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TIME COURSE OF CHANGE IN CRITICAL TORQUE AND IMPULSE ABOVE CRITICAL TORQUE FOLLOWING EXERCISE-INDUCED MUSCLE DAMAGE

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TIME COURSE OF CHANGE IN CRITICAL TORQUE AND IMPULSE ABOVE CRITICAL TORQUE FOLLOWING EXERCISE-INDUCED MUSCLE DAMAGE

A THESIS APPROVED FOR THE
DEPARTMENT OF HEALTH AND EXERCISE SCIENCE

BY

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ABSTRACT

Exercise-induced muscle damage (EIMD) is a result of high-force eccentric contractions and can lead to significant alterations in the structure and function of skeletal muscles. Critical torque (CT) and the impulse above critical torque (IACT) have both been reported to decrease following EIMD. **PURPOSE:** The purposes of this study were to 1) observe the time course of change in CT and IACT up to 7-days following EIMD, and 2) to assess the extent to which central and peripheral fatigue contribute to changes in CT and IACT following EIMD. **METHODS:** Participants (males = 6, females = 4) completed 2 familiarizations and 5 experimental visits. Fatigue patterns were assessed, and CT and IACT were derived at the 1st experimental visit. The 2nd experimental visit included an EIMD protocol consisting of 100 back squats. The 3rd, 4th, and 5th experimental visits were identical to the 1st. CT and IACT were acquired through voluntary and stimulated conditions. **RESULTS:** The participant's ratings of muscle soreness were significantly elevated up to 4-days following EIMD ($p<0.05$). Dominant leg MVIC was reduced up to 2-days ($p<0.05$) while non-dominant leg MVIC was reduced up to 4-days ($p<0.05$) following EIMD. Mean CT was decreased up to 4-days following EIMD in the voluntary condition ($p<0.05$) while decreases lasted up to 2-days in the stimulated condition ($p<0.05$). IACT was not significantly different following EIMD in either conditions ($p>0.05$). Voluntary activation was not significantly different following EIMD ($p>0.05$) and these results are the same for twitch torque ($p>0.05$). EMG RMS and twitch torque both showed a significant reduction during the voluntary CT test ($p<0.05$). There were no changes in low-frequency fatigue after the voluntary and stimulated conditions ($p>0.05$) or following

EIMD ($p>0.05$). **CONCLUSIONS:** Even though CT was lower following EIMD, IACT was not. Additionally, our results show no contribution of central or peripheral fatigue on torque production following EIMD. These findings suggest the loss in torque production following EIMD to be a factor of EIMD's effect on muscular function and not the central and peripheral mechanisms of fatigue.

CHAPTER I - Introduction

1.1 Introduction

Exercise-induced muscle damage (EIMD) commonly occurs following high intensity exercise involving eccentric contractions. EIMD results in predictable alterations in both the structure and function of skeletal muscle which leads to decreases in force production, delayed-onset muscle soreness (DOMS), and decreases in endurance exercise performance (Black & McCully, 2008; D. Burt, Lamb, Nicholas, & Twist, 2012; Carmichael et al., 2006; Davies, Rowlands, Poole, Jones, & Eston, 2011; Fouré et al., 2015; Highton, Twist, & Eston, 2009). The impact of EIMD on aerobic metabolic function has been increasingly studied in recent years. For example, resting muscle oxygen utilization has been shown to increase following EIMD; perhaps to aid in repair of damaged muscle fibers (Sirous Ahmadi, Sinclair, & Davis, 2008). Likewise, EIMD also increases blood volume and resting blood flow to skeletal muscle (Selkow et al., 2015). A growing number of studies have found EIMD negatively impacts performance in endurance time-trials perhaps due to decreased local endothelial flow-mediated dilation (Caldwell et al., 2016), increased ratings of perceived exertion (RPE) and muscle pain (Black & Dobson, 2013), reduced VO2 peak (Black & Dobson, 2012) and ventilatory threshold (Black & Dobson, 2012, 2013; D. G. Burt & Twist, 2011) and earlier accumulation of lactate (Gleeson, Blannin, Walsh, Field, & Pritchard, 1998).

Although less studied, critical power (CP)--defined as the maximal work rate that can be tolerated for a very long duration without fatigue (Jones, Vanhatalo, Burnley, Morton, & Poole, 2010; Monod & Scherrer, 1965) represents an emerging parameter of aerobic metabolic function that predicts exercise performance. Work performed at an

intensity above CP, utilizes a finite and fixed energy store termed W'. The magnitude of W' and thus the amount of work that can be performed above CP is likely determined by anaerobic energy stores such as muscle phosphocreatine (PCr), anaerobic glycolysis, and stored oxygen (Broxterman et al., 2014; Fukuba et al., 2003; Jones et al., 2010; A. Miura, Kino, Kajitani, Sato, & Fukuba, 1999; Monod & Scherrer, 1965). A study by Burnley (Burnley, 2009) has validated a 5-minute all-out test protocol that can be used to estimate W' and critical torque (CT), an isometric exercise analog of critical power. CT represents the maximal torque output a muscle can sustain for a very long duration without inexorably fatiguing (Monod & Scherrer, 1965). Using this protocol, W' is estimated as the impulse above the critical torque (IACT). In a recent study conducted in our lab the 5-minute all-out test (Burnley, 2009) was used to investigate changes in CT and IACT following EIMD (Szczyglowski, Ade, Campbell, & Black, 2017). In this study, significant decrements in both IACT and CT were found 48-hours following EIMD with CT being reduced 14% while IACT was reduced 33%. Interestingly, when CT was expressed as a percentage of MVC, which was reduced ~20% following EIMD, the difference no longer occurred—suggesting the decline in CT may have been related to the decline in MVC. The finding that EIMD seemed to preferentially affect IACT relative to CT suggests EIMD may preferentially alter anaerobic metabolism and deserves further study.

Given that both CT and W' appear to be reduced following EIMD, it would be interesting to assess their recovery over a longer duration. The recent study of Szczyglowski et al., (2017) also did not provide any data regarding the role of central and peripheral fatigue factors in the decline in CT and IACT following EIMD. The

inflammatory response that results from EIMD sensitizes group III and IV afferent fibers which could elevate perceptions of pain and discomfort and could lead to central fatigue and thus reduce voluntary activation of muscle (Black & Dobson, 2013; Graven-Nielsen & Mense, 2001; Proske & Morgan, 2001; Sidhu et al., 2017). EIMD has also been shown to affect peripheral fatigue sites such as excitation-contraction coupling and the disruption of sarcomere mechanics (Proske & Morgan, 2001). Furthermore, recovery time from EIMD can last several days to weeks (Burt, Lamb, Nicholas, & Twist, 2013). Studies have shown reduced gas exchange threshold (GET) and VO2 peak for up to 10 days (Black, Gonglach, Hight, & Renfroe, 2015; Davies, Rowlands, et al., 2011) and reduced maximal strength for up to 14 days depending on the intensity of the EIMD protocol (Black et al., 2015; D. Burt et al., 2012, 2013; Highton et al., 2009). The relative contribution of central vs. peripheral fatigue to decreases in endurance performance over the course of recovery from EIMD has not been widely studied.

In another recent study in our lab we developed a variation of Burley's 5-minute all-out test that is based on the use of electrical muscle stimulation (EMS), coined the stimulated CT test (Janzen, Hight, Patel, Campbell, Larson, & Black, 2018). EMS is the use of electrical current to stimulate muscle fibers to contract (Gregory & Bickel, 2005). Though it was suggested that EMS may cause a reversal of the size principle of muscle fiber recruitment, it is well accepted in current literature that EMS based muscle fiber recruitment follows a nonselective, spatially fixed, and temporally synchronous pattern (Crameri et al., 2007; Gregory & Bickel, 2005). Accordingly, only muscle fibers within the reach of the current field can be recruited. Using different frequencies of EMS, and looking at torque production under conditions of blood flow occlusion, we validated the

attainment of a stimulated version of CT using the stimulated CT test (Janzen et al., 2018). Thus, it would be interesting to examine how our EMS based variation of the 5-minute all-out test behaves following EIMD.

1.2 Purpose

The purpose of this study is to investigate the time course of change in impulse above critical torque (IACT) and critical torque (CT) following EIMD. A secondary purpose of this study is to examine the central and peripheral markers of fatigue during exercise bouts following EIMD.

1.3 Research Questions

1. Will impulse above critical torque (IACT), measured via the five-minute all-out test (Burnley, 2009) and stimulated CT test (Janzen et al., 2018), differ between the pre, 2-days post, 4-days post, and 7-days post visits in the Quadriceps Femoris muscle?
2. Will critical torque (CT), measured via the five-minute all-out test (Burnley, 2009) and stimulated CT test (Janzen et al., 2018), differ between the pre, 2-days post, 4-days post, and 7-days post visits in the Quadriceps Femoris muscle?
3. Will percent voluntary activation, assessed via the twitch interpolation technique using EMS (Behm, St-Pierre, & Perez, 1996; Belanger & McComas, 1981; Denny-Brown, 1928; Shield & Zhou, 2004), differ between the pre, 2-days post, 4-days post, and 7-days post visits in the Quadriceps Femoris muscle?

4. Will peripheral fatigue, assessed via twitch torques during the 5-minute all-out test, differ between the pre, 2-days post, 4-days post, and 7-days post visits in the Quadriceps Femoris muscle?
5. Will LFF, measured as the ratio of torque from a single pulse to a doublet before and following the 5-minute all-out and stimulated CT test (Janzen, *unpublished observations*), differ between the pre, 2-days post, 4-days post, and 7-days post visits in the Quadriceps Femoris muscle?

1.4 Research Hypotheses

1. IACT, acquired through the 5-minute all-out test and stimulated CT test, will differ between the pre, 2-days post, 4-days post, and 7-days post visits in the Quadriceps Femoris muscle.
2. CT, acquired through the 5-minute all-out test and stimulated CT test, will differ between the pre, 2-days post, 4-days post, and 7-days post visits in the Quadriceps Femoris muscle.
3. Percent voluntary activation, assessed during the 5-minute all-out test, will differ between the pre, 2-days post, 4-days post, and 7-days post visits in the Quadriceps Femoris muscle.
4. Peripheral fatigue, assessed via twitch torques during the 5-minute all-out test, will differ between the pre, 2-days post, 4-days post, and 7-days post visits in the Quadriceps Femoris muscle.

5. LFF, assessed before and after the 5-minute all-out test and the stimulated CT test, will differ between the pre, 2-days post, 4-days post, and 7-days post visits in the Quadriceps Femoris muscle.

1.5 Significance

EIMD is an expected outcome of exercise involving eccentric motions. Eccentric motions are evident not only in daily activities but also in sports. Because of eccentric muscle actions, a person's absolute ability to complete a task can be impaired. This can lead to a less fruitful workout or mediocre performance in a sports/ athletic setting. Ultimately, this can be detrimental for those seeking optimal results from training or at competitive events. Unfortunately, there exists no medicinal countermeasure to EIMD. Research has shown that sufficient rest can revert the losses in strength and endurance performance following EIMD. However, there is a lack of research when considering the recovery rate of CT and IACT following EIMD. Understanding how the loss in CT and IACT recovers can help athletes create a more stable training regimen that works within the constraints imposed by EIMD.

1.6 Delimitations

The delimitations of this study include:

1. Inclusion of males and females ranging from 18 – 35 years of age.
2. Inclusion of males and females who can tolerate EMS.
3. Inclusion of males and females who are capable of CT testing and undergoing an EIMD protocol.

4. Exclusion of individuals who have resistance trained their legs 6 months prior to the study.
5. Exclusion of males and females with health issues as ascertained via the physical activity readiness questionnaire (PAR-Q) and the Health Status Questionnaire.
6. Exclusion of males and females who supplement with non-steroidal anti-inflammatory drugs (NSAIDs) which could potentially affect results.
7. Exclusion of females who are pregnant or thinking of becoming pregnant.
8. Exclusion of current smokers, daily drinkers, and non-prescribed/illegal drug abusers.

1.7 Limitations

The limitations of this study include:

1. Participants were asked not to resistance train their legs for the duration of the study however their compliance to this request was not controlled.
2. The whole sample underwent an EIMD protocol, however, therapeutic modalities (ice/heat, massage etc.) outside of the lab setting was not controlled for.
3. Since participant recruitment was limited by training status, age, location, and those willing to volunteer the results may not be representative of the general population.
4. Participants were asked to maintain their normal diet, but their eating habits were not controlled for.

1.8 Assumptions

The assumptions of this study include:

1. Measuring IACT is a valid and reliable method to estimate the W' parameter.
2. Measuring the end test torque of the 5-minute all-out test is a valid and reliable method to estimate the critical torque.
3. The twitch interpolation technique is a valid and reliable method to determine percent voluntary activation and assess central fatigue.
4. Surface electromyography (EMG) is a valid and reliable method to evaluate muscular activity.
5. The EIMD protocol that will be utilized in this study is a valid and reliable approach to induce muscle damage.
6. Participants gave maximal effort during all visits of the study.
7. Participants adhered to instructions regarding lower body resistance training for the duration of the study.
8. Participants gave truthful health information prior to the study.

1.9 Operational Definitions

The operational definitions of this study include:

1. **Central fatigue** – a component of fatigue marking the decline in force production during an exhaustive task that is attributed to alteration in the transmission of neural output (Boerio, Jubeau, Zory, & Maffiuletti, 2005; Gandevia, 2001).
2. **Critical Torque (CT)** – a maximal isometric work rate that a muscle can withstand for a very long duration without fatiguing (Monod & Scherrer, 1965).

3. **Eccentric contraction** – a form of muscle contraction that involves the muscle being forcibly lengthened (Proske & Morgan, 2001).
4. **Electrical muscle stimulation or Electromyostimulation (EMS)** – the use of electrical current to stimulate muscle fibers to contract (Gregory & Bickel, 2005).
5. **Exercise-induced muscle damage (EIMD)** – a result of high force eccentric contractions experienced through resistance training and explosive training (Armstrong, Ogilvie, & Schwane, 1983).
6. **Impulse above critical torque (IACT)** – a fixed amount of work that can be performed above critical torque regardless of the rate of energy expenditure (Fukuba et al., 2003; A M Jones & Whipp, 2002).
7. **Low-frequency fatigue (LFF)** – a decline in force production that is greater at lower frequencies of EMS relative to higher frequencies (Edwards, Hill, Jones, & Merton, 1977; D. A. Jones, 1996).
8. **Peripheral fatigue** - a component of fatigue marking the decline in force production during an exhaustive task that is attributed to impairments at or below the neuromuscular junction (Boerio et al., 2005; Gandevia, 2001).
9. **Surface electromyography (EMG)** – a method of looking at the electrical signal evoked by muscle fibers over a select field (De Luca, Adam, Wotiz, Gilmore, & Nawab, 2006).
10. **Twitch interpolation** – a technique relying on the use of EMS to assess percent voluntary activation (Behm et al., 1996; Belanger & McComas, 1981; Denny-Brown, 1928; Shield & Zhou, 2004).

Chapter II – Literature Review

Exercise induced muscle damage (EIMD) has shown to be a disadvantage for performance (Black & McCully, 2008; D. Burt et al., 2012, 2013; Carmichael et al., 2006; Davies, Rowlands, et al., 2011; Fouré et al., 2015; Highton et al., 2009). We know of only one study that has investigated the effects of EIMD on CT and IACT (Szczyglowski et al., 2017). Interestingly, this study showed significant decreases in both variables. However, it is still unknown how long it would take for both these variables to return to baseline and how factors of fatigue may affect the pattern of recovery.

The purpose of this study is to investigate the time course of change in IACT and CT following EIMD. Additionally, this study also examines the central and peripheral markers of fatigue during exercise bouts following EIMD. This section provides a brief overview of the published literature on topics related to this study. Accordingly, this chapter is broken down into the following sections: EIMD, CP and W', central fatigue, peripheral fatigue, and LFF attempting to show outcomes in the current literature regarding each section.

This literature review includes studies acquired from the Google Scholar and Medline databases. Likewise, this literature review also contains studies that were manually searched from the reference list of retrieved documents. The search process included the following keywords: "Exercise Induced Muscle Damage", "Critical Power", "Critical Torque", "W Prime", "Impulse Above Critical Torque", "Interpolated Twitch", "Central Fatigue", "Voluntary Activation", "Motor-Unit Recruitment" "Low-Frequency Fatigue", "Peripheral Fatigue" and any combination of those keywords. Studies were

included regardless of whether they showed significant or non-significant differences in their results.

2.1 Exercise-Induced Muscle Damage

EIMD detriments:

It is well accepted in most findings that EIMD is an outcome of eccentric exercise (Caldwell et al., 2016; McCully & Faulkner, 1986; Proske & Morgan, 2001; Stacy, Bladon, Lawrence, McGlinchy, & Scheuermann, 2013). Eccentric exercise can potentially lead to impairments of the excitation-contraction coupling system and also disruption of sarcomeres causing EIMD (Proske & Morgan, 2001) which can trigger an inflammatory response as the muscle recovers from injury (Tidball, 2005). Equally, task specific ATP production can also be affected by this energy demanding repair process following EIMD as seen with increases in resting metabolic rate and oxygen saturation (Ahmadi, Sinclair, Foroughi, & Davis, 2008; Ahmadi et al., 2008; Dolezal, Potteiger, Jacobsen, & Benedict, 2000). Additionally, research has shown an increased inorganic phosphate concentration following EIMD, further suggesting an increase in energy production (Davies, Eston, et al., 2011; Fouré et al., 2015).

Depending on the intensity of and the level of sensitivity to eccentric contractions, EIMD can also result in a reduced capacity to generate force ranging from hours to days (Black et al., 2015; Highton et al., 2009; Newham, Jones, & Clarkson, 1987; Rodenburg, Boer, Schiereck, Echteld, & Bar, 1994). A reduction in force could, in part be attributed to a decreased oxidative capacity, which could impact overall ATP production as seen in human and animal studies (Newcomer, Sirikul, Hunter, Larson-Meyer, & Bamman, 2005; Pilegaard & Asp, 1998; Warren et al., 1996). A reduced oxidative capacity following

EIMD can be a result of impaired mitochondrial function (Fouré et al., 2015; Newcomer et al., 2005) as suggested by an increased ratio of oxygenated blood flow relative to oxygen utilization (Davies et al., 2008; Selkow et al., 2015). Reductions in oxidative capacity following EIMD could also be attributable to macrovascular and microvascular alterations. Macrovascular dysfunction following EIMD is likely due to decreases in flow-mediated dilation (Caldwell et al., 2016) while microvascular impairments are likely a result of a slowed contraction-induced vasodilation which alters the complementing of oxygen delivery to utilization (Larsen, Hirata, Madzak, Frøkjær, & Graven-Nielsen, 2015). The byproducts of eccentric exercise-induced tearing of muscle fibers serve as an additional reason for decreases in force production; as they induce a nociceptive stimulus in the form of soreness (Proske & Morgan, 2001). Paired with the inflammatory response as the muscle recovers, muscle soreness can persist for a significant amount of time (Burt et al., 2012; Highton et al., 2009; Martin, Millet, Lattier, & Perrod, 2004; Newcomer et al., 2005; Selkow et al., 2015). Collectively, EIMD can burden energy metabolism, impair blood flow delivery and utilization, and induce muscle soreness which can have a determining effect on force production.

EIMD on Performance Variables:

Maximal oxygen consumption (VO2max or VO2peak) has been shown to be both lowered and unaffected as a result EIMD (Black & Dobson, 2012; Black et al., 2015; D. G. Burt & Twist, 2011; Caldwell et al., 2016; Chrismas, Taylor, Siegler, & Midgley, 2017; Davies, Rowlands, et al., 2011; Gleeson et al., 1998). Similarly, a decrease in gas exchange threshold (GET) and an increase ventilation (Ve) has been shown as a result of EIMD all while seeing no changes in the lactate threshold (D. Burt et al., 2012; Davies,

Rowlands, et al., 2011). Likewise, maximal voluntary contraction (MVC) has been shown to decrease as a result of EIMD (Sirous Ahmadi et al., 2008; Newham et al., 1987). These performance moderating results are likely a result of the muscle damage induced inflammatory response and the effect it may have on the activation of type III and IV afferent fibers (Black & Dobson, 2012; Graven-Nielsen & Mense, 2001) which have been linked to affect not only the ventilatory response (Davies, Rowlands, et al., 2011) but also corticospinal excitability (Sidhu et al., 2017). It is likely that EIMD affects these performance variables through a combination of properties mentioned above.

Despite the abundance of literature reviewed for this section, only one study that has addressed the effects of EIMD on CT and IACT (Szczyglowski et al., 2017). This study utilized the 5-minute all-out test (Burnley, 2009) to inspect the decrements in CT and IACT, if any, that may be present following EIMD. This study saw a 14 ± 12% decline in CT and a 33 ± 13% decline in IACT following EIMD. These reductions were attributed to a loss of strength since no differences were seen in microvascular circulation.

2.2 Critical Power (CP) & W Prime (W')

CP can be defined as an intensity at which one can theoretically exercise at indefinitely (Jones et al., 2010; Monod & Scherrer, 1965) while W' can be interpreted as a finite, primarily anaerobic magnitude of work above CP that is funded by muscle phosphocreatine, anaerobic glycolysis, and stored oxygen (Broxterman et al., 2014; Fukuba et al., 2003; Jones et al., 2010; A. Miura et al., 1999; Monod & Scherrer, 1965). Furthermore, CP has been defined as the boundary between the heavy and severe intensity exercise domains (Poole, Ward, Gardner, & Whipp, 1988). It has been seen that the transition from CP to an intensity above CP disrupts the stable metabolic acidity related

to CP with unavoidable shifts in the rate of oxygen consumption to its maximal values (Poole et al., 1988). Likewise, it has been shown that exercising above CP (utilizing W') can result in fatigue-like metabolic perturbations including a fall in pH, an increase in inorganic phosphate, and a decrease in muscle phosphocreatine until exercise termination (Jones, Wilkerson, Dimenna, Fulford, & Poole, 2008). Accordingly, these measures attained a steady state when the exercise intensity was below CP (Jones et al., 2008). Since W' is a finite work capacity, athletes must be aware of its allocation in a competitive setting. In fact, it has been shown that competitive runners could greatly optimize their results while running at an intensity above CP so long as total distance has been considered (Jones & Whipp, 2002).

Blood flow occlusion has been seen to decrease CP while playing a heightening role on the W' in the flexor digitorum superficialis muscle (Broxterman, Ade, et al., 2015). Similarly, near-infrared spectroscopy has revealed a greater deoxygenated concentration of hemoglobin and myoglobin when the muscle is occluded suggesting a dependency of CP on continuous oxygen delivery and an enhanced ability of the stored oxygen content to supply the W' (Broxterman, Ade, et al., 2015). A potential association of the increase in W' with occlusion could be the build-up of fatigue, since a positive relationship has been shown between the amount of fatigue accrued and the range of W' (Broxterman, Craig, et al., 2015). Accordingly, a greater duty cycle has been shown to lower CP and increase W' relative to a lower duty cycle suggesting a decreased exercise tolerance and further implicating the influence of fatigue on W' (Broxterman et al., 2014). It is likely that a limitation on CP tends augment the W' and vice versa. In view of that, it has been seen that hyperoxic conditions reduced the rates of change in muscle

phosphocreatine and pH during exercise whereby increasing CP and decreasing W' (Vanhatalo, Fulford, Dimenna, & Jones, 2010). This study will be analyzing the torque analogues of CP and W' referred to as CT and IACT respectively to assess the duration of recovery following EIMD.

2.3 Central Fatigue

Central fatigue is a branch of fatigue responsible for the gradual decline in neural drive during exercise (Gandevia, 2001). One way to analyze central fatigue is via the use of the twitch interpolation technique (Gandevia, 2001). Twitch interpolation involves the use of EMS to apply a superimposed twitch on top of a voluntary contraction to assess motor-unit recruitment (Belanger & McComas, 1981; Denny-Brown, 1928). The following equation is used in the twitch interpolation technique where IT refers to the superimposed twitch and RT refers to the resting twitch:

% Voluntary Activation = 100% x (1 – (IT/RT)) (Shield & Zhou, 2004)

A high ability to activate a muscle during a contraction can result in a low superimposed twitch force from twitch interpolation (Shield & Zhou, 2004). Increases in the superimposed twitch force during fatiguing muscle contractions can be informative of central fatigue and could reflect an impairment in the recruitment of motor-units or maintaining firing rates (Gandevia, McNeil, Carroll, & Taylor, 2013). It has been seen that fatiguing contractions can lead to a decrease in percent voluntary activation which can be attributed to central fatigue (Kawakami, Amemiya, Kanehisa, Ikegawa, & Fukunaga, 2000). Voluntary activation has also been seen to be decreased up to 30 minutes following a fatiguing bout (Simpson, Burke, & Davis, 2004). Equally, voluntary activation has also been shown to be depressed immediately following EIMD (Behrens,

Mau-Moeller, & Bruhn, 2012; Martin et al., 2004). In comparison, for the quadriceps femoris, percent voluntary activation has also been seen to play no role in the loss of force during fatiguing contractions suggesting an absence of central fatigue (Bigland-Ritchie, Furbush, & Woods, 1986). The present study will investigate the role of central fatigue, through analyzing percent voluntary activation during the 5-minute all-out test, and how this measure may contribute to the change in CT and IACT following EIMD.

2.4 Peripheral Fatigue

Peripheral fatigue is a another type of fatigue whose effects on force production during an exhaustive bout can be attributed to alterations at or below the neuromuscular junction (Boerio et al., 2005; Gandevia, 2001). One possible mechanism of peripheral fatigue is the reduction in the intracellular calcium release paired with a reduced calcium sensitivity of myofilaments during prolonged exercise which could have a detrimental effect on the excitation-contraction coupling process (Allen, Westerblad, Lee, & Lännergren, 1992). As mentioned above, an impairment of the excitation-contraction coupling process is also a likely response to EIMD (see EIMD detriments). Accordingly, it has been suggested that peripheral factors including changes in the muscle contractile properties along with an altered excitation-contraction coupling process may be accountable for the prolonged force loss following EIMD (Behrens et al., 2012; Martin et al., 2004). Similarly, the loss of force production in response to a fatiguing protocol of the quadriceps femoris has been attributed to the muscles contractile properties due to a sustained motor-unit recruitment (Bigland-Ritchie et al., 1986).

To purely assess the role of peripheral fatigue during an exercise test motor-units need to be recruited using a constant stimulus. One potential way to do this is the use of

EMS. EMS involves the use of electrical current to stimulate muscle fibers to contract (Gregory & Bickel, 2005). However, the use of EMS yields a different recruitment pattern compared to voluntary contractions in that muscle fibers are recruited in a nonselective, spatially fixed, and temporally synchronous pattern (Crameri et al., 2007; Gregory & Bickel, 2005). Due to its spatially fixed nature, EMS based contractions result in the same motor-units being recruited which can lead to a greater rate of fatigue (Gregory & Bickel, 2005). This role of EMS can also be advantageous in analyzing peripheral fatigue since neural drive can be rendered constant. Suitably, following an EMS based protocol MVC has shown a decrease which has been attributed to peripheral fatigue (Fouré et al., 2014). Accordingly, the present study will utilize the application of electrical twitches to evoke twitch torques to aid in analysis of peripheral fatigue during the 5-minute all-out test before and following EIMD.

2.5 Low-Frequency Fatigue (LFF)

LFF is a form of peripheral fatigue and can be defined as the loss of force at low levels of stimulation that is relatively greater than the force depletion at higher levels of stimulation (Edwards et al., 1977; D. A. Jones, 1996). LFF has been attributed to alterations in the excitation-contraction coupling process and impairments in the release of calcium (Bigland-Ritchie et al., 1986; Edwards et al., 1977). Accordingly, upon fatiguing the quadriceps femoris the force from a single twitch has shown up to a 75% decline compared to a 54% decline following a 50 Hz train (Bigland-Ritchie et al., 1986). Similarly, following an EMS based muscle damaging protocol, the ratio of force from a 10 Hz train relative to a 100 Hz train has been shown to be reduced up to the following day suggesting a prolonged effect of LFF (Fouré et al., 2014). Likewise, the ratio of force

of the knee extensors from a 20 Hz to an 80 Hz train has shown complete recovery 48 hours after EIMD (Martin et al., 2004). Conversely, the present study will assess LFF to test its potential contribution to the loss in CT and IACT following EIMD.

2.6 Conclusions

In conclusion, taking the current research into considered we see that there is still a gap in the knowledge when measuring CT and IACT following EIMD. It is certain that CT and IACT are both informative parameters and that analyzing these variables following EIMD can increase the current level of knowledge. As we've seen, EIMD seems to play a reductive role on CT and IACT. However, there exist no studies that have analyzed the duration of recovery for CT and IACT following EIMD. Additionally, no study has investigated the relative contribution of the central and peripheral markers of fatigue factors to changes in CT and IACT following EIMD. In an attempt to clear these gaps in the literature concerning EIMD, the present study will apply the 5-minute all-out test (Burnley, 2009) and the stimulated CT test (Janzen et al., 2018) to investigate the time course over which CT and IACT return toward baseline following EIMD along with differences in the central and peripheral markers of fatigue.

Chapter III – Methodology

3.1 Introduction

In a recent study, we saw a powerful effect of EIMD on CT and IACT (Szczyglowski et al., 2017). Yet it remains unclear as to how CT and IACT recover in the days following EIMD. Additionally, it would be interesting to understand the contribution of central and peripheral fatigue to force production during exercise bouts following EIMD. This study aims to clarify some of the disparities in the current literature by analyzing the hyperbolic torque-time relationship and its variables CT and IACT following EIMD. The purpose of this study is to investigate the time course of recovery in impulse above critical torque (IACT) and critical torque (CT) following EIMD. Additionally, this study will also examine the central and peripheral markers of fatigue during exercise bouts following EIMD. To present an understanding of the investigation, the intent of this chapter will be to explain the methodology used to assess each variable and clarify the overall experimental process.

3.2 Sample

Ten participants of age 18 – 35 years volunteered and completed participation in this study. Participants were recreationally active individuals who did not perform lower-body resistance training in the past 6 months, specifically their Quadriceps Femoris. Recreationally active individuals included those who semi-regularly lift weights (upper body only), play sports, run, and/or walk. Both males and females were accepted for participation because EIMD has been shown to have a similar effect on both genders (Clarkson & Hubal, 2002; Rinard, Clarkson, Smith, & Grossman, 2000; Sayers & Clarkson, 2001; Stupka et al., 2000). Participants were volunteers and therefore a non-

probability sampling procedure was employed. Participants were excluded from this study if they could not tolerate EMS, had existing health conditions, were pregnant or considering pregnancy, were smokers, drank alcohol regularly, abused drugs, or if they answered "yes" to any questions on the Physical Activity Readiness Questionnaire (PAR-Q) (see Table 1). All participants were recruited from the University of Oklahoma (Norman, OK campus) and surrounding area by email, fliers, announcements made in classes, and word of mouth. Before beginning the study each participant's informed consent was obtained and they were instructed to honestly fill out the PAR-Q along with the Health Status Questionnaire (HSQ). Participants were advised to refrain from physical activity at least 24 hours preceding each visit along with the consumption of food by at least 3 hours and non-water beverages by at least 6 hours. Participants were also recommended to stay properly hydrated prior to each visit. Additionally, participants were directed to avoid supplementing with caffeine at least 6 hours before each visit (Statland & Demas, 1980), along with NSAIDs and other pain medications. Subjects were asked to not utilize any therapeutic modalities that may ease the feeling of muscle soreness associated with EIMD (ice, salt and cold-water baths, massages etc). Adherence to these instructions was confirmed throughout the study. Participants who did not display close to a 25% drop in maximal voluntary isometric contraction (MVIC) immediately following EIMD were discarded from data analysis for they were judged to have experienced an insufficient amount of muscle damage for this study. This study was approved by the University of Oklahoma Institutional Review Board and was also conducted in agreement with the Declaration of Helsinki.

Inclusion	**Exclusion**

People living in proximity to the OU Norman campus	Those who did experience sufficient muscle damage through the EIMD protocol
Males and females within the age range 18-35 years	Those with cardiovascular, pulmonary, or metabolic diseases that could impede maximal effort during testing
Those who did not resistance train their Quads but are recreationally active	Those who were pregnant, thinking of becoming pregnant, current smokers, daily drinkers, and non-prescribed/illegal drug abusers
Those who could tolerate EMS, 5-minute all-out testing, and the EIMD protocol	Those who answered "yes" to any questions on the PAR-Q and/or have any known cardiovascular, pulmonary, or metabolic diseases

Table 1: Subject criteria for participation in this study

3.3 Experimental Design

Since this study will consist of participants being measured over time, a repeated measures design will be employed. This study shall consist of a total of 7 visits including: 2 familiarization sessions, a pre (baseline) visit, an EIMD visit, a 2-days post visit, a 4-days post visit, and a 7-days post visit (see Table 2). All visits were conducted at the same location (Sensory & Muscle Function Lab, Dept. of Health & Exercise Science, the University of Oklahoma, Norman, OK).

Familiarization (Visit 1 and 2):

The first familiarization visit consisted of signing all the paperwork including: a signed consent form, a physical activity readiness questionnaire (PAR-Q), an

international physical activity questionnaire (IPAQ), a talent release form, a photo release form, and a health status questionnaire (HSQ). Each participant was also given a second copy of the consent form for their own record. The first familiarization also included Smith Machine 1-RM testing, dominant leg twitch-current (amplitude) determination, MVIC determination, and dominant leg familiarization to 5-minute all-out testing (Szczyglowski et al., 2017). Because each visit required effort, subjects were asked upon recruitment to have eaten 3 hours prior to coming in and to stay hydrated. 1-RM testing was conducted for purposes of the EIMD protocol and is further detailed below. Twitch-current was determined by gradually applying a doublet twitch (a 1 ms twitch followed in 5 ms by another 1 ms twitch) on the vastus lateralis and vastus medialis until either there was a plateau in torque or the stimulation intensity cannot be tolerated. Following this, 3 separate MVICs were performed with 2 minutes of rest in between. Voluntary activation was determined during the MVICs using the twitch interpolation technique (described below). Following a 10-minute rest, a familiarization to the 5-minute all-out test was initiated consisting of 36 MVICs with the duty cycle of 3 seconds on (contraction) and 2 seconds off (relaxation).

There was at least a 24-hour gap between the first and second familiarization visits. The second familiarization was similar to the first familiarization visit with the inclusion of MVIC determination and train current determination for the non-dominant leg prior to performing the stimulated CT test in that same leg. MVIC in the non-dominant leg was determined just like the dominant leg except motor-unit recruitment was not assessed. The train current determination included the application of a 3-second train of EMS at a frequency of 50 Hz. Like the twitch-current determination process, the

amplitude of the current was gradually increased during the train current determination until the torque was at or slightly above 25% of the participants MVIC. The MVIC that was considered for this was the highest of the three partaken. Following this, a 5-minute stimulated CT test was performed on the non-dominant leg at the current determined during the train current determination. This test consisted of 60 involuntary EMS based contractions with a 3 on (current) 2 off (no current) duty cycle. No data acquired during these two familiarization visits was analyzed.

Pre (visit 3):

The pre visit began at least 2 days following the second familiarization. This visit included dominant leg twitch-current determination and MVIC determination in that exact order. Ten minutes following this, the participant underwent the 5-minute all-out test (Burnley, 2009). This test consisted of 60 MVICs with a duty cycle of 3 seconds on (contraction) 2 seconds off (relaxation). Data regarding changes in LFF were acquired before and after the test, and voluntary activation/central fatigue was assessed during the test (detailed below).

After completion of the 5-minute all-out test the participant was given a 10-minute rest. Following this 10-minute rest the participant underwent an MVIC determination and a train current determination for the non-dominant leg. Following another 10-minute rest, participants underwent a stimulated CT test in the non-dominant leg. EMS based contractions result in a decline in torque at a faster rate due to a non-selective recruitment pattern (Crameri et al., 2007; Gregory & Bickel, 2005) and therefore may be helpful in interpreting changes, if any, that could be attributed to peripheral fatigue following EIMD. Like the 5-minute all-out test, data regarding CT,

IACT, and LFF were acquired during the stimulated CT test. Unlike the 5-minute all-out test, voluntary activation/central fatigue was not addressed during the stimulated CT test.

EIMD session (visit 4):

The EIMD session was held at least 2 days following the pre visit. On this day, the participants underwent a muscle damaging protocol consisting of active eccentric and semi-passive concentric contractions. The EIMD protocol involved 10 sets of 10 repetitions on the Smith Machine. These sets were conducted at the participants 1-RM (further details are provided below). On this visit, participants were also required to rate their perception of muscle soreness before and following EIMD (detailed below).

Immediately following the EIMD protocol, the participant partook in the determination of MVIC for each leg, dominant and non-dominant. Three MVICs were performed for each leg and the value of the two closest were considered and averaged. If this value for each leg was at least 25% lower than the criterion MVIC for each leg during the pre visit, then participants were perceived to have experienced a sufficient amount of EIMD. If the drop in MVIC for each leg was not close to 25%, then more sets of active eccentric and semi-passive concentric Smith Machine squats were incorporated accordingly. Participants were relieved from further participation if further increases in volume of up to 3 sets in the EIMD protocol show no decreases in MVIC for each leg.

2-days post (visit 5), 4-days post (visit 6), and 7-days post (visit 7).

The visits 2-days, 4-days, and 7-days post were held 2, 4, and 7 days following the EIMD session, respectively. These visits were identical to the baseline visit, except

ratings of muscle soreness were recorded at the beginning of each of these visits. At the end of the 7-days post visit, each participant was compensated for the lengthy participation in this study.

Visit	Procedures
Familiarization 1	1. Paperwork 2. 1-RM testing 3. Twitch-current determination (dominant leg) 4. MVIC (dominant leg) 5. Familiarization to 5-minute all-out test (dominant leg)
Familiarization 2	1. Twitch-current determination (dominant leg) 2. MVIC (dominant leg) 3. Familiarization to 5-minute all-out test (dominant leg) 4. MVIC (non-dominant leg) 5. Train current determination (non-dominant leg) 6. Stimulated CT test (non-dominant leg)
Pre	1. Twitch-current determination (dominant leg) 2. MVIC (dominant leg) 3. 5-minute all-out test/ LFF (dominant leg) 4. MVIC (non-dominant leg) 5. Train current determination (non-dominant leg) 6. Stimulated CT test/ LFF (non-dominant leg)
EIMD session	1. Rating of muscle soreness 2. EIMD protocol 3. Rating of muscle soreness 4. MVIC to see close to a 25% drop (dominant leg) 5. MVIC to see close to a 25% drop (non-dominant leg)
2-days post	1. Rating of muscle soreness 2. Twitch-current determination (dominant leg)

	3. MVIC (dominant leg) 4. 5-minute all-out test/ LFF (dominant leg) 5. MVIC (non-dominant leg) 6. Train current determination (non-dominant leg) 7. Stimulated CT test/ LFF (non-dominant leg)
4-days post	1. Rating of muscle soreness 2. Twitch-current determination (dominant leg) 3. MVIC (dominant leg) 4. 5-minute all-out test/ LFF (dominant leg) 5. MVIC (non-dominant leg) 6. Train current determination (non-dominant leg) 7. Stimulated CT test/ LFF (non-dominant leg)
7-days post	1. Rating of muscle soreness 2. Twitch-current determination (dominant leg) 3. MVIC (dominant leg) 4. 5-minute all-out test/ LFF (dominant leg) 5. MVIC (non-dominant leg) 6. Train current determination (non-dominant leg) 7. Stimulated CT test/ LFF (non-dominant leg)

Table 2: This table shows each visit and the procedures corresponding to each of those visits.

3.4 Experimental Procedures

Isokinetic Dynamometer:

All testing was conducted using the same isokinetic dynamometer (KinCom isokinetic dynamometer, Chattanooga, TN, USA). The dynamometer was setup similar to what has been seen (Burnley, 2009). During the first familiarization visit the KinCom was setup for the subject for both legs and the positions were recorded for future visits. The device was set to form a parallel between the axis of rotation of the KinCom lever arm and the knee joint. The distance of the moment arm was recorded and remained

constant for each subject. The subject's shin was strapped snugly to the cushioned force application device using an inelastic strap and the angle was set to a knee extension angle of 110 degrees (20 degrees above a seated 90-degree knee flexion). Using the KinCom, the upper body was strapped down to avoid extraneous movements that could potentially corrupt data.

1-RM Testing:

1-RM testing was conducted for Smith Machine back squats for all participants on the first familiarization visit. If participants had never done back squats before, then they were first shown how to do so. Upon learning, the weight (Kg) was gradually increased or decreased to achieve a 1-RM within 5 attempts. The first attempt was a warm-up to 10 repetitions and the second attempt involved selecting a weight the participant could squat for 5 repetitions. The final 3 repetitions included increasing or decreasing the weight accordingly to acquire a 1-RM. Each participant's 1-RM was recorded for the EIMD protocol.

Twitch Current Determination:

For the twitch interpolation technique, each visit involved the determination of a maximal doublet current (milliamps - mA). The goal was to determine a maximal tolerable EMS current upon which further increases in amplitude (mA) could not yield increases in the force. To do this, stimulation electrodes (3' x 4', PALS Platinum, Axelgaard, LTD, Fallbrook, CA, USA) were placed on the vastus lateralis around mid-thigh and on the vastus medialis at the distal end of the muscle. Every time before electrode placement, the site was wiped with an alcohol swipe. Placement of stimulation electrodes was marked with a permanent marker on the first visit and remarked thereafter.

These same stimulation electrode placement procedures were applied to each leg being tested. The electrodes were connected to a current stimulator (Digitimer DS7A Current Stimulator, Digitimer North America, LLC, Ft. Lauderdale, FL, USA) and the muscles were stimulated once at 30 mA with a doublet (a 1 ms pulse followed by another 1 ms pulse in 5 ms). Following 15 seconds of rest the current was increased by 10-20 mA. This process continued until a plateau in twitch force was achieved. The twitch force was recorded during each contraction using the Biopac Acknowledge software (Biopac, Goleta, CA, USA). The twitch current that was determined for each respective day was then used for the interpolated twitch technique during MVIC recordings and for assessing central fatigue during the 5-minute all-out test. Hence, participants who could not tolerate EMS were discarded from the study.

EMG electrodes were also placed and marked on the subjects. EMG electrodes were placed immediately following placement of stimulation electrodes. Equally, the site was wiped with an alcohol swipe which was preceded with dry shaving. Likewise, EMG electrodes were placed and marked for each leg being tested. Monopolar EMG electrodes (10 mm diameter) were placed only on the vastus lateralis in compliance with SENIAM recommendations. A ground electrode was also placed on the patella. The interelectrode distance was set at 30 mm with at least 50 mm of separation between the stimulation and EMG electrodes (Gruet et al., 2014; N. Miura & Watanabe, 2016). Bipolar EMG signals were retrieved to the Acknowledge software using a BioNomadix dual channel wireless receiver (Biopac, Goleta, CA, USA). The signal was acquired at a sampling rate of 2000 Hz and high and low pass filtered at 500 Hz and 10 Hz, respectively (Szczyglowski et al., 2017). EMG was used to acquire root mean square (RMS) for the vastus lateralis.

Maximal Voluntary Isometric Contraction (MVIC):

Subjects remained seated on the dynamometer as described above to test either their dominant or non-dominant leg. The MVIC determination included 3 trials with 2 minutes of rest between each trial. The mean of the two closest MVICs was used as the criterion MVIC for the day for each leg. Subjects were asked to wait on an auditory cue before an MVIC. The auditory cue lasted for 3 seconds and subjects were asked to maximally contract and relax in accordance with this signal. Approximately 2.5 seconds into the 3 second MVIC the subject received a doublet twitch. Likewise, the subject received another doublet twitch 1 second after the 3 second MVIC. The twitch-current (mA) for the two twitches was determined during the twitch-current determination process (detailed above). During each MVIC trial the subject was not presented with visual feedback but given verbal encouragement.

The reason behind the twitches during MVIC determination is the foundation of the interpolated twitch technique to look at voluntary activation. During the 5-minute all-out test this technique can be utilized to assess central fatigue. In the equation below (Gruet et al., 2014; Shield & Zhou, 2004) the doublet twitch that is applied 2.5 seconds into the MVIC is the interpolated twitch (IT) and the doublet twitch applied a second after the MVIC is the resting twitch (RT).

$$\% \text{ Voluntary Activation} = 100\% \times (1 - (IT/RT))$$

5-Minute All-Out Test:

Being seated to test the dominant leg on the isokinetic dynamometer with both stimulation and EMG electrodes placed and properly connected as described above, participants underwent the 5-minute all-out test following a 10-minute rest. This test

was 5 minutes long and consisted of 60 MVICs requiring the subject to maximally knee extend for 3 seconds and relax for 2 seconds (a 3 on 2 off duty cycle). Similar to the MVIC measurements, participants were provided with an auditory cue informing them when to contract and when not to. Equally, a doublet was applied during and following the 1st and every 6th contraction after to analyze voluntary activation and twitch torque. Participants were not presented with visual feedback to retain their attention solely to maximally kicking. Additionally, participants were encouraged by the researchers throughout the duration of the test to provide maximal effort. As validated (Burnley, 2009), the average torque of the final 6 contractions of the 5 minute protocol was used as the estimate of CT for data analysis. Similarly, IACT was calculated as the area under the torque-time curve by summing the difference between each contraction and the CT (Burnley, 2009; Kellawan & Tschakovsky, 2014), see equation below.

$$IACT = \sum (\text{Torque Impulse} - CT)$$

Train Current Determination:

Subjects were seated to test their non-dominant leg on the isokinetic dynamometer as described above. Non-dominant leg MVIC was determined before assessing train current determination. During train current determination, the participant received a 3 second stimulation train at 50 Hz, 50 individual 1 millisecond electrical stimuli every second (A total of 150 individual 1 millisecond stimuli over 3 seconds). The reason for this process was to yield a current amplitude (mA) that can elicit a force output close to 25% of the highest non-dominant leg MVIC for the day. Therefore, starting at 30 mA the current amplitude was increased progressively by 10 mA, with a

15-20 second rest period. The amplitude value that closely approximated 25% of MVIC was recorded and used for the stimulated CT test that followed.

Stimulated CT test:

The stimulated CT test followed 10 minutes after the train current determination process. This test's protocol was conducted similar to that described above in the 5-minute all-out test, except the subject was asked to relax and not voluntarily contract the knee extensors. Additionally, voluntary activation via the twitch interpolation technique was not assessed during this involuntary stimulated CT test. In this test, the participant received a stimulated duty cycle of 3 second on (current train) 2 second off (no current/relaxation) at 50 Hz at the current determined during the train current determination process. This test lasted 5 minutes similar to the 5-minute all-out test and provide 60 stimulated contractions for assessment of peripheral fatigue.

EIMD Protocol:

The muscle damaging protocol used in this study involved the execution of 100 Smith Machine squats. Participants were shown how to properly perform a squat during the first familiarization visit when 1-RM was measured. Participants were directed to lower the weight until the knees are at or slightly below a 90-degree angle (eccentric portion). Once a participant is at the bottom of the squat range of motion, the weight was smoothly lifted, along with partial help from the subject, by two researchers on each side of the smith machine bar to allow the participant to ease back to the initial position (semi-passive concentric). These eccentric squats were performed at each participant's 1-RM. The 100 eccentric squats were broken up in to 10 sets of 10 repetitions with 1 minute of rest in between sets. Upon completion of the EIMD protocol, the participant were sat on

the KinCom and MVIC was measured for each leg. More sets were incorporated if a participant did not show close to a 25% drop in MVIC.

Ratings of Muscle Soreness:

Ratings of the perception of muscle soreness were marked by participants on a visual analog scale (VAS). The VAS included a line ranging 100 mm in length and the words “no pain at all” and “worst imaginable pain” on opposite sides of the line. For each rating, participants were asked to squat their body to or slightly below 90 degrees and return to a stand themselves. During this process, participants were asked to keep the quadricep pain associated with the downward portion in mind. Participants were then asked to mark their feeling of pain on the VAS. These ratings were done five times for each subject, twice during the EIMD visit, and once at the beginning of the 2-days, 4-days, and 7-days post visits.

Low-frequency fatigue (LFF):

LFF was assessed before, immediately after, and 3 minutes after the 5-minute all-out test and the stimulated CT test (Janzen et al., *in press*) in the dominant and non-dominant legs, respectively. LFF was measured using the application of a doublet that was followed by a single twitch in 3 seconds. Each doublet followed by a single twitch made a pair. Each pair was separated by 3 seconds. There was a total of 10 pairs before, immediately after, and 3 minutes after the 5-minute all-out and the stimulated CT test. Likewise, the first 10 pairs were separated from the onset of the tests by 20 seconds. The second 10 pairs began 2 seconds following the offset of the tests and the last 10 pairs followed 2 minutes afterwards. LFF was calculated by looking at the twitch force values of the single twitch relative to the doublet. These ratios were averaged for each

of the three timeframes during which LFF was assessed. The current amplitude that was used during assessment of LFF during the 5-minute all-out test was that acquired during the twitch-current determination process. Similarly, the current amplitude that was used for assessment of LFF during the stimulated CT test was that acquired during the train current determination process.

3.5 Statistical Analysis

All tests were performed using the same statistical analysis software, SPSS version 21 (IBM Corp., Armonk, NY, USA). A one-way repeated measures ANOVA was conducted to test the differences between the visits for the variables CT, IACT, stimulated CT, stimulated IACT, soreness, and MVIC. Pairwise comparisons were made using least significant difference (LSD) and significant differences were reported relative to the pre visit. A two-way repeated measures ANOVA was conducted to test differences between visits and over timepoints during the 5-minute all-out test and the stimulated CT test for voluntary activation, twitch torque, EMG RMS, and LFF. Pairwise comparisons were performed using LSD and differences were reported relative to the pre visit. For all tests, the alpha level was set at a priori $p < 0.05$.

Chapter IV – Results

A total of 10 subjects (6 males and 4 females) complied with instructions concerning participation and managed to fully complete the study. Analysis for all the voluntary tests were conducted on data retrieved from 8 of 10 subjects, due to poor effort during the 5-minute all-out tests from 2 subjects. Analysis for all the stimulated tests were conducted on data retrieved from all 10 participants. Participant characteristics are shown in table 3. All participants performed 10 sets with 10 reps each of active eccentric, semi-passive concentric Smith Machine back squats with one minute of rest in between sets.

Setting	Age (yrs)	Height (cm)	Weight (Kg)
Voluntary (n = 8)	21.9 ± 2.0	176.5 ± 16.2	71.9 ± 11.6
Stimulated (n = 10)	22.1 ± 1.9	176.2 ± 14.3	73.3 ± 12.1

Table 3: Participant characteristics for those included in the data analysis in the voluntary and stimulated setting.

4.1 Assessment of Muscle Damage and Delayed Onset Muscle Soreness

Figure 1 displays the changes in the perception of pain associated with muscle soreness. The one-way repeated measures ANOVA conducted to assess VAS data for ratings of muscle soreness yielded a significant main effect for visits ($p<0.001$). Pairwise comparisons using least significant difference (LSD) showed that the ratings of muscle soreness relative to pre-EIMD were significantly greater post-EIMD ($p<0.001$), 2-days post ($p<0.001$), and 4-days post ($p=0.005$), but not 7-days post ($p>0.05$).

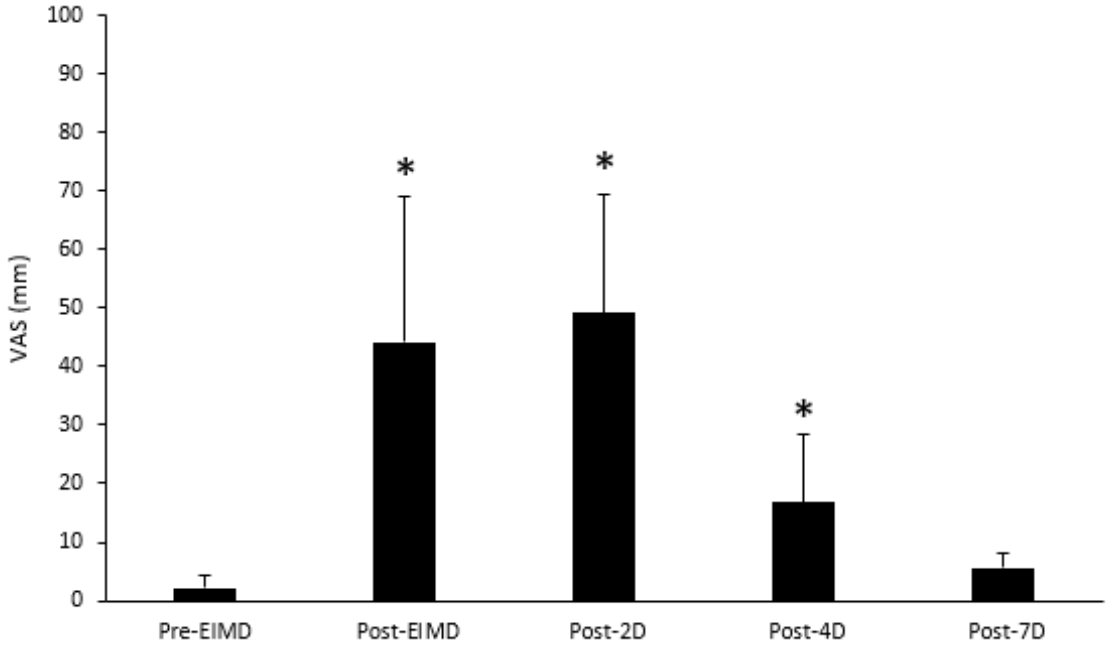

Figure 1: Ratings of the perception of pain associated with muscle soreness. Ratings were significantly greater ($p<0.05$) post-EIMD, 2-days post, and 4-days post. * indicates a significant difference from pre-EIMD. Values are mean ± SD.

Figure 2 displays the changes in MVIC for the dominant leg. The one-way repeated measures ANOVA showed a significant main effect for visits ($p<0.001$). Pairwise comparisons using LSD showed a significant decrease in MVIC post-EIMD ($p=0.004$) and 2-days post ($p=0.002$) relative to pre-EIMD. However, the visits 4-days and 7-days post were not significantly different from pre-EIMD ($p>0.05$). Figure 3 displays the changes in dominant leg MVIC as a percent of initial values at pre-EIMD. Like the results seen in Figure 2, there was a significant main effect for visit ($p<0.001$). Pairwise comparisons via LSD revealed a significant force decrement post-EIMD ($p<0.001$) and 2-days post ($p=0.006$). Force decrement was not significantly different from pre-EIMD on the visits 4-days and 7-days post ($p>0.05$).

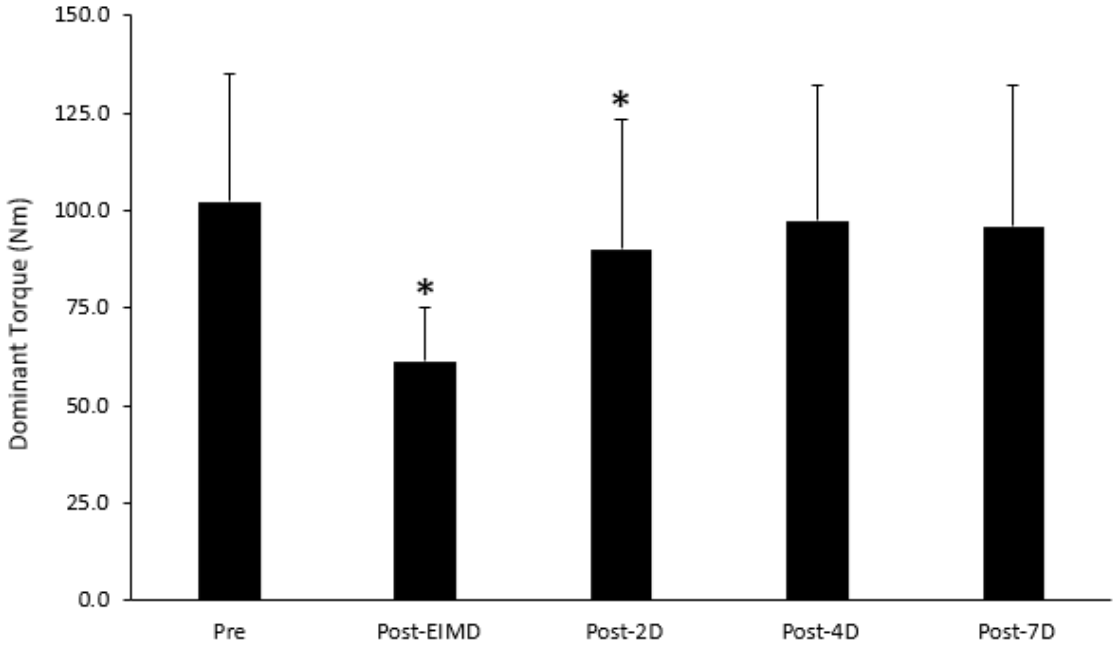

Figure 2: Dominant leg MVIC before muscle damage and the days following it. Force was significantly decreased ($p<0.05$) post-EIMD and 2-days post. * indicates a significant difference from pre-EIMD. Values are mean ± SD.

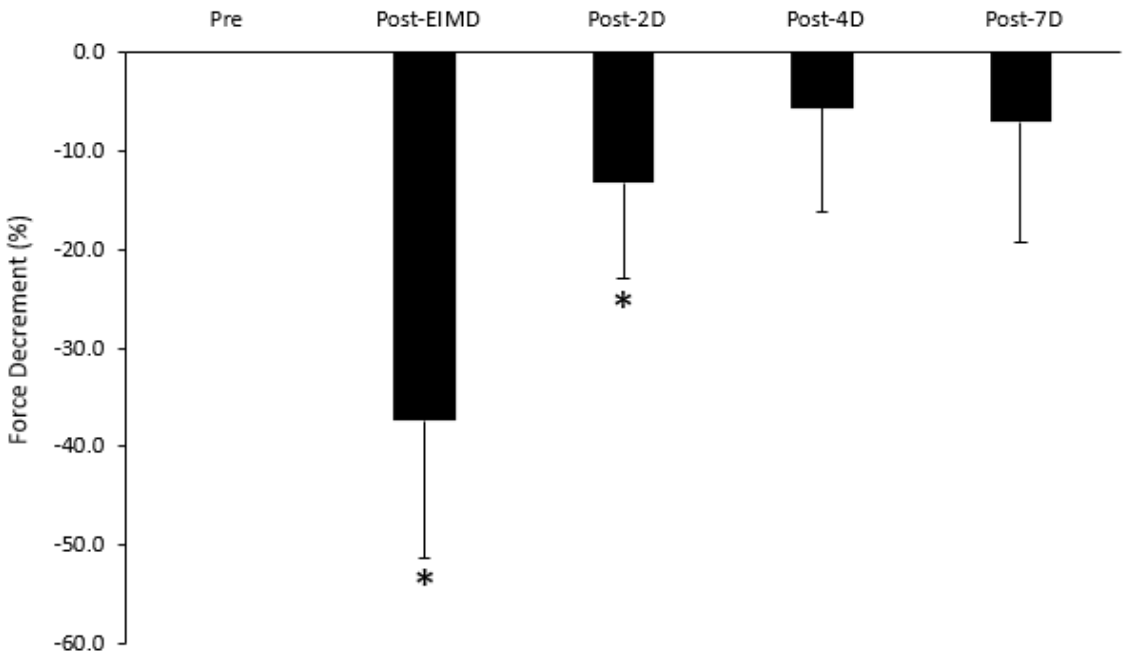

Figure 3: Decrease in dominant leg MVIC as a percent of MVIC at pre-EIMD. Force decrement was significant post-EIMD and 2-days post ($p<0.05$). * indicates a significant difference from pre-EIMD. Values are mean ± SD.

Figure 4 illustrates the changes in MVIC for the non-dominant leg. The one-way repeated measures ANOVA showed a significant main effect for visits ($p<0.001$).

Pairwise comparisons using LSD showed significant decreases post-EIMD ($p<0.001$), 2-days post ($p=0.001$), and 4-days post ($p=0.041$) relative to pre-EIMD. The change in non-dominant MVIC relative to pre-EIMD was not significant 7-days post ($p>0.05$). Figure 5 displays the changes in non-dominant leg MVIC as a percent of initial values at pre-EIMD. Relating to the results in figure 4, there was a significant main effect for visit ($p<0.001$) for percent decrement. Pairwise comparisons via LSD revealed significant percent force decrement post-EIMD ($p<0.001$), 2-days post ($p=0.001$), and 4-days post ($p=0.037$). However, force decrement was not significantly different 7-days post ($p>0.05$).

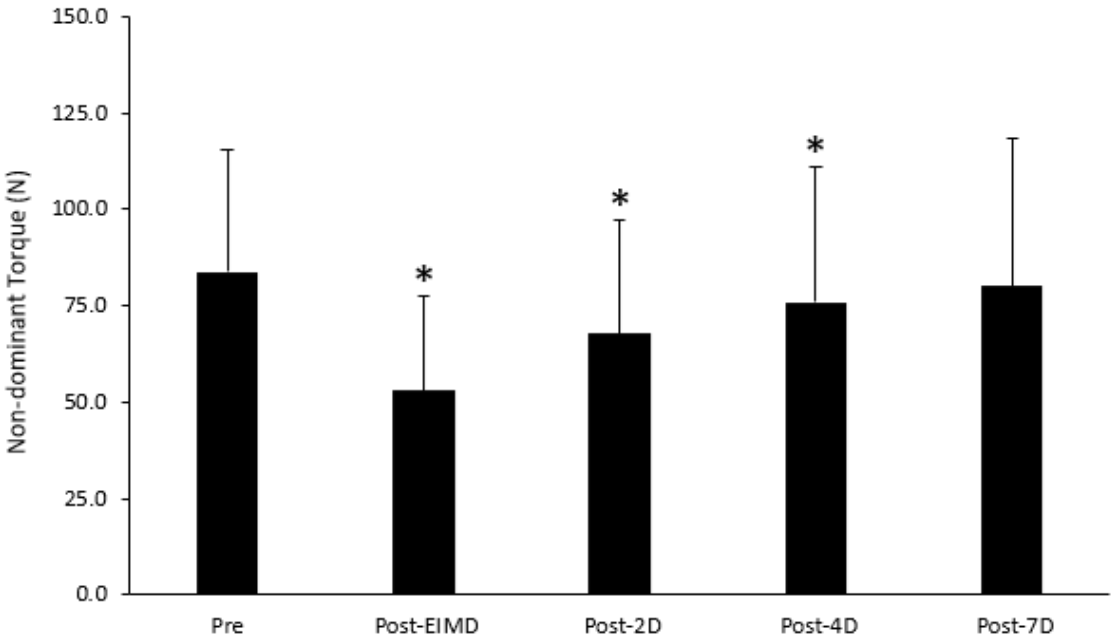

Figure 4: Non-dominant leg MVIC before muscle damage and the days following it. Force was significantly decreased ($p<0.05$) post-EIMD, 2-days post, and 4-days post. * indicates a significant difference from pre-EIMD. Values are mean ± SD.

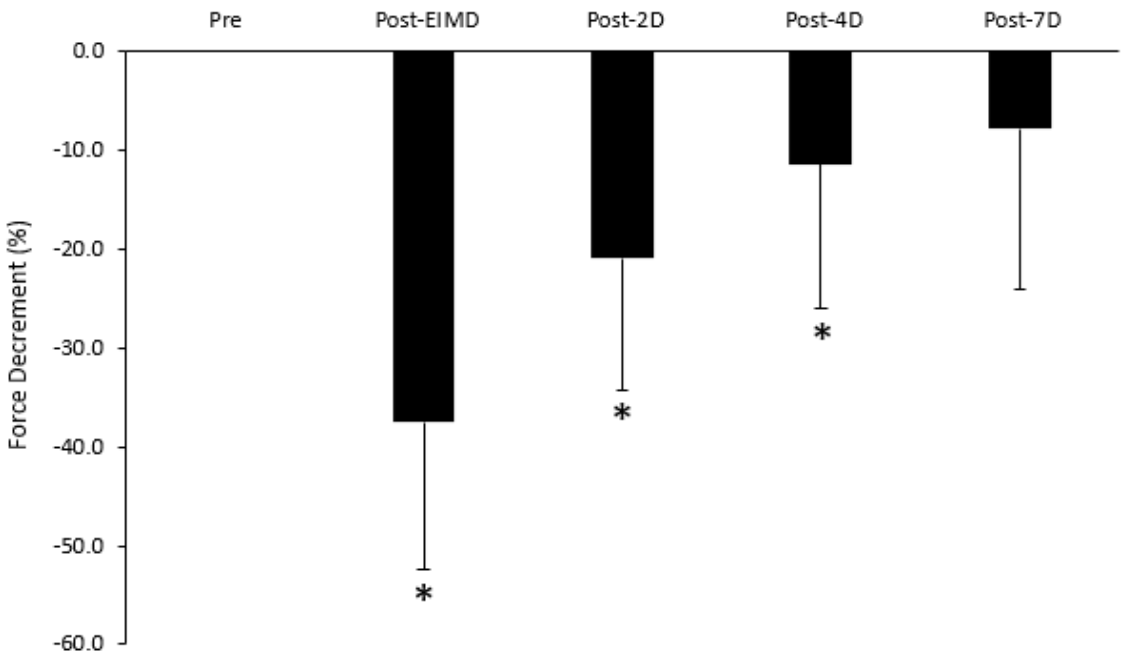

Figure 5: Decrease in non-dominant leg MVIC as a percent of MVIC at pre-EIMD. Force decrement was significant post-EIMD, 2-days post, and 4-days post ($p<0.05$). * indicates a significant difference from pre-EIMD. Values are mean ± SD.

4.2 Voluntary Critical Torque

Figure 6 displays the peak torque throughout the 5-minute all-out test for each visit. Likewise, figure 7 illustrates the peak torque relative to the first contraction of the 5-minute all-out test for each visit. A one-way repeated measures ANOVA was conducted to test differences in absolute peak CT, displayed in figure 8. A main effect for visit was significant ($p=0.047$) and pairwise comparisons via LSD showed a significant decrease at 48-post relative to pre-EIMD ($p=0.031$) but not during the other visits ($p>0.05$). Peak CT was also normalized relative to the initial contraction of the 5-minute all-out test. A one-way repeated measures ANOVA was run to test relative peak CT. The main effect for visit was not significant ($p>0.05$) for the data shown in figure 9.

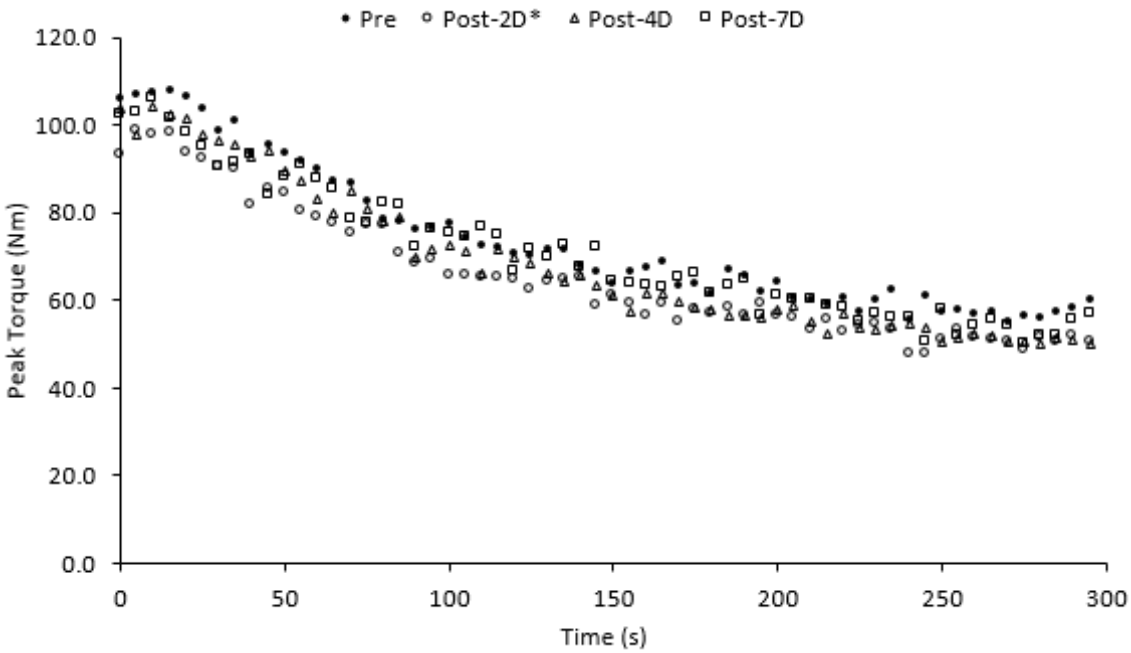

Figure 6: Peak torque for each contraction during the 5-minute all-out test for each visit.

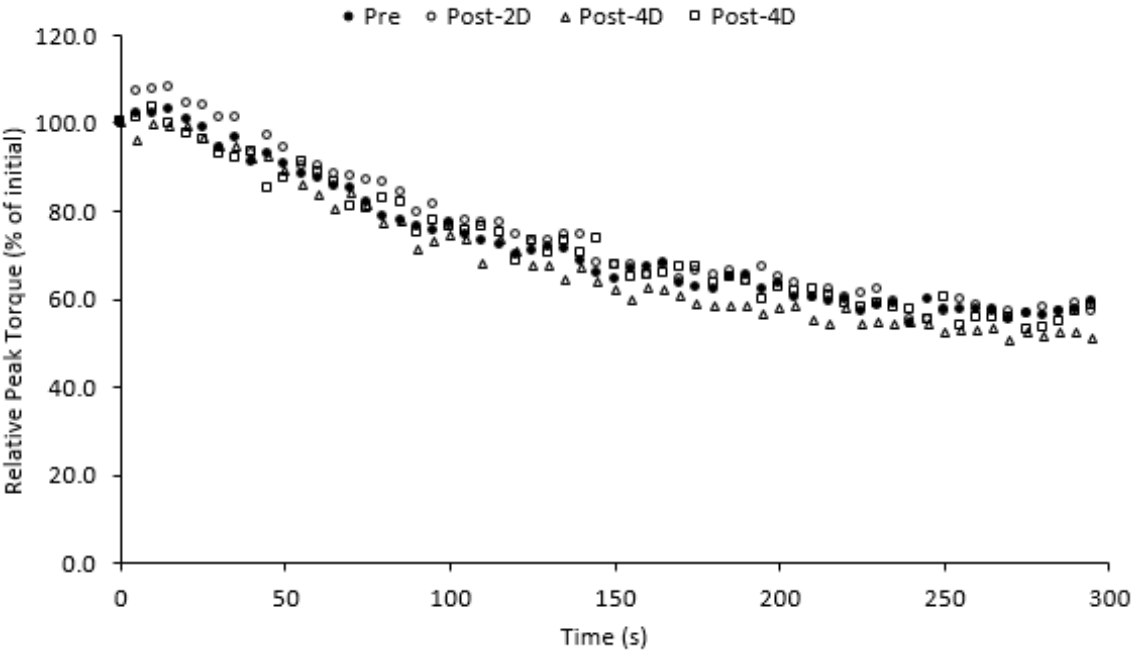

Figure 7: Peak torque for each contraction during the 5-minute all-out test relative to the first contraction.

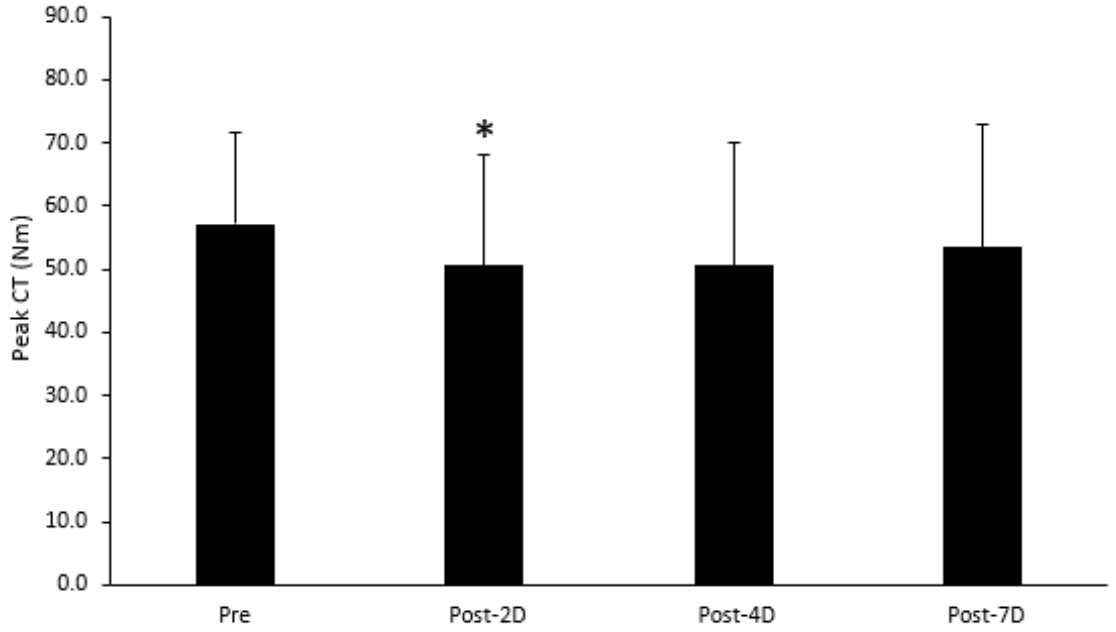

Figure 8: Peak CT for each visit. Values were significantly decreased at 2-days post ($p<0.05$). * indicates a significant difference from pre. Values are mean ± SD.

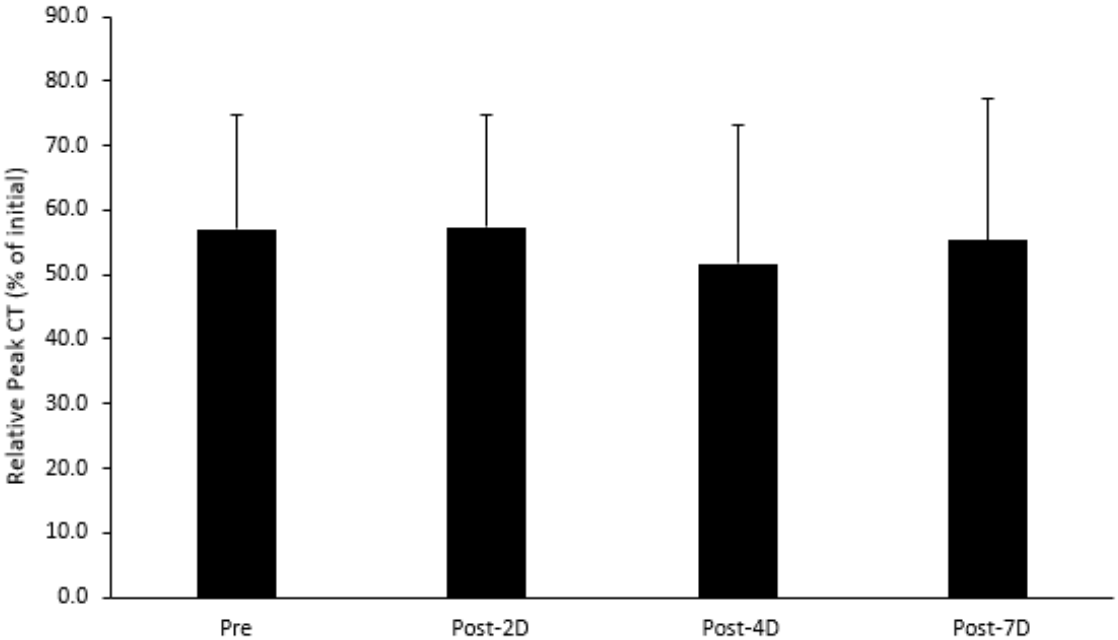

Figure 9: Peak CT relative to the initial contraction of the 5-minute all-out test. There were no significant differences. Values are mean ± SD.

Figure 10 illustrates the mean torque for each contraction during the 5-minute all-out test for each visit. Likewise, figure 11 shows the mean torque relative to the

MVIC for each contraction during the 5-minute all-out test for each visit.A one-way repeated measures ANOVA was conducted to test differences in absolute mean CT, displayed in figure 12. There was a significant main effect for visit (p=0.011). Pairwise comparison using LSD showed that mean CT was significantly lower on the visit 2-days post (p=0.011) and 4-days post (p=0.035) relative to pre. Mean CT was also analyzed relative to the mean torque of the MVIC prior to the 5-minute all-out test, displayed in figure 13. This showed no significant differences between the visits (p>0.05).

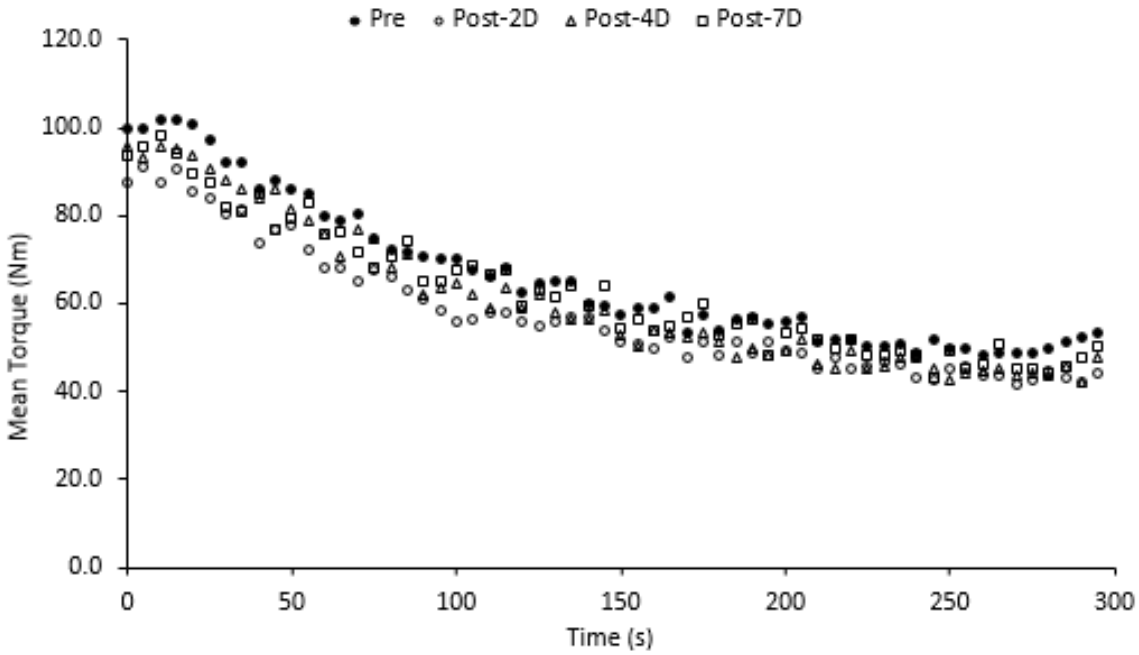

Figure 10: Mean torque for each contraction during the 5-minute all-out test for each visit.

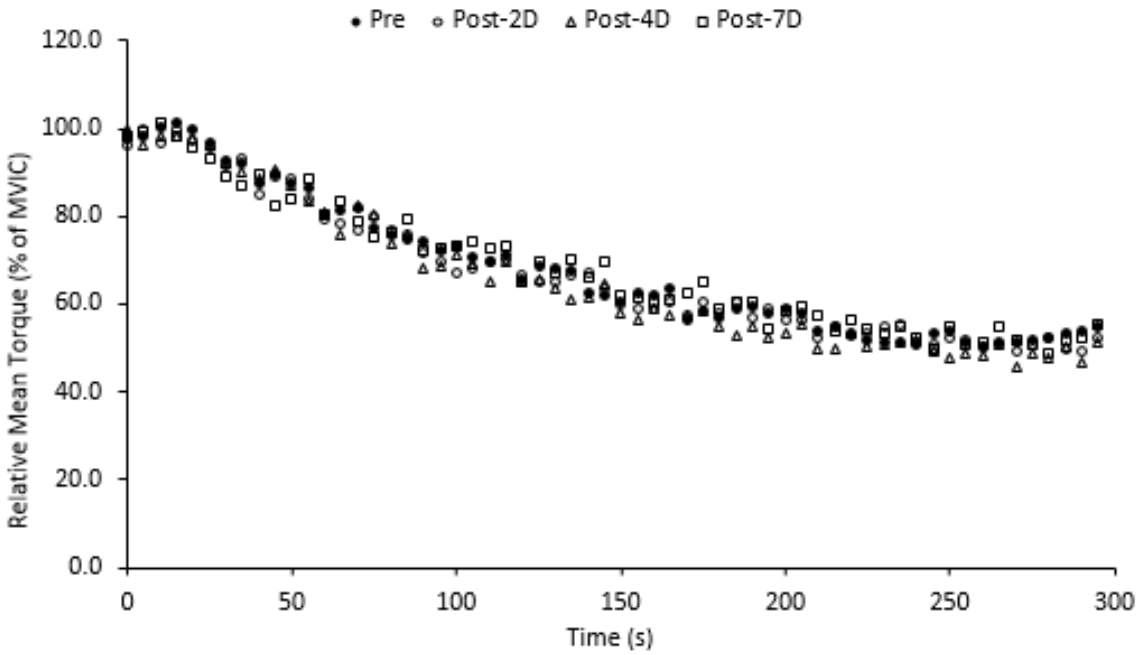

Figure 11: Mean torque for each contraction of the 5-minute all-out test as a percentage of the MVIC.

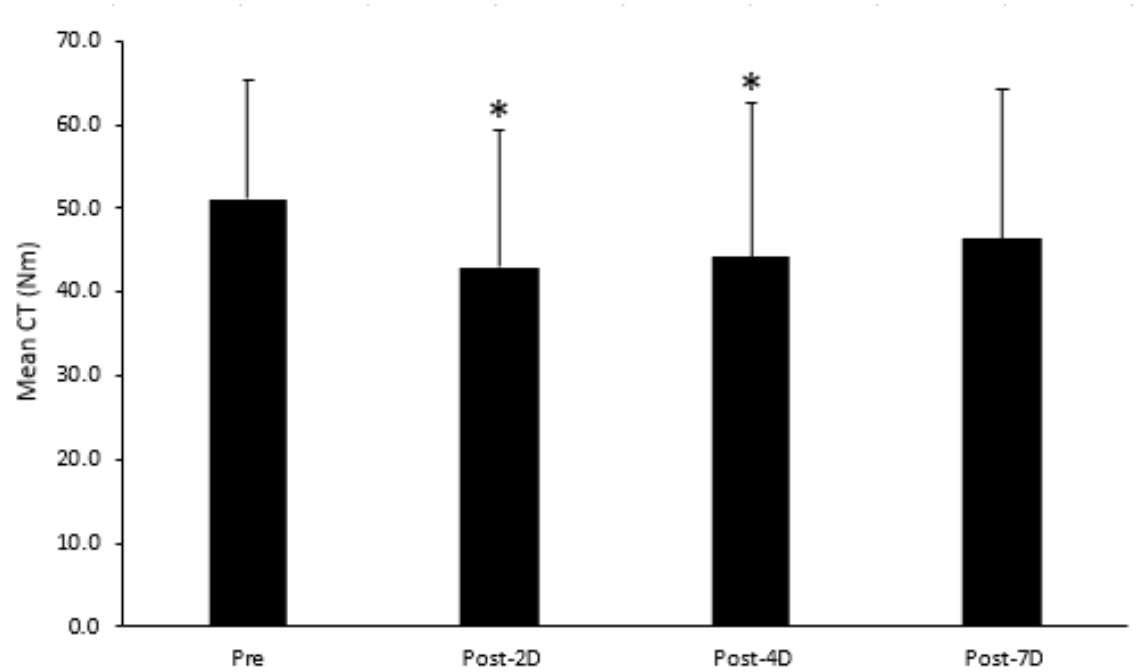

Figure 12: Mean CT for each visit. Values were significantly lower 2-days post and 4-days post ($p<0.05$). * indicates a significant difference from pre. Values are mean ± SD.

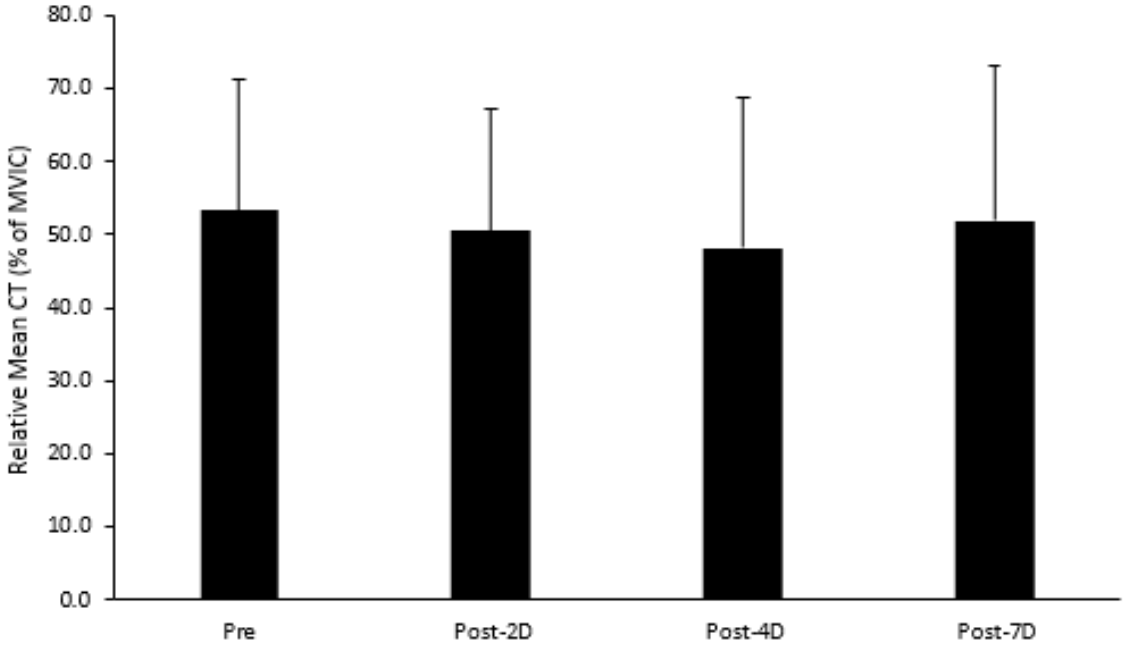

Figure 13: Mean CT relative to MVIC. No significant differences were seen ($p>0.05$). Values are mean ± SD.

4.3 Stimulated Critical Torque

Figure 14 shows the peak stimulated torque for each contraction of the stimulated CT test for each visit. Figure 15 illustrates each peak stimulated torque from the stimulated CT test relative to the initial. A one-way repeated measures ANOVA was conducted to test differences in peak stimulated CT. The test failed to see a significant main effect for visit ($p>0.05$), see figure 16. Peak stimulated CT was also analyzed relative to the initial contraction of the stimulated CT test. A one-way repeated measures ANOVA showed no significant main effect for visit ($p>0.05$) for relative peak stimulated CT, shown in figure 17.

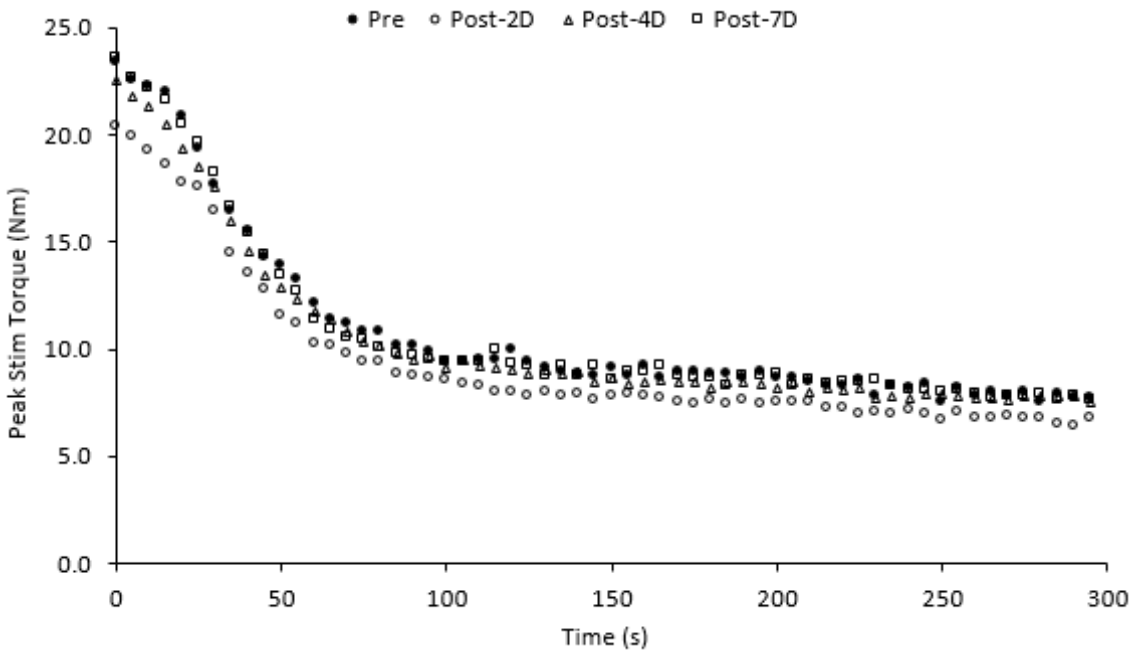

Figure 14: Peak stimulated torque for each contraction of the stimulated CT test per visit.

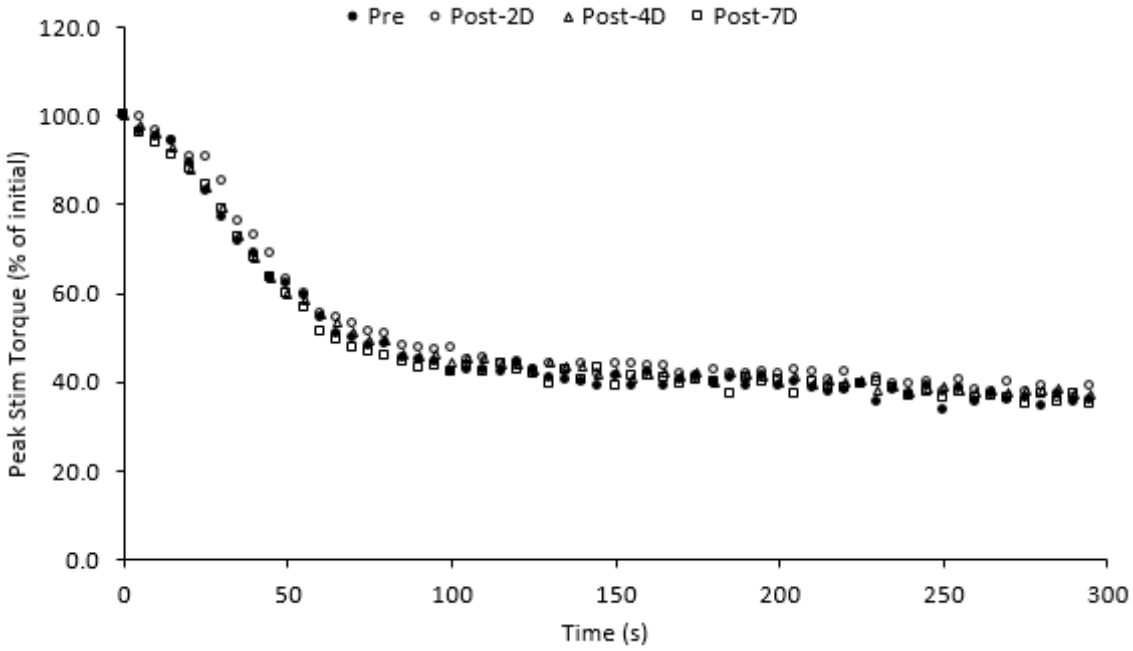

Figure 15: Peak stimulated torque for each contraction of the stimulated CT test as a percentage of the initial contraction.

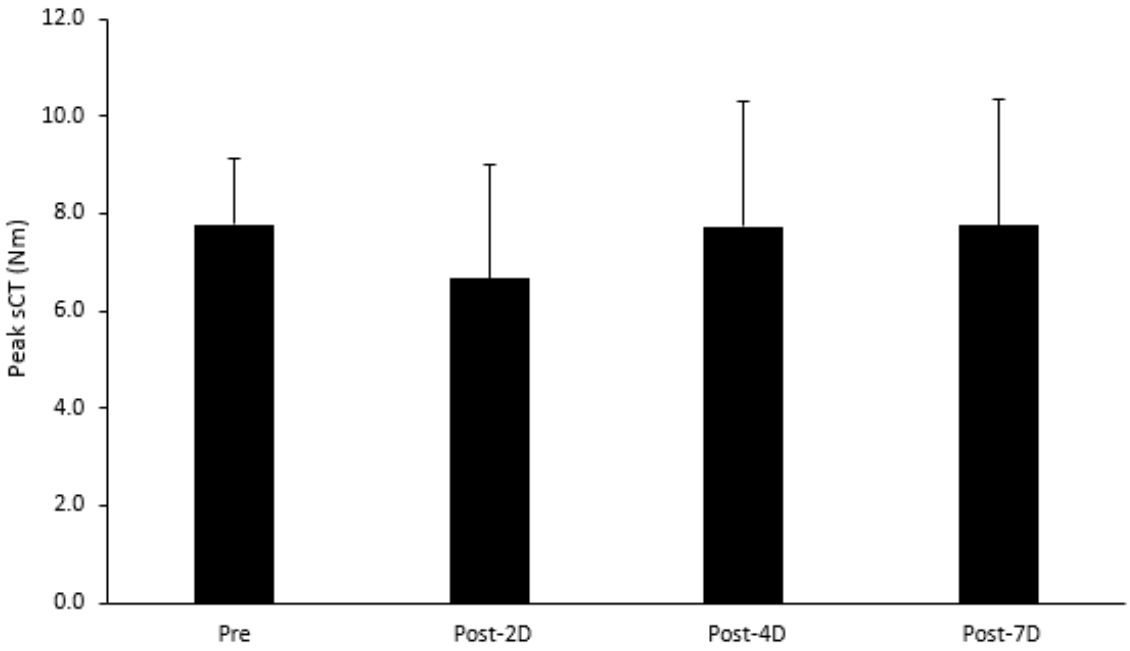

Figure 16: Peak stimulated CT from each visit. No significant differences were seen ($p>0.05$). Values are mean ± SD.

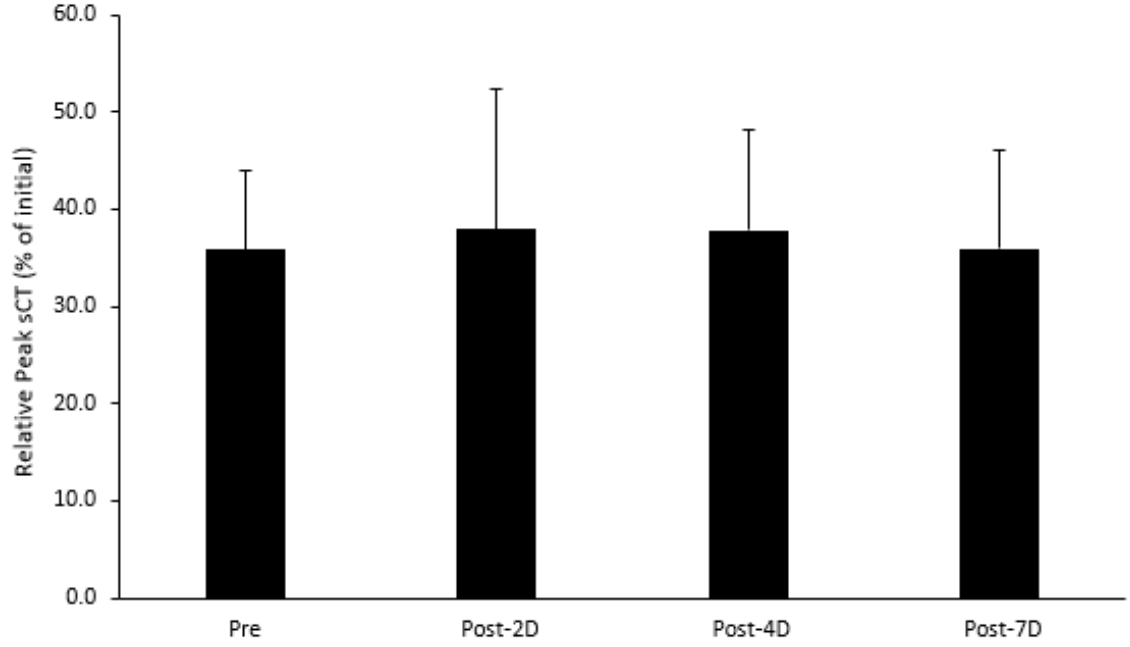

Figure 17: Peak stimulated CT as a percentage of the first contraction of the stimulated CT test. No significant differences were seen ($p>0.05$). Values are mean ± SD.

Figure 18 shows the mean stimulated torque for each stimulated contraction of the stimulated CT test per visit. Accordingly, figure 19 illustrates the mean stimulated

torque of each contraction of the stimulated CT test relative to the first contraction. Figure 20 shows the results of a one-way repeated measures ANOVA to test differences in mean stimulated CT. The results show a significant effect for visit ($p=0.014$). Pairwise comparisons via LSD reveal a significant decrease in mean stimulated CT at 2-days post relative to pre ($p=0.010$). There were no significant differences for the other visits relative to pre ($p>0.05$). Mean stimulated CT was also analyzed relative to the first contraction of the stimulated CT test. A one-way repeated measures ANOVA showed no significant differences between visits when looking at the relative mean stimulated CT ($p>0.05$), see figure 21.

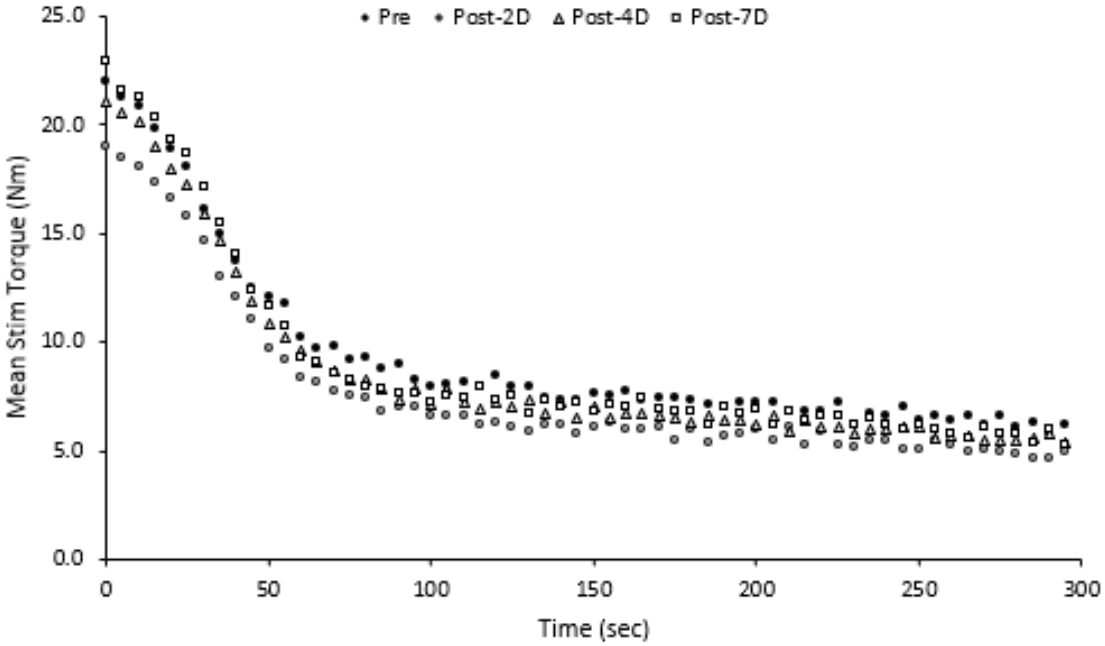

Figure 18: Mean stimulated torque for each contraction of the stimulated CT test per visit.

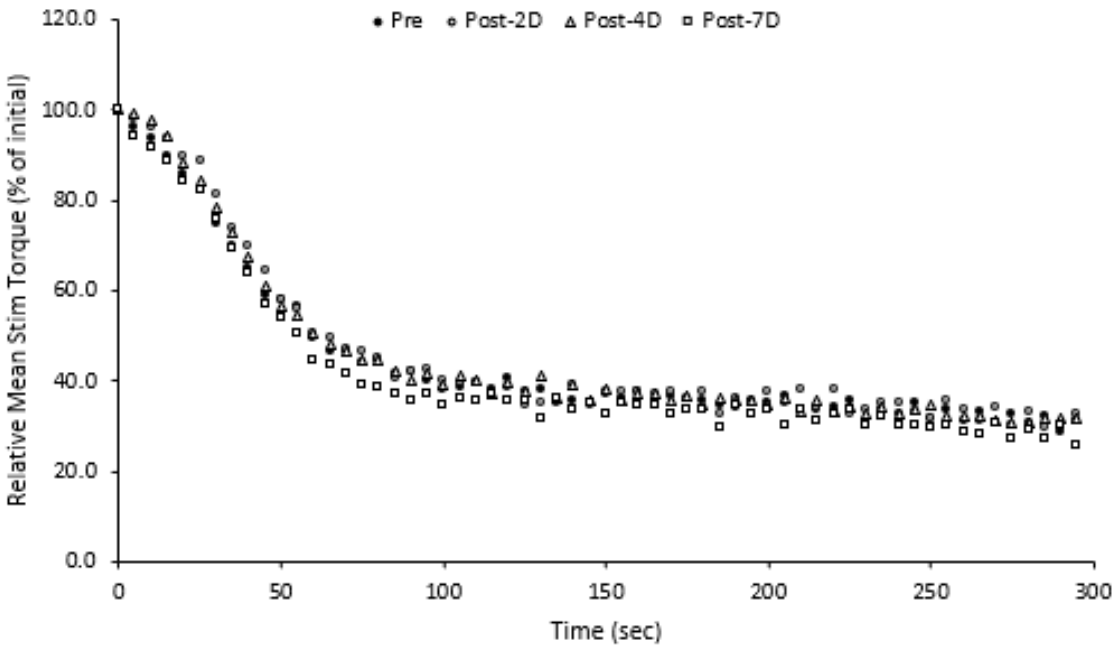

Figure 19: Mean stimulated torque for each contraction of the stimulated CT test relative to the first contraction.

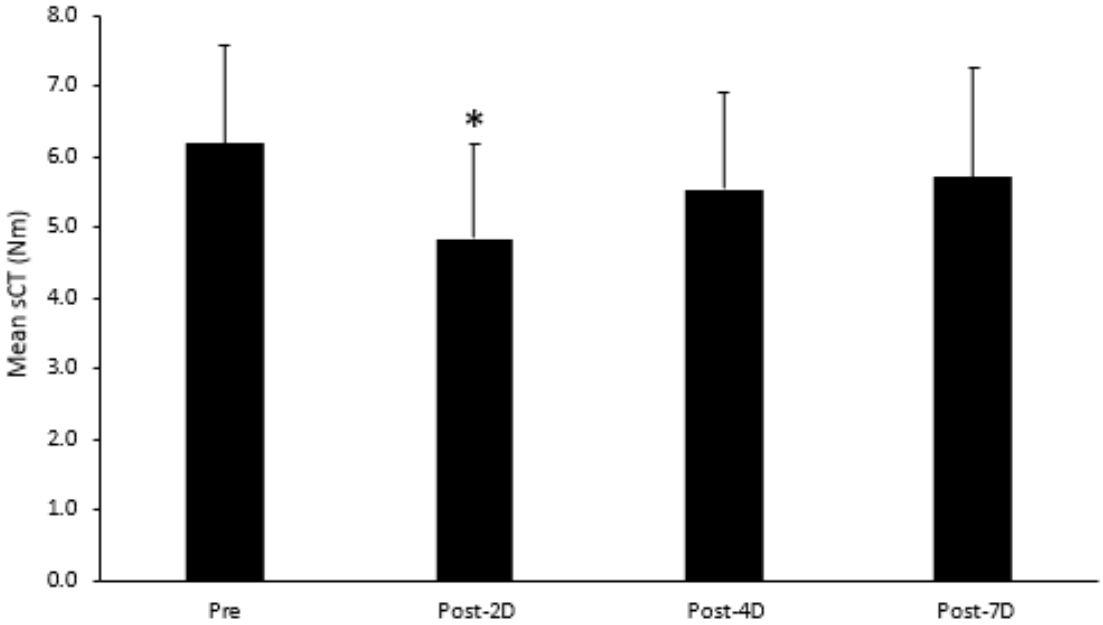

Figure 20: Mean stimulated CT for each visit. There was a significant decrease at 2-days post when compared to pre ($p<0.05$). * indicates a significant difference from pre. Values are mean ± SD.

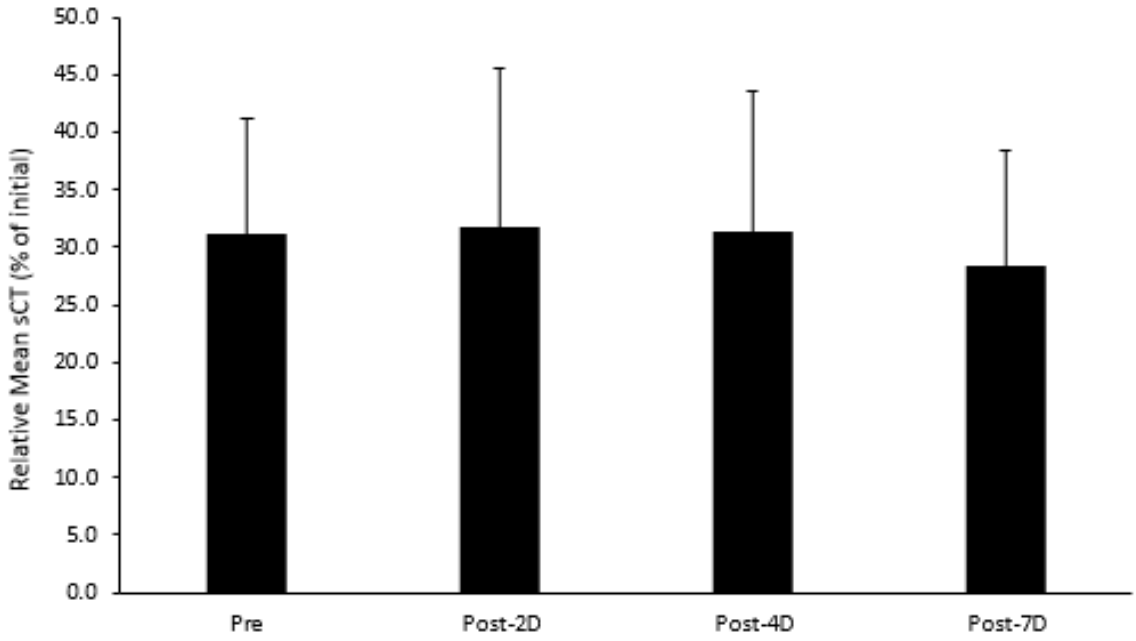

Figure 21: Mean stimulated CT as a percentage of the first contraction of the stimulated CT test. No significant differences were seen ($p>0.05$). Values are mean ± SD.

4.4 Voluntary IACT

IACT was analyzed using peak torque values (peak IACT) and mean torque values (mean IACT) from the 5-minute all-out test. A one-way repeated measures ANOVA was used to look at changes in peak IACT and mean IACT. There was no significant main effect for visit for both: peak IACT and mean IACT ($p>0.05$). Figure 22 displays changes in peak IACT and figure 23 shows changes in mean IACT for the visits.

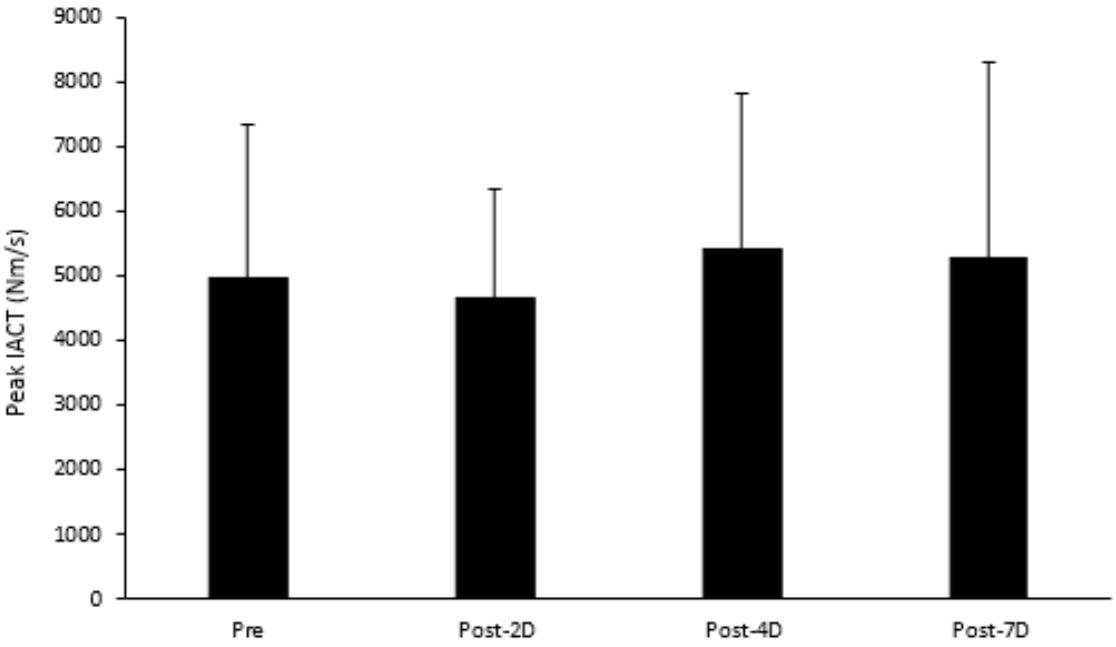

Figure 22: IACT analyzed using peak torque values from the 5-minute all-out test. No significant differences were seen ($p>0.05$). Values are mean ± SD.

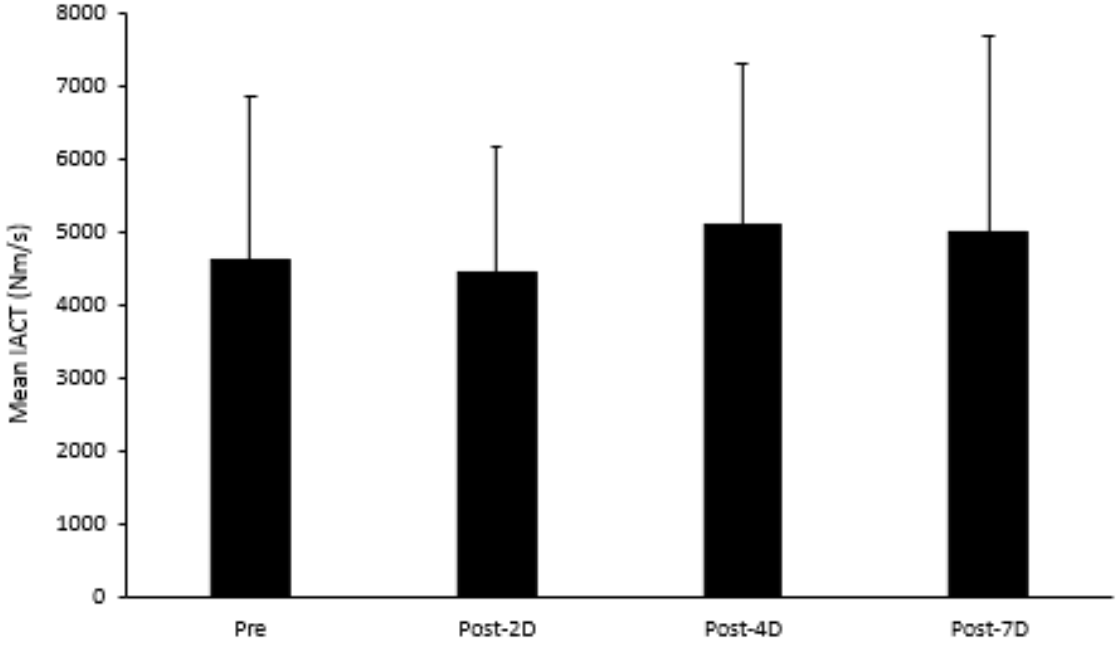

Figure 23: IACT analyzed using mean torque values from the 5-minute all-out test. No significant differences were seen ($p>0.05$). Values are mean ± SD.

4.5 Stimulated IACT

IACT from the stimulated CT test was also analyzed using peak torque values (stimulated peak IACT) and mean torque values (stimulated mean IACT). A one-way repeated measures ANOVA was conducted to test differences over visits in both stimulated peak IACT and stimulated mean IACT. The results yielded no significant main effect for visit for either stimulated peak IACT or stimulated mean IACT ($p>0.05$). Figure 24 shows the stimulated peak IACT and figure 25 shows the stimulated mean IACT for the visits.

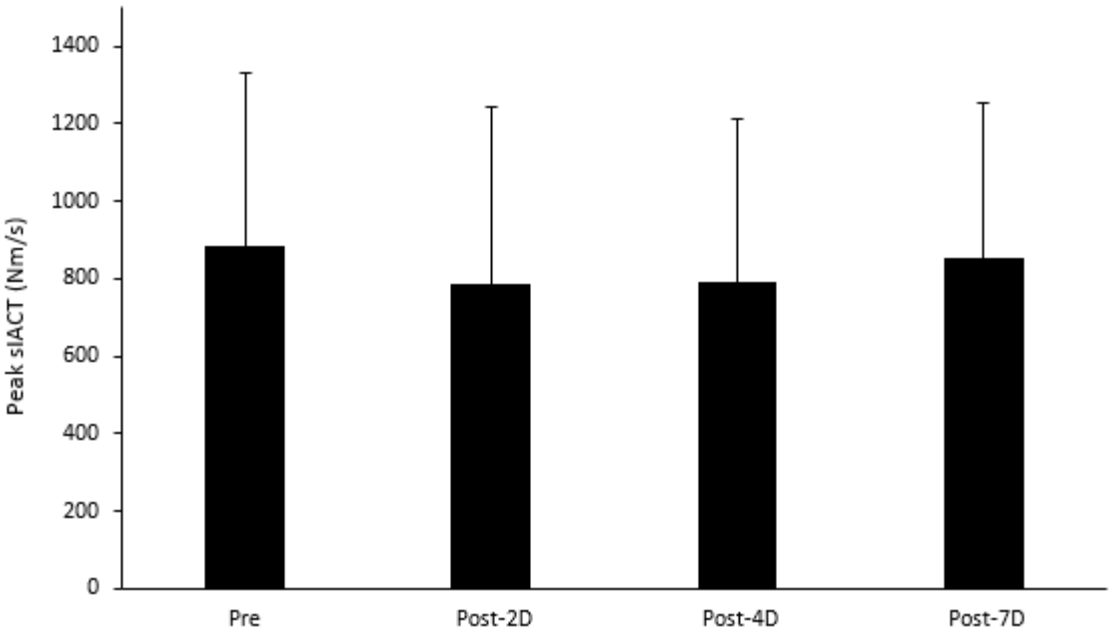

Figure 24: IACT analyzed using peak torque values from the stimulated CT test. No significant differences were found ($p>0.05$). Values are mean ± SD.

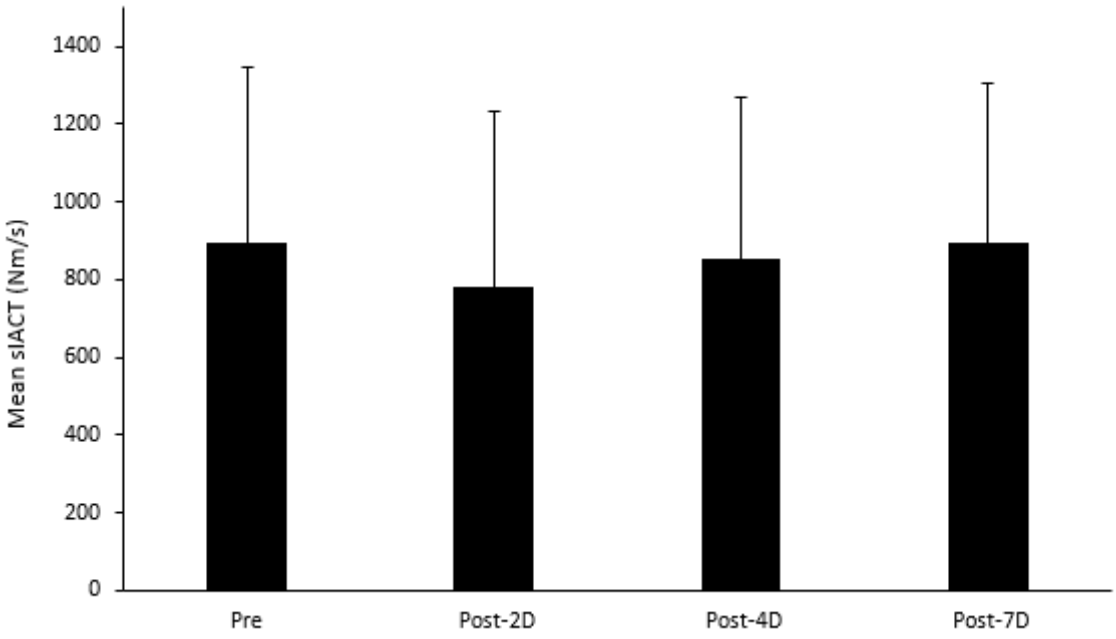

Figure 25: IACT analyzed using mean torque values from the stimulated CT test. No significant differences were found ($p>0.05$). Values are mean ± SD.

4.6 Voluntary Activation

Voluntary activation was assessed at different timepoints throughout the 5-minute all-out test. A two-way repeated measures ANOVA was used to see differences over visits and timepoints. The interaction of visit and timepoints was not significant ($p>0.05$). Furthermore, the results yielded no significant main effect for either visit ($p=0.34$) or timepoints ($p=0.06$). Figure 26 depicts percent voluntary activation for each timepoint per visit.

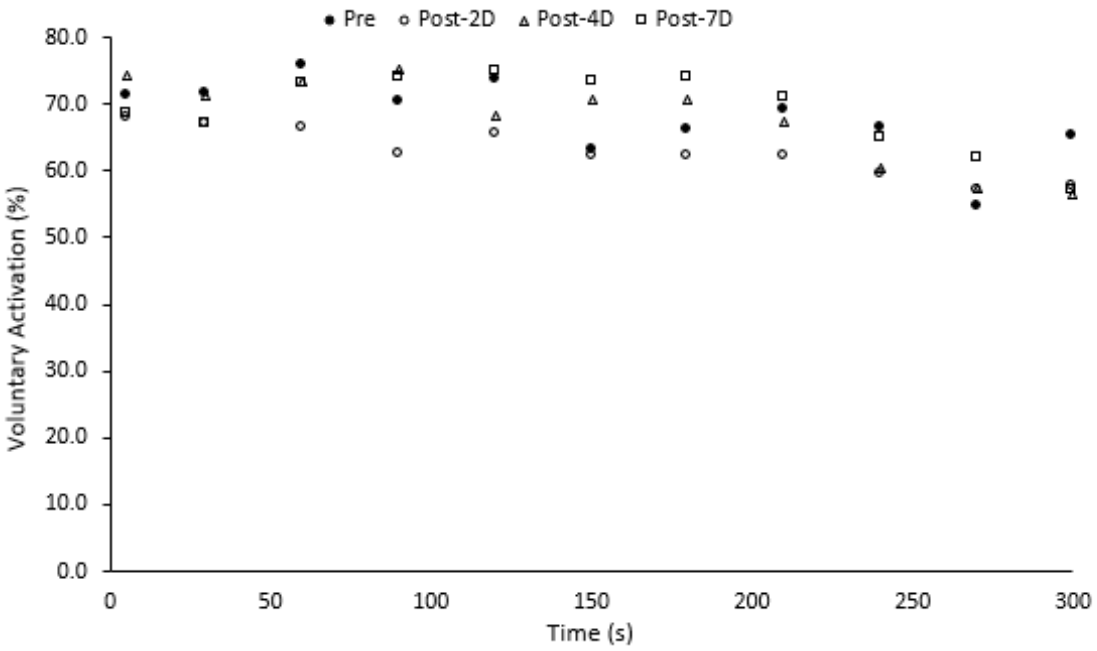

Figure 26: Change in voluntary activation during the 5-minute all-out test per visit. No significant differences were found between visits or timepoints ($p>0.05$).

4.7 EMG RMS

EMG RMS was expressed relative to the RMS value of the initial contraction of the 5-minute all-out test. A two-way repeated measures ANOVA was used to test differences over visits and timepoints. The results showed no significant interaction of visit and timepoints ($p>0.05$). Additionally, the results showed no significant main effect for visit ($p>0.05$), however, there was a significant main effect for timepoints ($p<0.001$). Pairwise comparisons using LSD was used to exam all timepoints of the 5-minute all-out test relative to the 1st (5 sec) timepoint. The results showed that the 8th (210 sec), 9th (240 sec), and 10th (270 sec) timepoints, were all significantly reduced compared to the 1st timepoint of the 300-second long 5-minute all-out test ($p=0.028$, 0.023, and 0.021 respectively). There were no significant differences for the rest of the timepoints relative to the first ($p>0.05$). Figure 27 depicts the EMG RMS for each timepoint relative to the first for each visit.

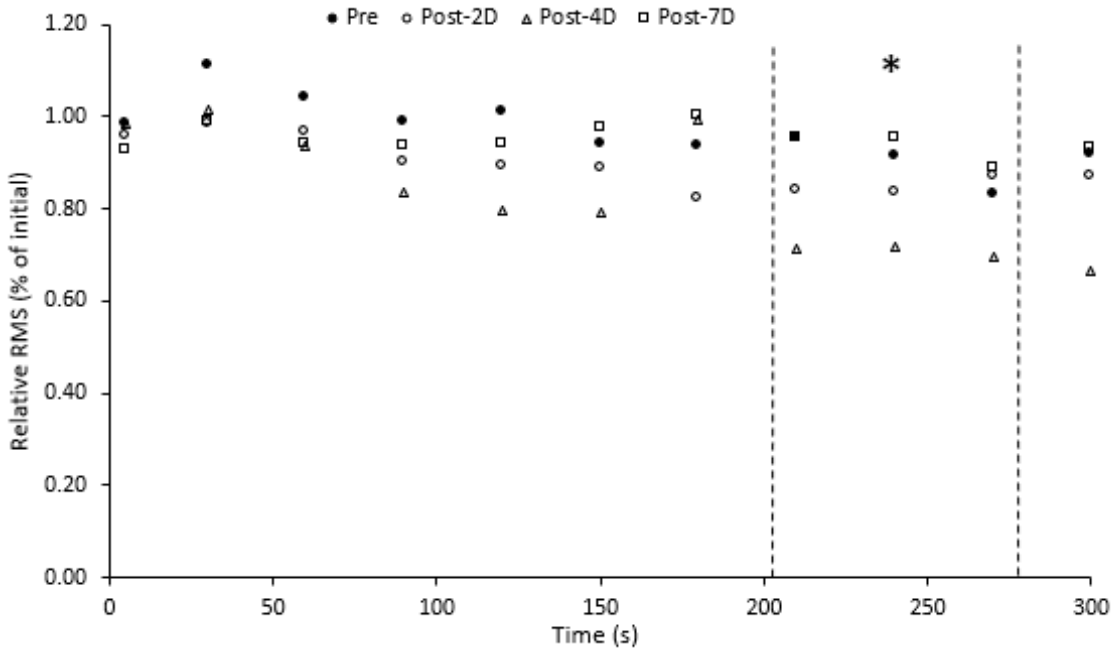

Figure 27: EMG RMS for each timepoint relative to the value of the first timepoint. * and the dashed lines show a significantly reduced EMG RMS at the 210, 240, and 270 second timepoints ($p<0.05$).

4.8 Twitch Torque

A two-way repeated measures ANOVA was used to test differences in twitch torque between the visits and timepoints. The results yielded a significant interaction of visit and timepoints ($p=0.033$). Additionally, there was no significant main effect for visit ($p>0.05$), however, there was a significant main effect for timepoints ($p<0.001$). Pairwise comparisons using LSD showed a significantly reduced twitch torque compared to the 1st timepoint from the 4th timepoint at 90 seconds to the last timepoint at 300 seconds ($p<0.05$). Twitch torque plateaued at the 7th timepoint (180 sec). Due to a significant interaction, eleven separate one-way repeated measures ANOVA were run to test for significant differences per individual timepoint over the visits. The results for the eleven separate one-way repeated measures ANOVAs showed no significant differences for any individual timepoint among visits ($p>0.05$). Figure 28 illustrates the

twitch torque for each timepoint during the 5-minute all-out test per visit.

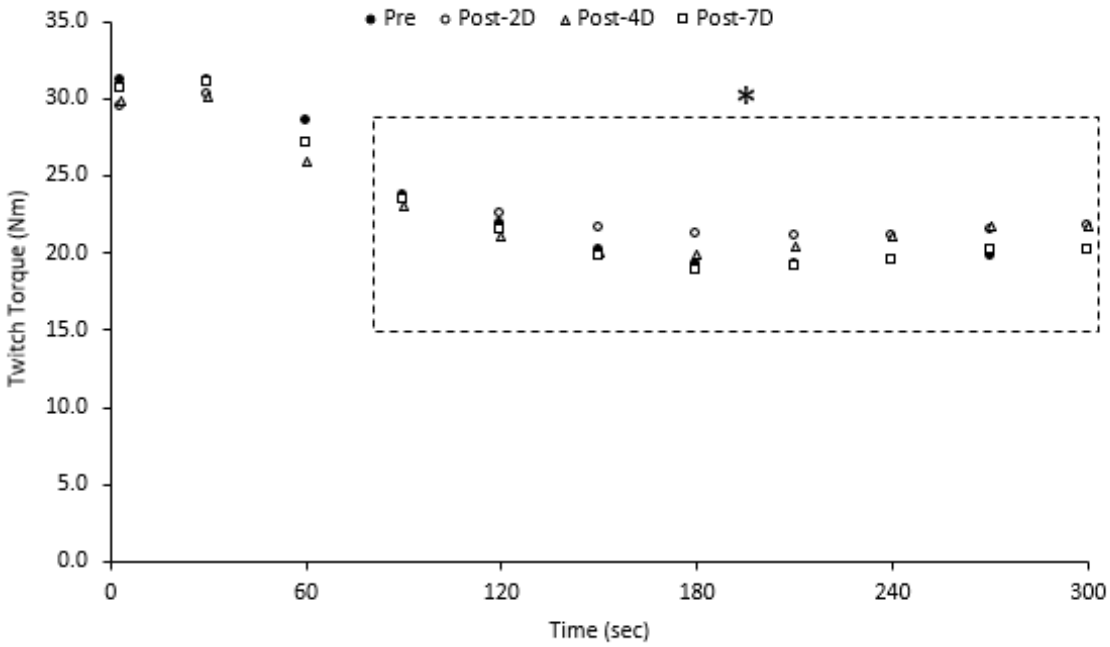

Figure 28: Twitch torque from each timepoint during the 5-minute all-out test. * and dashed rectangle indicate a significant decrease in twitch torque from the first timepoint ($p<0.05$).

Twitch torque was also analyzed relative to the value of the first timepoint. The results of the two-way repeated measures ANOVA showed no significant main effect for visit ($p>0.05$), however, there was a significant main effect for timepoints ($p<0.001$). The interaction of visit and timepoint was not significant ($p>0.05$). Thus, pairwise comparisons using LSD were performed to test differences between timepoints. The results showed that all timepoints ranging from the 3rd to the 11th (60 sec to 300 sec of the 5-minute all-out test) had a significantly reduced twitch torque relative to the 1st timepoint ($p<0.05$). Relative twitch torque also plateaued at the 7th timepoint (180 sec), see figure 29.

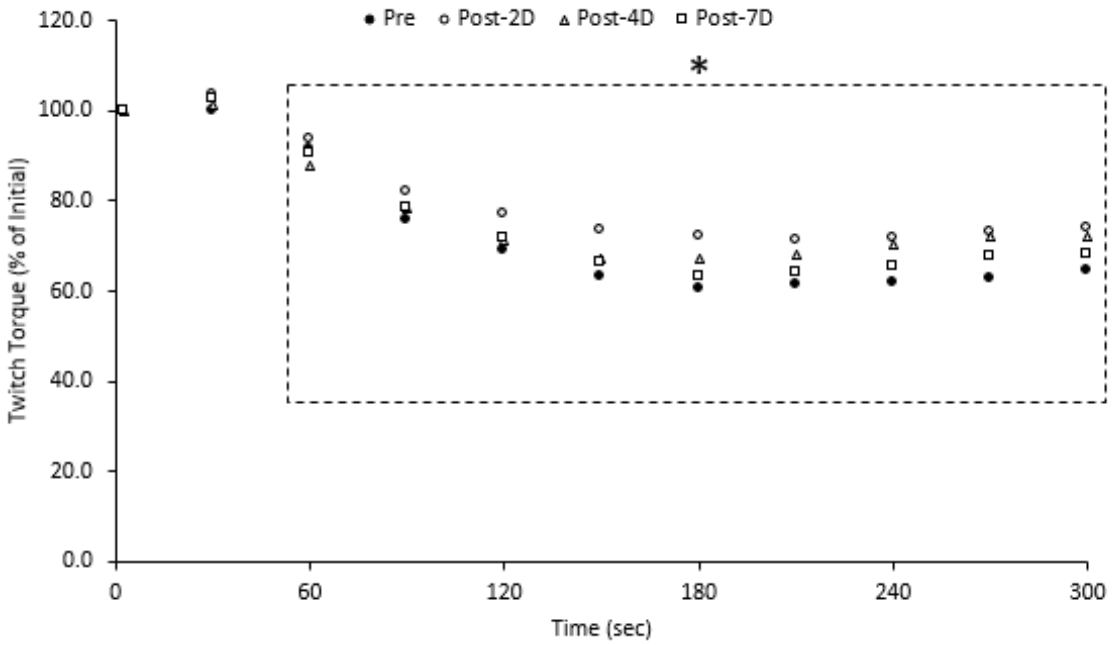

Figure 29: Twitch torque as a percentage of the value at the first timepoint. * and dashed rectangle indicate a significant percent decrease at timepoints from 60 to 300 seconds ($p<0.05$).

4.9 Low-Frequency Fatigue

Low-frequency fatigue was analyzed before, immediately after, and 3 minutes after the 5-minute all-out test. A two-way repeated measures ANOVA was conducted to test differences over timepoints and between visits. The results showed no significant main effect for visit or timepoint ($p>0.05$). The results also showed no significant interaction of visit and timepoint ($p>0.05$). Figure 30 illustrates these results.

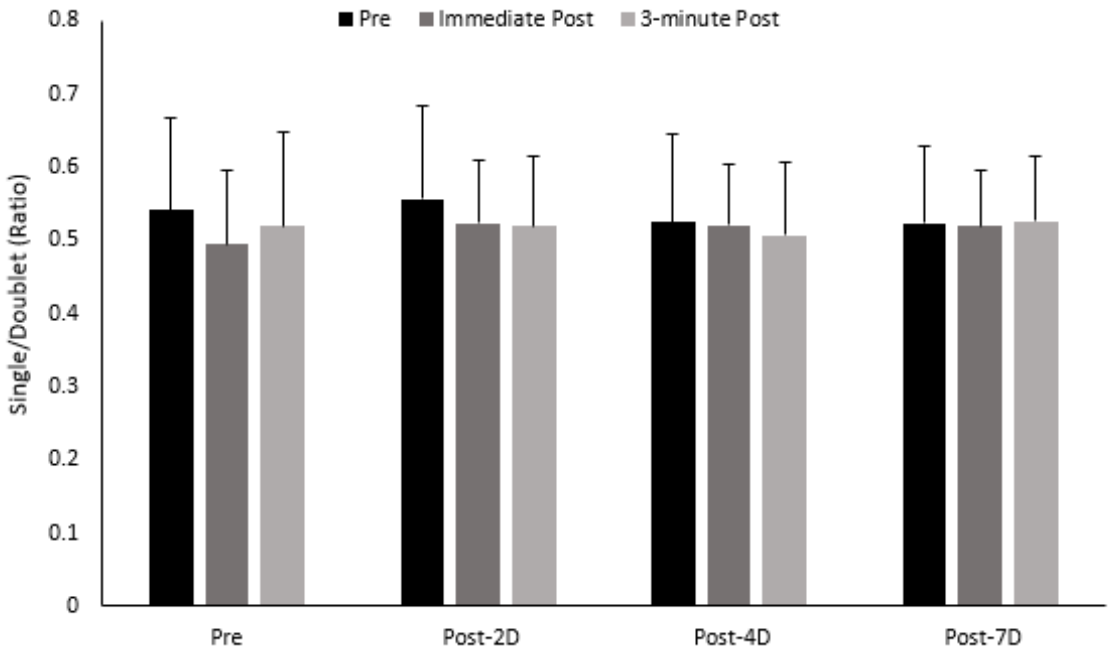

Figure 30: Low-frequency fatigue regarding the 5-minute all-out test. No significant differences were found between visits or timepoints ($p>0.05$). Values are mean ± SD.

Low-frequency fatigue was also analyzed before, immediately after, and 3 minutes after the stimulated CT test. A two-way repeated measures ANOVA was used to test differences between visits and over timepoints. The results showed no significant main effect for visit or timepoint ($p>0.05$). The results also showed no significant interaction of visit and timepoints ($p>0.05$). Figure 31 illustrates these results.

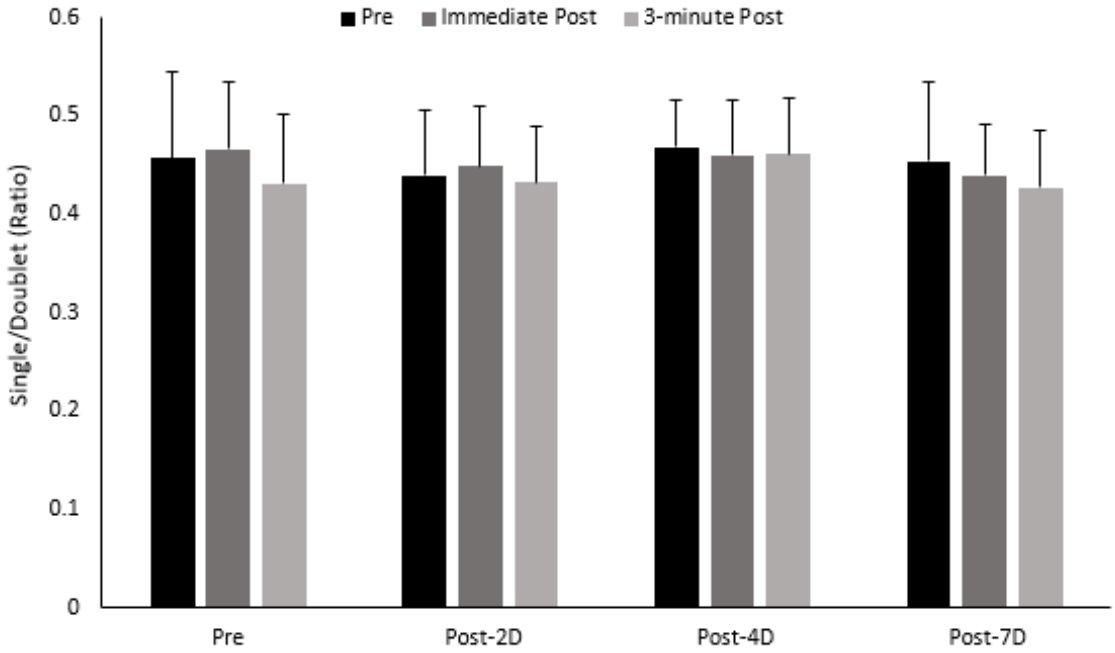

Figure 31: Low-frequency fatigue regarding the stimulated CT test. No significant differences were found between visits or timepoints ($p>0.05$). Values are mean ± SD.

Chapter V – Discussion & Conclusions

5.1 Exercise-Induced Muscle Damage

The EIMD protocol employed in this study is almost identical to what has previously been conducted in the literature to induce a significant degree of muscle damage (Burt et al., 2012, 2013; Davies et al., 2008; Davies, Eston, et al., 2011; Davies, Rowlands, et al., 2011). This study saw a significant drop in torque production up to 2-days post eccentric exercise in both the dominant and non-dominant legs—indicating damage occurred. These results at 2-days post for the dominant leg are similar to what has been reported in the literature using similar exercise protocols to induce EIMD (Burt et al., 2012, 2013; Davies et al., 2008; Davies, Eston, et al., 2011; Davies, Rowlands, et al., 2011). Interestingly, force production was reduced for a longer duration in the non-dominant leg, up to 4-days post exercise. Using a single-leg split squat muscle damaging protocol at 40% of body weight, Black et al., (2015) saw decreases in quadriceps force production for up to 4-days post. Additionally, the results of Hody et al., (2013) suggest no effect of leg dominance on the magnitude of EIMD. Thus, the differences in force loss between the dominant and non-dominant leg seen in this study may be a result of how the data were analyzed; since ten subjects were included for the non-dominant leg compared to eight for the dominant leg. The Cohen's d effect size at 4-days post, was 0.15 SD for the dominant leg and 0.24 SD for the non-dominant leg, suggesting a slightly larger effect in the non-dominant leg.

The results of the muscle soreness ratings saw a significant increase in soreness up to 4-days post eccentric exercise. Ratings of muscle soreness were done

simultaneously for both limbs to discount for any knee-joint related pain that might have been accounted for using single leg exercise that could potentially impact participants' perceptions of soreness and muscle pain. This study's results for muscle soreness are similar to what has been reported in the literature, showing a significant increase immediately post eccentric exercise (post-EIMD) up to 4-days post exercise (Black & McCully, 2008; Cleak & Eston, 1992; Ebbeling & Clarkson, 1989; Evans, Knight, Draper, & Parcell, 1892; Lee et al., 2002; Newham, Jones, & Edwards, 1983). Much of the current literature confirms muscle soreness can persist up to 2-days post (Black & Dobson, 2012; D. Burt et al., 2012; Davies et al., 2008; Davies, Eston, et al., 2011; Davies, Rowlands, et al., 2011) with soreness abating between 3 to 7 days following EIMD (Fouré et al., 2015; Highton et al., 2009). Our results, identical to Black & McCully (2008), may be a result of the EIMD protocol utilized in this study and the resulting magnitude of its effect. Likewise, these results could also be attributed to the participants not having done any lower-body resistance exercises in at least 6-months prior to testing according to data suggesting a reduced degree of EIMD following a repeated bout (Burt et al., 2013). Collectively, our finding that soreness has returned to baseline levels (essentially zero) by 7-days post suggests a return to baseline of the nociceptive inflammatory response that drives the increase of noxious biochemicals that augment perception of muscle soreness, similar to what has been observed by others (Black & Dobson, 2013; Crameri et al., 2007; Proske & Morgan, 2001).

5.2 Voluntary Critical Torque

This study saw a significant decrease in both peak CT and mean CT at 2-days

post. Our results showing a 17.2 ± 12.9 % decrease in mean CT at 2-days post are similar to those of Szczyglowski et al., (2017) who saw a 14 ± 10.2 % decrease at 2-days post. A novel aspect of our study was that we assessed CT over the course of 7-days of recovery from EIMD. To this end, mean CT was found to be decreased at 4-days post. Interestingly, peak CT showed no differences from pre to 4-days post—suggesting the method of quantifying torque over each contraction may play a role in the observed CT. Thus, measuring mean CT may represent a better approach when attempting to derive CT from the 5-minute all-out test as it encompasses the ability of the participant to maintain torque over the course of the 3 second contraction rather than simply the highest torque they can generate at any point in the contraction. Mean and peak CT were recovered by 7-days post, which is in alignment with the changes in the markers of EIMD. When both mean and peak CT were expressed relative to initial MVIC values on that testing day, no differences were seen between visits, identical to what was observed by Szczyglowski et al., (2017) . These changes suggest that the decline in strength following EIMD plays an important role in determining CT compared to any aerobic metabolic alterations consequent to EIMD (Szczyglowski et al., 2017).

5.3 Stimulated Critical Torque

Like Janzen et al., (2018), this study saw a hyperbolic decline in torque followed by a plateau during the stimulated CT test, suggesting the attainment of a metabolic steady-state. This study saw a decrease in the mean stimulated CT at 2-days post eccentric exercise, but not peak stimulated CT. These results could be explained through an understanding of how EMS contractions function. EMS based contractions

follow a nonselective, spatially fixed, and temporally synchronous recruitment pattern (Crameri et al., 2007; Gregory & Bickel, 2005). Therefore, when a muscle is being stimulated, all motor-units within reach of the current's field will fire. This would lead to a high peak torque for the onset of any 3-second stimulus which would lower significantly over a span of milliseconds as many of the type II fibers fatigue. This may explain why peak stimulated CT was not reduced following EIMD. Similar to the voluntary condition, when tracking changes following EIMD, looking at stimulated mean torque values may give a more physiologically grounded approach to measure CT. Since stimulation electrode placement was held constant, and there was little to no day-to-day differences in train current intensity, we assume stimulated mean torque values decreased following EIMD as a product of the resulting impairment in excitation-contraction coupling and sarcomere disruption (Proske & Morgan, 2001) that occurred with EIMD. Yet, EIMD was still evident (judged by a decline in voluntary MVC) in the non-dominant leg at 4-days post, but stimulated mean CT values showed a return to baseline. One possible explanation of this finding is that because the stimulated exercise did not recruit all of the knee extensor motor-units, just those within the current field, that there were damaged muscle fibers that were not activated—accounting for the continued decline in MVC but return of stimulated CT to baseline. This can be seen with the percent force decrement which was 20.9% at 2-days post, but only 11.3% at 4-days post in the non-dominant leg. Interestingly, when stimulated mean and peak CT were analyzed as a percentage of the first contraction of the stimulated CT test, no differences were seen. These results suggest a decline in torque that is more dependent upon the initial value of torque, and less so on the physiological muscular

imbalances accrued by EIMD. This pattern further validates the stimulated CT test of Janzen et al., (2018), as it follows a similar relative decrease in torque seen in voluntary conditions.

5.4 Voluntary & Stimulated IACT

IACT, the isometric torque analog of W', represents a finite energy store above CT that is depended upon muscle phosphocreatine (PCr), anaerobic glycolysis, and stored oxygen (Broxterman et al., 2014; Fukuba et al., 2003; Andrew M. Jones et al., 2010; A. Miura et al., 1999; Monod & Scherrer, 1965). Szczyglowski et al., (2017) saw a significantly reduced IACT following EIMD at 2-days post, with the magnitude of decrease for IACT (33%) being greater than that for CT (14%). EIMD has been suggested to increase the body's energy expenditure to help in its repair process as evident with increases in resting metabolic rate and oxygen saturation (Ahmadi et al., 2008; Ahmadi et al., 2008; Dolezal et al., 2000) which could appropriate from the anaerobic glycolysis that IACT is dependent upon. Additionally, the increased reliance on anaerobic metabolism following EIMD (Newcomer et al., 2005; Warren et al., 1996) could take away from the muscle PCr stores, known to be higher in type II fibers relative to type I (Casey, Constantin-Teodosiu, Howell, Hultman, & Greenhaff, 1996). Surprisingly, with evidence of EIMD, this study failed to see significant changes in IACT on any of the visits following EIMD for voluntary and stimulated conditions. Our results suggest no effect of EIMD on any combination of: muscle PCr stores, anaerobic glycolysis, and stored oxygen. These results, being different from those of Szczyglowski et al., (2017) , may be a representation of the chosen EIMD methodology. Since Szczyglowski et al., (2017) used a single-leg EMS based approach to EIMD up

to a 40% decline in MVIC post-EIMD, while this study used a voluntary approach to EIMD aiming to a 25% decline in MVIC post-EIMD. Perhaps not enough EIMD occurred in the present study to alter the anaerobic contributions to IACT. Further study of the effects of the magnitude of EIMD on IACT could help clarify this finding.

5.5 Central Fatigue During the CT Test

It has been observed that muscle fatigue can be influenced by central factors, evident with decreases in voluntary activation up to 30 minutes following a fatiguing bout (Kawakami et al., 2000; Simpson et al., 2004) and immediately following EIMD (Behrens et al., 2012; Martin et al., 2004). This study was interested in assessing voluntary activation during the 5-minute all-out test and how it may have changed because of EIMD. Central fatigue may occur following EIMD due to muscle soreness, swelling (inflammation), and stiffness (Byrne, Twist, & Eston, 2004) preventing maximal motor-unit recruitment. Following EIMD, Prasartwuth et al., (2005) saw up to a 23% decline in voluntary activation that remained significantly depressed up to 24 hours using nerve stimulation, however, no significant changes were reported using motor cortex stimulation. Similarly, no significant differences in voluntary activation were seen following EIMD in this study. Interestingly, our results contradict those of Janzen (*unpublished observations*), who saw a significantly lower voluntary activation toward the end of the 5-minute all-out test. Similarly, Burnley, 2009 also saw a significant decrease in voluntary activation throughout the 5-minute all-out test. However, Bigland-Ritchie et al., (1986) saw no decline in voluntary activation during a fatiguing bout for the quadriceps muscle attributing these results to muscle contractile properties in well-motivated subjects. Unlike Szczyglowski et al., (2017), this study saw

a significant decrease in net neuromuscular activation as seen with changes in EMG RMS. Seeing changes in EMG RMS towards the end of the 5-minute all-out test may indicate central impairments, however, no changes were seen in voluntary activation to supplement the EMG RMS results. Accordingly, EMG RMS did not change following EIMD. These results share a similar suggestion by Szczyglowski et al., (2017) that the total amount of electrical signal reaching the neuromuscular junction and traveling to the sarcolemma was unchanged before and following EIMD. Collectively, our findings suggest that the loss of force that was seen throughout the 5-minute all-out test and following EIMD may be a product of impairments below the neuromuscular junction that are attributed to peripheral fatigue, such as impairments in excitation-contraction coupling, and Calcium kinetics (Allen et al., 1992).

5.6 Peripheral Fatigue

Peripheral fatigue can effect force production through impairments at or below the neuromuscular junction (Boerio et al., 2005; Gandevia, 2001). Analyzing peripheral fatigue, this study saw a significant decrease in twitch torque during the 5-minute all-out test. These results are similar to those of Burnley (2009) who saw a decrease in twitch torque following exhaustive exercise. Similarly, our results also align with Janzen (*unpublished observations*) who showed a significant decrease in twitch torque throughout the beginning half of the 5-mnute all-out test with a plateau occurring near the end. Following EIMD, Black et al., (2015) saw a significant reduction in resting twitch torque up to 7-days post. These results are fairly consistent with EMS based EIMD protocols, showing reduced twitch torque values up to 4-days post (Fouré et al., 2014). Interestingly, our EIMD protocol had no effect on resting twitch torque. Since

peripheral fatigue is known to have a detrimental effect on the excitation-contraction coupling process among other things (Allen et al., 1992), we gather the lack of changes following EIMD to be a product of the EIMD protocol not significantly impairing the excitation-contraction coupling process to see an additional effect (Proske & Morgan, 2001). Thus, the decline in torque values throughout the 5-minute all-out test following EIMD were not affected by a higher degree of peripheral fatigue but rather the muscular alterations induced by EIMD, specifically the disruption of sarcomeres (Proske & Morgan, 2001).

Low-frequency fatigue (LFF) was also analyzed to further examine peripheral fatigue. LFF can indicate impairments not only in the excitation-contraction coupling processes, but also Calcium kinetics (Bigland-Ritchie et al., 1986; Edwards et al., 1977). Accordingly, the ratio of torque from 10 Hz/100 Hz has shown a reduction up to 1 day following EIMD (Fouré et al., 2014). Likewise, the ratio of torque from 1 Hz/50 Hz has also been shown to decrease following a fatiguing bout (Bigland-Ritchie et al., 1986). Janzen (*unpublished observations*) also reported a significant level of LFF following the 5-minute all-out test. LFF following EIMD has been reported to show a complete recovery at 2-days post when frequency ratios were 20 Hz/80 Hz (Martin et al., 2004). Our findings show no differences following the 5-minute all-out test, the stimulated CT test, or following EIMD. Our results are congruent with those of Martin et al., (2004) , however, it was interesting to see no LFF at any timepoint following the 5-minute all-out test. Since twitch torque values confirm a degree of peripheral fatigue following the 5-minute all-out test, this fatiguing bout may not have been sufficient in impairing Calcium kinetics to a significant degree to see evidence of LFF. Collectively,

our findings regarding twitch torque and LFF suggest no effect of the peripheral markers of fatigue to torque production following EIMD.

5.7 Conclusions

In conclusion, we accept our hypothesis seeing a significant decrease in CT and stimulated CT up to 4-days and 2-days post EIMD, respectively. Surprisingly, we failed to reject the null hypothesis with our results showing no differences in IACT in either voluntary or stimulated conditions. This is likely a product of the chosen EIMD protocol. Additionally, we failed to reject the null hypothesis as we saw no changes in the central markers of fatigue during an exhaustive bout following EIMD. Twitch torque did show a contribution in the decline in force in this study, but only throughout the 5-minute all-out tests. We fail to reject the null hypothesis when looking at the peripheral markers of fatigue over the course of EIMD as we saw no changes. Collectively, our findings suggest a return to baseline in CT and stimulated CT by 7 days and 4 days following EIMD, respectively. Moreover, these results suggest no contribution of central or peripheral markers of fatigue to the decline in torque production that was seen following EIMD. Interestingly, our results saw a decline in the stimulated CT following EIMD, similar to the voluntary condition in the current study and previously. These results further validate our stimulated CT showing its vulnerability to the effects of EIMD. Future directions for research would need to test out different approaches for EIMD to accept a recovery pattern for CT and IACT on the days following. Both EMS and voluntary approaches to EIMD should be employed to see if these two methods have a differing impact. Additionally, it would be interesting to look at trained individuals rather than those who have not done any lower-body

resistance training in the past 6 months. Furthermore, different conditions and supplementations should be tested to examine an attenuation effect on CT and IACT following EIMD including: hyperoxia, caffeine, and anti-inflammatory drugs.

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APPENDIX A: IRB APPROVAL LETTER

The UNIVERSITY of OKLAHOMA

Institutional Review Board for the Protection of Human Subjects

Approval of Initial Submission – Expedited Review – AP01

Date: December 06, 2017 **IRB#:** 8767

Principal Investigator: Christopher D Black, PhD **Approval Date:** 12/06/2017 **Expiration Date: 11/30/2018**

Study Title: Time Course of Change in Critical Torque and Impulse Above Critical Torque Following Exercise-Induced Muscle Damage.

Expedited Category: 4 & 7

Collection/Use of PHI: Yes

On behalf of the Institutional Review Board (IRB), I have reviewed and granted expedited approval of the above-referenced research study. To view the documents approved for this submission, open this study from the *My Studies* option, go to *Submission History*, go to *Completed Submissions* tab and then click the *Details* icon.

NOTE: The unsigned consent form is not being approved for this study due to the elevated risk in the protocol, as well as the compensation and use of photography. Please be sure to only use the IRB-approved signed consent form.

As principal investigator of this research study, you are responsible to:

- Conduct the research study in a manner consistent with the requirements of the IRB and federal regulations 45 CFR 46.
- Obtain informed consent and research privacy authorization using the currently approved, stamped forms and retain all original, signed forms, if applicable.
- Request approval from the IRB prior to implementing any/all modifications.
- Promptly report to the IRB any harm experienced by a participant that is both unanticipated and related per IRB policy.
- Maintain accurate and complete study records for evaluation by the HRPP Quality Improvement Program and, if applicable, inspection by regulatory agencies and/or the study sponsor.
- Promptly submit continuing review documents to the IRB upon notification approximately 60 days prior to the expiration date indicated above.
- Submit a final closure report at the completion of the project.

If you have questions about this notification or using iRIS, contact the IRB @ 405-325-8110 or irb@ou.edu.

Cordially,

Aimee Franklin, Ph.D.
Chair, Institutional Review Board

APPENDIX B: INFORMED CONSENT FORM

Signed Consent to Participate in Research

Would you like to be involved in research at the University of Oklahoma?

I am Darshit Patel from the Department of Health and Exercise Science, and I invite you to participate in my research project titled “Time Course of Change in Critical Torque and Impulse Above Critical Torque Following Exercise-Induced Muscle Damage”. This research is being conducted at the University of Oklahoma Norman Campus. You were selected as a possible participant because you have no history of lower leg injuries, have no contraindications to performing resistance exercise, and are not pregnant. You must be between the ages of 18 and 35 to participate in this study.

Please read this document and contact me to ask any questions that you may have BEFORE agreeing to take part in my research.

What is the purpose of this research? The purpose of this research is to assess the time course of change in critical torque (CT) and the impulse above critical torque (IACT) following exercise-induced muscle damage (EIMD).

How many participants will be in this research? About 20 men and women will take part in this research.

What will I be asked to do? If you take part in this study, you will undergo the following sessions: two familiarization sessions and five experimental sessions. There will be at least a 24-hour gap in between the two familiarization visits. On the first familiarization visit your Smith Machine back squat 1-RM will be taken, which will be followed with dominant leg twitch current determination. This process will involve the use of a stimulation electrode placed on your vastus lateralis and vastus medialis. A current (two 1 ms pulses separated by 5 ms) will be sent to these stimulation electrodes every 15-20 seconds with the stimulation intensity increasing by 10 milliamps each time. This will continue until you have achieved a plateau in torque. Following this, the dominant leg maximal voluntary isometric contraction (MVIC) will be determined. This process will involve the performance of 3 MVICs with 2 minutes of rest in between each. Each MVIC will last for 3 seconds and the peak to peak will be measured. Two and a half seconds into the MVIC you will receive a current, the one at which you plateaued, and then you will receive another a second following your MVIC. Your highest MVIC will be considered the criterion for the day. Following this, you will undergo a familiarization to the 5-minute all-out test in the dominant leg. This test consists of 60 MVICs performed at a 3 on (contraction) 2 off (relaxation) duty cycle. During this test, you will receive a current, the one at which

you plateaued, 2.5 seconds into every 6th contraction and a second after it. However, because this is a familiarization visit, this test will only last 3 minutes instead of the full 5 minutes.

The second familiarization visit will consist of the same measurements in the dominant leg, which will be followed by testing in the non-dominant leg. MVIC will be determined in the non-dominant similar to the dominant leg, however no current will be applied. The highest MVIC will then be considered and a 25% value will be derived. Following this, you will undergo a train current determination in the non-dominant leg. In this step, you will be stimulated via current for 3 seconds straight at 50 Hz (150 individual stimuli in 3 seconds). The current intensity will be increased by 10 milliamps every 15-20 seconds until 25% of the MVIC is achieved. This current will then be used for the stimulated critical torque test in the non-dominant leg. This test will be similar to the 5-minute all-out test except there will be no voluntary contractions being performed. Voluntary contractions will be replaced with stimulated contractions at the train current that was determined.

The same measurements will be conducted on the 1st, 3rd, 4th, and 5th experimental visits. The 2nd experimental visit will involve a muscle damaging protocol. The 2nd, 3rd, 4th, and 5th experimental visits will also include a measurement of the pain associated with muscle soreness. This will be done using a 100-millimeter visual analog scale with the word indicators “no pain at all” and “most intense pain imaginable” on opposite ends of the scale. You will be asked to perform the downward portion of a squat with your body and mark the pain associated with the motion on the visual analog scale. On the 1st, 3rd, 4th, and 5th experimental visit you will undergo the same measurement for the dominant and non-dominant leg as mentioned for the 2nd familiarization visit. However, during these visits you will perform the full length of the 5-minute all-out test. Additionally, before, immediately after, and 3 minutes after the 5-minute all-out test, and the stimulated critical torque test we will be measuring low-frequency fatigue. This will be done by applying 10 doublet/single twitch pairs each time. A doublet is two 1 ms currents that are separated by 5 ms, while a single twitch is only a 1 ms current. For the 5-minute all-out test the same current intensity at which you plateau will be used. Accordingly, for the stimulated critical torque test the current that will be used will be the one at which you achieved 25% of your MVIC.

The 2nd experimental visit will include performance of active eccentric and semi-passive concentric Smith Machine back squats. The weight will be set at your 1-RM and you will actively lower the weight to 90 degrees or slightly below. Following this the weight will be lifted back up to allow you to ease into the initial stance. This constitutes 1 repetition, you will

be performing 10 repetitions per set. Each set will be separated by 1 minute for a total of 10 sets. Following this your MVIC will be measured in each leg to see if your force production has dropped by at least 30%. If not, then more sets will be added until further increases in volume of up to 3 sets show no further decreases in you MVIC for each leg. If you fail to show at least a 30% decline in MVIC you will be dropped from further participation.

By signing at the end of this document you are agreeing to the procedures above and what will be required from you with regards to each procedure.

How long will this take? Your participation will take 7 visits, each lasting 60-90 minutes. The second visit will take place at least 24 hours after the first visit, and the following visits will take place at least 48 hours apart. The total time commitment for this study is approximately 11 hours.

What are the risks and/or benefits if I participate? During the exercise protocols, an electrical current will be applied to the vastus lateralis and vastus medialis muscles of your quadriceps. You may experience pain and/or discomfort in your quadriceps from the electrical stimulation and the force of the contractions. The intensity of pain or discomfort varies from person to person. It may gradually progress to the sensation similar to the stinging feeling in your hand after performing a very hard “high five”. There is minimal risk of developing muscle soreness or injury resulting from isometric exercise. However, the EIMD protocol will result in muscle soreness. The pain associated with muscle soreness is usually tolerable and normally decreases over a couple of days. During isometric contractions or the EIMD protocol you may experience lightheadedness or nausea. There is also a risk for cardiovascular events when performing maximal contractions. There are no direct benefits to participating in this study.

What do I do if I am injured? If you are injured during your participation, report this to a researcher immediately. Emergency medical treatment is available. However, you or your insurance company will be expected to pay the usual charge from this treatment. The University of Oklahoma Norman Campus has set aside no funds to compensate you in the event of injury.

Will I be compensated for participating? You will be given a $20 gift card for completing the study.

Who will see my information? In research reports, there will be no information that will make it possible to identify you. Research records will be stored securely and only approved researchers and the OU Institution Review Board will have access to the records.

You have the right to access the research data that has been collected about you as a part of this research. However, you may not have access to this information until the entire research has completely finished and you consent to

this temporary restriction.

Do I have to participate? No. If you do not participate, you will not be penalized or lose benefits or services unrelated to the research. If you decide to participate, you don't have to answer any question and can stop participating at any time.

Will my identity be anonymous or confidential? Your name will not be retained or linked with your responses. The data you provide will be destroyed unless you specifically agree for data retention or retention of contact information at the end of the research. Please check all of the options that you agree to:

I agree for the researcher to use my data in future studies. ___Yes ___ No

Photographing of Research Participants/Activities In order to preserve an image related to the research, photographs may be taken of participants. These photos may be used for research publication or for posters. You have the right to refuse to allow photographs to be taken without penalty. Please select one of the following options:

I consent to photographs. ___ Yes ___ No

Will I be contacted again? The researcher would like to contact you again to recruit you into this research or to gather additional information.

_____ I give my permission for the researcher to contact me in the future.

_____ I do not wish to be contacted by the researcher again.

Who do I contact with questions, concerns or complaints? If you have questions, concerns or complaints about the research or have experienced a research-related injury, contact me at 580-370-5957 or darpatel7@ou.edu. Additionally, you may contact Dr. Christopher Black at 405-325-7668 or cblack@ou.edu.

You can also contact the University of Oklahoma – Norman Campus Institutional Review Board (OU-NC IRB) at 405-325-8110 or irb@ou.edu if you have questions about your rights as a research participant, concerns, or complaints about the research and wish to talk to someone other than the researcher(s) or if you cannot reach the researcher(s).

You will be given a copy of this document for your records. By providing information to the researcher(s), I am agreeing to participate in this research*.*

Participant Signature	Print Name	Date
Signature of Researcher Obtaining Consent	Print Name	Date

Participant Signature	Print Name	Date
Signature of Witness (if applicable)	Print Name	Date

APPENDIX C: HIPAA

AUTHORIZATION TO USE or SHARE HEALTH INFORMATION[1] THAT IDENTIFIES YOU FOR RESEARCH

An Informed Consent Document for Research Participation may also be required.

Title of Research Project: **Time Course of Change in Critical Torque and Impulse Above Critical Torque Following Exercise-Induced Muscle Damage.**

IRB Number:

Leader of Research Team: **Christopher D. Black**

Address: **1401 Asp Ave., #110 HHC, Norman, OK 73019**

Phone Number**: 405-325-7668 (office); 706-255-3750 (cell)**

If you decide to sign this document, University of Oklahoma (OU) researchers may use or share information that identifies you (protected health information) for their research. Protected health information will be called PHI in this document.

PHI To Be Used or Shared. Federal law requires that researchers get your permission (authorization) to use or share your PHI. If you give permission, the researchers may use or share with the people identified in this Authorization any PHI related to this research from your medical records and from any test results. Information used or shared may include all information relating to any tests, procedures, surveys, or interviews as outlined in the consent form; medical records and charts; name, address, telephone number, date of birth, race, and government-issued identification numbers.

Purposes for Using or Sharing PHI. If you give permission, the researchers may use your PHI to determine if it is safe for you to participate in the exercise used in this study.

Other Use and Sharing of PHI. If you give permission, the researchers may also use your PHI to develop new procedures or commercial products. They may share your PHI with other researchers, the research sponsor and its agents, the OU Institutional Review Board, auditors and inspectors who check the research, and government agencies such as the Department of Health and Human Services (HHS), and when required by law. The researchers may also share your PHI with your physician and/or a University of

[1] **Protected Health Information includes all identifiable information relating to any aspect of an individual's health whether past, present or future, created or maintained by a Covered Entity.**

Oklahoma physician in the event of a serious health risk or adverse event that occurs during the study.

Confidentiality. Although the researchers may report their findings in scientific journals or meetings, they will not identify you in their reports. The researchers will try to keep your information confidential, but confidentiality is not guaranteed. The law does not require everyone receiving the information covered by this document to keep it confidential, so they could release it to others, and federal law may no longer protect it.

YOU UNDERSTAND THAT YOUR PROTECTED HEALTH INFORMATION MAY INCLUDE INFORMATION REGARDING A COMMUNICABLE OR NONCOMMUNICABLE DISEASE.

Voluntary Choice. The choice to give OU researchers permission to use or share your PHI for their research is voluntary. It is completely up to you. No one can force you to give permission. However, you must give permission for OU researchers to use or share your PHI if you want to participate in the research and, if you cancel your authorization, you can no longer participate in this study.

Refusing to give permission will not affect your ability to get routine treatment or health care unrelated to this study from OU.

Canceling Permission. If you give the OU researchers permission to use or share your PHI, you have a right to cancel your permission whenever you want. However, canceling your permission will not apply to information that the researchers have already used, relied on, or shared or to information necessary to maintain the reliability or integrity of this research.

End of Permission. Unless you cancel it, permission for OU researchers to use or share your PHI for their research will never end.

Contacting OU: You may find out if your PHI has been shared, get a copy of your PHI, or cancel your permission at any time by writing to:

Privacy Official or Privacy Board

University of Oklahoma

University of Oklahoma

PO Box 26901

201 Stephenson Pkwy, Suite 4300A

Oklahoma City, OK 73190

Norman, OK 73019

If you have questions, call: (405) 271-2511 or (405) 325-8110

Access to Information. You have the right to access the medical information that has been collected about you as a part of this research study. However, you may not have access to this medical information until the entire research study is completely finished. You consent to this temporary restriction.

Giving Permission. By signing this form, you give OU and OU's researchers led by the Research Team Leader permission to share your PHI for the research project listed at the top of this form.

Participant Name (Print): _____

_____ _____

Signature of Participant

Date

or Parent if Participant is a minor

Or

_____ _____

Signature of Legal Representative**

Date

**If signed by a Legal Representative of the Participant, provide a description of the relationship to the Participant and the authority to act as Legal Representative:

_____

OU may ask you to produce evidence of your relationship.

A signed copy of this form must be given to the Participant or the Legal Representative at the time this signed form is provided to the researcher or his representative.

APPENDIX D: HEALTH STATUS QUESTIONNAIRE

Health Status Questionnaire

Part 1. Information about the individual

1. _____
   Participant ID

2. _____
   Date

3. _____ _____
   Mailing Address Phone #
   _____
   _____ Email

4. _____ _____
   Primary Physician Physician Phone#

   _____
   Date of Last Physical Examination

5. _____ _____
   Person to contact in emergency Phone

6. Gender (circle one) Female Male

7. Age _____ Date of Birth _____/_____/_____

8. Height _____ Weight_____

9. Do you smoke? Yes No

10. If you are a smoker, indicate number smoked per day:
    Cigarettes: 40 or more 20-39 10-19 1-9
    Cigars or pipes only: 5 or more or any inhaled Less than 5, none inhaled

11. Are you currently taking prescription or over-the-counter medication(s)? If so, please list the medication, daily dose, and why you are taking it.

---

12. Are you currently taking any vitamins or nutritional supplements? If so, please list the vitamin/supplement, the daily dose, and why you are taking it.

Part 2. Medical History

You have had or currently have any of the following:

History
___ A heart attack
___ Heart surgery
___ Cardiac catheterization
___ Coronary angioplasty (PTCA)
___ Pacemaker-implantable cardiac defibrillatory/ rhythm disturbance
___ Heart valve disease
___ Heart failure
___ Heart transplantation
___ Congenital heart disease
___ Peripheral arterial disease
___ Stroke

Signs/Symptoms
___ You experience discomfort and/or pain with exertion in the chest, neck, jaw, arms
___ You experience unreasonable breathlessness at rest or with mild exertion
___ You experience dizziness, fainting, or blackouts
___ You experience ankle edema
___ You experience heart palpitations or tachycardia (unpleasant awareness of force or rapid heart beats)
___ You have or experience intermittent claudication (muscle pain due to ischemia)
___ You have a heart murmur
___ You take medication(s) for ANY type of heart condition or high blood pressure

Other health issues
___ You have diabetes
___ You have a thyroid disorder
___ You have a renal (kidney) disorder
___ You have liver disease (e.g. cirrhosis)
___ You have COPD, asthma, cystic fibrosis or other lung disease
___ You have burning or cramping sensation in your lower legs when walking short distances
___ You have musculoskeletal problems that limit your physical activity (arthritis, etc.)
___ You are pregnant

Part III: Cardiovascular Risk Factors

Age

___ You are a man older than 45 years
___ You are a woman older than 55 years, have had a hysterectomy, or are postmenopausal

Medical/Lifestyle

___ You smoke, or quit smoking within the previous 6 months

___ A physician has ever said have high blood pressure (>140/90)?

___ A physician has said you have high cholesterol (Total >200 mg/dl or LDL cholesterol is >130 mg/dl)

___ You have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister)

___ You are physically inactive (i.e., you get <30 minutes of physical activity 3 days per week)

___ You have impaired fasting glucose (> 100mg/dl) that has been confirmed by a doctor on two separate occasions

___ Your BMI is >30 **BMI_____**

I understand my signature signifies that I have read and understand all the information on the questionnaire, that I have truthfully answered all the questions, and that any questions/concerns I may have had have been addressed to my complete satisfaction.

Name (please print)_____

Signature _____Date _____

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

(October 2002)

http://www.ipaq.ki.se/ipaq.htm

LONG LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is encouraged to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back

translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ

International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective.* Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** and **moderate** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

PART 1: JOB-RELATED PHYSICAL ACTIVITY

The first section is about your work. This includes paid jobs, farming, volunteer work, course work, and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Part 3.

1. Do you currently have a job or do any unpaid work outside your home?

☐ Yes

☐ No → ***Skip to PART 2: TRANSPORTATION***

The next questions are about all the physical activity you did in the **last 7 days** as part of your paid or unpaid work. This does not include traveling to and from work.

2. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, heavy construction, or climbing up stairs **as part of your work**? Think about only those physical activities that you did for at least 10 minutes at a time.

_____ **days per week**

☐ No vigorous job-related physical activity → ***Skip to question 4***

3. How much time did you usually spend on one of those days doing **vigorous** physical activities as part of your work?

____ **hours per day**

____ **minutes per day**

4. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads **as part of your work**? Please do not include walking.

_____ **days per week**

☐ No moderate job-related physical activity →
Skip to question 6

5. How much time did you usually spend on one of those days doing **moderate** physical activities as part of your work?

____ **hours per day**

____ **minutes per day**

6. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **as part of your work**? Please do not count any walking you did to travel to or from work.

_____ **days per week**

☐ No job-related walking → ***Skip to PART 2: TRANSPORTATION***

7. How much time did you usually spend on one of those days **walking** as part of your work?

____ **hours per day**

____ **minutes per day**

PART 2: TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies, and so on.

8. During the **last 7 days**, on how many days did you **travel in a motor vehicle** like a train, bus, car, or tram?

_____ **days per week**

☐ No traveling in a motor vehicle → ***Skip to question 10***

9. How much time did you usually spend on one of those days **traveling** in a train, bus, car, tram, or other kind of motor vehicle?

____ **hours per day**

____ **minutes per day**

Now think only about the **bicycling** and **walking** you might have done to travel to and from work, to do errands, or to go from place to place.

10. During the **last 7 days**, on how many days did you **bicycle** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No bicycling from place to place → ***Skip to question 12***

11. How much time did you usually spend on one of those days to **bicycle** from place to place?

____ **hours per day**

____ **minutes per day**

12. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No walking from place to place → ***Skip to PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY***

13. How much time did you usually spend on one of those days *walking* ***from place to place?***

____ **hours per day**

____ **minutes per day**

PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

This section is about some of the physical activities you might have done in the **last 7 days** in and around your home, like housework, gardening, yard work, general maintenance work, and caring for your family.

14. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, chopping wood, shoveling snow, or digging **in the garden or yard**?

_____ **days per week**

☐ No vigorous activity in garden or yard → ***Skip to question 16***

15. How much time did you usually spend on one of those days doing **vigorous** physical activities in the garden or yard?

____ **hours per day**

____ **minutes per day**

16. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, sweeping, washing windows, and raking **in the garden or yard**?

_____ **days per week**

☐ No moderate activity in garden or yard → ***Skip to question 18***

17. How much time did you usually spend on one of those days doing **moderate** physical activities in the garden or yard?

____ **hours per day**

____ **minutes per day**

18. Once again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, washing windows, scrubbing floors and sweeping **inside your home**?

_____ **days per week**

☐ No moderate activity inside home → ***Skip to PART 4: RECREATION, SPORT AND LEISURE-TIME PHYSICAL ACTIVITY***

19. How much time did you usually spend on one of those days doing **moderate** physical activities inside your home?

____ **hours per day**

____ **minutes per day**

PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

This section is about all the physical activities that you did in the **last 7 days** solely for recreation, sport, exercise or leisure. Please do not include any activities you have already mentioned.

20. Not counting any walking you have already mentioned, during the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **in your leisure time**?

_____ **days per week**

☐ No walking in leisure time → ***Skip to question 22***

21. How much time did you usually spend on one of those days **walking** in your leisure time?

____ **hours per day**

____ **minutes per day**

22. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like aerobics, running, fast bicycling, or fast swimming **in your leisure time**?

_____ **days per week**

☐ No vigorous activity in leisure time → ***Skip to question 24***

23. How much time did you usually spend on one of those days doing **vigorous** physical activities in your leisure time?

____ **hours per day**

____ **minutes per day**

24. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis **in your leisure time**?

_____ **days per week**

☐ No moderate activity in leisure time → ***Skip to PART 5: TIME SPENT SITTING***

25. How much time did you usually spend on one of those days doing **moderate** physical activities in your leisure time?

____ **hours per day**

____ **minutes per day**

PART 5: TIME SPENT SITTING

The last questions are about the time you spend sitting while at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television. Do not include any time spent sitting in a motor vehicle that you have already told me about.

26. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekday**?

____ **hours per day**

____ **minutes per day**

27. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekend day**?

_____ **hours per day**

_____ **minutes per day**

This is the end of the questionnaire, thank you for participating.

APPENDIX F: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before starting to become much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by your doctor?
☐	☐	2. Do you feel pain in your chest when you do physical activity?
☐	☐	3. In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
☐	☐	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	7. Do you know of any other reason why you should not do physical activity?

If you answered

YES to one or more questions

Talk to your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may able to any activity you want – as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful to you.

NO to all questions

DELAY BECOMING MUCH MORE ACTIVE:

- If you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- Take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

- If you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME _____

SIGNATURE _____ DATE _____

SIGNATURE OF PARENT _____ WITNESS _____

Or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

APPENDIX G: TALENT RELEASE

The University of Oklahoma

TALENT RELEASE

PERFORMER (Name):_____

ADDRESS (Campus or Permanent):_____

CLIENT (Department):_____

JOB NAME: *Photography for departmental publications including but not limited to the department's Web site, promotional brochures, newsletters, postcards, etc.*

For the consideration received, including but not limited to publicity, the adequacy of which is hereby acknowledged, I hereby grant to the Board of Regents of the University of Oklahoma, its successors and assigns, and those acting under the permission, or upon their authority, or those by whom they are commissioned:

(1) The unqualified right and permission to reproduce, copyright, publish, circulate and otherwise use photographs and/or motion pictures of me, and voice reproduction, whether taken in a studio or elsewhere, in black-and-white or in colors, alone or in conjunction with other persons or characters, real or imaginary, in any part of the world including posting on social media sites such as YouTube. I hereby waive the opportunity or right to inspect or approve the finished photographs, films, or tapes or the use to which they may be put or the copy or illustrations used in connection therewith. This release covers composite, stunt, comic, freak, or any unusual photograph and/or motion picture or voice reproduction caused by optical illusion, distortion or alteration or made by retouching or by using parts of several photographs or by any other method. All such use shall be for the purpose of promoting, supporting, or otherwise furthering the mission of the University.

(2) All my right, title and interest in and to all negatives, prints, tapes, and reproductions thereof, and I so hereby release the aforesaid parties and their successors and assigns, if any, from any and all rights, claims, demands, actions, or suits which I may or can have against them on account of the use of publication of said photographs and/or motion pictures or tapes. I have read and understood the release stated above and do hereby agree to its terms and conditions.

SIGNATURE:_____

STUDENT ID NO.:_____ DATE:_____

APPENDIX H: PHOTO RELEASE

THE UNIVERSITY OF OKLAHOMA PHOTO RELEASE

Please check one of the following to indicate proper copyright authorization for photo reprint use in publications or for publicity by the University of Oklahoma:

☐ Attached is copyright permission from the photographer to use

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photo for the following purpose(s): _____

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☐ I own copyright to _____

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photo and give permission for the following use(s): _____

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_____

☐ I have permission from _____

(photographer magazine, etc.) to use

_____

_____

photo for the following purpose(s):

_____

_____

_____ _____

Signature Date

APPENDIX I: EMAIL RECRUITMENT SCRIPT

Email Recruitment

Are you interested in SCIENCE? Darshit Patel and Dr. Chris Black are looking for volunteers for a study titled "Time Course of Change in Critical Torque and Impulse Above Critical Torque Following Exercise-Induced Muscle Damage". This study investigates how critical torque and the impulse above critical torque change following muscle damage. Critical torque is an intensity which that can be sustain for a very long duration while the impulse above critical torque represents a finite energy store that can be utilized at intensities above critical torque. Recreationally active men and women between 18 to 35 years of age who have not performed any lower-body resistance training in the past 6 months may be eligible to participate. The study will involve 7 sessions with a total time commitment of 11 hours. You will be compensated for your time. If you have any questions or are interested in participating, contact Darshit Patel at darpatel7@ou.edu or 580-370-5957 or Dr. Chris Black at cblack@ou.edu or 705-255-3750.

The OU IRB has approved the content of this advertisement but the investigator is responsible for securing authorization to distribute this message by mass email.

The University of Oklahoma is an equal opportunity institution.

APPENDIX J: DIRECT CONTACT RECRUITMENT SCRIPT

Direct Contact Recruitment

Hello, my name is Darshit Patel, and I am looking for volunteers for a study titled "Time Course of Change in Critical Torque and Impulse Above Critical Torque Following Exercise-Induced Muscle Damage". This study will investigate how critical torque and the impulse above critical torque change following muscle damage. Critical torque is an intensity which you can sustain for a very long duration while the impulse above critical torque represents a finite energy store that can be utilized at intensities above critical torque. I am looking for recreationally active men and women who are ages 18 to 35 who have not lower-body resistance trained in the past 6 months. The study will involve 7 sessions with a total time commitment of 11 hours. You will be compensated for your time upon completion of the study. If you have any questions or are interested in participating, you can contact me at darpatel7@ou.edu or 580-3705957 or Dr. Chris Black at cblack@ou.edu or 705-255-3750. Thank you!

The University of Oklahoma is an equal opportunity institution.