. (2008) matched the number of contractions but did not match for total work, which lead to significantly more work being done during the fast velocity eccentric contractions. For this reason, the total amount of work being performed between bouts was matched within the current investigation.

After some careful pilot testing in the lab, it was determined it was generally only a few repetitions more or less that had to be completed to match total work. For each given participant total work was monitored throughout the repeated bout of eccentric exercise. When they reached their total work from the initial bout the eccentric bout was halted. If they had not completed the required amount of total work after the 6 sets of 8 they were instructed to complete extra repetitions until the required amount was completed.

Table 3.1 shows the results of the eccentric bouts of exercise. When all of the participants were pooled together there was no difference in the total work performed from the initial bout to repeated bout. As well there was no difference in the peak torque for the highest or peak torque for the lowest rep between the bouts. This data would indicate that the initial and repeated bouts of exercise were well controlled and the initial bout of eccentric exercise was the same as the repeated bout of eccentric exercise.

When the participants were split into those who trained at the SAME velocity compared to those that trained at a DIFF velocity at each bout, the results were similar. There was no difference in the total work performed between the initial and repeated bouts for either the SAME or DIFF velocity groups. There were no differences in lowest torque produced in either group. Within the SAME group it was determined that the peak torque was significantly higher at the initial bout compared to the repeated bout. This may provide an indication of a difference in activation patterns at the repeated bout of exercise. Consciously or unconsciously, there might be a protective strategy taken by the individual to protect against muscle damage. Alternatively, there could potentially be an increase in inhibition from the type III or IV afferent fibres or from the central nervous system leading to a decreased descending neural drive. The participant may have completed the same amount of work but may have maintained lower force production over a longer period of time in order to maintain total work. The data indicates that the initial and repeated bouts of exercise were well controlled for the total work being performed but differences in the peak activation of the SAME group may be an indication of an adaptive strategy to protect against muscle damage.

When the eccentric bouts are broken up into the four different groups by velocity pairings there are some interesting results which could have implications for the impact of velocity on the repeated bout effect. There were no differences in the total work performed for any of the groups. For the peak torque achieved during the bouts, there were no significant differences between the initial and repeated bouts for any of the groups. When looking at the peak torques our data maintains the expected relationship of the torque velocity curve. The fast velocity eccentric contractions produced a higher peak force than the slower velocity eccentric contractions. When looking at the lowest peak torque produced throughout the eccentric bout for the groups that trained at the same velocity at each bout, there appeared to be similar fatigue at the end of the eccentric bout. This is a good indication that maximal activation was achieved throughout each bout.

The eccentric bouts which were performed within this study were not different for any group between the initial and repeated bout for total work performed. Having participants aim to complete 6 sets of 8 repetitions of eccentric exercise while controlling for total work performed provided confidence that any differences in results were due to the velocity of contraction and time under tension and not other internal factors.

4.3 Difference in damage between velocities

Within the data there is a trend that the slow velocity eccentric contractions induced greater muscle damage than the fast velocity eccentric contractions. Post hoc analysis revealed a greater reduction in MVC strength for the SLOW-SLOW group compared to the FAST-FAST group. (refer to graphs 3.4.1.1 and 3.4.1.4). This is contrary to what has been traditionally seen in the literature. Farthing and Chilibeck (2003) found that eccentric training at fast velocities (180°/sec) was ideal for inducing greater strength and hypertrophy gains compared to slow velocity training (30°/sec). This was thought to be due to the greater forces produced with high velocity eccentric contractions which would induce greater muscle damage. This was also shown by Chapman et al. (2006 & 2008), as they showed fast velocity eccentric contractions induced greater muscle damage when matched for time under tension as well as when they were matched for number of contractions. The greater muscle damage was shown by greater reductions in isometric and dynamic strength, delayed recovery of ROM, and larger increases in upper arm circumference, soreness, and peak CK activity with fast velocity contractions. Within these studies the total work performed was significantly higher for the fast velocity group compared to the slow velocity group. Shepstone et al. (2005) also showed greater muscle damage with fast velocity eccentric training. They found greater Z-band streaming via muscle biopsy after fast velocity eccentric training compared with slow velocity eccentric training. Again, the number of repetitions was matched between the fast and slow velocity conditions with higher torques being produced within the fast velocity condition which could explain the greater muscle damage.

As discussed previously, within the current study there were higher peak forces produced by the fast velocity eccentric contractions, following the expected force velocity curve. However, an indication that the slow velocity contractions may be more damaging comes when looking at the lowest peak torque produced during the eccentric bouts. The SLOW-FAST and FAST-SLOW groups were not different in their peak torques produced from the initial to the repeated bout. However, for both groups the slow velocity bout was significantly more fatiguing and left the participants with a larger reduction in force production at the end of the eccentric bout (refer to chart 3.1.1). After completing the slow velocity eccentric bout both groups were significantly reduced in strength compared to the fast velocity eccentric bout. This would indicate the time under tension differences between the two contraction velocities produced significantly greater fatigue in the slow contraction velocity.

Related to or independent of fatigue, the slow eccentric bouts appeared to produce greater symptoms of muscle damage following the eccentric bout. Once again, post-hoc tests indicate that the SLOW-SLOW group has a significantly greater reduction in strength than the FAST-FAST group which would indicate greater fatigue or muscle damage (refer to graphs 3.4.1.1 and 3.4.1.4). Due to the smaller number of participants when the analysis was broken down into the four groups there were limited group interactions that were seen. Another indication comes from the voluntary muscle activation data. The interpolated twitch technique provides an indirect prediction of central activation. This technique provides an estimation of the percentage of muscle fibres being recruited within the muscle. Post-hoc analysis indicates that the FAST-SLOW group has a significant reduction in % activation compared to the FAST-FAST group on the repeated bout effect. This may indicate the estimated percent of muscle fibres being recruited was lower after the slow velocity eccentric bout than after the fast velocity eccentric bout. However, this could also indicate that the initial fast eccentric bout was protective only for a repeated bout at the same velocity. From these results it would appear that even though we matched the number of repetitions and the total work performed, the time under tension and not the velocity of the contraction was a better representation of the differences in muscle damage or fatigue related declines in function.

4.4 Evidence for Neural Adaptation?

The main objective of this study was to determine if there was specificity of contraction velocity with the repeated bout effect. Specificity is generally thought to be an adaptation associated with neural adaptation (Enoka, 1997). Common neuromuscular adaptations with strength training include a stronger neural drive to the agonist muscle for a specific task with a reduction in activation of the antagonist muscle (Gabriel, Kamen & Frost, 2006). Compared with isometric and concentric contractions, eccentric contractions require unique activation strategies by the nervous system. A reduction in muscle activation and an altered recruitment order of motor units may be part of a neural strategy to preserve the highest threshold motor units during eccentric contractions (Enoka, 1996). A change in the recruitment pattern or an increase in muscle activation could cause an increase in force production during maximal contractions. There may also be adaptations after eccentric exercise that involve motor planning (i.e. motor cortex, pre-motor cortex) which allow for the task to be completed more efficiently and effectively. This could be accomplished by greater agonist antagonist coordination along with greater postural stabilization.

The current study has shown that a significantly faster recovery of MVC strength after a second bout of eccentric exercise only occurs when the bouts are completed at the same velocity. All motor output has both central and peripheral contributions. A specificity of velocity for MVC strength with the other dependant variables (i.e. MT, DOMS, TT, ITT, EMG) being unaffected by the velocity of contraction may provide evidence of a supra-spinal adaptation leading to the faster recovery of strength. A reduction in interhemispheric inhibition, increase in motor cortex activation, or reduction in inhibitory input could lead to a stronger descending neural impulse or greater coordination of multiple muscles involved in contraction which could be contributing to neural adaptations associated with the repeated bout effect. The results of this project suggest that the specificity effect is likely related to changes in coordination of the muscles rather than an increase in descending neural drive because there was no significant difference between bouts for the SAME and DIFF groups for EMG or percent voluntary activation. However, since no measures of supra-spinal adaptation or cortical activation were taken, the contribution of supra-spinal adaptations to the specificity effect is uncertain.

There was some indication from the current study that an increase in neural drive to the agonist muscle might be associated with the repeated bout effect. When the participants were pooled together, there was a significant increase in biceps EMG activation, pooled across time, after the repeated bout of eccentric exercise. This is a unique result as the literature has been inconsistent with EMG data and the repeated bout effect. McHugh, Connolly, Eston, Gartman & Gleim (2001), found the EMG per unit torque and median frequency were not different between the initial and repeated bouts of isokinetic eccentric exercise of the hamstrings. They concluded there was no evidence that the repeated bout effect was due to neural adaptation. Falvo, Schilling, Bloomer & Smith (2008), found no difference in the median frequency of EMG for a bench press exercise in resistance trained men. However, Warren, Hermann, Ingalls, Masselli & Armstrong (2000), showed a reduction in the EMG median frequency in the tibialis anterior after the repeated bout of eccentric exercise. Their conclusion was that torque production was maintained through a greater contribution of slower motor units. Colson, Pousson, Martin & Van Hoecke (1999) have shown that with seven weeks of eccentric biceps training the activation of the biceps brachii is increased with no change in the triceps brachii. The authors concluded the influence of eccentric training on the torque gains under eccentric conditions was attributed essentially to neural adaptations. The results of the present study indicate that pooled across all time points through recovery after the repeated eccentric bout there was an increase in EMG activation of the biceps brachii. This could indicate a greater neural drive during the MVC contractions after the second bout of eccentric exercise.

After the repeated bout of eccentric exercise there was a significant reduction in muscle thickness and muscle soreness values. It is possible that after the repeated bout of eccentric exercise there was less cellular disruption to the sarcomeres, sarcoplasmic reticulum, transverse tubules, and sarcolemma. This would mean a reduction in inflammatory cytokines, proteolytic enzyme release, and products of inflammation (histamine, substance p, etc). There would be less sensitivity of the nociceptors leading to less signalling from type III and IV afferent fibres. This would lead to a reduction in soreness and possibly a reduction in inhibition from the muscle. This reduction in inhibition could lead to a stronger force of contraction with the same neural drive, or may enable increased neural drive. A reduction in soreness and inflammation would indicate a cellular mechanism contribution to the repeated bout effect. However, if the repeated bout effect was caused entirely by cellular mechanisms less muscle damage would be accompanied by a reduction in inflammation, a reduction in soreness, and a faster increase in strength for all of the groups. The results show only the groups that trained at the same velocity at each bout showed a repeated bout effect for MVC strength. With the DIFF group still showing a reduction in inflammation, and soreness after the repeated bout of eccentric exercise there is an indication that something else may be contributing to the faster recovery of strength.

Comparing the results from the different analysis approaches provides us with an overall indication of any possible neuromuscular adaptations which may be occurring. The twitch torque values across all three analyses look very similar. Post-hoc tests indicate there is a significant reduction in the electrically evoked torque after the eccentric exercise which recovers throughout the first 72 hours but does not recover to baseline. Twitch torque is the ideal way to assess peripheral muscle damage as it eliminates neural drive to the muscle and provides an indication of the ability of the muscle to form cross-bridges and produce force. For all analyses, there is no difference between groups or the initial and repeated bouts of eccentric exercise for twitch torque. These results would indicate that the ability of the agonist muscle to produce force is not different from the initial to the repeated bout even though at the repeated bout the participant's MVC isometric strength is significantly stronger.

Another possible neural adaptation causing an increase in strength is a greater percentage of muscle fibres being voluntarily recruited. The interpolated twitch technique is a peripheral estimation of central activation. The percent activation results in this study are similar across all three analyses and provide a similar story to the twitch torque data. Post-hoc tests indicate that after the eccentric exercise there was a reduction in the estimated number of motor units that are being recruited (refer to figure 3.2.5). This is generally caused by neural fatigue. In combination with the muscle damage (i.e., sarcomere disruption causing swelling and pain) this leads to a reduced force production at the muscle. Post-hoc tests indicate the estimated percentage of muscle fibres being recruited climbs back to baseline by 72 hours contributing to the recovery of strength. The estimated percentage of muscle fibres being recruited was not different at any time point between the initial and repeated bouts of eccentric exercise. This result is a confirmation of the study conducted by Kamandulis et al. (2010) who concluded that a repeated bout effect of eccentric exercise of the knee extensors appears to reduce muscle damage, but does not influence the level of voluntary activation. It would appear from the interpolated twitch data that the adaptation is not due to increasing the number of muscle fibres being recruited or by preventing central fatigue.

The data from this study indicates there may be a neurally mediated adaptation with eccentric exercise which allows for a faster recovery of strength after a repeated bout of eccentric exercise. From previous work in the literature it is clear that there is a contribution to the repeated bout effect from cellular mechanisms. However, this study provides evidence that there may be a more substantial contribution of neural mechanisms as well. With no differences in the twitch torque or interpolated twitch data it would appear that any adaptation is occurring at the supra-spinal level of the nervous system. An increase in EMG amplitude could indicate an increase in neural drive after the repeated bout of eccentric exercise. As well, the presence of a specificity effect for MVC strength allows for the possibility of a neural contribution to the repeated bout effect.

4.5 Limitations

There are several limitations to the current investigation. One obvious limitation is that no direct measures of inflammation, or internal muscle biochemistry were taken. For this reason we can only speculate as to what was going on inside the muscle after the eccentric bouts of exercise. This information would have been useful for accessing mechanisms, but was not feasible for the scope of the current investigation. As previously mentioned, this is an area that should be explored by future research.

When the analysis was broken down into the four group model we found ourselves underpowered. With only 31 participants to begin with we ended up with groups of n=8, n=7, n=8, and n=8 which did not allow us to detect any group interactions which may have been occurring. Our power calculation indicated that twelve participants per group would have been adequate. However, due to time constraints during recruitment and dropouts this was not obtained. It is difficult to make any conclusion on the increase in pooled EMG activation. With four different initial-repeated bout velocity combinations contributing to this effect and no differences for any of the groups it makes interpretation difficult. Our results may be due to the differences in activation patterns between the fast and slow velocity eccentric contractions. With a more highly powered design it is likely a significant effect might be evident and allow us to comment further.

Another limitation of the study was that the findings of the study are limited to a specific population and muscle group. This study used only college aged students, most of who were recruited from the College of Kinesiology at the University of Saskatchewan. Thus, caution should be exercised when trying to generalize these findings to other populations. As well, caution should be taken to generalize the results to all muscle groups as this study was performed using isokinetic dynamometry in a supervised laboratory setting. This raises questions about the real world applications and generalizability of the results.

Finally, a limitation of this study was that it was not blinded. The primary investigator supervised all eccentric bouts and made all of the muscle thickness and soreness measurements for the study. An ideal design would have been to have the muscle thickness and soreness measurements taken by a researcher blinded to the velocity of contraction that each participant had performed but again this was not practical or feasible for this project.

4.6 Practical Implications and Future Research

Specificity of velocity for MVC strength is a unique aspect of the repeated bout effect which has not been discussed in the literature. This finding may have important implications for both researchers and practitioners. If a faster recovery of strength is specific to the velocity of contraction performed it would be important from an athlete’s perspective to train at a velocity closest to their sport performance. With a faster recovery of strength an individual may be able to increase their training volume or maintain function in season. This knowledge may also be useful for someone working with an elderly population who is interested in maintaining their quality of life and functionality. If an individual can receive the strength and hypertrophy benefits of eccentric training without the prolonged decrease in muscle function it may be an effective tool in preventing sarcopenia.

In the future it will be necessary for researchers to assess as directly as possible any neural adaptations which may be occurring during the repeated bout effect. This experiment suggests any neural adaptations which are occurring might be at the supra-spinal level. Transcranial magnetic stimulation (TMS) or functional magnetic resonance imaging (fMRI) will be important measures to use in order to assess specific neuromuscular adaptations which may be occurring to contribute to the repeated bout effect.

It will also be important to confirm the strength specificity findings of this study with a larger sample size and measures of inflammation and muscle biochemistry. Assessment of this could provide valuable information on the cellular responses to different velocities of eccentric exercise. As a follow up study it may be valuable to assess differences in muscle fibre types between participants and how that relates to their response to different velocities of eccentric exercise. Within the data collection of this study it appeared people responded differently to fast and slow velocity eccentric bouts. Muscle fibre types could be one reason why people would respond differently to the same exercise session.

Chapter 5

Summary and Conclusions

5.1 Summary

The purpose of this study was to assess the effects of contraction velocity on the repeated bout effect. The data was analyzed in three different ways in order to get a complete picture of how contraction velocity affects muscle damage and the protective effect of previous eccentric bouts of resistance exercise. The total work performed during the eccentric bout in this study was not different for any group between the initial and repeated bouts. Having participants aim to complete the eccentric bout while matching for total work performed provides confidence that any differences in results were due to the velocity of contraction and time under tension and not other internal factors.

When participants were pooled into one group there was a faster recovery of strength, reduction in inflammation, decrease in soreness, and an increase in biceps EMG activity. This is consistent with previous findings in the literature. When participants were split by specificity into the SAME Vs. DIFF velocity groups it was discovered there was a faster recovery of MVC strength only for the individuals who trained at the SAME velocity at each bout. Further, there was a reduction in soreness and muscle thickness after the repeated bout of exercise with no difference between SAME and DIFF groups. Interpolated twitch and twitch torque were reduced after the eccentric bout and recovered to baseline after 72 hours. However, there was no difference between bouts at any time point or between groups which indicates these variables are not altered at the repeated bout. The four group analysis indicated both fast and slow velocity contractions offer similar protective effects against muscle damage during a repeated bout when it is completed at the same velocity as the initial bout. Contrary to the hypothesis, it appears that there is less protection against muscle damage when the repeated bout is not completed at the same velocity as the initial bout.

5.2 Conclusions

The unique result of this study is that the repeated bout effect shows specificity to contraction velocity for strength. This may indicate a neural contribution to the faster recovery of strength after the second bout of eccentric exercise. Since no differences between bouts were seen for interpolated twitch or EMG activation associated with the specificity effect for strength it would appear any neural adaptation is occurring at the supra spinal level of the central nervous system. However the increase in EMG activity for the pooled data (SAME vs. DIFF pooled) could indicate a greater agonist neural drive after the repeated bout. Overall, the results may indicate the slow velocity eccentric contractions produced significantly greater fatigue and muscle damage. Even though we matched the number of repetitions and the total work performed, the time under tension and not the velocity of the contraction was a better indicator of the amount of muscle damage. This study confirms much of the previous literature. When all of the participants were pooled, a second bout of eccentric exercise was associated with reduced indicators of muscle function and damage. The repeated bout effect for muscle soreness, and thickness regardless of velocity of contraction would indicate a contribution of cellular or mechanical adaptations to the repeated bout effect. The current findings of this study support the idea that there are multiple underlying mechanisms of the repeated-bout effect.

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Appendices

Appendix A Ethics: Certificate of Approval

UNIVERSITY OF SASKATCHEWAN

Biomedical Research Ethics Board (Bio-REB)

Certificate of Approval

PRINCIPAL INVESTIGATOR	DEPARTMENT	Bio #
Jonathan P. Farthing	Kinesiology	09-196

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT
College of Kinesiology
87 Campus Drive
Saskatoon SK S7N 5B2

STUDENT RESEARCHERS
Trevor Barss

SPONSORING AGENCIES
UNIVERSITY OF SASKATCHEWAN - PRESIDENT'S NSERC RESEARCH FUND

TITLE
: The Effect of Velocity of Contraction on the Repeated Bout Effect

ORIGINAL REVIEW DATE	APPROVED ON	APPROVAL OF	EXPIRY DATE
07-Dec-2009	23-Dec-2009	Researcher's summary (21-Dec-2009) Research Participant Information and Consent Form (18-Dec-2009) Previous Injury and Resistance Training Experience Form PAWS Announcement Acknowledgement of: Waterloo Handedness Questionnaire	06-Dec-2010

Delegated Review: ☐ Full Board Meeting: ☒ Date of Full Board Meeting: 07-Dec-2009

CERTIFICATION

The study is acceptable on scientific and ethical grounds. The Bio-REB considered the requirements of section 29 under the Health Information Protection Act (HIPA) and is satisfied that this study meets the privacy considerations outlined therein. The principal investigator has the responsibility for any other administrative or regulatory approvals that may pertain to this research study, and for ensuring that the authorized research is carried out according to governing law. This approval is valid for the specified period provided there is no change to the approved protocol or consent process.

FIRST TIME REVIEW AND CONTINUING APPROVAL

The University of Saskatchewan Biomedical Research Ethics Board reviews above minimal studies at a full-board (face-to-face) meeting. Any research classified as minimal risk is reviewed through the delegated (subcommittee) review process. The initial Certificate of Approval includes the approval period the REB has assigned to a study. The Status Report form must be submitted within one month prior to the assigned expiry date. The researcher shall indicate to the REB any specific requirements of the sponsoring organizations (e.g. requirement for full-board review and approval) for the continuing review process deemed necessary for that project. For more information visit http://www.usask.ca/research/ethics_review .

REB ATTESTATION

In respect to clinical trials, the University of Saskatchewan Research Ethics Board complies with the membership requirements for Research Ethics Boards defined in Division 5 of the Food and Drug Regulations and carries out its functions in a manner consistent with Good Clinical Practices. This approval and the views of this REB have been documented in writing. The University of Saskatchewan Biomedical Research Ethics Board has been approved by the Minister of Health, Province of Saskatchewan, to serve as a Research Ethics Board (REB) for research projects involving human subjects under section 29 of The Health Information Protection Act (HIPA).

Michel Desautels, Ph.D., Chair
University of Saskatchewan
Biomedical Research Ethics Board

Please send all correspondence to:

Research Ethics Office
University of Saskatchewan
Box 5000 RPO University
1607 - 110 Gymnasium Place
Saskatoon, SK Canada S7N 4J8

Appendix B: Consent Form

Research Participant Information and Consent Form

TITLE: The Effect of Velocity of Contraction on the Repeated Bout Effect
SPONSOR: None

PRINCIPAL INVESTIGATOR: Dr. Jon Farthing, College Kinesiology, University of Saskatchewan. Phone: 306-966-1068; Email: jon.farthing@usask.ca

SUB-INVESTIGATORS: Trevor Barss, M.Sc. candidate, Student researcher (supervised by Dr. Jon Farthing) College of Kinesiology, University of Saskatchewan. Phone: 306-966-1123; Email: tsb065@mail.usask.ca

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INTRODUCTION

You are invited to take part in this research study because we are interested in determining if a single bout of eccentric resistance exercise (i.e. the muscle lengthens during contractions) offers a protective effect against muscle soreness (i.e. damage) for future bouts of eccentric exercise. This protective adaptation is known as the "repeated bout effect". Approximately 40 participants will be recruited in order to determine if the repeated bout effect is specific to the velocity of muscle contraction (i.e. slow vs. fast) that was performed during the first bout of eccentric exercise. We also wish to determine if a single bout of eccentric resistance exercise offers protection to the non-exercised opposite limb during a future bout of eccentric exercise via a phenomenon called "cross-education". Cross-education is defined as an increase in function of the untrained limb after a training session of the opposite limb. This would mean if you performed a maximal bout of eccentric muscle contractions on one of your arms, you might also be protected against muscle damage in the opposite arm when you perform eccentric exercise.

If you wish to participate you will be asked to sign this form. Your participation is entirely voluntary, so it is up to you to decide whether or not you wish to take part. If you decide not to take part, you do not have to provide a reason and it will not affect your academic standing or your relationship with any of the researchers or the University of Saskatchewan. If you decide to take part in this study, you are still free to withdraw at any time and without giving any reasons for your decision.

Please ask the study investigators to explain any words or information that you do not clearly understand. You may ask as many questions as you need to understand what the study involves. Please feel free to discuss this with your family, friends or family physician.

STUDY PURPOSE

The primary purpose is to determine if the protective capacity of a single bout of eccentric resistance exercise, also known as the "repeated bout effect", is specific to the velocity of contraction (i.e. slow vs. fast) performed during the initial eccentric exercise bout. The secondary purpose is to determine if a single bout of eccentric resistance exercise offers a protective effect for the non-exercised opposite limb for future bouts of eccentric exercise.

STUDY DESIGN

You will be asked to visit the lab at the University of Saskatchewan a total of 9 times with a total time commitment of approximately 4-5 hours. Initially we will meet in order to go over the study protocols, fill out questionnaires and answer any questions that you have. The following day you will have your muscle function assessed which is then followed by an initial bout of eccentric exercise in your right arm. Immediately after this you will again have your muscle function assessed to see any changes that occur due to the bout of exercise. For each of the following 3 days, you will then come in for a short visit to assess your muscle function. After a three-week break the entire procedure will be completed again but this time for each arm. Muscle function will again be assessed for three days following the eccentric exercise, after which the study is complete.

STUDY PROCEDURES

If you agree to participate in the study, the following will occur:

Initially, the student researcher will ensure you are eligible to participate in the study. You must be right-handed, have no experience with eccentric or isokinetic training within the past year, and must have no previous injury to your shoulder, elbow, or wrist. You will be asked to fill out brief questionnaires to ensure you qualify for the study. You may choose not to answer any questions you are not comfortable with. You will then be asked to complete a physical activity readiness questionnaire (PAR-Q) to ensure, based on your current health, the physical testing is appropriate for you. If you are eligible for participation, we will carry on with the remaining study procedures.

Upon your first visit to the lab, you will complete a familiarization trial of the isometric elbow flexion (biceps curl) strength task to minimize any learning effect that occurs as you get more comfortable with the procedure. “Isometric” means that the joint angle does not change during the muscle contraction (i.e. you will be pulling as hard as you can but will be unable to move the apparatus). This strength task will be completed while laying flat on your back on a fully reclined chair with your elbow joint at 90 degrees. After this initial visit you will return to the lab two days later to have baseline measures of muscle function assessed in your right arm only.

Several measures will be used to assess any changes that occur in your muscle after the bout of eccentric exercise. These measures will be taken before and after the bout of eccentric exercise for both the initial bout and repeated bout completed 3 weeks later. The first measure will be the maximum voluntary isometric strength (also known as a 1-repetition maximum or “1-RM”). The isometric 1-RM strength test will be completed on an isokinetic dynamometer which is a machine that allows us to control the speed at which you contract your muscle. The highest force of contraction out of four repetitions will be recorded. You will be secured into the dynamometer chair using stability straps.

Electromyography (EMG) will be used to record the activity of your muscles during the maximal isometric contractions. EMG involves using little electrodes that stick to your skin surface and record the activity of your muscle. One surface electrode will be placed on the bulk of the biceps muscle with a second electrode on the bulk of the triceps muscle and a ground electrode placed on the knee cap. The EMG procedure is non-invasive and harmless.

Maximal activation of the muscles will be achieved by using a technique called “twitch interpolation”. The is done by asking you to contract your muscle as hard as you can, and then while you are still contracting, stimulating your muscle using a very short lasting electrical pulse (less than half a second long). The result will be a muscle contraction higher than is possible by contracting on your own. The short electrical pulse will feel like a pinch on your skin and will cause contraction of your muscle. The twitches will not harm you but may feel slightly uncomfortable.

Before you perform the maximal contractions, while you are relaxing your muscle, very brief electrical currents will be delivered to your muscle; starting at a very low intensity (you may not even feel it at first). The intensity will then be gradually increased until the maximum ‘twitch’ (the strongest contraction we can produce with stimulation) of the relaxed muscle is reached. This amount of current will then be used to stimulate the muscle when you are performing the maximal contractions.

Muscle thickness of the biceps brachii will be assessed by muscle ultrasound. Muscle thickness measures will help us to determine if inflammation caused the muscles to swell in response to the eccentric training session. A land-marking procedure will be used to ensure there is a consistent measurement site and involves making small markings on your skin using a non-permanent marker.

We will also be assessing any soreness that occurs due to the eccentric bout. On a sheet of paper with a visual scale (100mm continuous line), you will be asked to indicate how sore your muscle is by making a mark on the line, where 0mm represents “not sore at all” and 100mm represents “Very Very Sore”. You will also be asked to report the soreness of your muscles while the arm is in an extended position and being palpated by an Algometer. An Algometer is a device used to ensure consistent pressure is applied as you provide your soreness rating.

After completing the baseline measures you will be randomly assigned (assigned by chance by a computer) to perform an initial single bout of either fast (180°/s, group 1) or slow (30°/s, group 2) eccentric contractions of your dominant right arm only. The fast contraction takes approximately half a second to complete whereas the slow contraction takes about three seconds to complete. The exercise bout will include 6 sets of 8 maximal eccentric contractions. During these contractions you will start with your elbow bent at 90°, and then begin to contract your biceps muscles. The machine will then move your elbow into a fully extended position at a constant speed while you are trying to resist as hard as you can. The measures of muscle function and damage will be collected immediately after, and at 24, 48, and 72 hours post eccentric exercise.

After these three days of testing, you will have a three week break in which you are advised not to undergo any resistance training. After this break you will return to the lab and complete another bout of eccentric exercise (i.e. the “repeated bout”), but this time on each arm separately. This is done to assess any protective effect the initial bout had on the previously exercised dominant arm as well as the non-exercised non-dominant arm. Half the participants will complete the second bout with the same velocity of contraction as the initial bout, while half will complete the opposite velocity. Participants will again be randomly assigned to the fast or slow condition by a computer. This will help us determine if the repeated bout effect is specific to the velocity of muscle contraction. For the repeated exercise bout the same testing procedures will be followed for the next three days.

BENEFITS

If you choose to participate in this study you will gain information on your musculoskeletal health. However, it is not anticipated you will receive any physical benefits from participation in this study.

RISKS AND DISCOMFORTS

The maximal eccentric exercise session will cause you to experience some discomfort. Pain and soreness are to be expected with this protocol following the exercise bout and it will likely last for several days before subsiding. There is a small risk of injury (i.e. muscle pulls, strains or cramps) with eccentric exercise. Within our lab, less than 1% of participants have sustained an injury from a single eccentric exercise session or during eccentric training. Therefore, the likelihood of injury from this protocol is very low. Any risks will be minimized with a proper warm up (i.e. stretching) and familiarization with the procedures.

The electrical stimulation will feel like a pinch on your skin and will increase in discomfort as the amount of current being used increases. There is a small risk of muscle injury from electrical stimulation applied during maximal strength testing, but this will be minimized by becoming familiar with the procedure (i.e. practicing with low level electrical current) and a proper warm-up (i.e. stretching).

The isometric strength tests will be at maximal intensity and therefore will result in some discomfort and muscle fatigue. Testing may result in stiff muscles following the test. There is also a small risk of muscle injury during maximal strength testing, but this will be minimized by proper warm up (i.e. stretching).

There may be unknown or unforeseen risks during the study or after the study is completed.

ALTERNATIVES TO THIS STUDY

You do not have to participate in this study to have your musculoskeletal fitness assessed. A fitness assessment can be scheduled through the College of Kinesiology, University of Saskatchewan or other fitness centres.

RESEARCH-RELATED INJURY

In the case of a medical emergency related to the study, you should seek immediate care and, as soon as possible, notify the study doctor. Inform the medical staff you are participating in a clinical study. Necessary medical treatment will be made available at no cost to you. By signing this document, you do not waive any of your legal rights.

CONFIDENTIALITY

While absolute confidentiality cannot be guaranteed, every effort to make certain that your participation in the study, and information gathered during the study period will be kept confidential will be made. Your identity will be protected, and all data and information regarding the study will be kept together, locked in a cabinet in the College of Kinesiology for a period of five years, in the office of the principal investigator, Dr. Jon Farthing. All reporting of data in presentation or publication format will be done in aggregate form and will not refer directly to individual data.

VOLUNTARY WITHDRAWAL FROM THE STUDY

If you do decide to take part in this study, you are still free to withdraw at any time and without giving reasons for your decision. There will be no penalty or loss of benefits to which you are otherwise entitled, and your academic standing or relationship with the investigators will not be affected. If you choose to enter the study and then decide to withdraw at a later time, all data collected about you during enrolment in the study will be retained for analysis up to the point of your withdrawal.

CONTACT INFORMATION

If you have any questions about this study or desire further information before or during participation, you can contact Dr. Jon Farthing (principal investigator) at 966-1068 or Trevor Barss (student researcher) at 966-1123 or tsb065@mail.usask.ca.

If you have any questions about your rights as a research subject or concerns about the study, you can contact the Chair of the Biomedical Research Ethics Board, c/o the Ethics Office, University of Saskatchewan, at 306-966-4053.

Participants will have full access to the results of the study once it has been completed. Results from the study can be requested and obtained by making contact with the principal investigator Dr. Jon Farthing 966-1068 or student researcher Trevor Barss at 966-1123 or tsb065@mail.usask.ca.

This study has been reviewed and approved on ethical grounds by the University of Saskatchewan Biomedical Research Ethics Board. The Research Ethics Board reviews human research studies. It protects the rights and welfare of the people taking part in those studies.

CONSENT TO PARTICIPATE

I have read (or someone has read to me) the information in this consent form. I understand the purpose and procedures, the possible risks and benefits of the study. I was given sufficient time to think about it. I had the opportunity to ask questions and have received satisfactory answers to all of my questions.

I am free to withdraw from this study at any time for any reason and the decision to stop taking part will not affect my academic standing.

I voluntarily consent to take part in this research study.

By signing this document I do not waive any of my legal rights. I will be given a signed copy of this consent form.

Printed Name of Participant: Signature Date

Printed Name of Researcher: Signature Date

Appendix C: Data Collection Sheet

Data Sheet – Repeated Bout Effect Study

Subject # : ______________________
Name: ________________________
Sex: Male or Female
Height : ________________________ cm
Weight: ________________________ kg
Waterloo Handedness Score: _____
Testing Time of Day: ____________
Group: ____________________________

Velocity of Initial Bout: Fast or Slow
Velocity of Repeated Bout: Fast or Slow
PAR-Q Completed _____
Consent Form Completed: _____
Waterloo Handedness Completed: _____
Injury Questionnaire Completed: _____
Training Experience Completed: _____
Familiarization Completed: _____

<u>Muscle Thickness:</u>

Initial Bout (Biceps **<u>Right</u>** Arm):

Baseline	0	24	48	72
1.______	1. ______	1. ______	1. ______	1. ______
2. ______	2. ______	2. ______	2. ______	2. ______
3. ______	3. ______	3. ______	3. ______	3. ______
4. ______	4. ______	4. ______	4. ______	4. ______
TT:_____	TT:_____	TT:_____	TT:_____	TT:______

Repeated Bout (Biceps **<u>Right</u>** Arm):

Baseline	0	24	48	72
1.______	1. ______	1. ______	1. ______	1. ______
2. ______	2. ______	2. ______	2. ______	2. ______
3. ______	3. ______	3. ______	3. ______	3. ______
4. ______	4. ______	4. ______	4. ______	4. ______
TT:_____	TT:_____	TT:_____	TT:_____	TT:______

Repeated Bout (Biceps **<u>LEFT</u>** Arm):

Baseline	0	24	48	72
1.______	1. ______	1. ______	1. ______	1. ______
2. ______	2. ______	2. ______	2. ______	2. ______
3. ______	3. ______	3. ______	3. ______	3. ______
4. ______	4. ______	4. ______	4. ______	4. ______
TT:_____	TT:_____	TT:_____	TT:_____	TT:______

<u>Isometric Strength:</u>

Initial Bout (Biceps **<u>Right</u>** Arm):

Baseline	0	24	48	72
1.______	1. ______	1. ______	1. ______	1. ______
2. ______	2. ______	2. ______	2. ______	2. ______
3. ______	3. ______	3. ______	3. ______	3. ______
4. ______	4. ______	4. ______	4. ______	4. ______
TT:_____	TT:_____	TT:_____	TT:_____	TT:______

R

Repeated Bout (Biceps **<u>Right</u>** Arm):

Baseline	0	24	48	72
1.______	1. ______	1. ______	1. ______	1. ______
2. ______	2. ______	2. ______	2. ______	2. ______
3. ______	3. ______	3. ______	3. ______	3. ______
4. ______	4. ______	4. ______	4. ______	4. ______
TT:_____	TT:_____	TT:_____	TT:_____	TT:______

Repeated Bout (Biceps **<u>LEFT</u>** Arm):

Baseline	0	24	48	72
1.______	1. ______	1. ______	1. ______	1. ______
2. ______	2. ______	2. ______	2. ______	2. ______
3. ______	3. ______	3. ______	3. ______	3. ______
4. ______	4. ______	4. ______	4. ______	4. ______
TT:_____	TT:_____	TT:_____	TT:_____	TT:______

<u>CSMI Chair Settings</u>

Chair Rotation: ________________
Dyna Angle: __________________
Dyna Height: _________________
Monorail: ____________________
Attach Length Biceps: __________
Arm Rest Length Biceps: ________

<u>Delayed Onset Muscle Soreness (DOMS)</u>

Visual Analog Scale (Extended No-pressure)

Baseline	0	24	48	72
1.______	1. ______	1. ______	1. ______	1. ______

1=Tendon 2 = Belly 3= Most Sore

<u>EMG and ITT Electrode Placement</u>

EMG: Biceps (from crease) _______________cm
Triceps (from olecranon) ___________cm
ITT: Biceps Cathode (top red) _____________cm
Biceps Anode (bottom black) __________cm
Inter-electrode distance: _________________cm
ITT MAX stim: _________________________mA

<u>DOMS</u> -Visual Analog Scale (Algometer 3kgs)

Baseline	0	24	48	72
1.______	1. ______	1. ______	1. ______	1. ______
2. ______	2. ______	2. ______	2. ______	2. ______
3. ______	3. ______	3. ______	3. ______	3. ______

Appendix D: Waterloo Handedness Questionnaire

INSTRUCTIONS: Please indicate your hand preference for the following activities by circling the appropriate response. Think about each question. You might try to imagine yourself performing the task in question. Please take your time.

- If you use one hand 95% of the time to perform the described activity, then circle right always or left always as your response.
- If you use one hand about 75% of the time, then circle right usually or left usually.
- If you use both hands roughly the same amount of time, then circle equally.

1. Which hand do you use for writing?
Left Always Left Usually Equally Right Usually Right Always

2. With which hand would you unscrew a tight jar lid?
Left Always Left Usually Equally Right Usually Right Always

3. In which hand do you hold a toothbrush?
Left Always Left Usually Equally Right Usually Right Always

4. In which hand would you hold a match to strike it?
Left Always Left Usually Equally Right Usually Right Always

5. Which hand would you use to throw a baseball?
Left Always Left Usually Equally Right Usually Right Always

6. Which hand do you consider the strongest?
Left Always Left Usually Equally Right Usually Right Always

7. With which hand would you use a knife to cut bread?
Left Always Left Usually Equally Right Usually Right Always

8. With which hand do you hold a comb when combing your hair?
Left Always Left Usually Equally Right Usually Right Always

9. Which hand do you use to manipulate implements such as tools?
Left Always Left Usually Equally Right Usually Right Always

10. Which hand is the most adept to picking up small objects?
Left Always Left Usually Equally Right Usually Right Always

Appendix E: MVC Isometric Strength Raw Scores

Timepoint	Bout	**Pooled Participants (N=31)**
Baseline	Initial Bout	79.7 ± 20.0
	Repeated Bout	75.3 ± 24.7
0 Hr	Initial Bout	55.9 ± 19.8
	Repeated Bout	55.0 ± 23.0
24 Hr	Initial Bout	65.9 ± 19.8
	Repeated Bout	65.2 ± 21.6
48 Hr	Initial Bout	68.4 ± 23.3
	Repeated Bout	69.9 ± 25.4
72 Hr	Initial Bout	70.2 ± 23.2
	Repeated Bout	74.2 ± 27.3

MVC Strength Raw Scores – Values are mean ± standard deviation (Pooled)

Timepoint	Bout	**Same Velocity (N=16)**	**Different Velocity (N=15)**
Baseline	Initial Bout	78.6 ± 20.0	80.8 ± 20.5
	Repeated Bout	73.4 ± 24.2	77.3 ± 24.7
0 Hr	Initial Bout	57.7 ± 21.1	54.0 ± 18.8
	Repeated Bout	54.3 ± 21.9	55.7 ± 23.0
24 Hr	Initial Bout	64.9 ± 20.0	67.0 ± 20.3
	Repeated Bout	65.3 ± 20.1	65.2 ± 21.6
48 Hr	Initial Bout	65.0 ± 23.9	72.1 ± 22.8
	Repeated Bout	71.9 ± 26.1	67.7 ± 25.4
72 Hr	Initial Bout	67.8 ± 25.7	72.8 ± 20.8
	Repeated Bout	73.5 ± 27.9	74.9 ± 27.3

MVC Strength Raw Scores – Values are mean ± standard deviation (Split by Specificity)

Timepoint	Bout	**Slow-Slow (N=8)**	**Fast-Fast (N=8)**	**Slow-Fast (N=7)**	**Fast-Slow (N=8)**
Baseline	Initial Bout	73.0 ± 15.1	84.3 ± 23.6	91.7 ± 21.6	71.3 ± 14.8
	Repeated Bout	68.8 ± 26.2	78.1 ± 22.7	86.7± 24.2	69.0 ± 26.1
0 Hr	Initial Bout	45.0 ± 15.6	70.4 ± 18.5	56.7 ± 21.9	51.6 ± 16.9
	Repeated Bout	43.4 ± 20.5	65.3 ± 18.2	69.1 ± 24.6	44.0 ± 19.5
24 Hr	Initial Bout	60.3 ± 19.2	69.6 ± 20.9	70.6 ± 19.6	63.9 ± 21.7
	Repeated Bout	61.6 ± 24.8	68.9 ± 15.0	75.1 ± 20.3	56.5 ± 24.2
48 Hr	Initial Bout	61.1 ± 26.3	68.9 ± 22.3	74.7 ± 21.3	69.8 ± 25.3
	Repeated Bout	64.8± 27.2	79.0 ± 24.6	75.0 ± 25.9	61.4 ± 24.7
72 Hr	Initial Bout	63.5 ± 27.8	72.0 ± 24.5	76.9 ± 22.9	69.3 ± 19.6
	Repeated Bout	68.1 ± 28.5	78.9 ± 28.1	81.3 ± 25.8	69.4 ± 29.4

MVC Strength Raw Scores – Values are mean ± standard deviation (Split by 4 velocity groups)

Appendix F: Muscle Thickness Raw Scores

Timepoint	Bout	**Pooled Participants (N=31)**
Baseline	Initial Bout	3.94 ± 0.7
	Repeated Bout	3.93 ± 0.6
0 Hr	Initial Bout	4.24 ± 0.8
	Repeated Bout	4.18 ± 0.7
24 Hr	Initial Bout	4.15 ± 0.7
	Repeated Bout	4.04 ± 0.7
48 Hr	Initial Bout	4.11 ± 0.7
	Repeated Bout	4.04 ± 0.7
72 Hr	Initial Bout	4.09 ± 0.7
	Repeated Bout	3.97 ± 0.6

Muscle Thickness Raw Scores – Values are mean ± standard deviation (Pooled)

Timepoint	Bout	**Same Velocity (N=16)**	**Different Velocity (N=15)**
Baseline	Initial Bout	3.90 ± 0.7	3.98 ± 0.7
	Repeated Bout	3.92 ± 0.6	3.95 ± 0.7
0 Hr	Initial Bout	4.23 ± 0.7	4.25 ± 0.8
	Repeated Bout	4.15 ± 0.7	4.20 ± 0.8
24 Hr	Initial Bout	4.13 ± 0.7	4.18 ± 0.8
	Repeated Bout	4.03 ± 0.6	4.06 ± 0.7
48 Hr	Initial Bout	4.09 ± 0.7	4.14 ± 0.8
	Repeated Bout	4.04 ± 0.6	4.04 ± 0.7
72 Hr	Initial Bout	4.02 ± 0.7	4.16 ± 0.8
	Repeated Bout	3.96 ± 0.6	3.98 ± 0.7

Muscle Thickness Raw Scores – Values are mean ± standard deviation (Split by Specificity)

Timepoint	Bout	**Slow-Slow (N=8)**	**Fast-Fast (N=8)**	**Slow-Fast (N=7)**	**Fast-Slow (N=8)**
Baseline	Initial Bout	3.78 ± 0.7	4.02 ± 0.7	4.16 ± 0.7	3.81 ± 0.7
	Repeated Bout	3.87 ± 0.7	3.97 ± 0.6	4.18 ± 0.7	3.74 ± 0.7
0 Hr	Initial Bout	4.17 ± 0.8	4.28 ± 0.7	4.49 ± 0.8	4.05 ± 0.8
	Repeated Bout	4.19 ± 0.8	4.12 ± 0.7	4.35 ± 0.8	4.07 ± 0.8
24 Hr	Initial Bout	4.05 ± 0.6	4.20 ± 0.7	4.37 ± 0.8	4.00 ± 0.7
	Repeated Bout	4.03 ± 0.7	4.03 ± 0.6	4.27 ± 0.7	3.87 ± 0.7
48 Hr	Initial Bout	4.03 ± 0.6	4.15 ± 0.7	4.32 ± 0.8	3.98 ± 0.9
	Repeated Bout	4.05 ± 0.7	4.03 ± 0.6	4.27 ± 0.8	3.83 ± 0.6
72 Hr	Initial Bout	3.98 ± 0.6	4.07 ± 0.7	4.31 ± 0.8	4.03 ± 0.9
	Repeated Bout	3.95 ± 0.7	3.98 ± 0.7	4.16 ± 0.7	3.83 ± 0.6

Muscle Thickness Raw Scores – Values are mean ± standard deviation (Split by 4 velocity groups)