2016

Neural Recovery Rates of Knee Extensors Following a Resistance Exercise Protocol

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NEURAL RECOVERY RATES OF KNEE EXTENSORS FOLLOWING A RESISTANCE EXERCISE PROTOCOL

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The Department of Kinesiology

by
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B.S., Southeastern Louisiana University, 2013
May 2016

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ABSTRACT

Fatigue can manifest in the human body in a multitude of ways, one of these is neural-based fatigue. Neural-based fatigue occurs when the nerve fails to activate a muscle (Brooks et al., 2005). The purpose of this research is to investigate rates of neural recovery following a resistance exercise protocol. A pre-test consisting of a 5-second maximum voluntary isometric knee extension was performed. Next, each subject performed a resistance exercise protocol consisting of 5 sets of 10 repetitions of isokinetic knee extensions. Post-tests following the resistance exercise protocol consisted of 5-second maximum voluntary isometric knee extensions after 1, 5, 10, 15, 30, 45, 60, 90, and 120 minutes of sedentary rest. Following the exercise protocol, mean RMS values, mean EMG frequency, and median EMG frequency were not significantly impacted by the resistance exercise protocol ($p > 0.05$). Rates of neural recovery were unable to be determined from the muscular force and EMG data.

CHAPTER 1
INTRODUCTION

According to the 2012-2013 National Collegiate Athletic Association's (NCAA) Sports Sponsorship and Participation Rates Report (2013) an estimated 469,210 student-athletes participated in NCAA sanctioned sports during the 2012-2013 school year. With collegiate sports typically come intense practices and competitions and with such intense sessions of physical activity comes fatigue. Fatigue is the inability to maintain a desired power output (Fitts, 1994). Fatigue can manifest in the human body in a multitude of ways, one of these is neural-based fatigue. Neural-based fatigue has been shown to occur with rapid temporal summation (Häkkinen, 1993; Linnamo, Häkkinen, & Komi, 1998; Walker, Davis, Avela, & Häkkinen, 2012).

The most apparent effect of fatigue is a decrease in motor performance as demonstrated by Beck and colleagues (2012) when a 26% and 25% decrease in peak torque production of the forearm flexors was observed following a concentric exercise protocol and an eccentric exercise protocol, respectively. The results of other studies paralleled the results of Beck and colleagues (2012) when peak force production of the knee extensors decreased by 11.8% following four sets of three repetitions on a knee extension (Walker, Peltonen, Ahtiainen, Avela, & Häkkinen, 2009). Often times in intermittent sports such as football, basketball, and volleyball, neural-based fatigue is inevitable because some sport activities, for instance sprinting and jumping, require rapid temporal summation. However, if neural-based fatigue can be managed, especially during competition, performance could be positively affected.

Neural-based fatigue could play a role in injuries such as acute, noncontact hamstring strains (Gefen, 2002; Worrell & Perrin, 1992). When the onset of neural-based fatigue occurs, the fatigue will progress unless the individual ceases to perform activity that requires high levels of neural stimulation frequency (Häkkinen, 1993; Häkkinen, 1995; Linnamo et al., 1998;). As neural-based fatigue progresses to a certain point movement patterns will become compromised, resulting in dysfunctional movement patterns (Sahrmann, 2002). A positive correlation between dysfunction in movement patterns, as measured by the Functional Movement Screen™, and serious injury has been shown in professional football players (Kiesel, Plisky, & Voight, 2007).

Electromyography

Electromyography, or EMG, is a technique used to evaluate and record electrical activity produced by skeletal muscle and the associated motor neurons (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2014). Two different kinds of EMG exist, surface EMG and intramuscular EMG. Surface EMG uses electrodes placed onto the skin above the muscle being assessed. Intramuscular EMG uses a needle electrode that is inserted into the muscle being assessed.

EMG signals have two important characteristics; amplitude and frequency. Amplitude is an indicator of the magnitude of muscle activity (Robertson, et al., 2014). Frequency is an indicator of the number of motor units activated as well as the frequency at which they are being activated (Robertson, et al., 2014). Increasing the number of motor units being activated as well as increasing the frequency at which those motor units are being activated will cause an increase in both EMG amplitude and EMG frequency.

During an isometric contraction, neural fatigue can be inferred from EMG data when there is a decrease in signal amplitude (Babault, Desbrosses, Fabre, Michaut, & Pousson, 2006; Walker et al., 2012).

Neural-Based Fatigue

During sport activity, one of the biggest concerns for coaches and athletes is being able to perform at the athletes' highest level, if fatigue occurs then it is impossible to perform at the highest level one is capable of performing. Neural-based fatigue occurs when a motor unit fails to stimulate muscle contraction despite activation of the nerve cell. Neural-based fatigue can occur for several reasons, but for the purpose of this work, three causes will be highlighted, 1) failure of neuron to repolarize, 2) failure to release neurotransmitter, and 3) branch point failure.

A neuron may fail to repolarize for a number of reasons, among them are failure of the Na-K pumps. When neuron excitation occurs, the result is an influx of sodium into the cell causing depolarization. Once depolarization occurs calcium gates in the sarcoplasmic reticulum open. Calcium then empties into the cytoplasm and binds to troponin-C. Once calcium is bound to troponin-C, myosin can attach in a strong binding state and create a myosin-actin cross-bridge. After cross bridges are formed, myosin can then exert force on actin, resulting in a shortening of the sarcomere. If the Na-K pumps fail, then the cell cannot depolarize and thus the muscle contraction does not occur. The Na-K pumps may experience failure due to a lack of ATP, for the Na-K pump uses ATP as energy to push the electrolytes against their respective concentration gradients. As a result, force output decreases and thus power output, resulting in fatigue.

Other researchers have postulated a reduction of neurotransmitter release as the reason for neural-based fatigue (Klunger, Krupp, Enoka, 2013). For a muscle to contract, an action potential is generated in a motor nerve, resulting in the release of acetylcholine to be released from the synaptic vesicle. Acetylcholine is a neurotransmitter that binds to chemically-gated sodium channels and thus, T-tubules spread impulses along the triads. Chemical-gates are opened by neurotransmitters such as acetylcholine. This results in depolarization which causes calcium gates in the sarcoplasm reticulum to open and sets off a cascade of events that lead to the muscle contraction. If acetylcholine is reduced beyond what is required to open the chemically-gated sodium channels, the muscle contraction will not occur. If a muscle contraction does not occur power output will be reduced, thus resulting in fatigue.

Branch point failure is another potential site of neural fatigue. Branch point failure is hypothesized to occur when action potentials fail to propagate at a branch point, which may reduce transmission (Baccus, Burrell, Sahley, & Muller, 2000). Krnjevic and Miledi (1958, 1959) observed, in rat diaphragms, that prolonged, repetitive stimulation of the phrenic nerve resulted in a significant incidence of action potential propagation failure, which they attributed to a failure of propagation at the axonal branch points. When this occurs, fatigue is manifested by a failure of a single motor unit's individual muscles cells to contract.

Research by Linnamo and colleagues (1998) and Hakkinen (1993) investigated neural recovery after performing knee extensions and back squats, respectively. Linnamo

and colleagues (1998) and Hakkinen (1993) assessed neural recovery immediately after the exercise session as well as after resting 1 hour, 2 hours, 1 day, and 2 days. Assessing neural recovery at such distant increments of time has left short-term recovery to be questioned. The present study was geared towards investigating short-term neural recovery. Following an exercise protocol consisting of 5 sets of 10 repetitions of isokinetic knee extensions performed at 60-degrees per second, recovery was assessed after 1, 5, 10, 15, 30, 45, 60, 90, and 120 minutes of sedentary rest by assessing peak isometric force, EMG RMS, EMG mean frequency, and EMG median frequency. Therefore, the purpose of this study was to investigate the rate at which neural recovery occurs following a resistance exercise protocol. We hypothesize that following the loading scheme peak isometric force will decrease, as well as EMG RMS, EMG mean frequency, and EMG median frequency. We believed that neural recovery rates would initially be rapid, and then will attenuate as time passed.

CHAPTER 2
REVIEW OF LITERATURE

Previous research on neural fatigue has shed light on a number of issues surrounding neural fatigue; including, how different exercise protocols affect fatigue patterns, how different exercise protocols impact EMG and muscular force, and recovery from different exercise protocols. The purpose of this review is to critically compare and contrast previous research related to neural fatigue.

Contraction Type

In pursuance of investigating issues regarding neural-based fatigue, neural-based fatigue must first be induced. Muscle contraction type may influence neural-fatigue differently. The effect of concentric and isometric contraction will be discussed.

Research by Babault and colleagues (2005) sheds light on how concentric contractions and isometric contractions may affect neuromuscular fatigue differently. An isometric condition consisting of an isometric knee extension performed with the knee flexed at a 55-degree joint angle and held for three sets of 5-second isometric contraction, resulted in significant changes in twitch interpolation with a 6.1% decrease in twitch interpolation during set 2 and an 8.8% decrease in twitch interpolation during set 3 compared to set 1 (Babault, et al., 2005). The concentric condition, three sets of thirty maximal voluntary concentric knee extensions at 60 degrees per second from 95 degrees to 20 degrees of knee flexion, resulted in significant changes in twitch interpolation during set 3 with a 15.8% decrease in twitch interpolation compared to set 1 and an

11.8% decrease in twitch interpolation during set 3 compared to set 2 (Babault, et al., 2005).

In the study by Babault and colleagues (2005) EMG RMS amplitudes were not significantly different following the concentric exercise protocol compared with prefatigue values with only a 5.9%, -5.8%, and -3.9% change in EMG RMS values during set 1, 2, and 3 respectively. The isometric exercise protocol significantly reduced EMG RMS amplitude compared to the prefatigue values with a -24.9%, -24.7%, and a -23.3% change in EMG RMS values during set 1, 2, and 3 respectively (Babault, et al., 2005).

When the concentric and isometric protocols were compared, the concentric condition resulted in greater max double twitch amplitude reduction for both set 1 and 2 (Babault, et al., 2005). Significant differences were observed between the concentric and isometric exercise protocols during set 3 (Babault, et al., 2005).

Given the concentric and isometric exercise protocols uniquely effected activation level, EMG RMS amplitude, and max double twitch amplitude, the researchers concluded that the concentric exercise protocol resulted in the development of peripheral fatigue followed by central fatigue, whereas the isometric exercise protocol resulted in the development of central fatigue followed by peripheral fatigue (Babault, et al., 2005).

This research by Babault and colleagues (2005) may suggest that if one were to investigate matters of peripheral fatigue that a fatiguing exercise protocol consisting of concentric exercises may be ideal.

Wadden and colleagues (2012) elaborated on how different types of contractions affect neural-fatigue by investigating how rapid and slow stretch-shortening cycle movements affected neuromuscular fatigue. The rapid stretch-shortening protocol consisted of continuous drop jumps from a 30cm platform until a predetermined height could no longer be reached. The slow stretch-shortening cycle exercise protocol consisted of continuous squats to 90-degress of knee flexion at 65% of the subject's 1RM until no more successful repetitions could be completed. Integrated EMG (iEMG) was taken during a 1-s segment that exhibited peak amplitude of the root mean square during the precondition test maximum voluntary contraction 1, 3, 5, 10, 20, 30, 40, and 60 minutes after the exercise protocol was completed. After 1 minute of recovery iEMG was decreased by 20.6% and 32.1% following the rapid and slow stretch-shortening cycle exercise protocols respectively (Wadden, et al., 2012). This research by Wadden and colleagues (2012) supports the results found by Babault and colleagues (2005) in which they observed concentric knee extensions at 60 degrees per second, a slow stretch-shortening exercise, induce neural fatigue by demonstrating a 32.1% reduction in iEMG following the slow stretch-shortening cycle protocol. Numerous other research studies have demonstrated the efficacy of using concentric contractions to induce neural fatigue (Hakkinen, 1993; Linnamo, et al., 1998; Walker, et al. 2012).

Fatigue

Various EMG measures such as root mean square (RMS), mean frequency, median frequency, amplitude, and iEMG have been used in neuromuscular fatigue research to assess electrical activity produced by skeletal muscle. In this section, EMG measures will be discussed relevant to their response to fatiguing exercise protocols.

Babault and colleagues (2005) measured both RMS and median frequency following either a concentric exercise protocol, in which subjects performed three sets of thirty maximal voluntary concentric knee extensions at 60 degrees per second from 95 degrees to 20 degrees of knee flexion, or an isometric exercise protocol that required subjects to perform an isometric knee extension with the knee flexed at a 55-degree joint angle and held for three sets of 5-second isometric contraction. RMS amplitude was determined over a 500-ms period preceding an electrical stimulation. EMG RMS amplitudes were not significantly different following the concentric exercise protocol compared with pre-fatigue values with only a 5.9%, -5.8%, and -3.9% change in EMG RMS values during set 1, 2, and 3 respectively (Babault, et al., 2005). The isometric exercise protocol significantly reduced EMG RMS amplitude compared to the pre-fatigue values with a -24.9%, -24.7%, and a -23.3% change in EMG RMS values during set 1, 2, and 3 respectively (Babault, et al., 2005). Median frequency was significantly reduced by an average of 20% immediately following the completion of either the concentric and isometric protocols when compared to the pre-fatiguing values (Babault, et al., 2005). No differences were found between the concentric and isometric protocols in regards to how the protocols affected median frequency (Babault, et al., 2005). This decrease in median

frequency is in accordance with Walker and colleagues (2012). A 14% decrease in median frequency was observed following an exercise protocol that required subjects to perform 5 sets of a 10-repetition maximum on a leg press (Walker, et al., 2012).

Linnamo, Hakkinen, and Komi, (1998) measured iEMG from 500-1500ms following either a maximal strength protocol or an explosive strength protocol. The maximal strength protocol consisted of 5 sets of 10-repetition maximum in bilateral leg extensions. The explosive strength protocol also consisted of 5 sets of 10 repetitions in bilateral leg extensions, however each set used 40% of the load that was used in the maximal strength loading protocol. After following the maximal strength protocol, iEMG decreased by 15.1% in men and 5% in women. Following the explosive strength protocol, iEMG decreased by 13.5% in men and 14.1% in women.

Wadden and colleagues (2012) measured iEMG during a 1-s segment that exhibited the peak amplitude of the root mean square (RMS) during the precondition test MVC after 1, 3, 5, 10, 20, 30, 40, and 60 minutes after a rapid stretch-shortening or a slow stretch-shortening exercise protocol was completed. The rapid stretch-shortening protocol consisted of continuous drop jumps from a 30cm platform until a predetermined height could no longer be reached. The slow stretch-shortening cycle exercise protocol consisted of continuous squats to 90-degress of knee flexion at 65% of the subject's 1RM until no more successful repetitions could be completed. After 1 minute of recovery iEMG was decreased by 20.6% and 32.1% following the rapid and slow stretch-shortening cycle exercise protocols respectively.

iEMG data collected by Linnamo and colleagues (1998) and Wadden and colleagues (2012) parallel one another in that iEMG values decreased significantly following their respective exercise protocols, however Wadden and colleagues (2012) observed up to twice as much decrease in iEMG values with a 32.1% reduction following the slow stretch-shortening cycle protocol compared to Linnamo and colleagues (1998) in which a 15.1% reduction in iEMG values were observed in men following the maximal strength protocol.

Force measures are often utilized in neuromuscular fatigue research as a measure to assess fatigue. Hakkinen (1993) had subjects perform 20 sets of a 1 repetition maximum in the back squat. This exercise protocol resulted in a 24.1% decrease in maximal force exerted by males and a 20.5% decrease in maximal force exerted by females (Hakkinen, 1993). These force measurements were collected via an isometric maximum voluntary knee extension that was taken immediately after the completion of the exercise protocol. Similar findings were seen in research by Linnamo, Hakkinen, and Komi, (1998) after following a maximal strength protocol of 5 sets of 10-repetition maximum in bilateral leg extensions. Peak torque values, as measured via an isometric maximum voluntary contraction, decreased by 23.7% in men and 18.8% in women (Linnamo, et al., 1998).

Babault and colleagues (2005) also found torque decrements following a concentric exercise protocol, which subjects were to perform three sets of thirty maximal voluntary concentric knee extensions at 60 degrees per second from 95 degrees to 20

degrees of knee flexion. Torque decreased by 35.9%, 51.5%, and 59% after set 1, 2, and 3 respectively compared to pre-fatigue values. Following an isometric exercise protocol, which consisted of an isometric knee extension performed with the knee flexed at a 55-degree joint angle and held for three sets of 5-second isometric contraction, torque values decreased by 37.8%, 46.4%, and 57.9% after set 1, 2, and 3 respectively compared to pre-fatigue values.

Wadden and colleagues (2012) found that after following a rapid stretch-shortening cycle exercise protocol, which consisted of continuous drop jumps from a 30cm platform until a predetermined height could no longer be reached, peak force, as measured by isometric maximum voluntary contraction, was decreased by 16.15% and 13% after 1 minute and 60 minutes of rest after completion of the exercise protocol respectively. Wadden and colleagues (2012) found that after following a slow stretch-shortening cycle exercise protocol, which consisted of continuous squats to 90-degress of knee flexion at 65% of the subject’s 1RM until no more successful repetitions could be completed, peak force, measured by isometric maximum voluntary contraction, was decreased by 21%, 11% and 13% after 1, 5, and 60 minutes of rest after completion of the exercise protocol, respectively.

Research has demonstrated decreases in force outputs after following various different exercise protocols (Babault, et al., 2005; Hakkinen, 1993; Linnamo, et al., 1998; Wadden, et al., 2012). The greatest force decrements were realized following the

concentric exercise protocol in the research by Babault and colleagues (2005) in which they observed a 59% decrease in torque values.

Recovery

The previous section outlined effects fatiguing exercise protocols have on muscular force production and EMG measures such as RMS, mean frequency, median frequency, amplitude, and iEMG. Restoration of muscular force production and EMG measures to baseline values are looked at to assess recovery. The effects rest has on recovery will be addressed in this section.

In men, after following an explosive strength protocol, 5 sets of 10 repetitions in bilateral leg extensions using 40% of the subject's 10RM, maximal peak force production recovered to baseline values in 2 hours, whereas after following the maximal strength protocol, 5 sets of 10 repetitions in bilateral leg extensions using a load equal to the subject's 10RM, maximal peak force production recovery to baseline took 2 days (Linnamo, et al., 1998). In women, after following the explosive strength protocol, maximal peak force production recovered to baseline values in 1 hour (Linnamo, et al., 1998). Following the maximal strength protocol, maximal peak force production returned to baseline values after 1 day (Linnamo, et al., 1998). Hakkinen (1993) found that after following an exercise protocol comprised of 20 sets of a 1 repetition maximum in the back squat, after 2 days of rest maximal force values returned to 97.1% and 98.3% of baseline measures in men and women respectively. The results from the male subjects

that performed the maximal strength protocol in the research by Linnamo and colleagues (1998) support the findings of previous research by Hakkinen (1993).

Linnamo and colleagues (1998) found iEMG from 500-1500ms returned to baseline after 1 hour from both men and women in both the maximal strength protocol, 5 sets of 10 repetitions in bilateral leg extensions using a load equal to the subject's 10RM, and the explosive strength protocol, 5 sets of 10 repetitions in bilateral leg extensions using 40% of the subject's 10RM. Because iEMG values had reached baseline measures on the first post-exercise measure (1 hour post-measure), information on when recovery occurred is not clear. Research by Wadden and colleagues (2012) helps to address the issue of when recovery of iEMG values may take place. Wadden and colleagues (2012) measured iEMG during a 1-s segment that exhibited the peak amplitude of the root mean square (RMS) during the precondition test MVC after 1, 3, 5, 10, 20, 30, 40, and 60 minutes after the competition of either a rapid or slow stretch-shortening exercise protocol in which the rapid stretch-shortening protocol consisted of continuous drop jumps from a 30cm platform until a predetermined height could no longer be reached while the slow stretch-shortening cycle exercise protocol consisted of continuous squats to 90-degress of knee flexion at 65% of the subject's 1RM until no more successful repetitions could be completed. The researchers found that there were no significant differences in iEMG values past the 3-minute recovery point in which iEMG values returned to 88.46% and 92% of pretest values for the rapid and slow stretch-shortening cycle protocols respectively.

Various amounts of recovery have been reported in the literature. Linnamo and colleagues (1998) found maximal peak force production recovered to baseline values in 2 hours when an explosive strength protocol was followed, however maximal peak force production recovery to baseline took 2 days to recover from the maximum strength protocol. Research by Hakkinen (1993) supports the results found after following the maximal strength protocol in the study by Linnamo and colleagues (1998). Hakkinen (1993) found that after following an exercise protocol comprised of 20 sets of a 1 repetition maximum in the back squat, after 2 days of rest maximal force values returned to 97.1% and 98.3% of baseline measures in men and women respectively.

CHAPTER 3
METHODS

Subjects

Eight total subjects, four men and four women, were recruited as subjects. Subjects were physically active and had an exercise history of at least six months of consistent (2+ days per week) strength training. Their mean age ($\pm$SD), height, and body mass were 22.3 $\pm$ 3.9 yr, 171.5 $\pm$ 11.8 cm, and 70.2 $\pm$ 14.8kg respectively. Approval from the Louisiana State University institutional review board and written consent from each individual were obtained prior to the commencement of the experiment. All subjects read and signed a consent form prior to experimentation.

Procedure

On the day of the experiment, subjects first got their skin prepared so that surface electrodes may be placed on them. The preparation process entailed shaving body hair off of the areas where the electrodes are to be placed, as well as cleaning and abrading the skin with rubbing alcohol. After the preparation process was complete surface electrodes were placed over the muscle belly of the vastus lateralis, vastus medialis, and rectus femoris. The electrodes used to collect muscle activation included Motion Lab Systems Inc. designed pre-amplifiers that have stainless steel contacts for the skin as well as the traditional silver-silver chloride gel electrodes. The electrodes were placed on the bellies of the specific muscles with the location determined using SENIAM guidelines or by palpation. The electrodes will initially be affixed using hypoallergenic tape, then reinforced using a larger latex-free, self-adhering, cohesive wrap. The subject then

performed a 5-minute warm-up on a stationary air resistance exercise bike. Following the warm-up, subjects performed the isometric maximum voluntary contraction protocol using a Biodex dynamometer. Next the subjects performed the resistance exercise protocol using the Biodex dynamometer. Upon completion of the resistance exercise protocol the subject then performed the isometric maximum voluntary contraction protocol 1 minute after the completion of the exercise protocol and after 5, 10, 15, 30, 45, 60, 90, and 120 minutes of sedentary rest.

Resistance Exercise Protocol

The resistance excise protocol was comprised of knee extensions performed on a Biodex dynamometer. During the resistance exercise protocol subjects performed five sets of ten repetitions of knee extensions with the dynamometer set at 60-degrees per second during knee extension and 500-degrees per second during knee flexion. A one-minute sedentary rest was provided after the completion of each set.

Maximum Isometric Voluntary Contraction Protocol

With the subject's knee was fixed at a 60-degree angle, the subject was instructed to extend their knee as hard as they could for 5 seconds, being that this was isometric contraction the knee angle did not change during the contraction. Once the 5 seconds had passed, the subject was then allowed to rest.

Measurements

Peak torque measures were taken from the Biodex dynamometer for each set of the resistance exercise protocol and for each isometric MVC. Peak torque values for each measurement were determined based on the highest value in the torque curve. Average power for each set performed during the resistance exercise protocol was also determined via the Biodex dynamometer.

To assess the impact of the loading scheme maximal isometric force, EMG root mean square (RMS) (of the vastus lateralis, vastus medialis, and rectus femoris), EMG mean frequency (of the vastus lateralis, vastus medialis, and rectus femoris), and EMG median frequeny (of the vastus lateralis, vastus medialis, and rectus femoris) will be measured. The EMG data was taken at 1800 Hz.

Statistical Analysis

Descriptive statics of torque measures obtained during the isometric MVC's and during the resistance exercise protocol were analyzed. Descriptive statistics were also used to analyze average power output during each the resistance exercise protocol. A repeated measures ANOVA followed by Fisher's LSD post hoc test was used to assess EMG variables over time and also force data over time. The alpha level was set to ≤ 0.05.

CHAPTER 4
RESULTS

Mean Peak Torque Values During Working Sets

Mean peak torque values varied throughout each set of the exercise protocol without a general trend and with the greatest mean value realized during set 2 (128.26 ± 31.36 Nm) and the lowest mean value observed the first set (121.63 + 41.59 Nm), (Table 1 and Figure 1). There were no significant differences in mean peak torque outputs (p > 0.05).

Table 1. Mean Peak Torque During Working Sets

Trial	Torque (NM)	Standard Deviation
Set 1	121.6	41.6
Set 2	128.3	31.4
Set 3	123.2	40.3
Set 4	125.4	40.2
Set 5	124.7	38.8

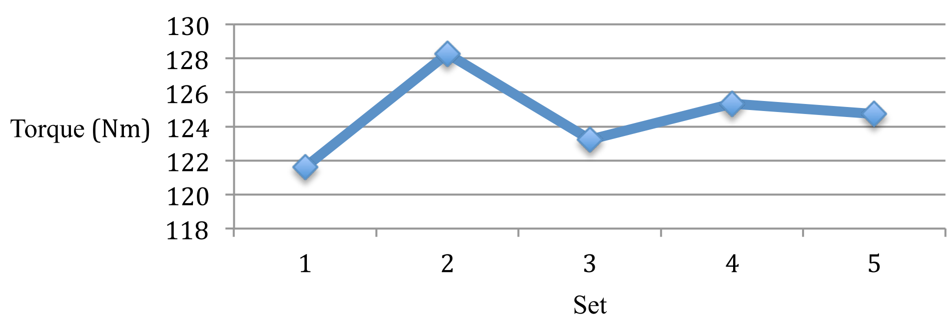

Figure 1. Mean peak torque values during working sets

Average Power Output During Working Sets

Mean average power throughout each set of the exercise protocol paralleled mean peak torque values with the largest mean value seen during set 2 (71.01 W) and the lowest mean value seen the first set (64.9 W) (Table 2 and Figure 2). No significant differences in average power output between sets were observed (p >0.05).

Table 2. Mean Power Output During Working Sets

Trial	Power (W)	Standard Deviation
Set 1	64.9	20.9
Set 2	71	19.1
Set 3	6.7	23.5
Set 4	67.1	21.5
Set 5	67.3	21.3

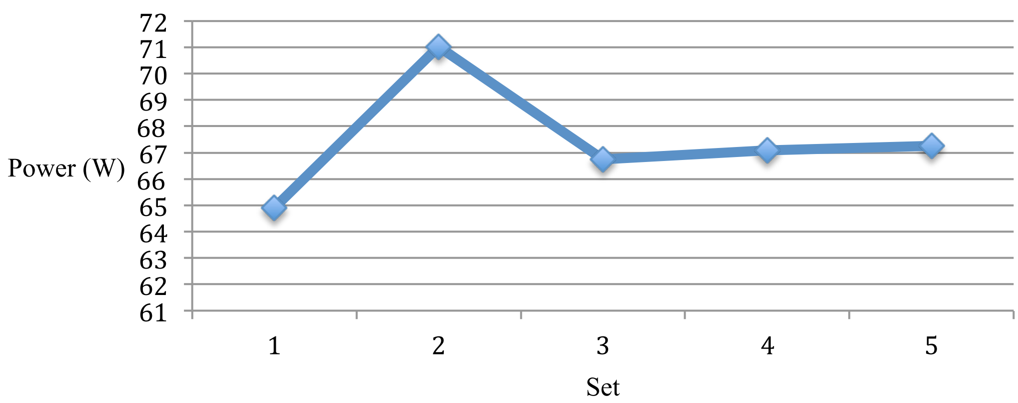

Figure 2. Mean average power output during working sets

Peak Isometric Force Outputs

Mean peak isometric force outputs during maximum voluntary contractions followed a slightly upward trend from the 1-minute post-test to the 30-minute post-test going from 97.5% to 107.8% of baseline measurement (Figure 3). Mean values slightly decreased past the 30-minute post-test until the 90-minutes post-test going from 107.8% to 105.35% of baseline measurement. At the 120-minute post-test mean values dropped compared to the 90-minute post-test, decreasing by 16.29%. There were no significant differences in mean peak isometric force outputs ($p > 0.05$). Mean peak force outputs during isometric maximum voluntary contractions are listed in Table 3.

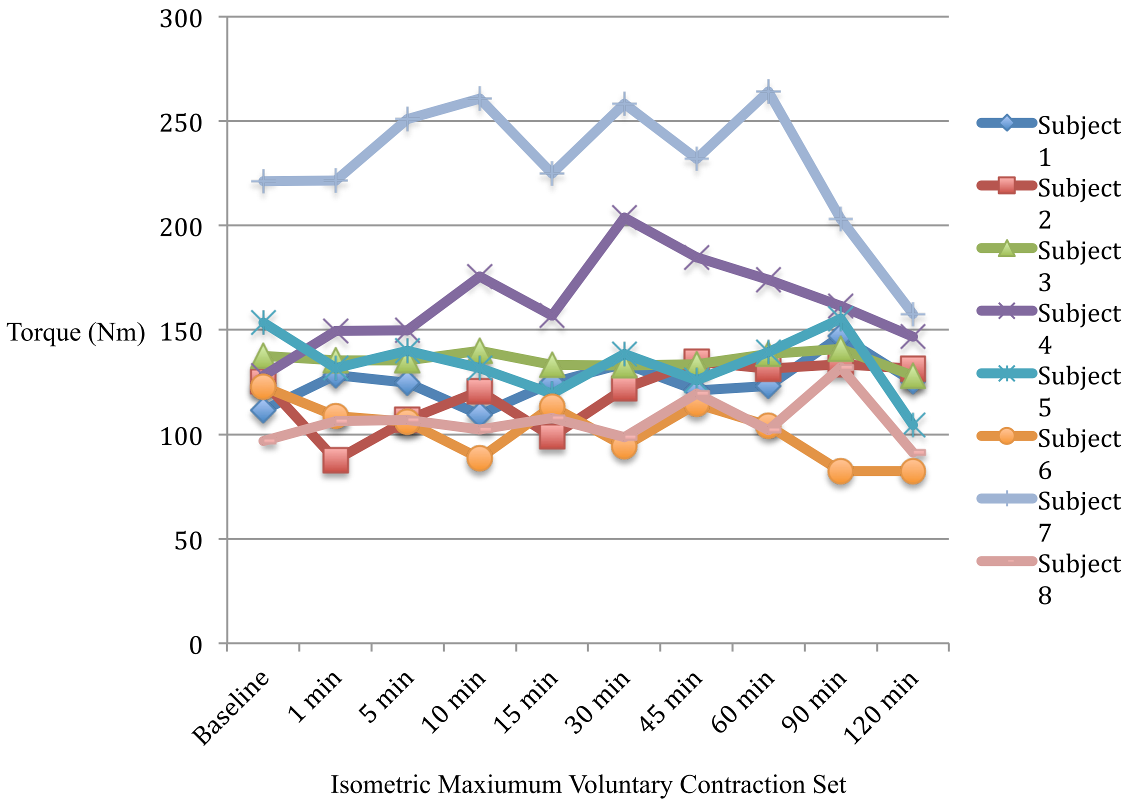

Figure 3. Peak isometric forces exerted during isometric maxiumum voluntary contractions at baseline and after 1, 5, 10, 15, 30, 45, 60, 90 and 120 minutes of sedentary rest following the resistance-exercise protocol

Table 3. Mean Peak Torque Values During Isometric Maximum Voluntary Contractions

Trial	Torque (NM)	Standard Deviation
Baseline	137.1	37.9
1 Min	133.7	40.5
5 Min	140.1	47.8
10 Min	141.1	55.1
15 Min	134.9	40.4
30 Min	147.8	55.7
45 Min	145.8	41.2
60 Min	147.1	52.5
90 Min	144.4	33.8

120 Min	120.9	26.3

EMG Data

Following the exercise protocol, mean EMG RMS, EMG mean frequency, and EMG median frequency values were not significantly impacted by the resistance exercise protocol (p >0.05) (Figure 4, Figure 5, and Figure 6).

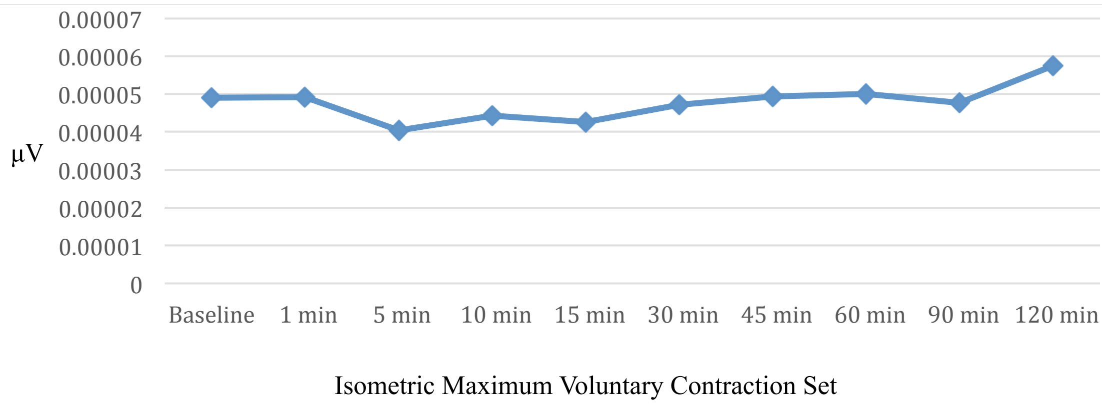

Figure 4. Mean EMG RMS values during isometric maxiumum voluntary contractions at baseline and after 1, 5, 10, 15, 30, 45, 60, 90 and 120 minutes of sedentary rest following the resistance-exercise protocol

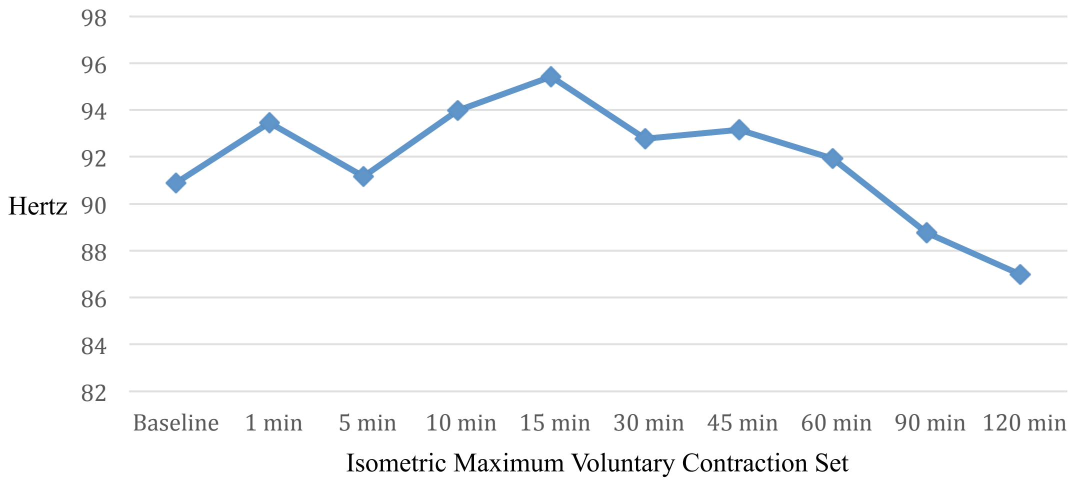

Figure 5. Mean EMG mean frequency values during isometric maxiumum voluntary contractions at baseline and after 1, 5, 10, 15, 30, 45, 60, 90 and 120 minutes of sedentary rest following the resistance-exercise protocol

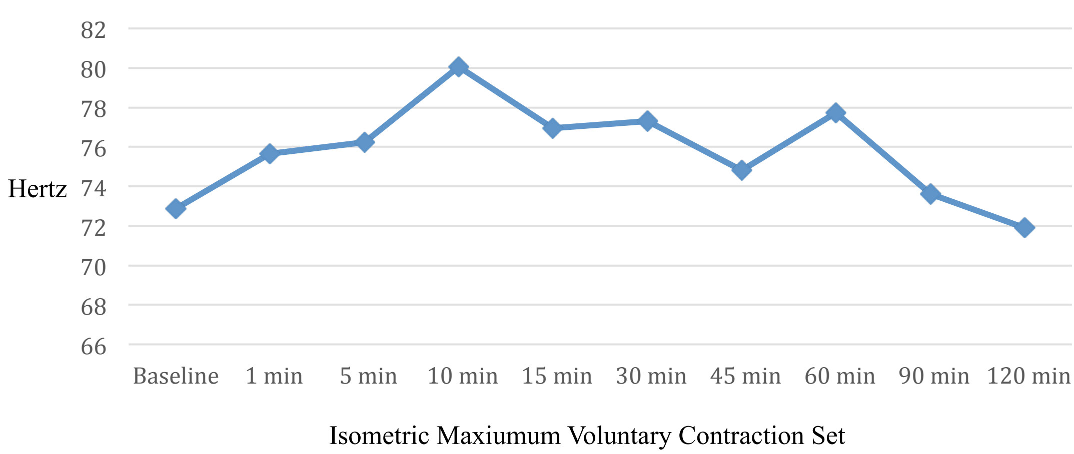

Figure 6. Mean EMG median frequency values during isometric maxiumum voluntary contractions at baseline and after 1, 5, 10, 15, 30, 45, 60, 90 and 120 minutes of sedentary rest following the resistance-exercise protocol

Mean values for EMG RMS, EMG mean frequency, and EMG median frequency are listed in Table 4, Table 5, and Table 6 respectively. Mean frequency values trended

Table 4. Mean EMG RMS Values During Isometric Maximum Voluntary Contractions		
Trial	RMS (µV)	Standard Deviation
Baseline	0.0000524	0.0000275
1 Min	0.0000543	0.0000361
5 Min	0.0000490	0.0000385
10 Min	0.0000511	0.0000419
15 Min	0.0000545	0.0000420
30 Min	0.0000566	0.0000403
45 Min	0.0000576	0.0000347
60 Min	0.0000565	0.0000368
90 Min	0.0000582	0.0000477
120 Min	0.0000582	0.0000330

Table 5. Mean EMG Mean Frequency Values During Isometric Maximum Voluntary Contractions		
Trial	Mean Frequency (Hz)	Standard Deviation
Baseline	98.6	21.5
1 Min	99.8	20.7
5 Min	104.2	20.7
10 Min	108.6	21.9
15 Min	109.3	21.3
30 Min	105.3	21.6
45 Min	103.9	20.7
60 Min	103.1	19.9
90 Min	101.4	20.4
120 Min	100.6	21.4

upwards from the 1-minute post-test until the 15-minute post-test with values reaching 101.2% and 110.9% of baseline values, respectively. Median frequency values trended

upwardly from the 1-minute post-test until the 10-minute post-test with values reaching 104.9% and 114.8% of baseline values, respectively.

Table 6. Mean EMG Median Frequency Values During Isometric Maximum Voluntary Contractions		
Trial	Median Frequency (Hz)	Standard Deviation
Baseline	77.1	14.6
1 Min	80.9	14.5
5 Min	83.2	16.9
10 Min	88.5	17.2
15 Min	87.9	17.9
30 Min	85.4	18.1
45 Min	82.2	15.6
60 Min	81.9	12.5
90 Min	79.1	12.7
120 Min	80.7	17.2

CHAPTER 5
DISCUSSION

The purpose of this study was to determine rates of neural recovery following a fatiguing bout of isokinetic resistance exercise. During the resistance exercise protocol there were no significant differences in mean peak torque output or average power output between sets were observed. There were also no significant differences in mean peak isometric force outputs, mean EMG RMS, EMG mean frequency, and EMG median frequency during the maximal isometric voluntary contractions performed at baseline and 1, 5, 10, 15, 30, 45, 60, 90, and 120 minutes after the completion of the resistance exercise protocol.

The changes in force as a result of the resistance exercise protocol found in the present study do not parallel the findings of previous studies. Babault and colleagues (2005) found that after following a concentric exercise protocol, three sets of thirty maximal voluntary concentric knee extensions at 60 degrees per second, resulted in peak torque decreased of 35.9%, 51.5%, and 59% after set 1, 2, and 3 respectively compared to pre-fatigue values. While following the resistance exercise protocol, five sets of ten maximal voluntary concentric knee extensions at 60 degrees per second, the greatest decrease in mean peak torque during each set was 4% between set 2 and set 3. Wadden and colleagues (2012) found that after following a slow stretch-shortening cycle exercise protocol, continuous squats to 90-degress of knee flexion at 65% of the subject's 1RM until no more successful repetitions could be completed, peak force decreased by 21%, 11% and 13% after 1, 5, and 60 minutes of rest after completion of the exercise protocol

respectively. Following the resistance exercise protocol in the present study, mean peak torque values decreased by 3% after 1 minute of sedentary rest when compared to baseline measures. After 5 and 60 minutes of sedentary rest following the resistance exercise protocol, mean peak torque values increased by 2% and 7%, respectively.

The impact the resistance exercise protocol had on RMS in the present study is supported by past research (Babault et al., 2005). Babault and colleagues (2005) found RMS amplitudes were not significantly different following the concentric exercise protocol compared with pre-fatigue values with only a 5.9%, -5.8%, and -3.9% change in EMG RMS values during set 1, 2, and 3 respectively. In the present study, the resistance exercise protocol did not appear to have a significant impact on RMS with values increasing by 3.6% when 1-minute post-test values were compared to baseline values. Babault and colleagues (2005) found median frequency was significantly reduced by an average of 20% immediately following the completion of the concentric protocol when compared to the pre-fatiguing values. Our data does not correspond to the findings of Babault and colleagues (2005). In the present study, after one minute following the resistance exercise protocol, median frequency increased by 4.9%.

There were numerous limitations that handicapped this study. The resistance exercise protocol that was intended to induce neural fatigue failed to do so. This is evident by the lack of a decrease in peak torque production and total work performed during each working set. Furthermore, differences in peak torque production during the maximal voluntary contractions were insignificant, specifically when comparing baseline

measures to the 1-minute post-test where it would be expected to see the largest difference.

Reliability may also have played a major role in polluting the results. A study published in 2003 investigated reliability of maximum voluntary isometric contractions (MVIC) and if a learning effect existed in a relatively new user of the system (Meldrum, Cahalane, Keogan, & Hardiman, 2003). The study reported an intra-class correlation co-efficient as low as 0.50 for knee extension MVIC's. Furthermore, they also demonstrated a learning effect in relatively new users. In the present study, each of the subjects that participated was a new user. Based of research by Meldrum and colleagues (2003), it is possible that reliability of the MVIC's and ultimately the results may have been influenced by a learning effect, thus effecting reliability.

Future research may consider choosing to have a familiarization period to help eliminate a learning effect influencing the data. Choosing subjects who have a considerable athletic background may also be helpful when trying to control for a learning effect and they may aid in producing more consistent results. Future research should include a more rigorous resistance exercise protocol. One possible solution may be to perform squats. Another solution may be to simply be to perform more sets with the resistance exercise protocol that was outlined in this research. Due to the reliability of the maximum isometric voluntary contractions, researchers may want to consider having subjects perform several maximum isometric voluntary contractions so that an average could be taken.

Muscular force and EMG measures were not significant different following a resistance exercise protocol of 5 sets of 10 repetitions of isokinetic knee extensions. Thus, rates of neural recovery were unable to be determined from the muscular force and EMG data.

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VITA

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