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THE EFFECTS OF MUSCLE LENGTH ON FORCE STEADINESS AND EMG RESPONSES FOLLOWING A FATIGUING PROTOCOL

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Abstract

The purpose of this study was to examine the effect of muscle length on force steadiness and EMG responses following a fatiguing intervention. Twenty-three subjects, fifteen men and eight women, were required to perform isometric contractions of their dominant forearm flexors at both 60 degrees of elbow flexion and 90 degrees of elbow flexion. The protocol consisted of three pre-fatigue MVC's, two pre-fatigue submaximal trapezoid contractions set at 50% MVC, a fatiguing protocol, three post-fatigue MVC's, and finally two post-fatigue trapezoid contractions. The subjects performed this protocol at both joint positions, and each position was tested on separate visits to the laboratory. During all contractions, data were collected for force and EMG signal of the biceps brachii. The findings of this study indicated that the 60 degree flexion position produced a less steady submaximal contraction than the 90 degree flexion position during both pre and post fatiguing submaximal contractions. The results also indicated that there were no significant differences in EMG responses during submaximal contractions between the two joint positions tested. In conclusion, the present study suggests that force steadiness may be reduced when a muscle is in a lengthened position when compared to a shortened position and this phenomenon may not be due to neural changes during the contractions.

Chapter I

Introduction

The ability to maintain a constant level of force plays a critical role in performance during precise movements. In athletics, an athlete's performance in activities such as gymnastics, shooting, and archery is largely dictated by their ability to maintain a constant force. For example, elite shooters are able to hold a steady body posture significantly better than less experienced shooters (Era, 1996). This steadiness in posture allows them to be accurate and consistent. Impairment of the athlete's ability to hold a steady force will result in decreased performance. This is true for many sports which require balance, accuracy, and prolonged static contractions.

Steady and accurate force production is also essential for activities of daily living, especially in special populations, such as elderly adults. Muscle function begins to decline as we age, making it increasingly more difficult to perform submaximal tasks with accuracy (Hortobagyi, 2003). Daily tasks, including pouring a glass of water, sitting into a chair, or unlocking a door, become increasingly more difficult to perform as the ability to control force output is hindered.

A muscle can increase the level of force produced by increasing the number of active motor units, which are groups of muscle fibers innervated by a single motor neuron, or increasing the firing rates of the active motor units. Thus, the force produced by a muscle can be regulated by altering the number of active motor units or varying the firing rates of the active pool of motor units. Due to the nature of muscle force regulation, the force produced by the motor units is not perfectly stable; instead, it will vary around an average value, as more motor units are recruited the fluctuations are magnified (Taylor, 2003). Force variation is inevitable in muscle contractions; however, the degree of these variations can be influenced by a number of factors, such as age, the level of fatigue, and contraction intensity. There is also evidence to suggest it may be influenced by muscle length as well.

When a muscle is positioned in a stretched or lengthened position, it causes a change to the structure of the muscle fibers, particularly the actin-myosin interaction. The structural changes that occur due to lengthening a muscle alter the performance of that muscle. This can be demonstrated by a concept known as the force-length relationship, where the force produced by a muscle is dependent on the length of the muscle during the contraction due to a change in overlap of actin and myosin as the sarcomeres are stretched or compressed beyond their optimal length (Rassier, 1999). Therefore, when a muscle is lengthened too much, the number of cross bridges that can form is decreased due to a decrease in the overlap of actin and myosin. There is evidence to suggest that the length of the muscle can also affect the motor unit activity characteristics, such as recruitment threshold and firing rate (Pasquet, 2005).

Purpose of Research

The primary purpose of this study is to determine the effect of muscle length on force steadiness and EMG responses in the biceps brachii before and after fatiguing exercise.

Research Questions

What effect will muscle length (joint angle) have on force steadiness following a fatiguing intervention?

What effect will muscle length (joint angle) have on EMG responses following a fatiguing intervention?

Hypotheses

H_{a1}: There will be greater force steadiness for contractions at 90 degrees of elbow flexion than contractions at 60 degrees of elbow flexion following a fatiguing intervention.

H_{a2}: There will be greater EMG responses for contractions at 60 degrees of elbow flexion than contractions at 90 degrees of elbow flexion following a fatiguing intervention.

Significance of the Study

There are several instances when a muscle is tasked with performing under a limited range of motion or in a static position, such as when rehabilitating an injured joint or certain postures in sport. However, this position may not be an ideal position to maximize the performance of the muscle and/or may not be a typical position for that muscle. Thus, the relationship between muscle length, force steadiness, and neuromuscular responses may be important in comparing performance at various joint angles or in developing training programs to improve performance at less than optimal joint positions. The current body of research provides a great amount of information regarding the changes in force output by lengthening a muscle beyond optimal length; however, this research tends to focus on the changes in muscle structure. The neuromuscular changes associated with altering muscle length have been researched very little.

Delimitations

Delimitations of this study include:

1. The use of approximately twenty-five recreationally active males between the ages of 18 and 35 years.
2. Participants will be free of neuromuscular and musculoskeletal disorders.
3. Participants will have no recent injuries to their dominant elbow flexors.
4. Each subject will be given a written informed consent and a health history questionnaire to fill out and sign prior to any testing.

Limitations

Limitations of this study include:

1. Subjects for this study will be recruited predominately from OU Norman Campus. The subjects will be volunteers recruited from departmental courses, flyers, and face to face interactions. Therefore, the subjects and sampling method do not meet the assumption of random selection, thus we do not have a truly random sample.
2. Subjects may not be truthful when providing information about issues or injuries of the muscles being examined.

Assumptions

1. Subjects will give a maximum effort during the MVCs and perform the force--matching task to the best of their ability.
2. Subjects represent a random sample from the target population.
3. The equipment used for data collection is accurate and functioning properly.

4. Subjects will respond honestly to the questions on the health history questionnaire.

Operational Definitions

Electromyography – Measure of electrical activity in a muscle.

Force Steadiness - Degree of variation in force around a mean value.

Isometric contraction – a muscle contraction where force is produced with no change in muscle length or joint angle.

Long muscle length – the muscle length when the elbow is positioned at 60 degrees of flexion.

Maximum voluntary contraction - the greatest amount of force that can be produced by the subject during an isometric contraction.

Motor unit – a motor neuron and all the fibers it innervates.

Short muscle length – the muscle length when the elbow is positioned at 90 degrees of flexion.

Trapezoid Contraction – a submaximal contraction in which the subject slowly and steadily increases force up to a given %MVC and holds that force for a set time interval before slowly and steadily decreasing the force back down to baseline.

Chapter II

Review of Literature

Introduction

The purpose of the present study is to examine the effects of muscle length on force steadiness and EMG responses following a fatiguing intervention. It has already been shown that muscle length can affect the force output of a given muscle due to structural changes in the arrangement of actin and myosin. It is also commonly known that fatiguing a muscle will result in decreased performance of that muscle, and it appears that performance decrease is largely due to changes in the neural components of muscle contraction. However, current research provides little insight to the impact of muscle length on neural strategies during prolonged muscle contractions. Therefore, the aim of this study is to help bridge the gap and determine the link, if any, between muscle length and motor control strategies. The findings of this study could be of potential use for those comparing muscle performance across various joint angles, such as may be seen during joint injury rehabilitation.

This chapter will be used to review literature related to force control, muscle length, and various properties of EMG signals. This section will also seek to identify any gaps in the current body of literature, through the examination of the findings of previous studies. Furthermore, this section will be broken down into general categories, and the related research will be grouped accordingly.

Research on Force Control

De Luca (1985)

In this review, De Luca examined what, if any, strategies by the nervous system exist when controlling force. Common drive is a key concept discussed in this review. The term common drive essentially means that the nervous system will regulate the firing rates of the entire pool of active motor units as a group, rather than individually. This concept can be used to explain a number of phenomena seen with various types of muscle contractions.

Fluctuations in firing rate appear to play a large role in a muscles ability to produce a perfectly smooth constant force. Therefore, the idea that all active motor units vary firing rate together, only intensifies this effect. Since the alterations in firing rates occur at nearly the same time and rate, this causes an oscillating effect in the firing rates as a whole. This oscillation in firing rates can explain why we see fluctuations in force output during prolonged contractions.

Yao et al. (2000)

The purpose of this study was to examine the effects of motor unit synchronization on EMG amplitude and force variability. The researchers used computer generated simulations of motor neuron pools to evaluate the recruitment properties of motor units, isometric force output, and EMG amplitude during constant force isometric contractions. There were no human subjects, and all data was based on computer simulation. Motor unit synchronization was created by shifting some of the individually generated motor unit action potentials such that they were approximately in the same time frame. Though it has been suggested that motor unit synchronization appears to occur in clusters, this study randomly distributed the synchronized firings. Finally, simulations of 11 isometric contractions were performed at 5% MVC, and then in 10% increments starting 10% MVC, and incrementing all the way up to 100% MVC.

The findings of this study indicate that as motor unit synchrony increases, the corresponding EMG signal displays an increase in amplitude. This relationship was true for all force levels. Also, it was shown that as the percentage of MVC was increased, the effects of synchrony on EMG amplitude were amplified. Another important finding of this study was that increased synchrony led to greater force fluctuations, but not increased force. Alignment of action potentials may explain the increase in EMG amplitude with no corresponding increase in force due to reductions in the cancellation effect seen with EMG.

The most important finding from this study was that motor unit synchronization had no impact on force output at any given level of activation. However, when synchronization of motor unit firings was increased, the consequence was increased EMG amplitude, likely due to decreased cancellation. It also led to a greater degree of force fluctuations during submaximal isometric contractions.

Lavender et al. (2005).

The purpose of this study was to examine the difference between the effects concentric and eccentric exercise on force steadiness for a given time period following exercise. The researchers hypothesized that there would be decreased force steadiness for the eccentric exercise for a few days, while concentric exercise would not create these changes.

This study involved twelve men who were not involved in resistance training in the last six months. The subjects performed six sets of five repetitions at 50% MVC. Changes in isometric MVC, range of motion, arm circumference, ratings of muscle soreness, and plasma creatine kinase and myoglobin levels were used to gauge muscle damage. Two sets of constant force isometric contractions at intensities of 30%, 50%, and 80% MVC were used to evaluate force steadiness and were quantified with a coefficient of variation. These variables were measured immediately, one hour after, and every day for five days following the exercise protocol.

The results indicated that eccentric exercise resulted in greater changes in all markers for muscle damage when compared to concentric exercise. Prior to exercise, there were no significant differences in force fluctuations between eccentric and concentric exercise. However, eccentric exercise produced a significant increase in force fluctuations immediately after and one hour after exercise at all intensities with no significant changes for concentric exercise at any time points.

The study concluded that the decreases in force steadiness were not related to reduced muscle strength, and did not correlate with the time course of muscle damage, since decreased force steadiness was only seen immediately after and one hour after the eccentric exercise. On the other hand, the concentric exercise did not significantly affect force steadiness at any time point.

Future studies could investigate the effects of concentric exercise on force steadiness with greater fatigue. A more intense exercise protocol could lead to increased fatigue and may lead to results similar to what was seen with eccentric exercise.

Contessa et al. (2009)

The purpose of this study was to determine the intrinsic motor control strategies utilized during fatigue in relation to increases in force fluctuations. This study involved four healthy men with no neurological disorders who were 20-22 years of age. The subjects performed sets of isometric contractions of the vastus lateralis muscle sustained at 20% MVC. Sets were performed until the desired mean force value could not be maintained, with 6 seconds between sets. Force and EMG data were recorded during the contractions for analysis.

A total of five contractions spread across different time periods from beginning to end were analyzed. The standard deviation and coefficient of variation were determined for force data at each of the selected time points. The EMG data were decomposed, and only motor units active during at least two consecutive contractions were analyzed. Cross-correlation functions during a time interval of ±100 ms were used to determine common drive and a cross-interval histogram was used to calculate synchronization.

The findings of this study showed that the variability in force increased from the first to the last contraction. They did not find any changes across time for firing rate variability or synchronization, which were thought to lead to increased force fluctuations. However, they did see significant changes in common drive and an increasing number of active motor units, which are correlated to the changes in force steadiness across time.

A question that could be examined in the future is whether the motor control strategies responsible for the increased variation in force during constant contractions would be the same if the fatigue were evoked from separate contractions instead of during the prolonged constant force contractions.

Missenard et al. (2009).

The purpose of this study was to investigate the mechanisms responsible for force steadiness impairment with fatigue. This study involved 16 recreationally active subjects. The study was comprised of three experimental protocols to determine where the cause of increased force fluctuations was coming from. The first of the three experiments involved matching a given force both prior to and after the fatiguing exercise to see if there were differences in the level of muscle activation needed to reach this force. The objective of the second experiment was to match the activation level before and after the fatiguing exercise, thereby allowing for differences in force variability to be examined at a given activation level. The third experiment isolated the contractile properties, to evaluate their influence on force steadiness, using electrical stimulation.

Experiment one showed a significant increase in force fluctuations following fatigue for all four force levels examined. This was assessed with a coefficient of variation (CV) of force data. They also found a significant increase in EMG amplitude from pre to post for the two high force levels.

When the researchers controlled for muscle activation, they found that the force generated at a given level of activation was significantly lower for all force levels. The results showed significant changes in CV for the low force levels from pre to post, but this was not seen during the more intense contractions.

Experiment three found that force fluctuations remained constant at all intensities following fatigue when given a constant stimulation frequency. However, the higher force levels produced significantly less force following fatigue, given the same electrical stimulation.

This study provides evidence to suggest that changes in muscle activation play a large role in force variability, but it is not the sole cause of decreased force steadiness, particularly at lower force levels. The study also suggested that the cause of the declines in steadiness were not peripheral in nature since there were no differences in force steadiness with electrical stimulation. Thus, it was suggested that future studies should investigate the characteristics of neural drive during fatigue.

Beck et al. (2010)

The purpose of this study was to examine the impact of resistance training on common drive and force smoothness. The study included eight untrained male subjects free of neuromuscular or musculoskeletal disorders. The training protocol consisted of bench press, leg press and leg extension performed three times per week for eight weeks. The exercises were performed for three sets of 8-12 repetitions at an intensity of 80% of the one repetition maximum. At the end of each week, the subjects performed maximal isometric contractions and submaximal contractions at 80% MVC of the leg extensors. The EMG signal from the vastus lateralis and the force produced during the contractions were recorded for analysis. They also recorded the EMG signal from the biceps femoris to ensure that the force produced was not altered by co-contractions.

The results indicated that resistance training had no effect on force steadiness or common drive. Also, as expected, the training protocol lead to an increase in force production over time. The results reported were in line with the hypothesis that resistance training would not elicit any changes in motor unit recruitment or firing rate.

<u>Ye et al. (2015)</u>

The purpose of this study was to compare the acute effects of eccentric versus concentric exercise on electromyographic responses and force steadiness in the biceps brachii. The study included fifteen resistance trained men who were free from any musculoskeletal or neuromuscular issues. The subjects were asked to come in on two different occasions and perform six sets of ten repetitions at maximal capacity using eccentric loading for one visit and concentric loading for the other. Measures of MVC and submaximal contractions at 40% MVC were performed before and after the exercise intervention.

The results indicated that both the concentric and eccentric exercise caused a similar loss in strength measured by force decline during the MVC. However, the eccentric mode increased force fluctuations to a greater extent than the concentric loading. Since the submaximal contraction was based upon the pre MVC value, it was expected that the changes in force fluctuations would be similar following eccentric and concentric exercise, which would align with the similar declines in force, but this was not the case. They also found significant changes in normalized EMG amplitude and mean frequency; however, the changes were similar for both modes of exercise.

These results lead to the conclusion that the differences in the force steadiness seen after eccentric and concentric exercise could be due to effects of eccentric exercise on motor control strategies. They also suggested that future research should investigate the time course of these effects by taking measurements at time intervals such as immediately post, 24 hours post, 48 hours post, etc.

Summary

For a muscle to produce and regulate force it must either recruit new motor units or increase the firing rates of previously recruited motor units. The nervous system utilizes a strategy known as common drive to regulate the firing rates of all currently active motor units simultaneously. Therefore, the firing rates of active motor units tend to increase and/or decrease at the same time and by approximately the same amount. If a new motor unit is recruited, the firing rates of previously recruited motor units will decrease. This is because when the total amount of neural drive given to a muscle increases enough to bring in a new motor unit, the total doesn’t increase to accommodate this new motor unit. Therefore, the amount of stimulation, in a sense, must now be partitioned between more motor units. If the stimulation is increased further, the entire pool of motor units will begin to increase together until a new motor unit is recruited, at which point we would see another drop across all active motor units to compensate for the added motor unit.

These strategies of force control make it impossible for the muscle to produce a perfectly smooth force, instead, it will vary around an average value. The degree to which the force varies around this value, however, can be influenced by a number of factors. For example, the steadiness of force produced by a muscle can be influenced by contraction intensity, contraction duration, and fatigue. These factors seem to influence the neural components of muscle contraction, such as increased motor unit recruitment and increased common drive.

Research on Muscle Length

Mannion and Dolan (1996)

The purpose of this study was to determine the relationship between muscle length, force, and EMG frequency. Ten male subjects were asked to perform static contractions of the back extensors at different muscle lengths and intensities. The intensities performed ranged from 20-80% MVC and were each performed at three different degrees of spinal flexion.

The results of this study showed a significant relationship between increased contraction intensity and the increase in EMG amplitude (RMS), which is an expected finding due to the relationship between RMS and increased motor unit recruitment seen at higher intensities. There was also a significant effect seen between EMG median frequency (MDF) by both contraction intensity and muscle length. Further, there was an inverse relationship between contraction intensity and MDF. They also found that shorter muscle length was related to an increased MDF and MDF decreased further with increased muscle length.

The findings of this study provided evidence for changes in the neural strategies required for different muscle lengths. These changes could influence the ability of the muscle to produce smooth forces at longer muscle lengths when compared to shorter muscle lengths. However, further research would need to be done to confirm the existence of this relationship.

Mohamed et al. (2002)

The purpose of this study was to determine the relationship between torque, muscle length, and total EMG activity using the fine wire EMG technique. The subjects recruited for this study included 19 healthy females. These subjects were asked to perform isometric MVCs of the hamstrings at several different positions. The positions included various combinations of knee and hip flexion totaling nine positions. EMG signals were recorded in several muscles of the hamstrings using fine wire EMG.

The data in this study suggested that muscle length may have little or no impact on neural activity during muscle contractions. However, there are some limitations to the findings in this study. First, the use of fine wire EMG does not provide a very clear picture of total muscle activity because it is localized to only a handful of motor units activated near the location of the electrodes. Secondly, it appears the authors did not look into potential EMG frequency changes and only looked at total EMG activity. Perhaps they may have drawn different conclusions had they taken into account other aspects of the information contained in an EMG signal, or looked at a more global picture of the muscle activity.

Nonetheless, the results in this study may indicate that either muscle length does not impact neural components of muscle contractions, or this phenomenon is specific to only certain muscles with certain functions. Further investigation could provide an answer to whether the findings of this study were due to study design or actual muscular events.

<u>Nourbakhsh and Kukulka (2003)</u>

The purpose of this study was to examine the effect of muscle length and moment arm on EMG responses. Ten healthy subjects performed submaximal plantar flexion contractions under three different conditions; shortened muscle length with a shortened moment arm, shortened muscle length with a constant moment arm, and constant muscle length with a shortened moment arm. During each condition, the EMG activity was recorded by both surface and wire EMG electrodes.

Interestingly, the results indicate that shortening both the muscle length and the moment arm resulted in increased activity of the triceps surae. However, shortening just the muscle length resulted in no change in muscle activity. These findings suggested that moment arm length is more important in muscle activity than the length of the muscle.

The findings indicate that muscle length may not affect neural activities of muscle contractions. However, this study only considered changes in EMG amplitude and did not investigate potential frequency changes of the EMG signal, which may exist even in the absence of amplitude changes. Further research is needed to determine if muscle length impacts EMG frequency.

Pasquet et al. (2005)

The purpose of this study was to examine the effects of muscle length on discharge rate and recruitment threshold during isometric contractions. Eight men and women performed isometric contractions of the tibialis anterior at two different ankle positions (muscle lengths) at various intensities. EMG activity of the tibialis anterior was recorded using wire EMG placed at multiple sites over many trials.

The results indicated that muscle length had an effect on motor unit recruitment threshold and discharge rate. Specifically, shorter muscle lengths resulted in a greater discharge rate and recruitment threshold. This study also provided evidence to suggest that firing rate may be increased during low intensity contractions at shorter muscle lengths due to increased muscle-tendon unit compliance. This suggests that a shorter muscle length should produce a smoother force than a longer muscle length at low intensities due to the influence of firing rate on force steadiness.

Sosnoff et al. (2010)

The purpose of this study was to determine the effect of muscle length on force control during submaximal isometric contractions. Twelve subjects performed submaximal isometric contractions at four different knee joint angles (15˚, 30˚, 60˚, and 90˚ of flexion). The intensities performed were set a 15%, 30%, and 45% of the MVC determined for each joint angle. Force data was analyzed for steadiness by calculating the coefficient of variation of force.

The results of this study indicated that the quadriceps force variability was greatest at the shortest muscle length tested. However, there were no significant differences in force variability between any of the other lengths tested. The origins of these change in force steadiness are unknown. The authors of this study did not collect EMG data; thus any neural changes that may have occurred at the short muscle length are unknown but possible. Further investigation could help determine if neural components of muscle contractions were responsible for this change or not.

Krishnan et al. (2010)

The purpose of this study was to determine the effects of different knee angles on force steadiness and EMG responses. Twenty-two subjects were asked to perform submaximal contractions from 2-50% MVC at two different knee positions (30˚ and 90˚ knee flexion). The two different knee joint angles are considered short (30˚) and long (90˚) muscle lengths respectively. During the contractions, EMG data were collected from the vastus medialis, vastus lateralis, rectus femoris, biceps femoris, and semitendinosus to provide information regarding activation of the agonist and antagonist muscles.

The results of this study indicate that a shorter muscle length resulted in smoother force production compared to the long muscle length. Further, this study found that a shorter muscle length produced lower EMG amplitude and higher EMG median frequency. These findings suggested that alterations in muscle length during isometric contractions influences neural components of the contraction. There also appears to be a relationship between muscle length and the muscle's ability to produce a smooth force. This relationship may be explained by the neural changes associated with altering muscle length during the contractions.

Summary

It is commonly known that muscle length influences various aspects of a muscle contraction, most notably the length-force relationship. This relationship has been widely studied and there is a consensus that lengthening or shortening a muscle beyond its optimal length leads to decreased force output by that muscle. This is primarily due to structural changes resulting in less actin-myosin interaction, thus, fewer cross-bridges.

There is also emerging evidence which suggest muscle length may influence the neural strategies of a contracting muscle, such as the firing rates of active motor units, frequency spectrum, and overall activation. However, the current body of research seems to be contradicting. Nonetheless, further investigation seems logical due to the relationship between muscle length and force steadiness, which is a consequence of neural aspects of the contraction. Future research in this area may help tip the scale one way or another on this evenly divided topic.

Chapter III

Methodology

Introduction

The purpose of the present study was to examine the effects of muscle length on force steadiness and EMG responses following a fatiguing exercise intervention. Current research suggests that muscle length may alter the muscle's ability to control force and perhaps even the neuromuscular strategies of controlling force. This knowledge could provide beneficial insight to improving exercise testing and/or programming for rehabilitation and performance. Therefore, this study aimed to determine how joint angle (muscle length) influences force steadiness and EMG responses following a fatiguing exercise intervention. The findings could be of potential use for those using exercise as a means to increase performance for sport and/or function during daily living. This study was approved by the University of Oklahoma's Institutional Review Board. This chapter served to outline the following aspects: sample description, instrumentation/measurement protocols, research design, data management and statistical analysis.

Research Design

This study consisted of three visits to the lab. The subjects filled out a health questionnaire and consent form and then were familiarized with the testing procedures. The subjects then returned to the laboratory on two separate occasions to perform the experimental testing. The subjects performed a different joint position, 90 degrees or 60 degrees of elbow flexion, at each of the two visits. Therefore, this study used each subject as their own control for a pre/post repeated measures design.

Sample

Twenty three subjects, 15 males and 8 females, between the ages of 18 and 35 years participated in this study. The sample size was calculated with a priori sample size estimator using G*Power software (version 3.1.9.2). The G*Power software provided a sample size of 24 subjects, and six subjects were added to account for possible attrition. The subjects were free of any neuromuscular and/or musculoskeletal disorders of the dominant arm. The subjects will be volunteers primarily from the University of Oklahoma. Therefore, this study will utilize convenience sampling. All subjects filled out and signed an informed consent and health questionnaire prior to any testing. The sampling for this study is similar to that of Ye et al. (2014) who recruited twenty- five resistance trained males who were asked to perform isometric contractions of the forearm flexors while recording EMG (Ye, 2014).

Instrumentation/Measurement Procedures

Each subject was required to perform three visits consisting of a familiarization visit and two experimental visits. A description of each visit is detailed below. All testing was performed on the subject's dominant arm, which was determined by asking which hand though throw a ball with. There were two joint positions tested, 60 degrees of elbow flexion and 90 degrees of elbow flexion. These positions were chosen to represent a relatively short and long muscle lengths with respect to each other. The 60 degree flexion position is the most lengthened position we could accurately achieve due to limitations of our testing apparatus.

The first visit was the familiarization visit. During this visit, the subjects filled out an informed consent and health questionnaire before any testing occurs. Following the consent process, the subjects were familiarized with the experimental protocol to practice the procedures and become comfortable with the equipment to be used. The subjects performed a series of MVCs, followed by a sub-maximal force matching task. The subjects then performed an abbreviated version of the fatiguing protocol. The familiarization visit was concluded with post exercise MVCs and sub-maximal force matching tasks. An MVC required the subject to produce a maximal amount of force during an isometric contraction. The sub-maximal force matching task required the subject to match a force line at a given percentage of the MVC.

Experimental visit one occurred at least 48 hours following the familiarization visit. The subjects were randomly assigned to perform tasks at either 90-degree elbow flexion or 60-degree elbow flexion position. The tasks were performed at the remaining muscle positions during the third and final visit. Once the joint position was determined, the subjects performed three separate MVCs and a sub-maximal force matching task set at 50% MVC. The subjects then performed the fatiguing intervention, which consisted of sets of 10 second MVCs followed by 10 seconds of rest until their force declined to 60% of their original MVC. This allowed for each subject to be fatigued to a similar level regardless of their endurance level. This visit was concluded by the subjects performing three more separate MVCs and a sub-maximal force matching task set at 50% MVC. Force and EMG data were collected during all MVCs and sub-maximal tasks.

Experimental visit two took place at least 48 hours after the completion of experimental visit one. During this visit, the subjects performed the exact same tasks as the first experimental visit, but at the other joint position. So, if the subject was assigned to 60 degrees of flexion for experimental visit 1, then they performed experimental visit 2 at 90 degrees of flexion, and vice versa. As in experimental visit 1, force and EMG data were recorded during all MVCs and sub-maximal tasks.

The force data were measured using a tension/compression load cell (Model SSM-AJ-500; Interface, Inc.), and stored in a password protected computer.

A preamplified bipolar surface EMG sensor (DE 2.1 Single Differential Surface EMG Sensor; Delsys, Inc., Boston, MA, USA) was placed on the muscle belly of the biceps brachii proximal to the innervation zone (De Luca, 1997 and Ye, 2015). A reference electrode (DermaSport Electrode 2.0 Inch Diameter; American IMEX, Irvine, CA, USA) was placed on the C7 vertebrae. The EMG signal was preamplified with a Bagnoli 16-channel EMG system (Dellsys, Inc.) and filtered with high- and low-pass filters set at 10 and 500 Hz, respectively. To ensure consistent placement of the electrodes, a measurement from the electrode to the medial epicondyle was made and recorded. The EMG sensors were secured over the muscle using surgical tape. Prior to application of the sensors, the skin was prepped by cleansing the area with rubbing alcohol and shaving excess hair as necessary.

The EMG and force signals was processed using a custom-built software program (Labview 8.2; National Instruments). Maximal force was recorded as the highest two second portion of each MVC. Force steadiness was calculated using the coefficient of variation (CV= [SD/mean] x 100%) of the force during the flat portion of the sub-maximal contractions (at 50% of MVC). Also, the RMS and mean frequency (MNF) of the EMG signal were determined and EMG RMS was normalized to the pre-MVC values.

Data Management Procedures

The data were collected by the primary investigator and stored in a locked file cabinet and password-protected computer. The data included subjects' information including age, height, weight, health history, EMG, and force values. Subjects were also assigned a random identifier so that their data is not directly linked to their names. The key containing the subjects' names and code names was stored in a locked drawer.

Statistical Analysis

Statistical analyses of the data were run using SPSS 19.0 with an alpha level of $p \leq 0.05$. Descriptive statistics were calculated for age, height and weight, and are displayed as mean ± SD. Force and EMG data were analyzed for mean differences across the different joint positions, at each time point, pre and post-fatigue and between gender using a 3-way repeated measures ANOVA to determine if there were any significant main effects or interactions (time x condition; time x gender; condition x gender; or time x condition gender) differences. Coefficients of variation were calculated as [SD/mean] x 100%, for force produced during the flat portion of the submaximal trapezoid contractions (50% MVC). Pre and post submaximal trapezoid trials were calculated for reliability between the two contractions at both pre and post-fatigue using a paired samples t-test.

Chapter IV

Results & Discussion

Subject Characteristics

Table 1 represents the subject characteristics for men, women and all subjects together, and is displayed as means ± SD. There were 15 males and 8 females in this study. The descriptive statistics show that men had a greater average age, though not statistically significant (p=0.615). Men were significantly taller than the women (p=0.004). Men were significantly heavier than women (p=0.035).

Table 1. Subject Characteristics (Mean ± SD)

	N	Age (years)	Height (cm)	Weight (kg)
Men	15	22.00 ± 3.36	179.15 ± 10.60^{a}	82.02 ± 12.7^{c}
Women	8	21.38 ± 0.74	164.47 ± 9.48^{b}	67.93 ± 16.99^{d}
All Subjects	23	21.78 ± 2.73	174.05 ± 12.29	77.12 ± 15.55

$^{a,\,b}$ *Indicates a significant difference in weight ($p \leq 0.01$).*

$^{c,\,d}$ *Indicates a significant difference in height ($p \leq 0.05$).*

Maximal Strength

Table 2 represents the collapsed MVC values for men and women at both joint positions from pre to post-fatigue. Values are displayed as mean ± SD and force is expressed in newtons.

Table 2. Collapsed MVC Values in Newtons (Mean ± SD)

	90 degree flexion[a]		60 degree flexion[b]	
	Pre[c]	Post[d]	Pre[c]	Post[d]
Men[e]	433.53 ± 102.31	394.35 ± 108.25	426.83 ± 91.35	361.51 ± 97.20
Women[f]	238.30 ± 51.73	203.22 ± 65.65	202.56 ± 78.48	171.45 ± 72.94
All Subjects	365.63 ± 128.65	327.87 ± 132.25	348.82 ± 138.56	295.40 ± 127.56

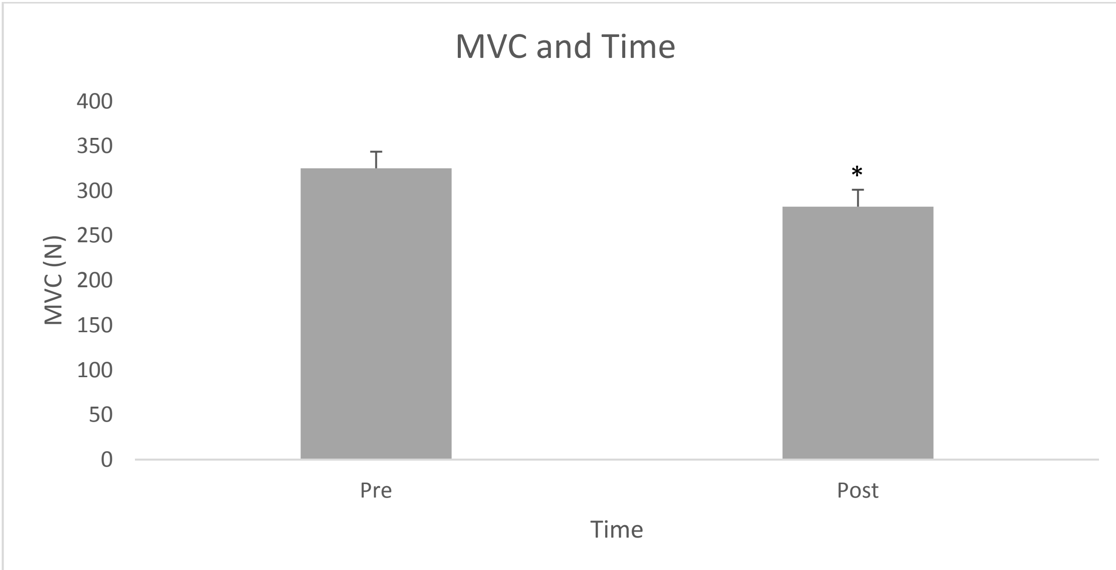
[a, b] *Indicates a significant difference between conditions ($p \leq 0.05$).*

[c, d] *Indicates a significant difference between time points ($p \leq 0.01$).*

[e, f] *Indicates a significant difference between genders ($p \leq 0.01$).*

A three-way repeated measure ANOVA (condition x time x gender) was run for MVC strength values. The results of the ANOVA indicated there were main effects for time (p=0.000), condition (p=0.012), and gender (p=0.000). However there were no significant interactions for condition x gender (p=0.481), time x gender (p=0.366), and condition x time x gender (p=0.257).

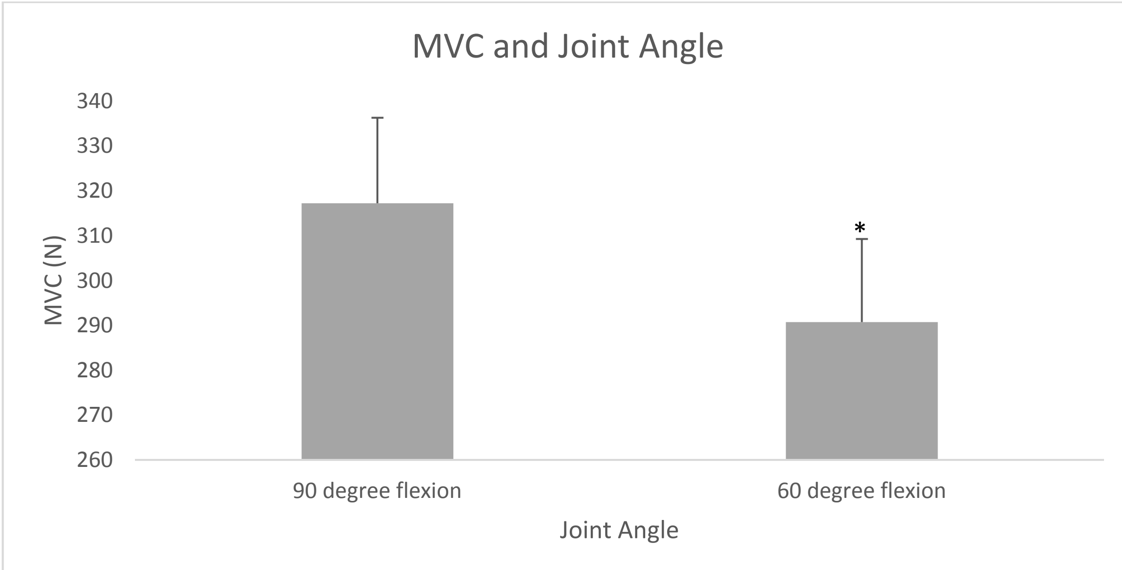
Figure 1: A Comparison of MVC Strength from Pre to Post-fatigue.



* *Indicates significant decrease from pre to post-fatigue ($p \leq 0.01$).*

Figure 1 Illustrates the time effect seen in this study. The results indicated that MVC strength, when collapsed across condition and gender, was significantly decreased from pre to post-fatigue. The pre fatigue and post-fatigue MVC values were 325.15 ± 18.53 N and 282.26 ± 19.06 N, respectively.

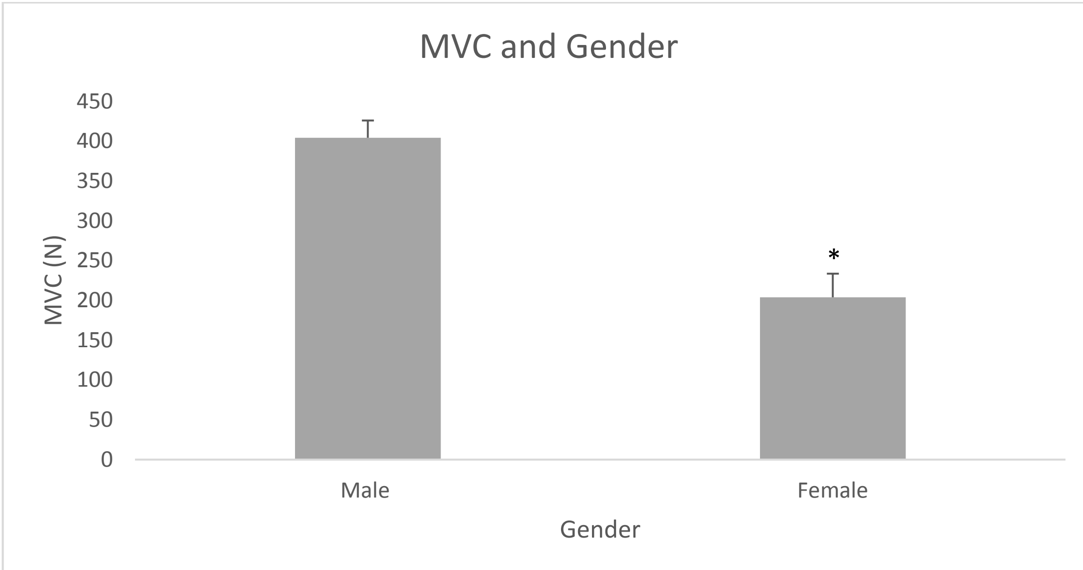
Figure 2: A Comparison of MVC Strength Between 90 Degree Flexion and 60 Degree Flexion.



** Indicates 60 degrees flexion is significantly lower than 90 degrees flexion ($p \leq 0.05$).*

Figure 2 illustrates the muscle length effect seen in this study. The results indicated the MVC values, when collapsed across time and gender, were significantly lower at the long muscle length. The short and long muscle length MVC values were 317.21 ± 19.06 N and 290.73 ± 18.53 N, respectively.

Figure 3: A Comparison of MVC Strength Between Genders.



* *Indicates female MVC is significantly lower than male MVC ($p \leq 0.01$).*

Figure 3 illustrates the gender effect seen in this study. The results indicated the MVC values, when collapsed across time and condition, were significantly lower for females. The male and female MVC values were 404.05 ± 21.71 N and 203.88 ± 29.66 N, respectively.

Force Steadiness

Table 3 represents collapsed coefficient of variation values for force for men and women at both joint positions, pre and post-fatigue, during the flat portion of the submaximal contractions.

Table 3. Collapsed Force Coefficient of Variation (%) from Trapezoid Contractions (Mean ± SD).

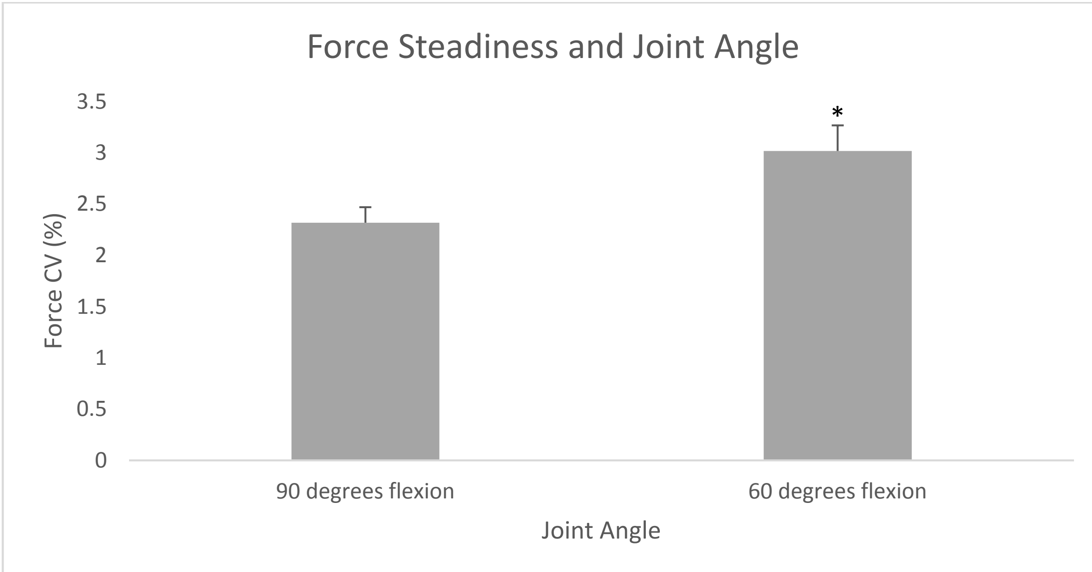
	90 degree flexion[a]		60 degree flexion[b]	
	Pre[c]	Post[d]	Pre[c]	Post[d]
Men	2.13 ± 0.61	2.57 ± 0.83	2.70 ± 1.10	3.23 ± 1.38
Women	1.98 ± 0.39	2.59 ± 1.63	2.88 ± 0.75	3.25 ± 1.61
All Subjects	2.08 ± 0.54	2.58 ± 1.13	2.76 ± 0.98	3.24 ± 1.43

[a, b] *Indicates a significant difference between condition ($p \leq 0.01$).*

[c, d] *Indicates a significant difference between pre and post ($p \leq 0.05$).*

Force steadiness was calculated using a coefficient of variation for force during the flat portion of the sub maximal contractions. The values were then analyzed using a three-way (condition x time x gender) ANOVA. The results of the ANOVA indicate there were main effects for condition (p=0.002) and time (p=0.028). However, there were no significant condition x gender interaction (p=0.678), time x gender interaction (p=0.986), condition x time interaction (p=0.7940), condition x time x gender interaction (p=0.526), or main effect for gender (p=0.966). An increase in force steadiness means that the degree of force fluctuations were decreased, in other words, the muscle produced a smoother force.

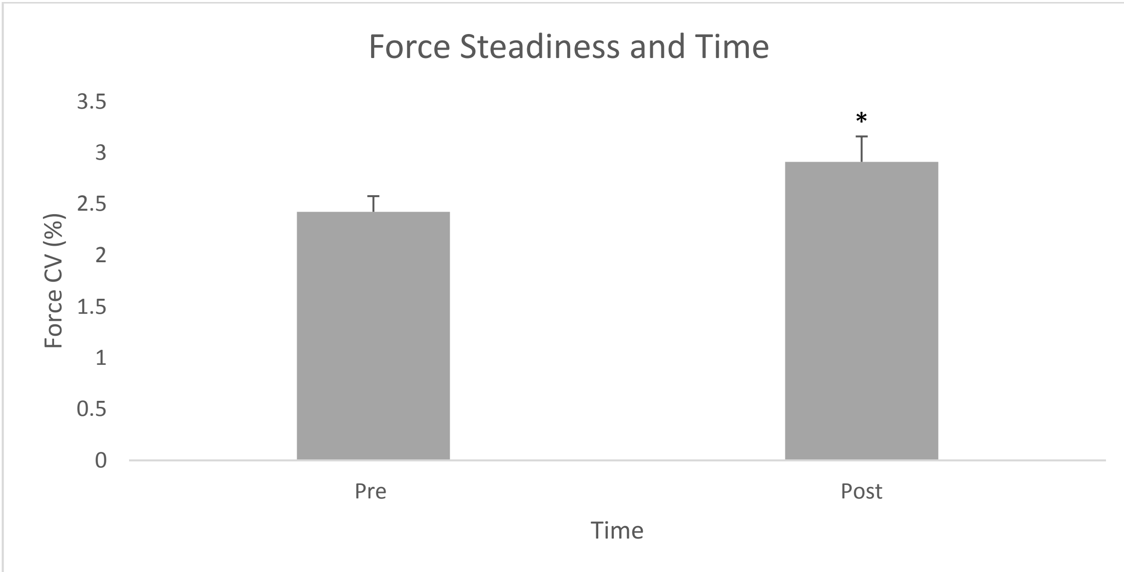
Figure 4: A Comparison of Force Steadiness and Joint Angle.



* *Indicates force steadiness was significantly less for the contractions at 60 degrees flexion than contractions at 90 degrees flexion (p ≤ 0.01).*

Figure 4 illustrates the condition effect seen in this study. The results indicated the force steadiness values, when collapsed across time and gender, were significantly lower for short muscle length than long muscle length. The short and long muscle length force steadiness values were 2.318 ± 0.150 % and 3.017 ± 0.249 %, respectively.

Figure 5: A Comparison of Force Steadiness and Time.



* *Indicates force steadiness was significantly decreased from pre to post-fatigue ($p \leq 0.05$).*

Figure 5 illustrates the time effect seen in this study. The results indicated the force steadiness values, when collapsed across condition and gender, were significantly higher following fatigue. The pre and post-fatigue force steadiness values were 2.423 ± 0.153 % and 2.911 ± 0.248 %, respectively.

Normalized EMG Amplitude

Table 4 represents collapsed EMG RMS normalized to the pre MVC RMS value for men and women at both joint positions, pre and post-fatigue, from the trapezoid contractions. The values are presented as a percentage of the pre MVC values.

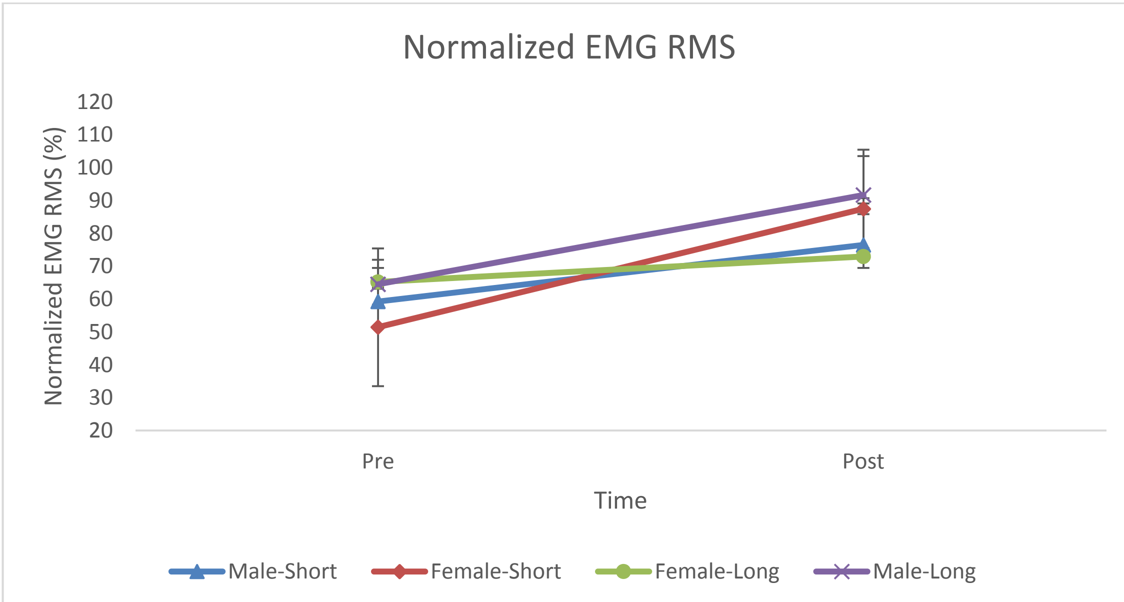
Table 4. Collapsed Normalized EMG RMS (%) from Trapezoid Contractions (Mean ± SD).

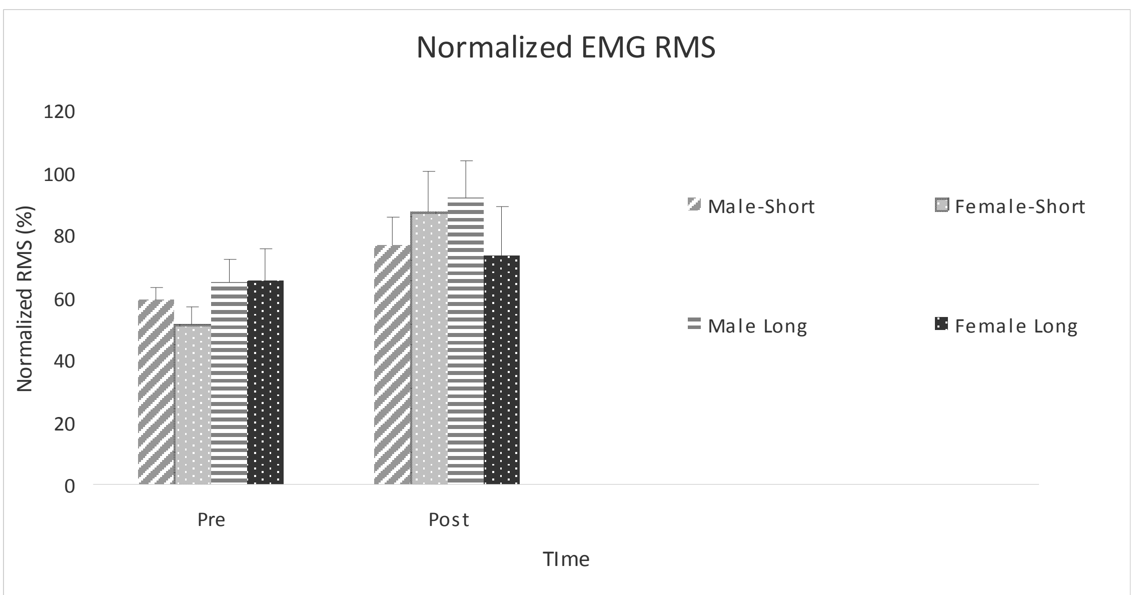
	90 degree flexion		60 degree flexion	
	Pre[a]	Post[b]	Pre[a]	Post[b]
Men	59.29 ± 14.93	76.49 ± 32.78	64.56 ± 30.61	91.71 ± 53.39
Women	51.52 ± 15.04	87.49 ± 42.30	65.24 ± 24.82	72.97 ± 23.60
All Subjects	56.58 ± 15.11	80.32 ± 35.80	64.80 ± 28.15	85.19 ± 45.55

[a,b] *Indicates a significant differences between pre and post ($p \leq 0.01$).*

EMG amplitude was calculated as RMS during the flat portion of the sub maximal contraction and was normalized to the pre MVC RMS value. The values were then analyzed using a three-way repeated measure ANOVA. The results of the ANOVA indicate there was a three-way (time x condition x gender) interaction (p=0.01) and a main effect for time (p=0.002).

Figures 6 & 7: A Comparison of Normalized EMG RMS for Time, Condition, and Gender.





Figures 6 and 7 illustrate the significant three-way (time x condition x gender) interaction for normalized EMG RMS (p=0.01). There were no significant main effects for condition (p=0.474) or gender (p=.738). There was also no significant time x gender interaction (p=0.979), condition x gender interaction (p=0.439) or condition x time interaction (p=0.189). The results indicated that for the short muscle length the males had a greater starting normalized RMS value than females, 59.288 ± 3.864% and 51.517 ± 5.291%, respectively. However, the females' normalized RMS value increased more from pre to post at the short muscle length than the men. The short muscle length, post-fatigue values were 76.488 ± 9.355% for men and 87.492 ± 12.810% for women, a 29.0% increase and 69.8% increase, respectively. For the long muscle length the males and females began with similar normalized RMS values, 64.560 ± 7.439% and 65.243 ± 10.187%, respectively. However, the males showed a greater percent increase than women from pre to post-fatigue, 42.0% and 10.6%, respectively. The long muscle length, post-fatigue values for men and women were, 91.706 ± 11.793% and 72.973 ± 16.148%, respectively. The short muscle length appears to lead to a greater increase than the long muscle length from pre to post-fatigue with percent change of 47.1% and 34.5%, respectively.

EMG Mean Frequency

Table 5 represents the collapsed EMG mean frequency values for men and women at both joint positions, pre and post-fatigue. The values are expressed in hertz (Hz).

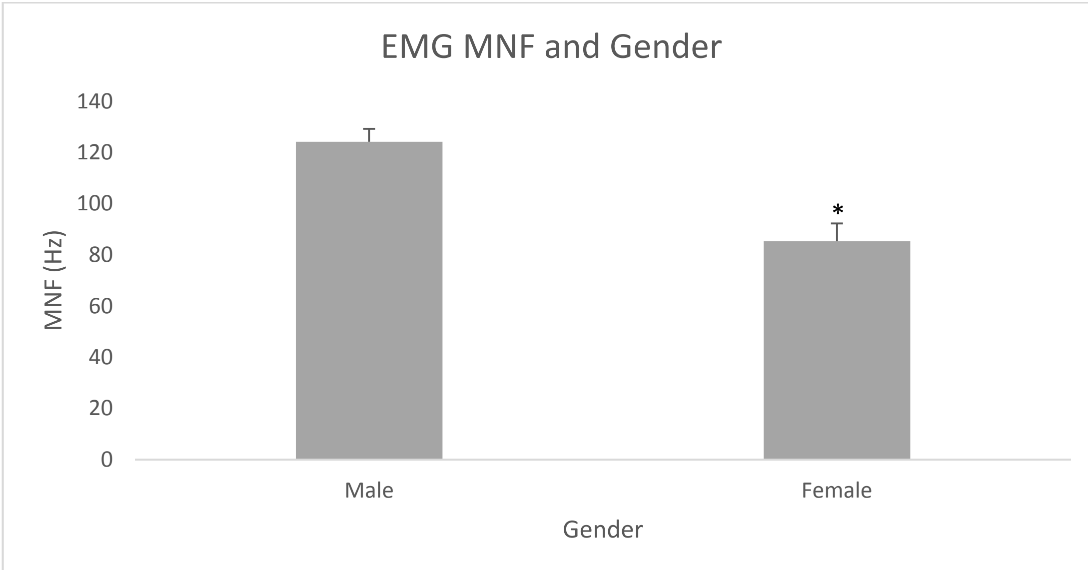
Table 5. Collapsed EMG MNF (Hz) from Trapezoid Contractions (Mean ± SD).

	90 degree flexion		60 degree flexion	
	Pre	Post	Pre	Post
Men[a]	128.25 ± 22.17	127.38 ± 31.33	120.94 ± 22.31	120.06 ± 22.28
Women[b]	86.72 ± 19.11	86.32 ± 18.73	84.08 ± 15.22	84.20 ± 18.51
All Subjects	113.80 ± 28.95	113.10 ± 33.71	108.12 ± 26.70	107.59 ± 27.02

[a, b] Indicates a significant difference between genders ($p \leq 0.01$).

EMG mean frequency was quantified during the flat portions of the sub maximal contractions and analyzed using a three-way repeated measure ANOVA. The results of the ANOVA indicated there was a significant main effect for gender (p=0.000). However, there were no significant interactions for condition x gender (p=0.481), time x gender (p=0.894), or condition x time x gender (p=0.961). There were also no significant main effects for condition (p=0.172) or time (p=0.854).

Figure 8: A Comparison of EMG MNF for Gender.



* *Indicates EMG MNF was significantly lower for females than males ($p \leq 0.01$).*

Figure 8 illustrates the gender effect for MNF seen in this study. The results indicated that the EMG MNF values, when collapsed across time and condition, were significantly greater for males than females. The MNF values for men and women were 124.146 ± 5.041 Hz and 85.329 ± 6.902 Hz, respectively.

Reliability

The results from the paired samples t-test indicate there were no significant differences between the two submaximal contractions at pre (p=0.268) and at post (p=0.631) fatigue. The results also showed that the pair of pre fatigue and post-fatigue contractions were significantly correlated (p=0.00 for both), with correlation coefficients of r = 0.643 and r = 0.549, respectively.

Discussion

Maximal Strength

The findings of this study for maximal isometric strength were in line with what we would expect to see. As we would suspect, MVC strength was decreased from pre to post-fatigue. This result agrees with several studies which incorporate a fatiguing protocol with isometric contractions. Such as Ye et al. (2015), who found a significant decrease in MVC strength following a fatiguing protocol (Ye, 2015).

Furthermore, maximal strength was significantly lower when the biceps muscle was in a lengthened position compared to the short position. This finding could be explained by changes in the actin-myosin overlap from changing the muscle position. It is well known that the amount of force that a muscle will produce is altered by the number of cross-bridges formed by overlapping actin and myosin and a muscle will produce its maximum force at a point of optimal filament overlap (Rassier, 1999). As a muscle is lengthened a muscle beyond its optimal position, the number of overlapping actin and myosin filaments is reduced. This reduces the number of cross-bridges that are able to form, thus decreasing the amount of tension that can be produced.

Finally, the results of this study indicate that males had a significantly higher level of isometric strength than their female counterparts. This finding is also not surprising. The discrepancies in strength are could possibly be due to the differing amounts of muscle mass between men and women. We would expect the levels of strength to be more similar if we analyzed the maximal strength relative to muscle mass. Looking at the descriptive statistics, we see that the mean weight for males was nearly 15 kilograms greater than that of the females. The gender difference in muscle strength may also be due to differences in fiber type dominance between men and women. It is thought that men may typically have a higher percentage of type II fibers than females. If this were the case we would expect men to be stronger even if we set the values relative to muscle mass. This is similar to what was seen by Miller et al. (1992), who found men to be significantly stronger than women in absolute terms and relative to muscle mass (Miller, 1992).

Force Steadiness

The present study also found a decrease in force steadiness from pre to post-fatigue. This finding is in line with the results from Ye et al. (2015), who also saw reduced force steadiness following a fatiguing protocol. Also, similarly to this study, the decrease in force steadiness was accompanied by an increase in EMG amplitude. An increase in EMG amplitude is indicative of increased motor unit recruitment which is known to cause a decrease in force steadiness (Ye, 2015).

With respect to muscle length, the present study found that force output was less steady for the long muscle position than the short muscle position. This finding is similar to those of Krishnan et al. (2010), who also saw smoother force production at a shorter muscle length (Krishnan, 2010). There are a couple possibilities for this, a greater EMG amplitude and/or the change in muscle architecture associated with lengthening the muscle.

We know that when changing the length of the muscle we change the architecture of the muscle. This is one potential source of the decreased force steadiness. Perhaps the fewer number of cross-bridges in the lengthened state causes the muscle to be less stable, or perhaps having the limb further from the body creates a less stable position. These mechanisms are only speculative and further testing would be required to determine their role.

A second source of the decreased force steadiness at the lengthened muscle length is a difference in EMG amplitude between the two positions. Krishnan et al. (2010), saw significantly greater EMG amplitude for the lengthened muscle than the shortened muscle (Krishnan, 2010). However, when we collapse across group and time, we do not see a statistically significant difference between EMG amplitude for either long or short muscle position, visual inspection of the graphs appears to show a greater amplitude for long muscle length compared to short muscle length for contractions from the same gender and time point. One exception is an apparently lower EMG amplitude for the long muscle length than the short muscle length from the post-fatigue contractions for females, which could explain why there was no significant condition effect. Overall, the general trend appears to show a greater amplitude at a long muscle length, though it was not statistically significant. Further investigation could find a significant difference between the two with the appropriate study design and sample size.

Normalized EMG Amplitude

The present study found EMG amplitude increased from pre to post-fatigue; this is in line with previous findings from Ye et al. (2014) and Missenard et al. (2009) who both saw increased EMG amplitude following a fatiguing protocol (Ye, 2014, Missenard, 2009). This finding is expected and can be explained by the fatigued muscles need for increased motor unit recruitment to produce the target force.

Although not statistically significant in the present study, there does appear to be a trend of greater EMG amplitude at long muscle lengths compared to short muscle lengths. As mentioned this trend is supported by Krishnan et al. (2010), who saw increased EMG amplitude at a long muscle length compared to a short muscle length. If muscle length does alter EMG amplitude, it may explain why we see a difference in force steadiness between the two muscle lengths. Since increases in EMG amplitude are associated with decreased force steadiness, an increase in amplitude at a long muscle length would explain the decreased force steadiness we saw in the present study.

EMG Mean Frequency

The present study found no significant differences between EMG mean frequency when analyzed across time or condition. In fact, we saw nearly identical values across muscle lengths and across time. These results differ from several previous studies, such as Ye et al. (2014), Mannion and Dolan (1996), and Krishnan et al. (2010)., an increase in frequency following fatigue, while Mannion and Dolan and Krishnan et al. both found a decrease in frequency at a long muscle length (Ye, 2014, Mannion and Dolan, 1996, and Krishnan, 2010).

It is unclear the cause of the discrepancy between the present study and previous research, but it could potentially be due to differences in the fatiguing protocol, the muscle being tested, length of rest periods, or the sub maximal contraction intensity.

When mean frequency was analyzed across genders, the results showed a significantly higher mean frequency for males compared to females. This suggests that the males have greater conduction velocity than their female counterparts. This could potentially be due to greater percentage of type II fibers in men, as suggested by Miller et al. (Miller, 1992).

Chapter V

Conclusion

The purpose of this study was to examine the effect of muscle length on force steadiness and EMG responses following a fatiguing protocol. This study examined two joint positions, 90 degrees of elbow flexion and 60 degrees of elbow flexion.

Hypotheses

H_{a1}: There will be greater force steadiness for contractions at 90 degrees of elbow flexion than contractions at 60 degrees of elbow flexion following a fatiguing intervention.

There was sufficient evidence at an alpha level of $p=0.05$ to accept the alternative hypothesis that there would be greater force steadiness for contractions at 90 degrees of elbow flexion than contractions at 60 degrees of elbow flexion following a fatiguing intervention.

H_{a2}: There will be greater EMG responses for contractions at 60 degrees of elbow flexion than contractions at 90 degrees of elbow flexion following a fatiguing intervention.

There was not sufficient evidence at an alpha level of $p=0.05$ to accept the alternative hypothesis that there would be greater EMG responses for contractions at 60 degrees of elbow flexion than contractions at 90 degrees of elbow flexion following a fatiguing intervention.

In conclusion, the findings of the present study indicate that the length of a muscle may have an impact on a muscles ability to produce force and is not gender specific. The source of this difference could arise from structural changes of the muscle as it is stretched to a lengthened position, or from changes in EMG amplitude at a lengthened muscle position. However, these mechanisms are only speculative as we did not take appropriate measures for structural changes, nor did we see a significant difference in EMG amplitude between the two joint positions tested.

Limitations

There were a few limitations of the present study that could be addressed in future research. First, the alignment of joint angle was set using a handheld goniometer and once set there was no mechanism in place to ensure absolutely no movement during contractions. Therefore, the joint angles could have varied slightly during contractions, and future studies may elect to use a mechanism to hold the joint in exactly the same position throughout the contraction. Secondly, the compression/load cell used to collect was not calibrated between each visit/subject. Therefore, the load cell could have become slightly off over the course of the study. Finally, there were no measures anthropometric measures of the muscle/arm being tested. Therefore, differences in muscle size could not be compared to differences in muscle strength or EMG activity.

Future Direction

Future studies could aim to investigate structural/mechanical mechanisms for force steadiness or seek to analyze differences in EMG amplitude for different muscle lengths. Perhaps with a larger sample size, testing different muscles or more muscle lengths could provide more insight to the relationship between muscle length and neural motor control.

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Appendices

Appendix A: Institutional Review Board Letter of Approval

The UNIVERSITY of OKLAHOMA

Institutional Review Board for the Protection of Human Subjects

Approval of Continuing Review – Expedited Review – AP0

Date:	August 10, 2016	**IRB#:**	6070
Principal Investigator:	Hayden Meyer Tharp	**Approval Date:**	08/10/2016
		Expiration Date:	07/31/2017

Expedited Category: 4

Study Title: The effects of muscle length on force steadiness in the forearm flexors following isometric fatigue

Based on the information submitted, your study is currently: Active, closed to enrollment. On behalf the Institutional Review Board (IRB), I have reviewed and approved your continuing review application. 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.

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.

You will receive notification approximately 60 days prior to the expiration date noted above. You are responsible for submitting continuing review documents in a timely fashion in order to maintain continued IRB approval.

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

Cordially,

Fred Beard, Ph.D.
Vice Chair, Institutional Review Board

Appendix B: Informed Consent

701-A-1

Signed Consent to Participate in Research

Would you like to be involved in research at the University of Oklahoma?
I am Hayden Tharp from the Department of Health and Exercise Science and I invite you to participate in my research project entitled The effects of muscle length on force steadiness following isometric fatigue. This research is being conducted at Biophysics Laboratory on the OU Norman Campus. You were selected as a possible participant because you showed interest in the study and meet all the inclusion criteria. You must be at least 18 years of age 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 examine what effects muscle length has on the ability to generate a constant force in forearm flexor muscles following fatiguing isometric exercise at short and long muscle lengths. Muscle length is determined by the angle of the elbow and categorized as either long or short muscle length. The long muscle length will be at an elbow angle of 120 degree elbow flexion and the short length being at 90 degree elbow flexion. Isometric contractions are contractions that occur with no change in joint angle/muscle length, which is done by contracting against an immovable object. The fatiguing protocol for this study will include sets of 10 second maximal contractions followed by 10 seconds of rest completed until the force values decline 50% of the original strength.

How many participants will be in this research? About 40 people will take part in this research.

What will I be asked to do? If you agree to be in this research, you will be asked to come to the Biophysics Laboratory for 3 visits. The 1st visit will be a familiarization session so that you will practice some of the experimental procedures. The next two visits (Visits 2 and 3) will be conducted in a randomized fashion as follows: fatiguing dominant elbow flexor-Testing dominant elbow flexor at a long muscle length (120 degree flexion) Visit (Long Muscle Visit); Fatiguing dominant elbow flexor- Testing dominant elbow flexor at a short muscle length (90 degree flexion) Visit (Short Muscle Visit)
At the beginning of each experimental visit, you will be asked to perform maximal voluntary contraction of your dominant limb. This type of muscle contraction is also known as static contraction, which refers to the muscle contraction in which the joint angle and muscle length do not change during contraction. Therefore, you will be contracting your muscle as hard as you can against an immoveable object. You will then perform a submaximal isometric contraction at 50% of your maximal strength. After this submaximal contraction, you will perform a fatiguing exercise intervention, during which you will do sets of 10-second maximal contraction with 10-second rest period between consecutive muscle contractions until you are no longer able to sustain 60% of your maximal strength during the maximal contraction. Immediately after the exercise intervention, you will be asked to perform exactly the same testing as you did before the exercise. At least 72 hours after this experimental visit, you will be asked to return to the

lab to finish another experimental visit. The general experimental procedure will be similar across all the experimental visits, the only differences are the muscle lengths being tested. In addition, during all strength testing, special sensors will be used to record the muscle activity on the surface of your arm. The sensors will be placed on the muscle belly of the bicep muscle. The exact location will be determined with a tape measure and visual inspection. Once the location has been determined the the area will be shaved and cleaned with an alcohol pad to remove any hair, dead skin, and/or dirt that may interfere with the signal

How long will this take? Your participation will take about 3 hours in total. You will be required to make 3 visits to the lab. Each visit will take approximately 1 hour to complete.

What are the risks and/or benefits if I participate? The risks of being involved in the study are minimal. There is a risk of muscle strain or muscle tear from strength testing. In addition, muscle soreness is also expected. However, warm-up activities will be performed to minimize these risks.

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 not be reimbursed for your time and participation in this research.

Who will see my information? There are organizations that may inspect and/or copy your research records for quality assurance and data analysis. This includes the OU Institutional Review Board. 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 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 Primary Investigator: Hayden Tharp. Email: htharp@ou.edu. Telephone number: (405)-618-1661. Faculty Sponsor: Dr. Travis Beck. Email: tbeck@ou.edu. Telephone number: (405)-325-1378.
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
Signature of Witness (if applicable)
Print Name
Date

Appendix C: Health Questionnaire

PRE-EXERCISE TESTING HEALTH & EXERCISE STATUS QUESTIONNAIRE

The University of Oklahoma
DEPARTMENT OF HEALTH AND EXERCISE SCIENCE

Name ______________________________ Date__________

Home Address ____

Phone ______________

Person to contact in case of emergency ______________________

Emergency Contact Phone ______________ Birthday (mm/dd/yy)____/____/_____

Gender________ Age _____(yrs) Height _____(ft)_____(in) Weight_____(lbs)

Does the above weight indicate: a gain____ a loss____ no change____ in the past year?
If a change, how many pounds?__________(lbs)

A. JOINT-MUSCLE STATUS (✓Check areas where you currently have problems)

Joint Areas	Muscle Areas
( ) Wrists	( ) Arms
( ) Elbows	( ) Shoulders
( ) Shoulders	( ) Chest
( ) Upper Spine & Neck	( ) Upper Back & Neck
( ) Lower Spine	( ) Abdominal Regions
( ) Hips	( ) Lower Back
( ) Knees	( ) Buttocks
( ) Ankles	( ) Thighs
( ) Feet	( ) Lower Leg
( ) Other_______________	( ) Feet
	( ) Other_______________

B. HEALTH STATUS (✓Check if you currently have any of the following conditions)

( ) High Blood Pressure	( ) Acute Infection
( ) Heart Disease or Dysfunction	( ) Diabetes or Blood Sugar Level Abnormality
( ) Peripheral Circulatory Disorder	( ) Anemia
( ) Lung Disease or Dysfunction	( ) Hernias
( ) Arthritis or Gout	( ) Thyroid Dysfunction
( ) Edema	( ) Pancreas Dysfunction
( ) Epilepsy	( ) Liver Dysfunction
( ) Multiply Sclerosis	( ) Kidney Dysfunction
( ) High Blood Cholesterol or Triglyceride Levels	( ) Phenylketonuria (PKU)
( ) Allergic reactions to rubbing alcohol	( ) Loss of Consciousness

* *NOTE: If any of these conditions are checked, then a physician's health clearance will be required.*

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C. PHYSICAL EXAMINATION HISTORY

Approximate date of your last physical examination____________________________

Physical problems noted at that time______________________________________

Has a physician ever made any recommendations relative to limiting your level of physical exertion? _________YES __________NO

If YES, what limitations were recommended?_________________________________

____

D. CURRENT MEDICATION USAGE (List the drug name and the condition being managed)

MEDICATION	CONDITION
____________________	____________________________
____________________	____________________________
____________________	____________________________

E. PHYSICAL PERCEPTIONS (Indicate any unusual sensations or perceptions. ✓Check if you have recently experienced any of the following during or soon after *physical activity* (PA); or during *sedentary periods* (SED))

PA	SED		PA	SED	
( )	( )	Chest Pain	( )	( )	Nausea
( )	( )	Heart Palpitations	( )	( )	Light Headedness
( )	( )	Unusually Rapid Breathing	( )	( )	Loss of Consciousness
( )	( )	Overheating	( )	( )	Loss of Balance
( )	( )	Muscle Cramping	( )	( )	Loss of Coordination
( )	( )	Muscle Pain	( )	( )	Extreme Weakness
( )	( )	Joint Pain	( )	( )	Numbness
( )	( )	Other____________________	( )	( )	Mental Confusion

F. EXERCISE STATUS

Do you regularly engage in aerobic forms of exercise (i.e., jogging, cycling, walking, etc.)? YES NO

How long have you engaged in this form of exercise? ______ years ______ months

How many hours per week do you spend for this type of exercise? _______ hours

Do you regularly lift weights? YES NO

How long have you engaged in this form of exercise? ______ years ______ months

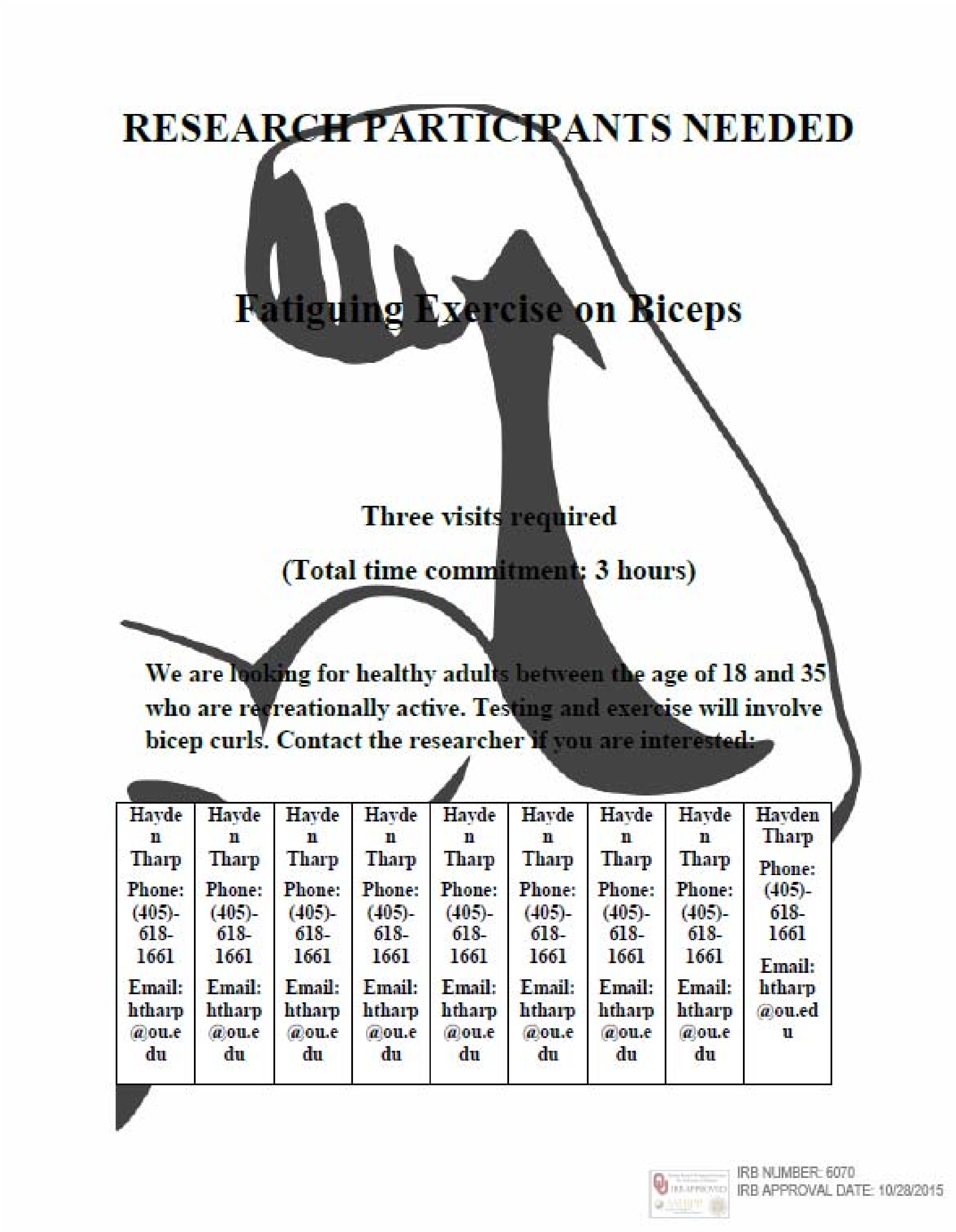
How many hours per week do you spend for this type of exercise? _______ hours

Do you regularly play recreational sports (i.e., basketball, racquetball, volleyball, etc.)? YES NO

How long have you engaged in this form of exercise? ______ years ______ months

How many hours per week do you spend for this type of exercise? _______ hours

Appendix D: Recruitment Flyer



RESEARCH PARTICIPANTS NEEDED

Fatiguing Exercise on Biceps

Three visits required

(Total time commitment: 3 hours)

We are looking for healthy adults between the age of 18 and 35 who are recreationally active. Testing and exercise will involve bicep curls. Contact the researcher if you are interested:

Hayde n Tharp Phone: (405)- 618- 1661 Email: htharp @ou.e du	Hayde n Tharp Phone: (405)- 618- 1661 Email: htharp @ou.e du	Hayde n Tharp Phone: (405)- 618- 1661 Email: htharp @ou.e du	Hayde n Tharp Phone: (405)- 618- 1661 Email: htharp @ou.e du	Hayde n Tharp Phone: (405)- 618- 1661 Email: htharp @ou.e du	Hayde n Tharp Phone: (405)- 618- 1661 Email: htharp @ou.e du	Hayde n Tharp Phone: (405)- 618- 1661 Email: htharp @ou.e du	Hayde n Tharp Phone: (405)- 618- 1661 Email: htharp @ou.e du	Hayden Tharp Phone: (405)- 618- 1661 Email: htharp @ou.ed u

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