1-1-2016

The Acute and Chronic Muscle Adaptations Following six weeks of "No Load" and Traditional High Load Resistance Training

Brittany Counts
University of Mississippi

THE ACUTE AND CHRONIC MUSCLE ADAPTATIONS FOLLOWING SIX WEEKS OF "NO LOAD" AND TRADITIONAL HIGH LOAD RESISTANCE TRAINING

A Thesis
presented in partial fulfillment of requirements
for the degree of Master of Science
in the Department of Health, Exercise Science, and Recreation Management
The University of Mississippi

by

BRITTANY R. COUNTS

2016

ABSTRACT

Muscle growth is postulated to occur through mechanisms initiated by local muscle tension. This appears to be true, independent of the external load, provided sufficient tension is achieved. **PURPOSE:** The purpose of this study was to remove the influence of an external load and compare the acute and chronic muscle adaptations of “No Load” training to traditional High Load training. **METHODS:** Thirteen participants completed six weeks of thrice weekly unilateral elbow flexion exercise. Using a within subject design, each arm was designated to either the No Load or the High Load (70% one repetition maximum) condition. The No Load condition had the participants repeatedly contract through the full range of motion without the use of body weight or an external load. Muscle size, strength and endurance were measured pre and post training. Acute muscle responses of muscle swelling, fatigue and activation were measured within the training study. **RESULTS:** Anterior muscle thickness increased pre to post training with no differences between conditions 50% [pre: 2.7 (0.8) vs. post: 2.9 (0.7) cm], 60% [pre: 2.9 (0.7) vs. post: 3.1 (0.7) cm] or 70% [pre: 3.2 (0.7) vs. post: 3.5 (0.7) cm] sites. There was a significant condition x time interaction for one repetition maximum ($p=0.017$), with High Load (+2.3 kg) increasing more than the No Load condition (+1 kg). For the acute responses, there was a main effect of time for muscle fatigue [pre 40.8 (13.2) vs. post 36 (9.1) Nm $p=0.037$] and muscle swelling [pre 3.5 (0.6) vs. post 3.8 (0.6) cm, $p<0.001$]. For the biceps brachii EMG amplitude, the High load condition was greater than the No Load condition for the last three repetitions ($p=0.019$). Regarding the triceps brachii EMG amplitude, the No Load condition was significantly greater than the High Load condition for the first three and the last three repetitions ($p \leq 0.001$). **Conclusion**: Based on these results, muscle growth can occur independent of the external load provided that sufficient local tension is applied to the muscle.

ACKNOWLEDGMENTS

This study would not have been possible without the help of numerous individuals that were essential for this studies completion.

Dr. Jeremy Loenneke, thank you for being the first person to show me how to be a scientist. I appreciate all the time and energy you have given me as my mentor, and the countless hours I rambled on and yet you still listened and provided honest feedback. These past two years have been a roller coaster of lab experiences; despite my facial expressions I have loved every second. I cannot thank you enough for the opportunities you have given me and will forever appreciate your guidance, encouragement and honesty that have helped shape the researcher I have become.

Scott Dankel, thank you baby boss for your daily reminders of how physiology can be somewhat applied to any and every scenario. You encompass the ability to render inappropriate comments on a whim while at the same time compose a masterpiece. We have matured as researchers a great deal and it has been a privilege working with you.

Samuel Buckner, thank you for making me hate the concept of time. Somehow you manage to look happier and happier everyday which is a trait I am highly jealous of (RBF can only go so far). I cannot thank you enough for helping out with No Load anytime possible, especially with work conflicts.

Matthew Jessee, with two e's thank you for making Spring 2015 a semester to remember or lack there of; "the semester we lost our minds". I have greatly enjoyed our time in and outside of the lab and I respect your ability to out study design anyone. I wish you the best of luck.

Kevin Mattocks or as The Chipmunks could say…KKKEEEVVVINN…thank you for your stylish ways and hopefully one day you will inspire the rest of the gang. With your "on point" shoes and sarcastic comebacks, there will never be a dull moment in the lab. I wish you nothing but the best.

Grant Mouser, thank you for your brutal honesty and editing expertise. Your comments are always appreciated, regardless of the initial eye rolling ☺. Thank you for editing countless papers of mine!

Dr. Paul Loprinzi, thank you for all that you have done for me. From the opportunities to work with NHANES data to throwing around ideas or to giving me advice, I appreciate all the time and effort that you have put in to making me a better scientist. I will miss the big news of when you get your hair cut and your funny remarks, but I am sure the labs will keep me in the loop. Thank you for everything.

Dr. Garner, thank you for the time and effort you have given me as well as the insightful feedback regarding my thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

Skeletal muscle mass is important for the completion of all movements as well as metabolism; given that skeletal muscle is the largest disposal site of ingested glucose (Ivy, Lee, Brozinick, & Reed, 1988). However, skeletal muscle atrophy can occur due to disuse and is commonly observed with cancer cachexia (Johns, Stephens, & Fearon, 2013), in bed-ridden patients (Ikezoe, Mori, Nakamura, & Ichihashi, 2012) and during space travel (Vandenburgh, Chromiak, Shansky, Del Tatto, & Lemaire, 1999). Muscle atrophy during extended periods of microgravity are of concern because muscle loss of up to 20% was reported (Fitts et al., 2010) which could hinder completion of space travel missions. Therefore, resistance training approaches to elicit muscle hypertrophy are of great interest.

The American College of Sports Medicine (ACSM) recommends that the greatest potential for muscle hypertrophy occur at loads of 70-85% of the one repetition maximum (1RM) (ACSM 2009). However, when comparing high load (80% 1RM) resistance training with low load (30% 1RM) resistance training to volitional fatigue, a similar increase in muscle size was reported (Mitchell et al., 2012). Additionally, the application of blood flow restriction during low load resistance training (20-30% 1RM) produced muscle size increases similar to that of high load training (Loenneke, Abe, et al., 2012). Thus, the previous recommendation by ACSM is not completely supported because other methods of lower load resistance training had a similar hypertrophic response to that of traditional higher load training.

Skeletal muscle growth occurs when levels of protein synthesis throughout the day exceed protein breakdown (Phillips et al. 2004). Given that mechanical activation of the skeletal muscle (mechanotransduction) is thought to play a primary role in skeletal muscle growth, any contraction producing adequate tension should elicit activation of hypertrophic pathways, resulting in muscle growth (Rennie, Wackerhage, Spangenburg, & Booth, 2004). This muscle growth is thought to occur through repeated activation of the mechanistic target of rapamycin 1 (mTORC1) complex following an acute bout of resistance exercise. While the exact mechanism behind the activation is unknown, when mTORC1 is not activated, muscle growth from mechanical tension does not occur. Additionally, muscle growth is thought to be a local response because training one limb does not cause an increase in size of the contralateral limb unless it is also trained (Wilkinson, Tarnopolsky, Grant, Correia, & Phillips, 2006).

This local response can be initiated through three distinct muscle actions. Previous studies have shown that muscle growth occurs following isotonic (Bemben, Fetters, Bemben, Nabavi, & Koh, 2000), isokinetic (Esposito, Ce, Gobbo, Veicsteinas, & Orizio, 2005) and isometric (Ikai & Fukunaga, 1970) resistance training. If tension is the main driver of training induced muscle growth, maximal contractions of the muscle that result in adequate exercise volume should result in muscle growth. Thus, maximally contracting the muscle through a full range of motion without the use of an external load or lever arm to resist against, hypothetically, should produce robust increases in muscle size. This new method termed No Load training, to our knowledge, has never been investigated in the literature.

Purpose

The purpose of this study was to compare the acute and chronic muscular response of No Load and High Load resistance exercise. We used a within subject design, the participants trained for six weeks and we compared muscle size, strength and endurance between No Load and High Load training. Within the training study, we compared acute changes in muscle cell swelling, torque and muscle activation after an exercise bout of No Load and High Load resistance exercise.

Research Questions

Does No Load training result in similar increases in muscle size, strength and endurance to that of High Load resistance training? Furthermore, is the acute muscle swelling response, muscle fatigue response and muscle activation similar between No Load and High Load resistance exercise?

Hypothesis

In the acute study we hypothesized that there would be a similar response in muscle swelling, changes in torque and muscle activation with both No Load and High Load resistance exercise. During the training study, we hypothesized that there would be a similar hypertrophic response between No Load and High Load resistance training. With 1RM strength we hypothesized that the High Load condition would have a greater increase compared to No Load training due to the principles of specificity. However, we hypothesized that there would be a similar increase in isokinetic and isometric strength given that neither would be accustomed to isokinetic and isometric tests. Additionally, we hypothesized that the No Load condition would have a greater increase in muscular endurance than the High Load condition because the No Load condition would be completing more repetitions during each training session.

Significance of Study

To our knowledge, No Load resistance training had not been previously investigated. We defined No Load training as contracting the muscle through a full range of motion without using an external load or resistance at a fixed cadence. If No Load training elicited a training response similar to that of High Load resistance training than No Load training could be applicable in a variety of settings. Future studies could investigate No Load training to possibly reduce muscle atrophy while bed-ridden, under microgravity and other clinical settings where severe muscle loss is common.

Assumptions

1. All participants maximally voluntary contracted their biceps during tests and training.
2. All participants answered questions honestly.
3. The participants did not consume alcohol 24 hours prior and were adequately hydrated prior to testing visits.

Delimitations

1. Participants were between the ages of 18-35 years.
2. Testing only took place in the elbow flexors and extensors.
3. The results are limited to participants untrained in the upper body.

Limitations

1. We did not measure growth at the fiber level, but instead measured the whole muscle.

2. There is the possibility of cross over of muscle strength; however, this is unlikely because both arms trained.

Operational Definitions

1. No load training - Contracting the muscle, through a full range of motion, without the use of body weight or an external load at a fixed cadence.

2. Load - The amount of weight that was lifted.

3. One Repetition Maximum (1RM) - The amount of weight that can be successfully lifted through a full range of motion.

4. Muscle Thickness - Measurement from the muscle adipose layer to the muscle bone layer.

5. Surface Electromyography (EMG) - Application of electrodes to estimate the amount of muscle activation that is occurring during the muscle contraction

CHAPTER 2: LITERATURE REVIEW

History of Resistance Training

The history of progressive resistance training can be traced back to Milo of Croton. The Olympian carried his bull, from birth through its developmental years, till the bull could no longer be carried (Masterson 1976). Since then, a variety of objects have been used that replicate lifting a load ranging from various sized rocks (Stojiljkovic et al. 2013) to different weighted objects (Todd 1995) to the current day barbell/dumbbell.

Mechanisms of Muscle Growth

The mechanisms behind muscle growth are not completely understood, however, it is known that muscle growth occurs when daily muscle protein synthesis is greater than muscle protein breakdown (Phillips, 2004). Regulation of muscle growth occurs through signaling pathways; one in particular is the activation of the mechanistic target of rapamycin complex 1 (mTORC1), which appears necessary for skeletal muscle growth following resistance type exercise. To illustrate, mTORC1 was initially investigated in rats by administering rapamycin, which inhibits mTORC1 signaling. In a synergistic ablation model, rats given rapamycin produced no further increase in muscle weight or size. This is in sharp contrast to the synergistically ablated condition without rapamycin, which produced robust increases in muscle size (Bodine et al., 2001). Drummond et al. (2009) extended these findings in humans, by noting that blocking of the mTORC1 pathway via rapamycin inhibited muscle protein synthesis following resistance exercise.

In order for substantial muscular growth to occur, satellite cells may be required (Morgan & Partridge, 2003) In an animal model, mice were injected for five days with either tamoxifen, which is used to deplete satellite cells, or a saline solution (McCarthy et al., 2011). After two and six weeks of being synergistically ablated, the muscle hypertrophic response was similar between those with and without satellite cells, however, mice without satellite cells had impaired muscle regenerative capacity. This suggests that while muscle has the capability to grow independent of satellite cells, satellite cell availability is important for muscle regeneration. Interestingly, some data suggests that while short-term muscle growth can occur independent of satellite cells, long-term changes in muscle growth may be blunted (Fry et al., 2014). Similar findings have been suggested in humans, given that the baseline amount of satellite cells may have an influence on an individual's capacity for growth (Petrella, Kim, Mayhew, Cross, & Bamman, 2008). This could be due to an increased capacity to recruit more myonuclei that aid in muscle growth. Therefore, satellite cells appear to be necessary for muscular regeneration and long-term growth, and the initial amount of these cells may determine one's potential for muscle hypertrophy.

There are conflicting perspectives on the relationship between acute exercise induced changes in systemic hormones (i.e. growth hormone, testosterone) and muscle growth in adults. Kraemer et al. (1998) emphasized that the significant short-term elevations in systemic hormones may influence muscle growth. Further investigation of the hypothesized acute systemic hormonal influence compared two exercise protocols that were designed to elicit different hormonal responses within the same person: low hormone [unilateral arm curl to volitional fatigue] and high hormone [contralateral arm of low hormone and leg extension/press/curl] (West et al., 2010). The high hormone exercise bout produced an acute elevation in systemic hormones, however, this did not influence the degree of muscle hypertrophy in the elbow flexors. Further, if the acute increases in systemic hormones had influenced muscle growth then the circulation of these hormones would result in muscle growth of untrained limbs; however, this does not occur (Wilkinson et al., 2006). As expected, leg press and knee extension training increased muscle cross sectional area in the trained limb with no change in the untrained contralateral leg. Therefore, the hypothesized importance of acute elevations of growth hormone and testosterone aiding in muscle hypertrophy appears unlikely due to lack of supporting evidence.

Taken together, the mechanisms of muscle growth allude to the importance of local tension within the muscle. The activation of both mTORC1 and satellite cells in the exercising muscle appears necessary for substantial muscle growth. On the contrary, acute increases of growth hormone and testosterone do not augment muscle hypertrophy and increases in these systemic hormones do not further augment muscle adaptations following resistance exercise. Furthermore, these locally driven mechanisms behind muscle growth are supported by hypertrophy only in the exercising muscle as evidenced by muscle growth that occurred in the resistance trained limb (Wilkinson et al. 2006).

Muscle Activation

The mechanisms behind local muscle growth are not available to test in all research settings; therefore, other non-invasive methods associated with changes in skeletal muscle are commonly used (Warren, Lowe, & Armstrong, 1999). One way often employed is the measurement of muscle fatigue, which appears to be an important feature for muscle growth. This acute fatigue from resistance exercise is represented by decrements in torque following an exercise bout that is reversible by rest (Michaut, Pousson, Millet, Belleville, & Van Hoecke, 2003). This is in contrast to prolonged decrements in torque, which appears to be more indicative of muscle damage (Clarkson & Sayers, 1999). As a muscle becomes fatigued, additional higher threshold fibers are recruited and this can be estimated by changes in surface electromyography (EMG) activity (Rudroff, Staudenmann, & Enoka, 2008). Recruitment of these higher threshold fibers may be important, as these fibers appear to have the greatest potential for hypertrophy; therefore, recruitment of these fibers may be important for overall muscle growth.

Interestingly, the relationship between fatigue and muscle growth from resistance exercise may be similar across a wide range of loading conditions (high versus low) provided the exercise is taken to volitional fatigue. When comparing high load resistance training to low load resistance exercise to fatigue, both elicited a similar hypertrophic response (Mitchell et al. 2012, (Ogasawara, Thiebaud, Loenneke, Loftin, & Abe, 2012) This may be explained by both protocols producing similar fatiguing responses (Loenneke et al., 2015) that resulted in similar increases in muscle activation (Rudroff et al., 2008). Thus, this acute muscle activation appears to be associated to some degree with the muscle hypertrophic response. Taken together, the load required for muscle hypertrophy appears to be of minimal importance as long as there is muscle fatigue resulting in high levels of muscle activation during the resistance exercise bout. It stands to reason that a condition producing more muscle activation would result in greater muscle growth compared to a condition producing less muscle activation.

Muscle Swelling

During exercise, there is a fluid shift to the exercising muscle and a reduction of plasma to the unused tissues (Senay & Pivarnik, 1985).The increases in fluid to the exercising muscle results in an acute increase in muscle size; termed muscle cell swelling. This increase in muscle size from the acute fluid shift from the plasma into the exercised muscle immediately following an acute bout of resistance exercise may influence muscle growth (Ploutz-Snyder, Convertino, & Dudley, 1995). To illustrate, Yasuda et al. (2012) found that after an exercise bout the arm that swelled the most saw a greater increase in muscle size following six weeks of training. It has been suggested that the accumulation of fluid in the muscle following blood flow restriction may activate anabolic/anti-catabolic pathways. This may provide some explanation for muscle growth following exercise (Yasuda, Loenneke, Thiebaud, & Abe, 2012) or a mechanistic understanding of the attenuation of atrophy following its application independent of muscle contraction (Loenneke, Fahs, Rossow, Abe, & Bemben, 2012). Thus, this acute increase in muscle size following an exercise bout appears to be associated with muscle hypertrophy, but further understanding is necessary.

Resistance Training Actions

Isotonic

As previously discussed, muscle growth appears to be locally driven from local muscle tension. This can be elicited through an isotonic muscle action, which is lifting a constant load while the muscle length changes. The load can be lifted through the full range of motion or studied separately by the concentric or eccentric portion of the lift. A number of isotonic resistance training programs have been shown to increase muscle size across a number of populations:

older women (Charette et al., 1991) elderly men and women (Pyka, Lindenberger, Charette, & Marcus, 1994) and young men and women (Kosek, Kim, Petrella, Cross, & Bamman, 2006). Charette et al. (1991) trained elderly women [69 (1) years] for 12 weeks and reported a gradual increase in muscle size. Pyka et al. (1994) continued to test the relationship between muscle strength and hypertrophy; however, they included men and extended the study from nine weeks to one year. Both studies incorporated a progressive resistance program from 60% to 75% 1RM. Pyka et al. (1994) concluded that a long term progressive isotonic resistance training program can produce significant increases in muscle size and strength. Additionally, they noted that the increased muscle strength occurred because of increases in muscle size and a progressively increased load. Collectively, these studies saw a range of (18 - 22%) increases in muscle size, however, within Abe et al. (2000) study a wider range of 7-31% was observed. The 25-year age range and inclusion of upper and lower body growth in Abe et al. (2000) study could help explain the range. A review paper by Wernbom et al. (2007) reported an average increase in the biceps of 15.8%, whereas Abe et al (2000) observed a range of 10-31% in the upper body [biceps, triceps and chest]. Furthermore, the range is reduced in the lower body [quadriceps and hamstring] to 7-9% (Abe, DeHoyos, Pollock, & Garzarella, 2000) with an average reported quadriceps increase of 8.5% (Wernbom, Augustsson, & Thomee, 2007). The variation in ranges can be explained by the participant's age, measurement location, genetic variability and initial muscle size.

Isokinetic

Muscle growth has been observed following isokinetic muscle actions (Narici, Roi, Landoni, Minetti, & Cerretelli, 1989), (Housh, Housh, Johnson, & Chu, 1992), (Akima et al., 1999), which is the action of moving against a lever arm at a fixed speed. Similar to isotonic actions, isokinetic muscle actions can be separated by the concentric or eccentric portion of the lift. After 60 days of completing maximal isokinetic contractions, cross sectional area of the quadriceps significantly increased compared to the untrained limb (Narici et al., 1989). To extend Narici's findings, Housh et al. (1992) trained thirteen men, three times per week, for eight weeks. Unlike Narici's study, Housh included the upper body and specified that training took place on the non-dominant limb. As expected, the control arm did not increase in muscle size compared to the experimental group. Using the same speed as Narici et al. (1989) and Housh et al. (1992) (120 degrees per second), Akima and colleagues (1999) trained seven men for 13 days. The participants completed a total of 9 maximal isokinetic knee extension training sessions and after 13 days, thigh cross sectional area significantly increased compared to the controls. Even though there were methodological variations between the studies maximal increases in lower body muscle mass from isokinetic training ranged from 8-34.4%.

Isometric

Isometric muscle action involves the pushing or pulling against an immovable object and has been utilized to increase muscle size. For 100 days, Ikae and Fukunanga (1970) had five males complete 3 maximal isometric contractions on their right arm; their left arm was used as the control. After the 100th day, biceps cross sectional area in the trained arm increased compared to the control arm, which did not change. However, the condition and control groups both had significant increases in maximal strength after the 100th session, but the trained arm observed a greater strength increase. This could be due to a cross over training effect or from continual use since the dominant arm was not specified. Significant increases in the biceps cross sectional area were also observed following six weeks of maximal isometric contractions at 90 degrees (Davies, Parker, Rutherford, & Jones, 1988). However, there was less of an increase in muscle cross sectional area than Ikae and Fukunanaga (1970). This may be attributed to fewer training days despite completing more contractions during each session. More control over the tested variables occurred when Jones and Rutherford (1987) participants received visual feedback during their maximal isometric contractions of the quadriceps in addition to having the experimental and control limb randomized. The participants trained for 12 weeks and maximally contracted for 4 seconds with 2 seconds of rest between. Compared to the untrained limb, cross sectional area of the trained limb significantly increased. Thus, it is plausible to identify maximal isometric training as a method to increase a targeted muscle's size since the collective increases ranged from 5-23%. The different ranges are likely due to varied training durations in addition to the number of contractions and contraction duration.

Muscle Adaptations: Hypertrophy vs Strength

When isotonic, isokinetic and isometric muscle actions are collapsed together, the increase in muscle size ranged from 5-34%. It appears that the method of testing can explain the range more than the muscle action itself since muscle growth was similar between studies. The equipment ranged from a computed tomography scan (Davies et al., 1988) to ultrasound (Abe et al., 2000) to magnetic resonance imaging (Narici et al., 1989). Furthermore, the limb tested in addition to the measurement location on the muscle can add to this range. In a review, the average increases in muscle cross sectional for isotonic, isokinetic and isometric resistance training were 8.5%, 5.8% and 8.9% respectively (Wernbom et al., 2007). Due to the lack of data for isokinetic and isometric training, the average daily increases of biceps cross sectional area were reported:

0.20%, 0.16%, 0.12% and 0.14% [isotonic, concentric isokinetic, eccentric isokinetic and isometric] (Wernbom et al 2007). As expected, when comparing muscle hypertrophy between isotonic training and isometric training, similar increases in muscle size occurred (Jones & Rutherford, 1987). Furthermore, contrary to the author's interpretation, recent data suggests that isotonic and isokinetic resistance training produced a similar skeletal muscle hypertrophic response (Matta et al., 2015).

Although the hypertrophic effects are similar across differing muscle actions, the strength change appears to be more dependent on the specific muscle action. As expected, greater strength increases after twelve weeks of resistance training were specific to the muscle action completed (Symons, Vandervoort, Rice, Overend, & Marsh, 2005). Furthermore, comparison of isometric and isotonic resistance training reported greater percent increase in strength specific to the resistance training modality (Ward & Fisk, 1964). As expected, the greatest strength improvements after eight weeks of isokinetic training was during isokinetic testing, whereas isotonic training produced increases in isotonic and isokinetic testing (Pipes & Wilmore, 1975). This may suggest that isotonic contractions have better skill carryover to isokinetic contractions in comparison to the transfer from isokinetic to isotonic. Thus, it stands to reason that if someone were repeatedly practicing a muscle action that individual would test better in the trained action compared to a person practicing a different muscle action.

CHAPTER 3: METHODS

Participants

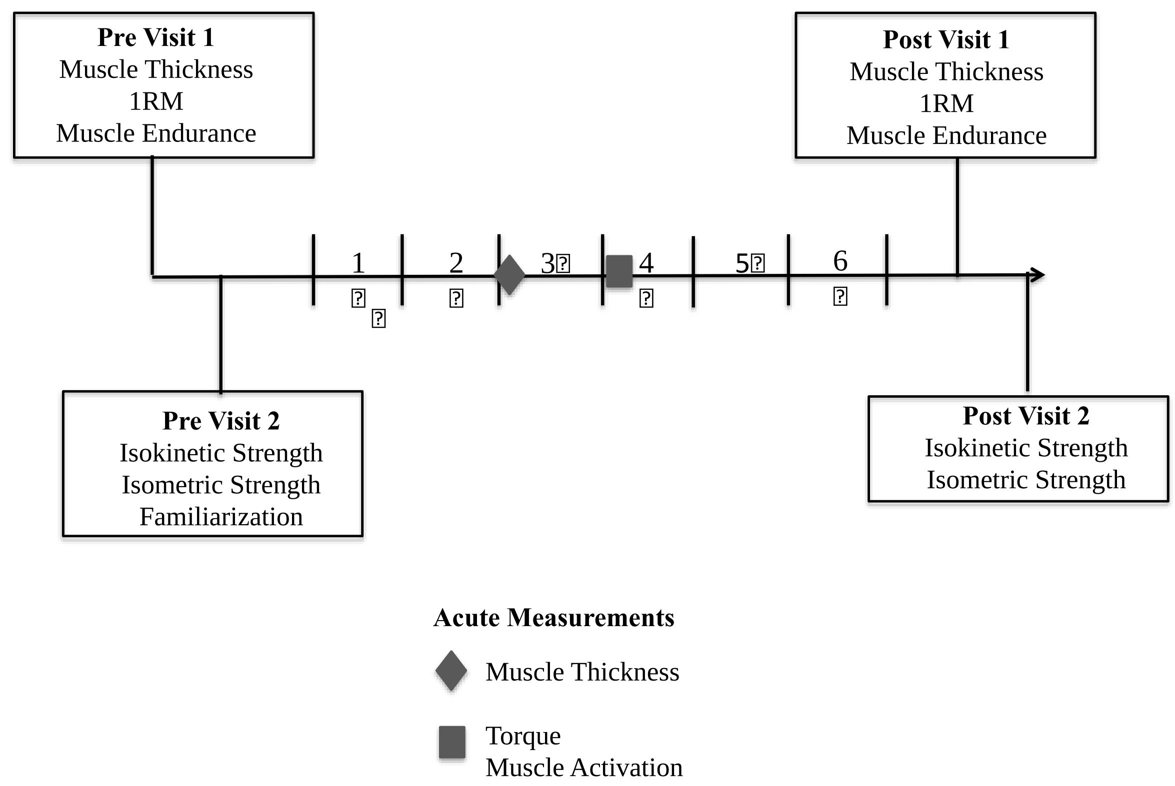
Fifteen males and females between the ages of 18-35 years were recruited for this study. The sample size was chosen based on an estimated effect size of 0.79, which was averaged from three similar studies [0.53 (Hubal et al., 2005), 0.63 (Farup et al., 2015), and 1.2 (Yasuda et al., 2012)]. Using G*Power software (GPower 3.1), an estimated sample size of 12 people was recommended to appropriately observe statistical significance at the 0.05 alpha level with a power level of 0.8; therefore, fifteen people were recruited to maintain statistical power in the event that some participants withdrew. All participants were recruited via flyers or by word of mouth. They were untrained in the upper body, which was defined as not having participated in structured exercise program within the past 6 months. The participants did not have any contraindications to participating in upper body elbow flexion exercise. In order to participate they had to meet the following inclusion criteria: non-smoker, between the ages of 18-35 years, BMI <30 kg/m^2 and untrained in the upper body. Prior to participation, the participants completed a PAR-Q and an informed consent.

Study Design

Participants recruited for the study were informed of the study requirements. After the participants read through the informed consent, they were asked if they had any questions. If the participant did not have any questions and had no contraindications to exercise, they were asked to sign the Institutional Review Boards accepted consent form.

Each participant visited the laboratory for a total of 22 visits; two pre visits, 18 training sessions and two post visits (Figure 1). Pre visit 1 consisted of paperwork, anthropometric measurements (height and body mass), muscle thickness measurements, one repetition maximum (1RM) testing, and a test of muscular endurance with both arms. Pre visit 2, 48-72 hours later, consisted of isokinetic and isometric testing, and familiarization of both training conditions. During the No Load exercise condition, the participants were accustomed to using visual feedback which allowed participants to see how hard they contracted during the exercise. Next, the participant's were familiarized with high load resistance exercise. The following week, the participants started six consecutive weeks of unilateral bicep curls for each condition: No Load training and High Load training. On the initial training visit, No Load condition was randomized to one arm and the contralateral arm was the High Load condition, and was held constant throughout the training period. Each week the participants had three training sessions with at least 24 hours separating each visit, and five minutes of rest between conditions. During each training session, the condition that went first was randomized for that training session and a counterbalanced design was used for the following training sessions. Both conditions completed the same exercise; unilateral elbow flexion, with different external loads. No Load resistance exercise required the participant to contract as hard as they can, through a full range of motion, without the use of an external load. In the contralateral arm, High Load resistance exercise consisted of unilateral bicep curls at 70% of their 1RM. After weeks 2 and 3, acute responses (muscle swelling, fatigue and muscle activation) of each condition were tested and occurred during the participants scheduled training sessions. This allowed adequate time (6 training sessions) to quantify acute changes that were more reflective of the training stimulus and less reflective of muscle damage/stress from an unaccustomed bout of exercise. At least 72 hours after the completion of the training study post testing visits began. Post testing visits 1 and 2 replicated the order of pre visits 1 and 2, without anthropometric measurements taken.

Figure 1 Displays the Study Design.



One Repetition Maximum (1RM)

Participants stood with their back and heels against the wall with their heels shoulder width apart. They completed a 3-5 repetition warm-up of unilateral bicep curls, using roughly 30% of their 1RM. The participant then progressed to lifting a heavier load roughly 60-75% 1RM for 1-3 repetitions. Next, they attempted to complete a 1RM, which was defined as the maximal weight the participant could lift through the concentric portion of the lift while maintaining proper form.

One repetition maximum was completed within five attempts, with three to five minutes of rest between attempts and alternating arms between attempts. The highest amount of weight lifted with proper form through a full range of motion was considered that arms 1RM. One repetition maximum testing occurred on both arms and was tested pre and post training.

Muscular Endurance

The participants completed as many repetitions as possible using 35% of their 1RM tested that day. Thirty-five percent was chosen to represent 50% of the external load between the two conditions (i.e. halfway between 0% and 70% of the external load). The participants exercised to a metronome of 1.5 seconds for the concentric and 1.5 seconds for the eccentric portion of the lift; for a total of 3 seconds per repetition. The test was terminated if they were not able to keep pace to the metronome or could not lift the load through a full range of motion. The last successful repetition completed was used for analysis. The participants rested for five minutes between conditions and tested pre and post training.

Isokinetic and Isometric Strength

Isokinetic and isometric maximal voluntary contractions (MVC) were tested on the dynamometer (Biodex Quickset System 4). For each participant, they sat in the chair with their respective arm at the appropriate angle of which we were testing and appropriate lever arm length and chair position was determined and recorded. During isokinetic testing, the participants were asked to pull the lever arm as quick and as hard as possible. The participants were given 2 attempts at 60 and 180 degrees per second, with 60 seconds of rest between each attempt and test. Using the same arm, the participant completed 2 isometric MVC’s at 90 degrees of elbow flexion. Each participant pulled against the fixed lever arm as hard as possible for three seconds with a 60 second rest between the MVC's. Next, the participant completed the same protocol on the contralateral arm. Testing was completed pre and post training and the highest torque produced during isokinetic and isometric testing was used for analysis.

Muscle Thickness

Muscle thickness was measured with the B-mode ultrasound (Aloka, SSD-550 with a 5MHz probe). Muscle thickness is the distance from the muscle bone layer to the muscle adipose layer; measured in centimeters. Upper body muscle thickness measurements were completed on both arms. Three different measurement locations were taken on the anterior and posterior upper arm at 50%, 60% and 70% the distance from the acromion process to the lateral epicondyle (Abe et al. 1994). Each measurement location was completed twice and the average of the two measurements was used for analysis. Lower body muscle thickness on the anterior portion of the upper right leg was measured as well; halfway between the greater trochanter and lateral condyle (Abe et al. 1994); which served as an internal control. Muscle thickness measurements were taken pre and post training by the same tester. Additionally, upper body muscle thickness measurements of the anterior portion of the upper arm were measured during the acute exercise bout at pre, immediately post and 15 minutes post exercise. The same investigator took all measurements.

Electromyography Activity

Electromyography (EMG) activity was estimated from the biceps brachii for both conditions. A mark was placed on the anterior upper arm, 2/3 distal of the medial acromion to the fossa cubit while the elbow was held at 90 degrees (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Two additional electrodes were applied to the posterior upper arm at two fingers medial to 50% distance of the posterior crista of the acromion and olecranon, while the palm was faced downward and the arm was at 90 degrees elbow flexion (Hermens et al., 2000). The skin was shaved, abraded and wiped with an alcohol wipe. Bipolar surface electrodes were applied, with an inter-electrode distance of 20mm. The ground electrode was placed on the 7^{th} cervical vertebrae at the neck. The surface electrodes were connected to an amplifier and digitized (iWorkx, Dover, New Hampshire). The signal was filtered (low-pass filter 500 kHz; high-pass filter 10 kHz), amplified (1000x) and sampled at a rate of 1 KHz. Before each exercise session during EMG testing, each participant performed two MVCs with the biceps brachii at a joint angle of 90° with 60s rest between MVCs on the dynamometer (Biodex Quickset System 4). Participants performed two MVC's for the triceps pushdown exercise at a joint angle of 90 degrees with 60 seconds of rest between. EMG was recorded continuously from the biceps brachii during each exercise bout. The computer software, Lab Scribe 2, was used to analyze the data. EMG amplitude (root mean square, RMS) was analyzed from the average of the first three repetitions and an average of the last three repetitions for each set and expressed relative to the highest pre exercise MVC (%MVC). In addition to acute testing, surface electrodes were applied during each No Load training session which gave the participant visual feedback.

Training Protocol

The participants completed unilateral bicep curls, three times per week for six consecutive weeks. During each training session, the participants completed two conditions: No Load and High Load exercise. The No Load condition was randomized to the right or left arm and High

Load condition was the contralateral arm. At the start of each training session, we randomized as to which condition went first and then alternated from that session forward. No Load training consisted of the participant contracting as hard as possible through the full range of motion of unilateral bicep curls without the use of an external load and without bearing body weight. Each participant completed four sets of 20 repetitions with 30 seconds of rest between sets. The concentric and eccentric portion of the lift was set a 1.5 seconds for a total of a 3 second contraction and the participant was given visual feedback to encourage maximal effort. High load resistance training condition consisted of attempting to complete 4 sets of 8-12 repetitions at 70% 1RM with 90 seconds of rest between sets (ACSM 2009), using the same contraction speed as No Load training. The load was progressed if they were achieving more than 12 repetitions, to ensure they maintained approximately 70% of their 1RM. Each condition was separated by five minutes of seated rest.

Acute Response

During the participant's regular scheduled training sessions, muscle swelling and muscle fatigue for each condition was tested pre, immediately post and fifteen minutes after exercise completion. Muscle activation was measured during the 10^{th} training session in order to estimate activation of the first three and last three repetitions of each set. Muscle swelling was tested after 2 weeks (visit 7), and muscle fatigue and activation were tested after 3 weeks (visit 10). Muscle thickness was used to measure muscle swelling in each condition and measured at 50%, 60% and 70% the distance from the acromion process to the lateral epicondyle. During a separate visit, muscle activation was recorded by measuring EMG activity during each set. The participant completed an isometric MCV while EMG activity was recording; termed pre, and all subsequent

EMG was normalized to the pre test. Then the participants completed their normal training protocol for both conditions, while EMG activity was continuously recorded. After the fourth set, each participant completed an MVC immediately post and fifteen minutes post exercise (i.e. subsequent time points) for both conditions.

Statistical Analysis

All data was analyzed with SPSS 22.0 statistical software package (SPSS Inc. Chicago, IL). A 2 (condition) x 2 (time) repeated measures ANOVA was used to determine if there were significant differences in muscle thickness, 1RM, muscle endurance, isokinetic strength and isometric strength. If there was a significant interaction, paired sample t-tests were used to determine changes between and within conditions at each time point. If there was no interaction, we examined the main effects.

Acute changes in fatigue and muscle thickness were analyzed using a 2 (condition) x 3 (time) repeated measures ANOVA. If there was a significant interaction, a one way repeated measures ANOVA was used to determine where the differences lie across time within each condition and a paired sample t-test was used to determine changes between conditions within each time point (pre, immediate and 15 minutes post). If there was no interaction, we examined main effects. For muscle activation, a 2 (condition) x 4 (time) repeated measures ANOVA was used for the first three and last three repetitions. If there was a significant interaction, a one way repeated measures ANOVA was used to determine where the differences lie across time within each condition and a paired sample t-test was used to determine changes between conditions within each time point (sets 1, 2, 3 and 4). If there was no interaction, we examined the main effects. All statistical tests were set at level of significance of $p \leq 0.05$.

CHAPTER 4: RESULTS

Demographics

Fifteen participants were recruited, however, one participant was unable to start the study and a second individual dropped out following week two because of issues not related to the study. Therefore, a total of 13 participants completed the study with an average age of 22 (2) years, height 170 (7) cm, body mass 72 (14) kg and BMI 24 (3) kg/m^2. Table 1 displays the characteristics of all participants that completed the six weeks of training.

Table 1: Participant Characteristics

Participant	Sex	Age (yrs)	Height (cm)	Body Mass (kg)	BMI (kg/m^2)
01	Female	19	172	74.3	25.0
02	Female	23	164.4	55.6	20.5
03	Female	26	169.6	71.3	24.7
04	Female	20	166.8	79.6	28.6
05	Male	19	170.6	54.8	18.8
07	Male	23	172	73.4	24.8
09	Female	23	167	55.8	20.0
10	Male	25	167.7	80.8	28.7
11	Male	22	183.9	101.2	29.9
12	Female	26	165.6	60	21.8
13	Female	24	165.7	72.1	26.2
14	Male	21	160.4	62.7	24.3
15	Male	25	186.7	95.8	27.4

Chronic Measurements

Muscle Thickness

Anterior Upper Arm

Mean values for anterior muscle thickness can be found in Table 2. For anterior upper arm muscle thickness at the 50% site (Figure 2) there was no significant condition x time interaction ($p=0.549$). Additionally, there was no main effect of condition ($p=0.084$), but there was a main effect of time ($p=0.002$). In addition, for anterior upper arm muscle thickness at the 60% site (Figure 2) there was no significant condition x time interaction ($p=0.550$) or main effect of condition ($p=0.196$), but there was a main effect of time ($p\leq0.001$). For anterior upper arm muscle thickness at the 70% site (Figure 2) there was no condition x time interaction ($p=0.203$) or main effect of condition ($p=0.173$), but there was a main effect of time ($p=0.001$). Individual data plots for anterior upper arm muscle thickness are illustrated in Figure 3 and Figure 4.

Table 2: Mean anterior upper arm muscle thickness (cm) at 50%, 60% and 70% sites at pre and post training. * Significant main effect of time from pre to post training.

	50%		**60%**		**70%**	
	Pre	**Post***	**Pre**	**Post***	**Pre**	**Post***
No Load	2.6 (0.8)	2.8 (0.7)	2.9 (0.7)	3.0 (0.7)	3.2 (0.7)	3.4 (0.7)
High Load	2.8 (0.7)	2.9 (0.7)	3.0 (0.6)	3.1 (0.6)	3.3 (0.6)	3.5 (0.7)

Figure 2: Mean muscle thickness (cm) of the anterior upper arm at the 50%, 60% and 70% sites from pre to post training for the No Load condition (A) and High Load condition (B).
*** Significant time effect from pre to post training.**

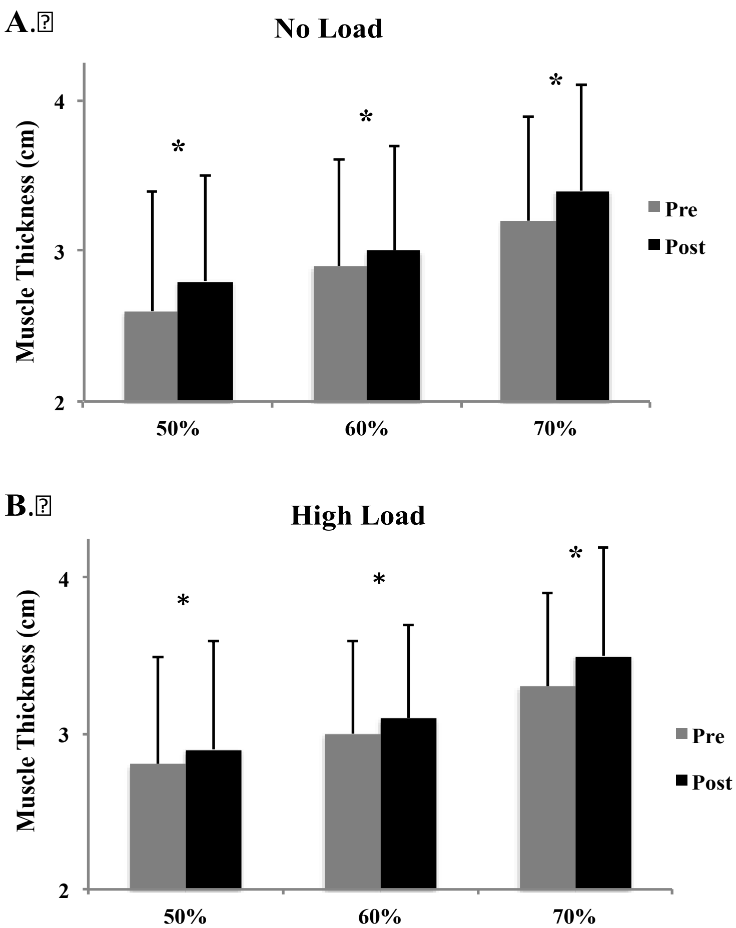


Figure 3: Individual changes from pre to post training at the anterior upper arm muscle thickness at the 50% (A), 60% (B) and 70% (C) sites.

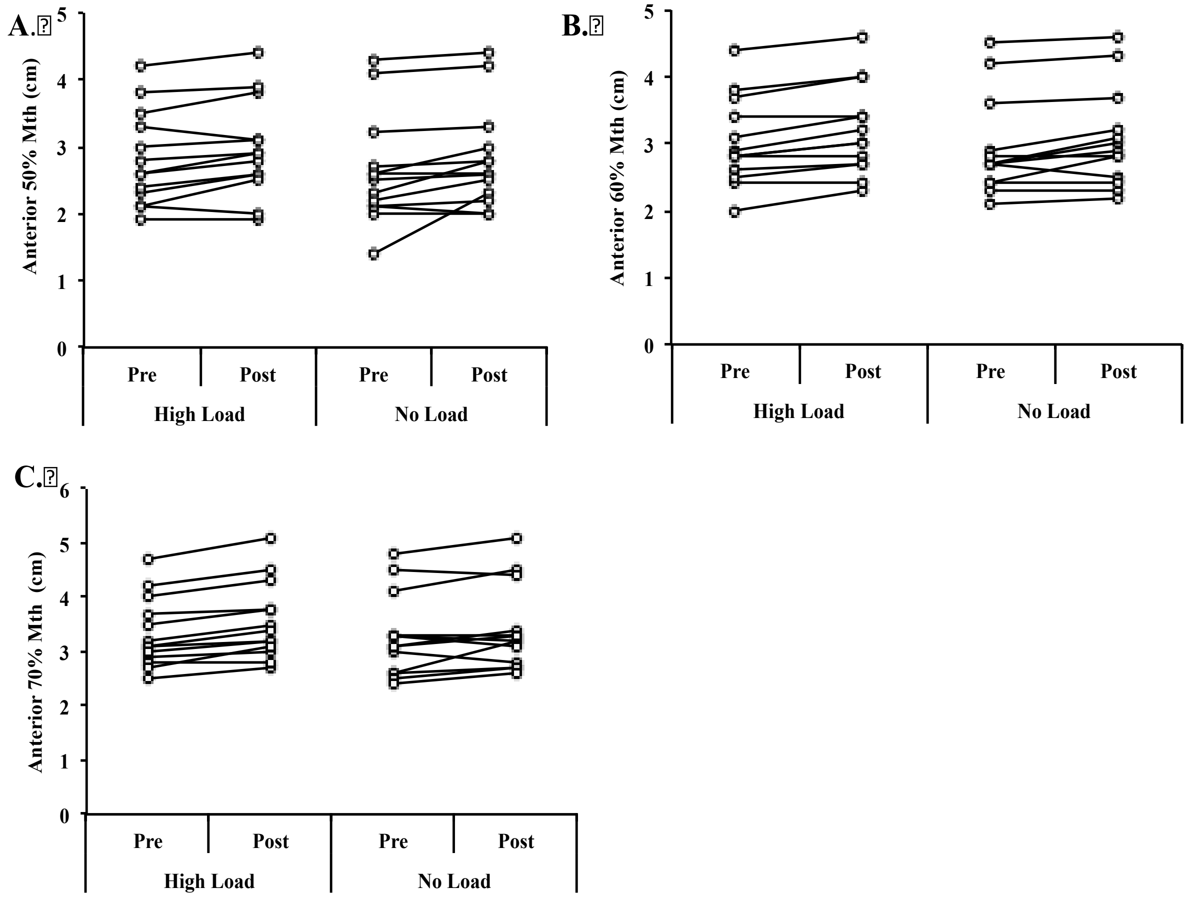
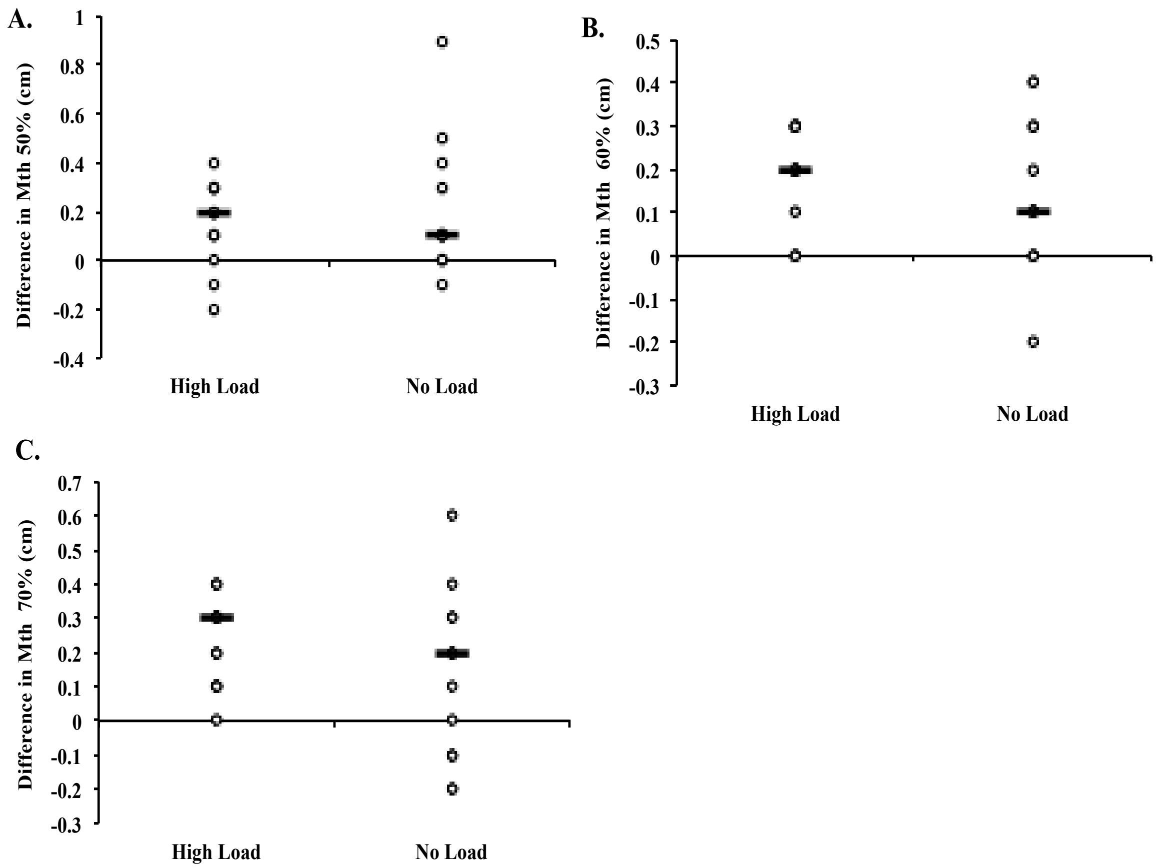


Figure 4: Individual differences from pre to post training for anterior upper muscle thickness at the 50% (A), 60% (B) and 70%(C) sites. Circles represent individual median differences (some circles may represent more than one individual, if they both had similar median difference). Black bar indicates the group median difference from pre to post training.



Posterior Upper Arm

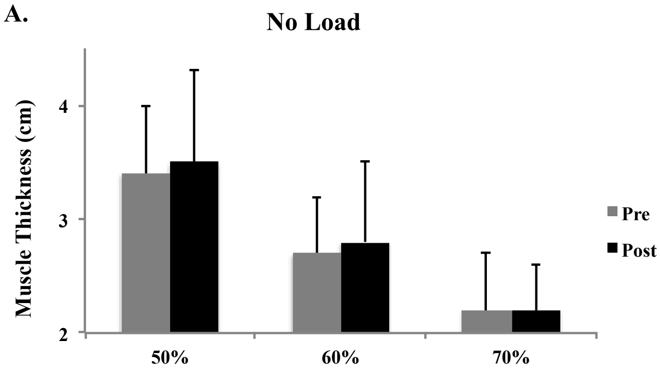
Mean values for posterior upper arm muscle thickness can be found in Table 3. For posterior upper arm muscle thickness at the 50% site (Figure 5), there was a significant condition x time interaction (p=0.003). Post hoc analysis revealed that the High Load condition decreased from pre to post (p=0.001) training. Additionally, for posterior upper arm muscle thickness at the 60% site there was a significant condition x time interaction (p=0.014, Figure 5). Further post hoc analysis revealed that the High Load condition decreased from pre to post (p=0.001), and High Load post was significantly less than No Load post (p=0.031). For posterior upper arm muscle thickness at the 70% site there was a significant condition x time interaction (p=0.018, Figure 5). Post hoc analysis did not reveal any significant differences from pre to post training or between conditions. Individual data plots for posterior upper arm muscle thickness are presented in Figure 6 and Figure 7.

Table 3: Mean posterior upper arm muscle thickness (cm) at 50%, 60% and 70% sites. * Significant decrease pre to post for that condition, High Load decreased from pre to post. Different letters represent significant differences between conditions at that time point, such that *a* was greater than *b*.

	50%		60%		70%	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**
No Load	3.4 (0.6)	3.5 (0.8)	2.7 (0.5)	2.8 (0.7) [a]	2.2 (0.5)	2.2 (0.4)
High Load	3.5 (0.8)	3.2 (0.7)*	2.8 (0.6)	2.6 (0.5)*[b]	2.2 (0.4)	2.1 (0.4)

Figure 5: Mean muscle thickness (cm) of the posterior upper arm at pre and post training at the 50%, 60%, and 70% site for the No Load Condition (A) and High Load (B) condition. # High Load decreased from pre to post. + High Load post was significantly less than No Load post at that specific site.

A.



B.

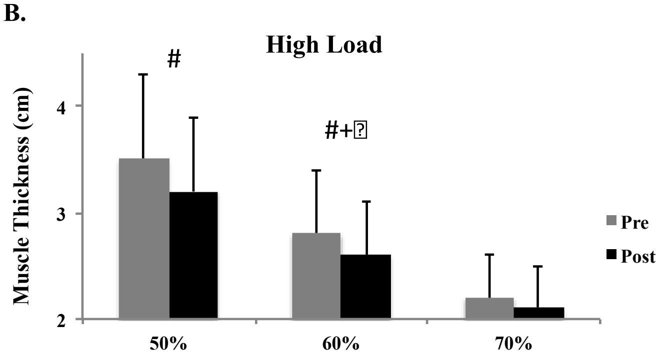


Figure 6: Individual changes from pre to post for posterior upper arm muscle thickness at the 50%(A), 60% (B) and 70% (C) site.

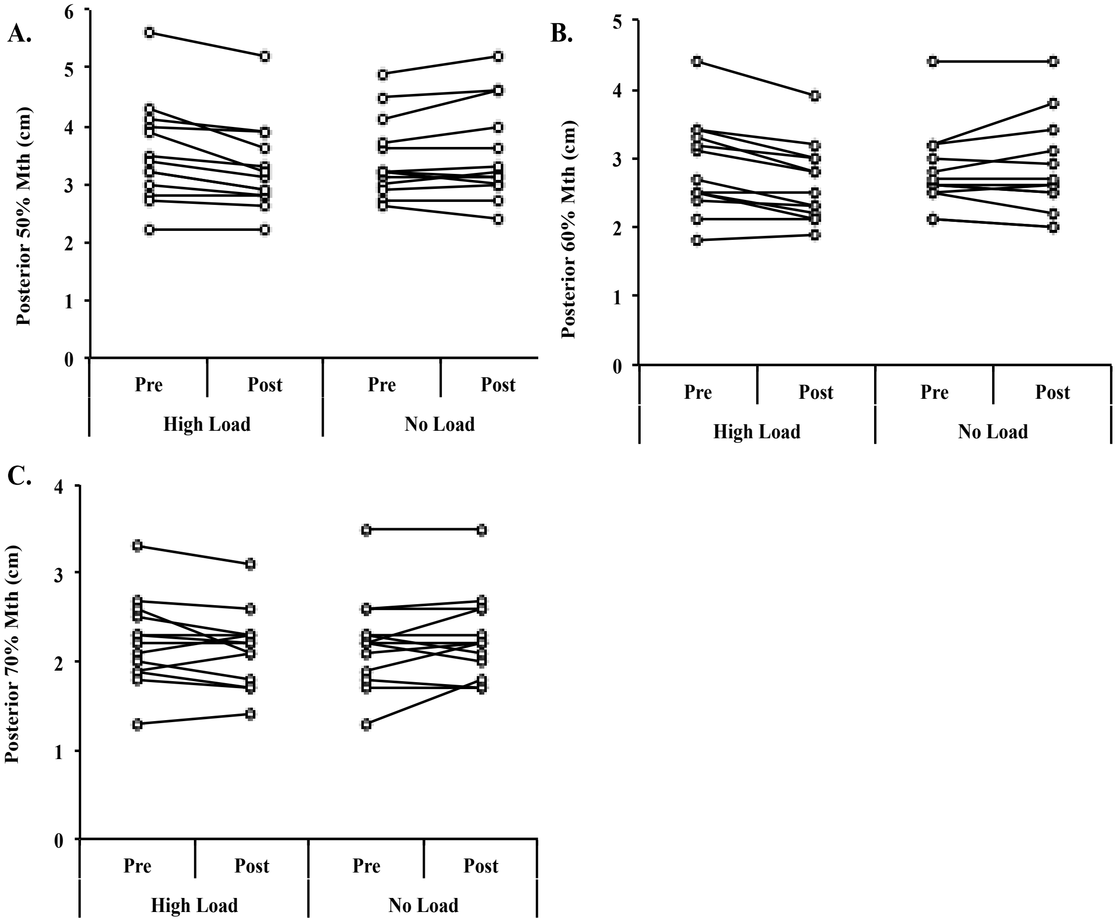
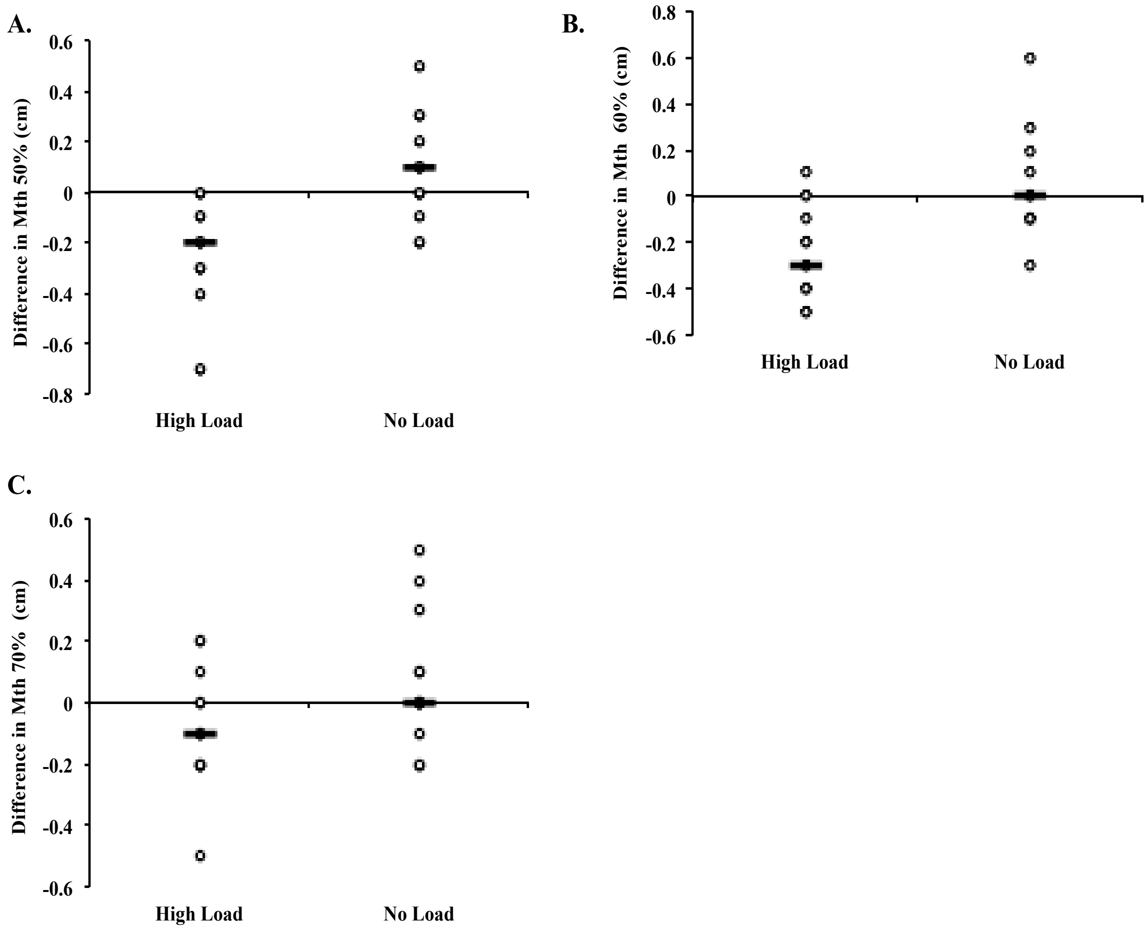


Figure 7: Individual differences from pre to post training for posterior upper muscle thickness at the 50% (A), 60% (B) and 70%(C) sites. Circles represent individual median differences (some circles may represent more than one individual, if they both had a similar median difference). Black bar indicates the group median difference from pre to post training.



Anterior Upper Right Leg

For our internal control, the upper right leg, there was no change in muscle thickness [pre: 4.9 (1.0) cm and post: 4.7 (0.9) cm, p=0.106].

One Repetition Maximum (1RM)

For 1RM strength, there was a condition x time interaction (p=0.017, Figure 8). In addition, post hoc analysis revealed an increase in the High Load [Pre 13.9 (5.8) kg to Post 16.2 (5.1) kg, p≤.001] and No Load [Pre 13.8 (5.5) kg to Post 14.8 (5.1) kg (p=0.015)] condition. However, High Load post was significantly greater than No Load post (p=0.032), but High Load pre and No Load pre were not significantly different from each other (p=0.773). Individual data plots for 1RM are illustrated in Figure 9.

Figure 8: Mean 1RM from pre to post training for both conditions. * Significant increase pre to post training, # significant difference between conditions at post, where High Load increased more than No Load.

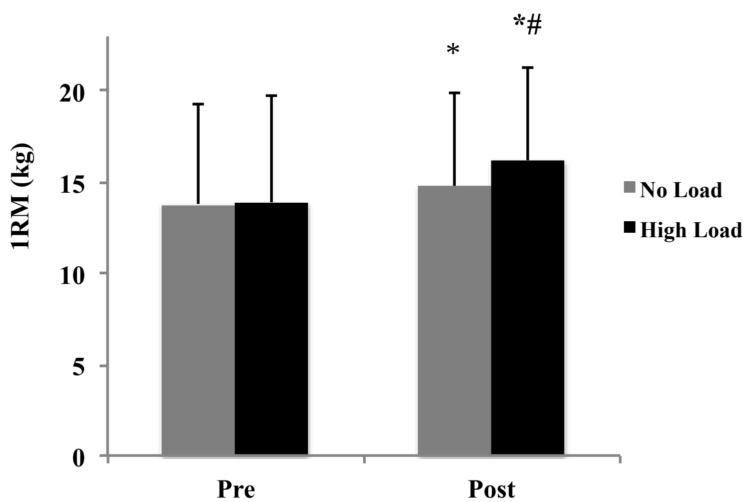
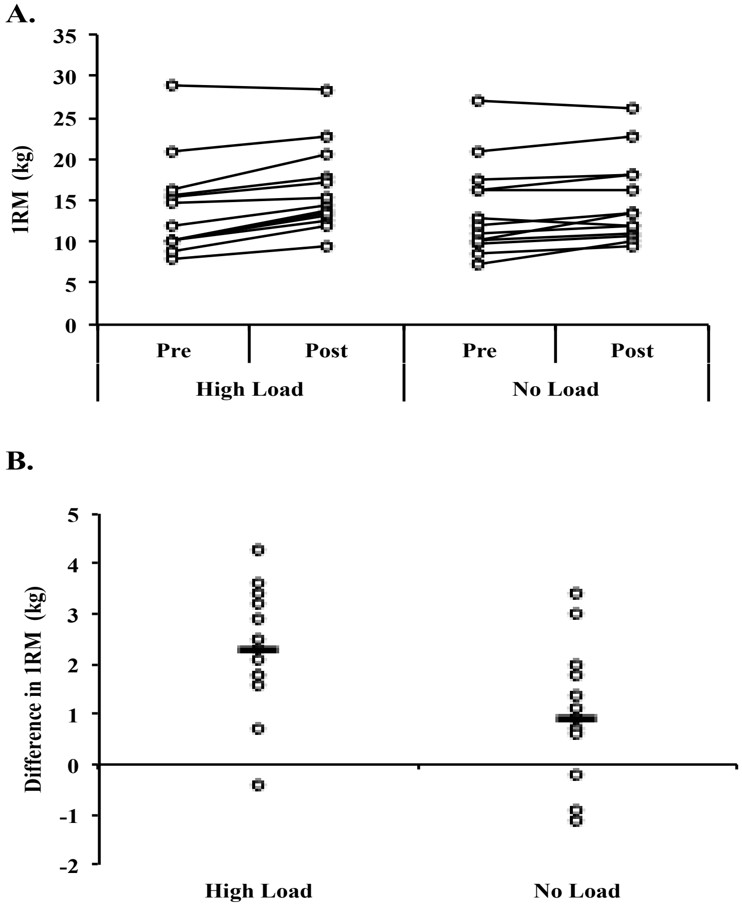


Figure 9: (A) Individual changes in 1RM strength from pre to post training. (B) Individual 1RM differences from pre to post training. Circles represent individual median differences (some circles may represent more than one individual, if they both had a similar median difference). The black bar indicates the group median difference from pre to post training



Muscle Endurance

Muscle endurance analysis was only completed on 12 participants because one participant was unable to complete the pre muscle endurance test. There was a condition x time interaction ($p=0.049$, Figure 10) for repetitions to fatigue. Post hoc analysis revealed that the only difference was from High Load pre [37 (14) repetitions] to post [51 (20) repetitions, $p=0.006$]. There were no significant differences, from No Load pre [39 (20) repetitions] to post [47 (21) repetitions, $p=0.052$]. In addition, there were no differences between conditions at pre ($p=0.391$) or post ($p=0.053$). Individual data plots for muscle endurance are presented in Figure 11.

Figure 10: Mean repetitions completed for the endurance test at pre and post training. Time points with different letters represent significant differences for that condition between time points (p≤0.05), ***b*** **was greater than** ***a*****.**

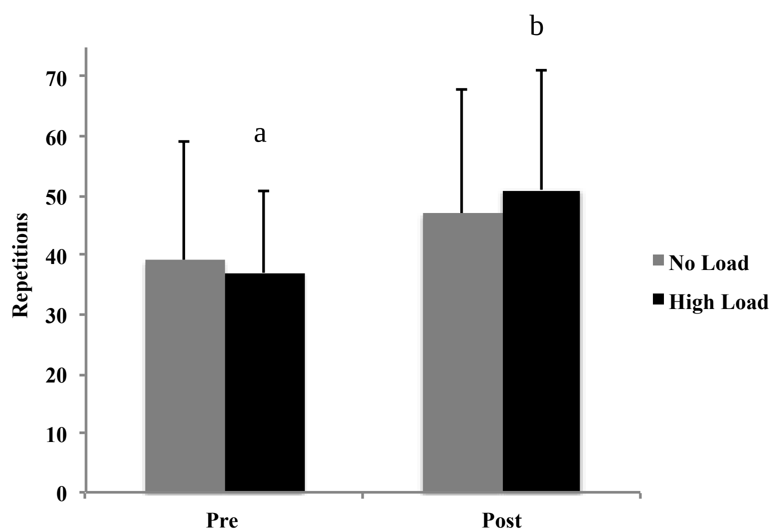
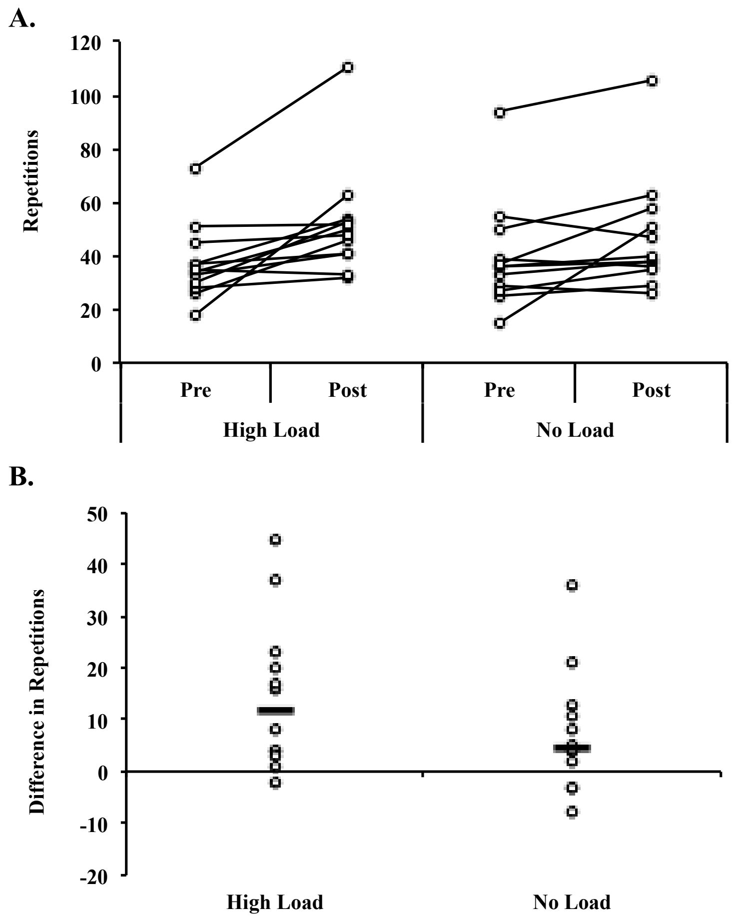


Figure 11: (A) Individual changes for repetitions completed during the endurance test from pre to post training. (B) Individual differences in repetitions completed during muscle endurance test. Circles represent individual median differences from pre to post training (some circles may represent more than one individual, if they both had a similar median difference). The black bar represents the group median difference from pre to post training.



Isokinetic and Isometric Strength

Mean values for isokinetic strength at 180°/sec and 60°/sec, and isometric strength at 90° are presented in Table 4. For isokinetic strength at 180°/sec, there was no condition x time interaction (p=0.521, Figure 12A), no main effect of condition (p=0.303) or main effect of time (p=0.502). For isokinetic strength at 60°/sec there was a condition x time interaction (p=0.024, Figure 12B) and post hoc analysis revealed that High Load increased from pre to post training (p=0.001), whereas No Load did not change pre to post training (p=0.365), and there were no differences between conditions at pre (p=0.415) or post (p=0.583). For isometric strength, there was no condition x time interaction (p=0.376, Figure 12C). In addition, there was no main effect of condition (p=0.726), however there was a main effect of time [pre 40.4 (12.2) and post 44.1 (15.4), p=0.022]. Individual data plots for isokinetic and isometric strength are illustrated in Figure 13 and Figure 14.

Table 4: Mean isokinetic strength (Nm) at 180^{O}/sec and 60^{O}/sec, and isometric strength at 90° from pre to post training. There were no differences for isokinetic strength at 180^{O}/sec. At 60^{O}/sec, different letters represent significant differences for that condition (simple effect) between time points. * Main effect of time, both conditions increased from pre to post training.

	180°/sec		**60°/sec**		**90°**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post***
No Load	34.4(12.8)	34.4(13.8)	40.0(17.3)	40.8(16.1)	41.3(12.0)	44.1(14.9)
High Load	32.7(13.1)	33.4(13.3)	38.9(17.7)^{a}	41.8(17.1)^{b}	39.6(13.9)	44.1(18.2)

Figure 12: Mean isokinetic strength from pre to post training for 180°/sec (A), 60°/sec (B) and 90° (C). At 60^{O}/sec, different letters represent significant differences for that condition between time points, such that *b* was greater than *a*. * Main effect of time, both No Load and High Load increased isometric torque from pre to post training.

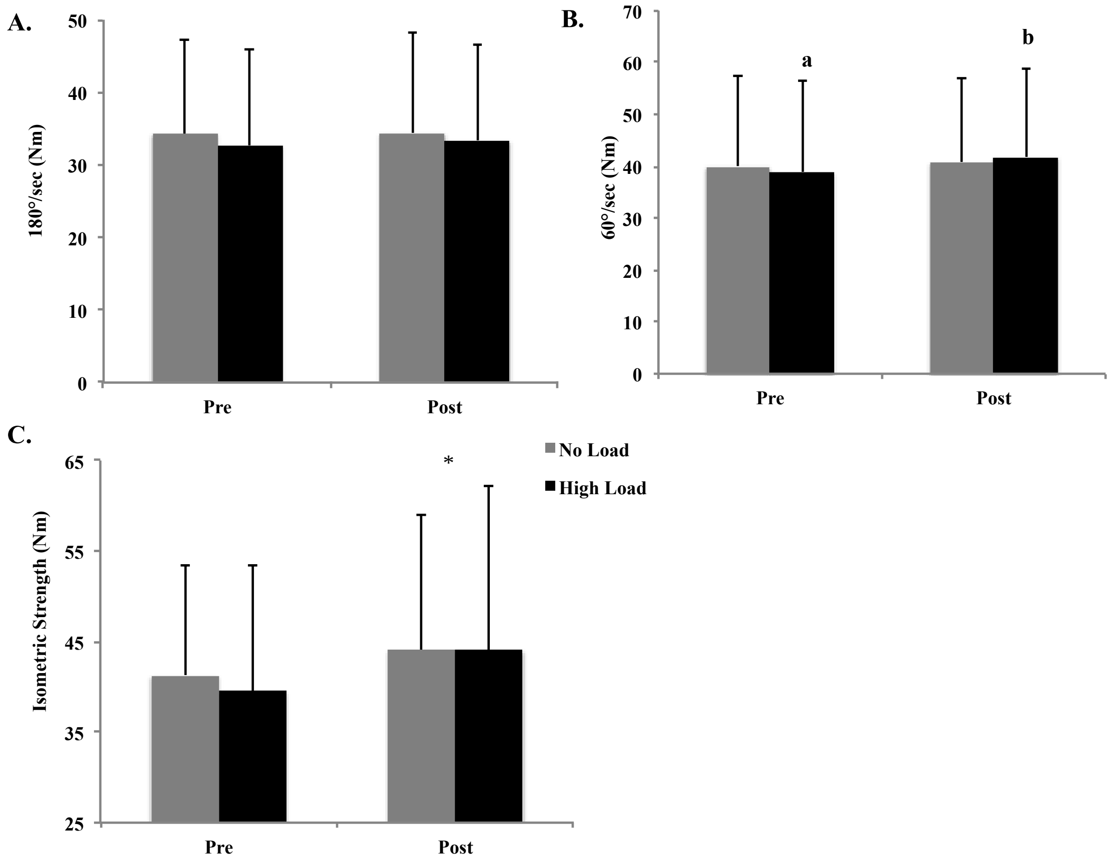


Figure 13: Individual changes for isokinetic test at 180°/sec (A), 60°/sec (B) and 90° (C) from pre to post training.

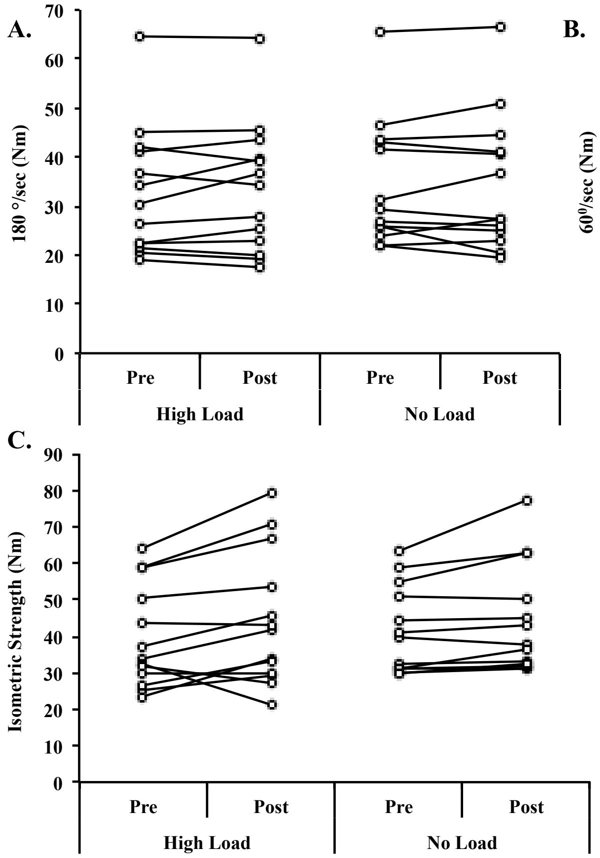
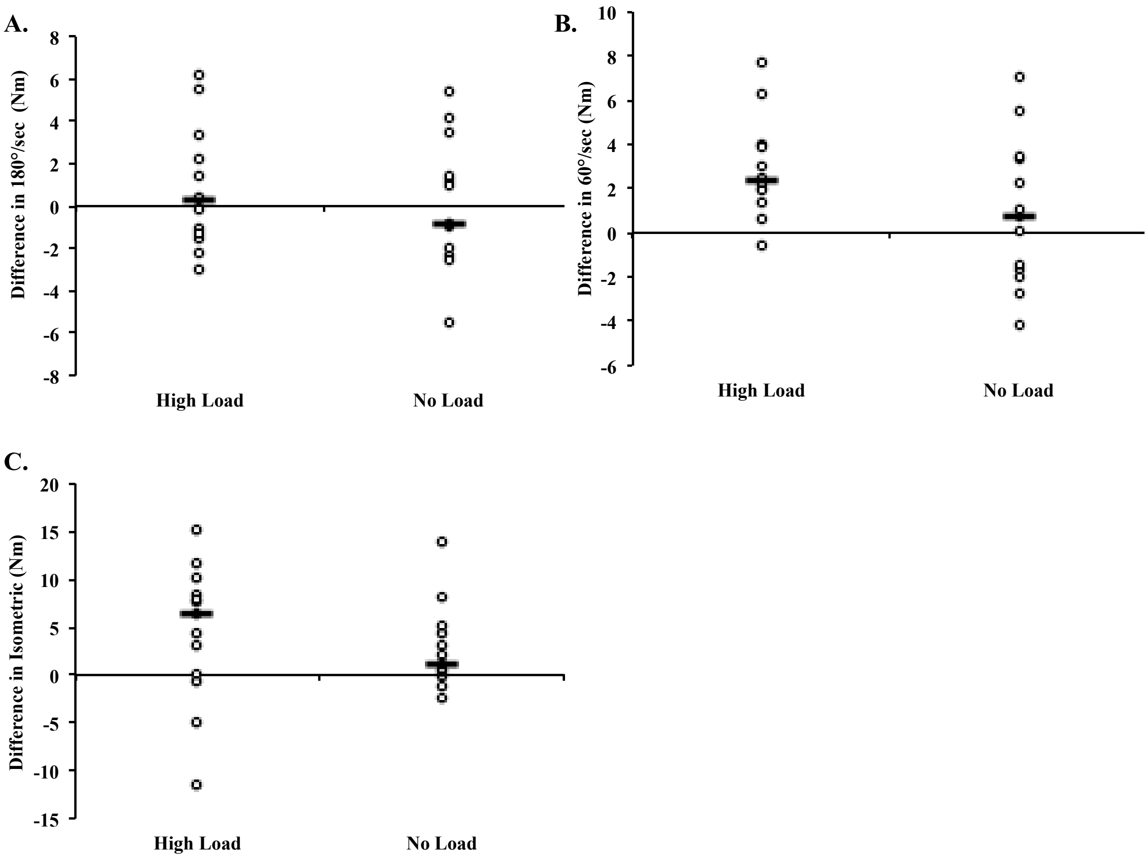


Figure 14: Individual changes from pre to post training for 180°/sec (A), 60°/sec (B) and 90° (C). Circles represent individual median differences (some circles may represent more than one individual, if they both had a similar median difference). The black bar represents the group median difference from pre to post training.



Ratings of Perceived Exertion

Ratings of perceived exertion were determined by comparing between conditions within each set for the first half of training (Sessions 1-9) and the second half of training (Sessions 10-18). This was determined by calculating each participant's median RPE for each set for the first 9 sessions (Sessions 1-9) and again for the second half of training (Sessions 10-18). The 25th, 50th and 75th percentiles are displayed in Table 5. For Sessions 1-9, there was a significant difference with the No Load condition having a higher RPE than High Load training at set 1 (p=0.033), but there were no significant differences between conditions for sets 2-4 [set 2 (p=0.136), set 3 (p=0.673) and set 4 (p=0.271)]. For the Sessions 10-18, there was a significant difference with the No Load condition having a greater RPE than High Load training at set 1 (p=0.026), but there were no significant differences between conditions for sets 2-4 [set 2 (p=0.058), set 3 (p=0.599) and set 4 (p=0.732)].

Table 5: Displays 25th, 50th, 75th percentiles for RPE during Sessions 1-9 and Sessions 10-18. * For all significant differences, RPE was greater for the No Load condition.

		Sessions 1-9			Sessions 10-18		
	RPE	**25th**	**50th**	**75th**	**25th**	**50th**	**75th**
Pre	**No Load**	6	6	6	6	6	6
	High Load	6	6	6	6	6	6
Set 1	**No Load**	9	11*	15.5	8	11*	14.5
	High Load	8	10	13.5	8	10	13.5
Set 2	**No Load**	11.5	13	17	10.5	13	15.5
	High Load	12	12	14.5	10.5	12	14
Set 3	**No Load**	13	14	17.5	12	15	17
	High Load	13	14	17	11.5	14	16
Set 4	**No Load**	14.5	16	18	13	15	17.5
	High Load	13.5	15	17.5	14	15	17

Ratings of Discomfort

Ratings of discomfort were determined by comparing between conditions within each set for the first half of training (Sessions 1-9) and the second half of training (Sessions 10-18). This was determined by calculating each participant's median ratings of discomfort for each set for the first 9 sessions (Sessions 1-9) and again for the second half of training (Sessions 10-18). The 25th, 50th and 75th percentiles are displayed in Table 6. For Sessions 1-9, there was a significant difference only at set 1 with the No Load condition having a greater rating of discomfort than High Load training (p=0.024). There were no other differences for sets 2-4, [set 2 (p=0.119), set

3 (p=0.339) and set 4 (p=0.175)]. For Sessions 10-18, there were no significant differences between conditions for sets 1-4 [set 1 (p=0.932), set 2 (p=0.859), set 3 (p=0.858), and set 4 (p=0.611)].

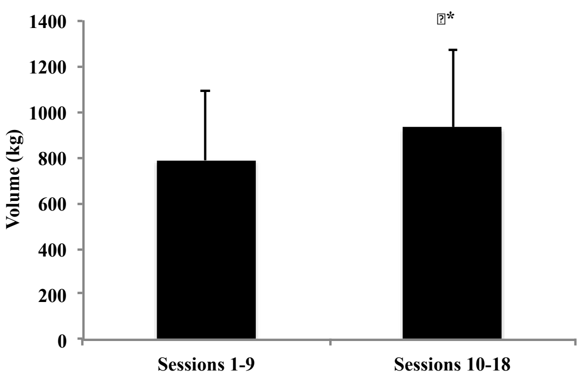
Table 6: Displays the ratings of discomfort separated by the 25th, 50th, 75th percentile for Sessions 1-9 and Sessions 10-18. * No Load was significantly higher than High Load.

		Sessions 1-9			**Sessions 10-18**		
	Discomfort	**25th**	**50th**	**75th**	**25th**	**50th**	**75th**
Pre	**No Load**	0	0	0	0	0	0
	High Load	0	0	0	0	0	0
Set 1	**No Load**	0.3	0.5*	1	0	0.7	1
	High Load	0	0.5	0.7	0	0.5	1
Set 2	**No Load**	0.4	1.5	2	0.1	1	2
	High Load	0.4	1	2	0.1	0.7	1.7
Set 3	**No Load**	0.5	2	3	0.2	2	3
	High Load	0.6	1.5	2.5	0.3	1	3
Set 4	**No Load**	0.6	2.5	3.5	0.5	1.5	3.5
	High Load	0.7	2	3	0.5	2	3.2

Exercise Volume

We were unable to quantify volume for No Load training [repetitions (80) x load (0)] therefore changes in volume are only shown for the High Load condition. Volume was analyzed by taking the mean volume of work completed during training Sessions 1-9 [786.6 (308.70 kg] and Sessions 10-18 [927.5 (341) kg], and a paired samples t-test indicated a significant increase ($p \leq 0.001$) from Sessions 1-9 to Sessions 10-18 (Figure 15).

Figure 15: Mean volume of work completed during Session 1-9 to Sessions 10-18 for High Load training. * Significant increase from Sessions 1-9 to Sessions 10-18.



Acute Measurements

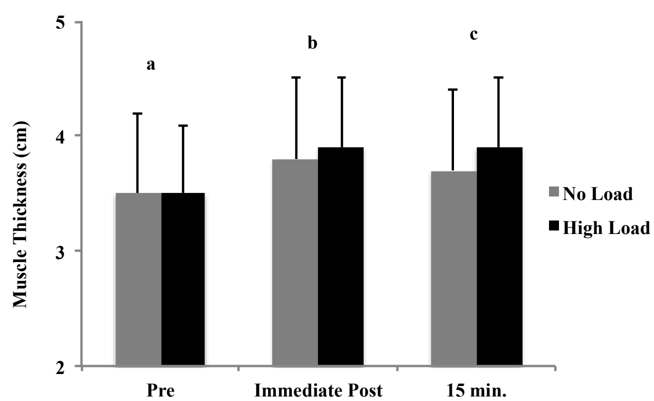
Muscle Thickness

Mean values of anterior muscle thickness for each condition are shown in Table 7. For the acute measurement of muscle thickness, there was no condition x time interaction (p=0.130) or main effect of condition (p=0.20); however, there was a main effect of time (p≤0.001, Figure 16). Muscle thickness significantly increased from pre [3.5 (0.3) cm] to immediate post [3.9 (0.3) cm], and 15 minutes post [3.8 (0.3) cm] was less than immediate post but greater than pre.

Table 7: Mean acute muscle thickness (cm) at pre, immediately post and 15 minutes post exercise. Time points with different letters represent significance differences between time points (p≤0.05).

	Pre [a]	Immediate Post [b]	15 Min Post [c]
No Load	3.5 (0.7)	3.8 (0.7)	3.7 (0.7)
High Load	3.5 (0.6)	3.9 (0.6)	3.9 (0.6)

Figure 16: Mean acute muscle thickness (cm) response of the biceps pre, immediate post and fifteen minutes post exercise. Time points with different letters represent significant differences between time points (p≤0.05).



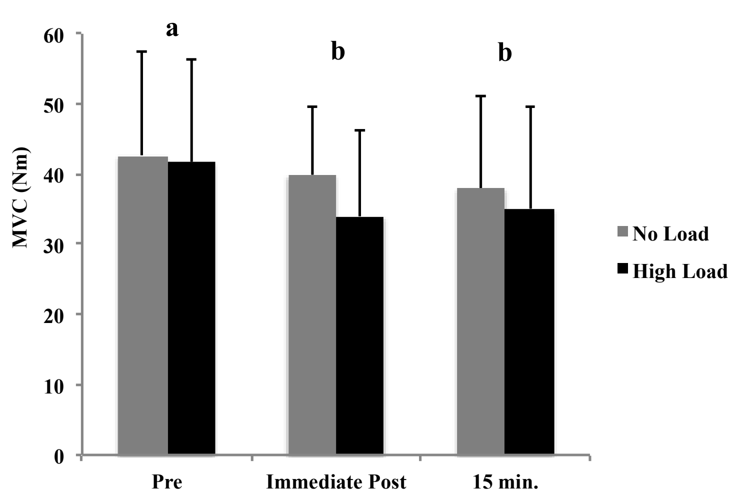
Muscle Fatigue

Mean values for isometric torque at pre, immediate post and fifteen minutes post exercise are displayed in Table 8. There was no condition x time interaction (p=0.124) or main effect of condition (p=0.277) for torque, but there was a main effect of time (p=0.002). Torque significantly decreased from pre [42.2 (14.0) Nm] to immediate post [37.0 (9.3) Nm], and remained decreased from pre at 15 minutes post [36.6 (11.5) Nm].

Table 8: Mean isometric torque (Nm) at pre, immediate post and fifteen minutes post exercise. Time points with different letters represent significant differences between time points ($p \leq 0.05$).

	Pre [a]	Immediate Post [b]	15 min Post[b]
No Load	42.7 (14.8)	39.9 (9.7)	38 (13.0)
High Load	41.7 (14.7)	34.0 (12.2)	35.1(14.6)

Figure 17: Mean isometric torque (Nm) at pre, immediate post and fifteen minutes after exercise. Time points with different letters represent significant differences between time points ($p \leq 0.05$).



Muscle Activation

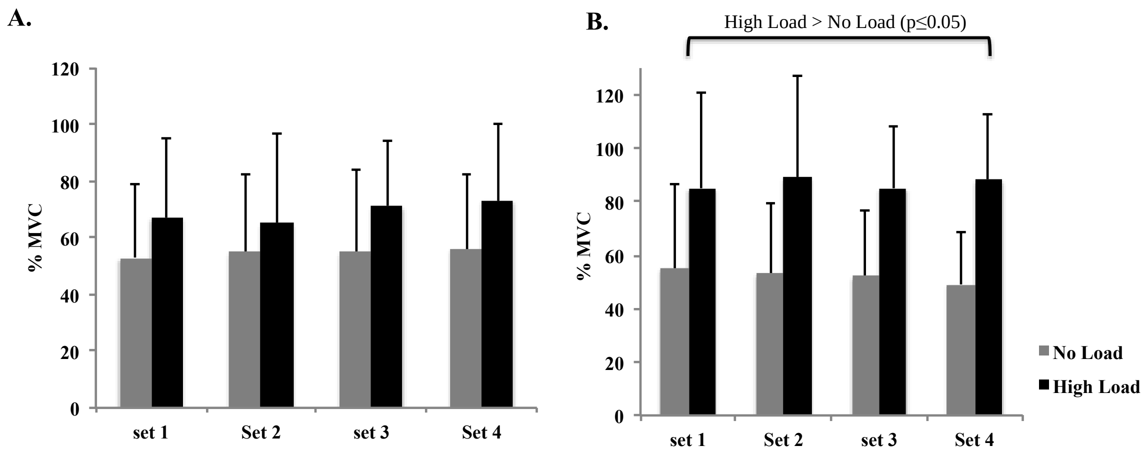
Biceps Brachii

Mean values for the EMG amplitude of the biceps brachii is presented in Table 9. EMG amplitude was analyzed on the average of the first three repetitions and the average of the last three repetitions, expressed as percentage of the MVC. For the first three repetitions, there was no condition x time interaction (p=0.423), main effect of condition (p=0.239) or main effect of time (p=0.207, Figure 18A). For the last three repetitions, there was no condition x time interaction (p=0.423) or main effect of time (p=0.679), but there was a main effect of condition (p=0.019), such that High Load was greater than No Load for the last three repetitions for all sets (Figure 18B).

Table 9: Mean EMG amplitude of the biceps brachii during the first 3 and last 3 repetitions of each set, expressed as % MVC. Conditions with different letters represent significance differences between conditions (p≤0.05).

Repetitions		Set 1	Set 2	Set 3	Set 4
First 3	**No Load**	53 (26)	55 (27)	55 (29)	56 (26)
	High Load	67 (28)	65 (32)	71 (23)	73 (27)
Last 3	**No Load**[a]	55 (32)	55 (26)	52(26)	49 (20)
	High Load[b]	89 (36)	89 (38)	85 (23)	88 (25)

Figure 18: Mean EMG amplitude of the biceps brachii for the first 3 repetitions (A) and last 3 repetitions (B) of each set, expressed as % MVC. There was main effect of condition during the last three repetitions; High Load was greater than No Load.



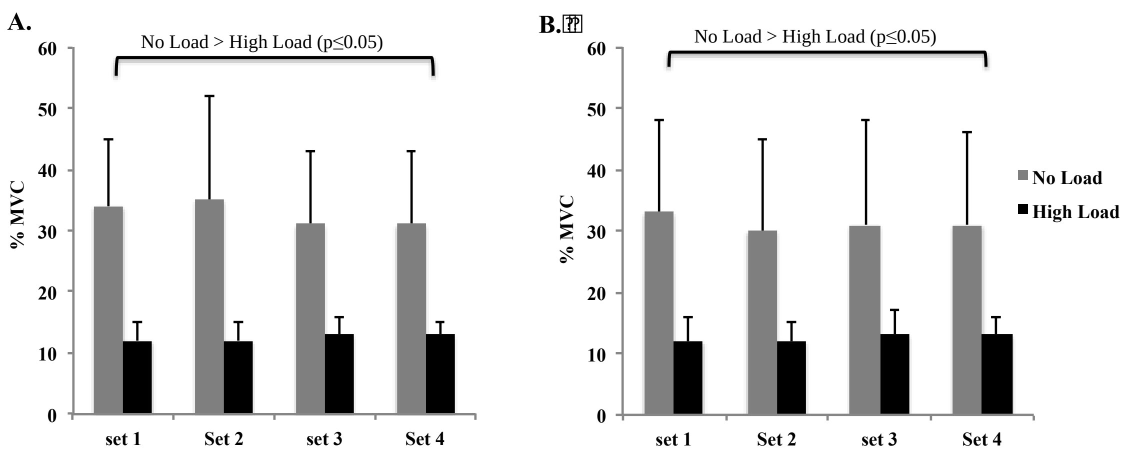
Triceps Brachii

Mean values for the EMG amplitude of the triceps brachii is presented in Table 10. EMG amplitude was analyzed on the average of the first three repetitions and the average of the last three repetitions, expressed as percentage of the MVC. For the first three repetitions, there was no condition x time interaction (p=0.336, Figure 19A) or main effect of time (p=0.392), however, there was a main effect of condition (p≤0.001) such that No Load was greater than High Load during the first three repetitions for all sets. For the last three repetitions, there was no condition x time interaction, (p=0.336, Figure 19B) or main effect of time (p=0.392), but there was a main effect of condition (p=0.001) such that No Load was greater than High Load for the last three repetitions for all sets.

Table 10: Mean EMG amplitude for the triceps brachii of the first three and last three repetitions of each set, expressed as %MVC. Conditions with different letters represent significant differences between conditions (p≤0.05), *a* was greater than *b*.

Repetitions		Set 1	Set 2	Set 3	Set 4
First 3	**No Load[a]**	34(11)	35(17)	31(12)	34(12)
	High Load[b]	10(3)	9(3)	10(3)	10(2)
Last 3	**No Load [a]**	33(15)	30(15)	31(17)	31(15)
	High Load[b]	12(4)	12(3)	13(4)	13(3)

Figure 19: Mean EMG amplitude for the triceps brachii of the first three repetitions (A) and last three repetitions (B) of each set, expressed as %MVC. There was main effect of condition during the first and last three repetitions; No Load was greater than High Load for all sets.



CHAPTER 5. DISCUSSION

This study suggests that muscle growth can occur without the use of body weight or an external load if you contract the muscle maximally through a full range of motion. Though more variable at the individual level, the increase in muscle size following No Load training was similar to that observed following traditional High Load training at the overall group level. Additionally, we found that posterior arm muscle size decreased in the High Load condition, but remained unchanged in the No Load condition. Tests of muscle strength and endurance increased more in the High Load condition and may be due to the specificity of the tests employed. Acute measurements of muscle swelling and muscle fatigue were similar between No Load and High Load conditions. Biceps brachii electromyography (EMG) amplitude was greater for the last three repetitions in the High Load condition compared to the No Load condition. The triceps brachii EMG amplitude was greater for the first three repetitions and the last three repetitions in the No Load condition compared to the High Load condition.

Main Findings

1. Muscle size of the anterior upper arm increased from pre to post training in the No Load condition and the High Load condition.
2. Muscle size of the posterior upper arm decreased from pre to post training in the High Load condition, but was maintained in the No Load condition.

3. One repetition maximum (1RM) strength increased pre to post training in both conditions, but the High Load condition increased more than the No Load condition.
4. Muscle endurance increased in the High Load condition from pre to post training, whereas the No Load condition remained unchanged.
5. Acute measurements of muscle fatigue and muscle swelling were similar between the No Load and High Load conditions.
6. EMG amplitude for the biceps brachii was greater during the last three repetitions for the High Load condition compared to the No Load condition.
7. EMG amplitude for the triceps brachii was greater during the first three and last three repetitions for the No Load condition compared to the High Load condition.

Chronic Measurements

Muscle Thickness

As hypothesized, anterior upper arm muscle thickness increased following No Load training without the use of body weight or an external load as a form of resistance. This increase in muscle size was similar to the High Load condition, which is a stimulus known to increase muscle size (Mitchell et al., 2012; Ogasawara et al., 2012; Pyka et al., 1994). Our findings further support the Maeo et al (2014b) investigation which found that maximal isometric contractions held at 90° elbow flexion can increase muscle size following 12 weeks of training, despite not using an external load. This is in contrast to their earlier study that did not observe measurable increases in muscle size (Maeo, Yoshitake, Takai, Fukunaga, & Kanehisa, 2014a) which may be due to the shorter training duration (4 weeks). However, this "No Load" model had never been tested through the full range of motion, which better replicates traditional exercise nor was this method compared to another exercising group. Our findings extend those of Maeo et al. and suggest that maximally contracting a muscle through the full range of motion produces a growth stimulus similar to that of high load resistance training.

When comparing the individual muscle thicknesses from pre to post training, there appeared to be greater variability in the No Load condition compared to the High Load condition. During the No Load condition we utilized visual feedback, which allowed us to encourage the participant to "squeeze" harder. Despite using visual feedback, it is conceivable that the participants were still not contracting maximally. For example, high muscle activation is a requisite for successful completion of the movement in the High Load condition. Thus, the inability to quantify "tension" of the No Load condition may provide some explanation for the variability in muscle size between conditions.

Despite No Load's greater variability, the group level change supports Rennie et al. (2004) suggestion that muscle growth is mediated by mechanotransduction, which describes the process whereby local mechanical tension activates hypertrophic pathways within the muscle. Our findings and the addition of those that resistance trained with protocols using low loads to failure (Mitchell et al., 2012; Ogasawara et al., 2012; Pyka et al., 1994), low loads with blood flow restriction (Loenneke, Abe, et al., 2012), different muscle actions (Farup et al., 2015; Ikai & Fukunaga, 1970) and the recent work of Maeo et al (2014) suggest that the external load is of little importance as long as there is sufficient tension.

With respect to posterior upper arm muscle thickness, we were surprised to find that the High Load condition decreased from pre to post training. This is in contrast to the No Load condition that remained unchanged. This finding in the No Load condition is similar to Maeo et al. (2014a) who reported no change in triceps size after four weeks of maximally contracting at 90 degrees without the use of an external load. Interestingly, a follow-up study of longer duration (12 weeks) (Maeo, Yoshitake, Takai, Fukunaga, & Kanehisa, 2014b) found an increase in triceps muscle size at the 60% site. Our lack of change may be due to study duration which was only half that of the Maeo et al. investigation. It is possible that by extending the study duration, measurable increases in triceps muscle thickness may have occurred. The discrepancy may also be explained by differences in muscle activation across studies. For example, Maeo et al. (2014b) reported triceps brachii EMG amplitude to be roughly 60 %MVC whereas our protocol elicited roughly 30% of "maximal" activation.

For the High Load condition, the decrease in posterior muscle thickness following training was not expected. To our knowledge, there are no studies that investigated High Load resistance training that targeted the biceps brachii and measured muscle size of the biceps brachii and triceps brachii. On the surface it may seem that the triceps brachii muscle size loss in the High Load condition may be of some relation to the triceps brachii EMG amplitude being significantly less in the High Load condition compared to the No Load condition. Despite this lower EMG amplitude of the triceps brachii in the High Load condition, we expected that muscle thickness would have at least been maintained given that our population was ambulatory. It is possible that this was an error, however, we are confident in our measurement given that our tester was blinded to the condition during analysis of each image and that the decrease only occurred following High Load training. Thus, we are presently unable to provide adequate reasoning as to the triceps brachii muscle loss following High Load training and future studies should investigate this further.

Strength and Endurance

In agreement with our hypothesis, the No Load condition and the High Load condition increased maximal isotonic strength from pre to post training, however, the strength increase was greater in the High Load condition. This was not surprising given that high load training is known to increase isotonic strength (Mitchell et al., 2012; Pyka et al., 1994; Wernbom et al., 2007) and the participants in the High Load condition had repeated practice of lifting an external load during training. Despite the No Load condition not lifting a dumbbell in six weeks, the increase in isotonic strength suggests that a sufficient stimulus was provided. The discrepancy in isotonic strength increases can likely be explained by test specificity. For example, previous findings suggest that those that were tested with a task that most closely resembled the condition repeatedly practiced during training, increased the most in that task (e.g. lifting heavy load in a particular lift and testing their highest load achieved in that lift) (Pipes & Wilmore, 1975; Symons et al., 2005; Ward & Fisk, 1964). Therefore, an additional strength test that better replicates the No Load condition may provide a more fair comparison of strength.

We employed isokinetic and isometric dynamometry to try and circumvent the subjective nature of the strength test. With respect to the first isokinetic test at 180°/sec there were no changes from pre to post training for the No Load condition and the High Load condition which may be due to the speed of the test. Increases in torque at 180°/sec have been observed in previous resistance training studies, but these studies used a faster training cadence which may be more specific to the test (Counts et al., 2016). For the isokinetic strength test at 60°/sec, the High Load condition increased torque which appears to suggest that the High Load condition elicited superior strength adaptations. However, the No Load condition never pulled against an external load during training and this may explain the lack of change in torque at this velocity. Regarding the isometric test, the similar torque increase in both conditions suggests that this test may have been more replicable of the condition practiced. For example, the participants during No Load training appeared to squeeze the hardest at the end of the concentric portion, closely replicating the 90° isometric test. These findings are in line with previous reports of increases in isometric torque at 90° elbow flexion following isometric "No Load" training (MacKenzie, Rannelli, & Yurchevich, 2010; Maeo et al., 2014b).

Regarding our test of muscle endurance, we expected to find an increase in both conditions with the No Load condition increasing more than the High Load condition due to completing more repetitions each training session. However, lifting with an external load may have a greater influence on a test where you have to lift an external load and this further compliments the idea that specificity of testing is important. In regards to the High Load condition, the increased repetitions were expected, as previous studies have increased endurance performance while training with an external load (Campos et al., 2002; Counts et al., 2016). Therefore, an alternative test to measure endurance performance from pre to post training could be of importance. Overall, we have provided evidence that strength and performance test outcomes are subjective to the condition most practiced.

Perceptual Responses

Overall, the RPE and discomfort ratings were similar between conditions for each set of exercise. However, RPE for the No Load condition was significantly higher than the High Load condition during the first set for all sessions and suggests that it is a slightly greater perceived stimulus. However, these median differences were minimal (No Load 11; High Load 10) and the meaningfulness of this difference is presently unknown. The RPE comparisons of traditional high loads to moderate loads have been associated with higher RPE's for the high load condition despite completing less work (Day, McGuigan, Brice, & Foster, 2004). When traditional high loads were compared to low loads taken to failure, the ratings appear similar despite one condition lifting a higher external load (Loenneke et al., 2015). While studies most similar to No Load training did not measure perceptual responses, our ratings here appear to be similar to those observed with low loads taken to failure (Loenneke et al., 2015). This may be due to the participants having to repeatedly maximally contract or possibly the longer duration of each set.

Ratings of discomfort were statistically different during the first set of Sessions 1-9, but there was no median difference between the No Load condition and the High Load condition (0.5 for both conditions). These ratings of discomfort appear to be lower than that previously reported (Loenneke et al., 2015) but these previous ratings were in the lower body. The ratings of discomfort observed in the present study appear to be negligible and would be unlikely to negatively influence participation or completion of the exercises.

Acute Measurements

Acute muscle swelling was of interest given that transient increases are suggested to increase signaling of anabolic/anti-catabolic pathways and this acute muscle swelling has previously been associated with long term muscle growth (Ploutz-Snyder et al., 1995). For example, Yasuda et al. (2012) found that the arm that had the greatest increase in acute muscle swelling had greater muscle growth than the contralateral arm that had less swelling. We observed a similar acute muscle swelling response in the No Load condition and the High Load condition of the anterior upper arm and observed similar increases in long term anterior upper arm muscle size. Although retrospective in nature, it stands to reason that the acute muscle swelling response may, in part, be of some importance for muscle growth.

Regarding fatigability, transient decrements in torque are associated with fatigue (Clarkson & Sayers, 1999) as the muscle fatigues it is believed to recruit higher threshold muscle fibers (Rudroff et al., 2008). In this study, we found similar acute decrements in torque and similar increases in muscle size which compliments the previous association that protocols producing similar decrements in torque (Loenneke et al., 2015) may elicit similar increases in muscle size (Counts et al., 2016). With respect to EMG amplitude, increases may indicate higher threshold fiber recruitment and recruitment of these fibers appears to be important for significant muscle growth (Agergaard et al., 2013; Morton, McGlory, & Phillips, 2015). It has been previously demonstrated that high load's elicit higher EMG amplitudes than lower loads with or without blood flow restriction (Loenneke et al., 2015). Further, as the muscle becomes fatigued more fibers are recruited in order to continue lifting the load, which may explain the higher EMG amplitudes in the High Load condition compared to the No Load condition in the last three repetitions. However, surface EMG amplitudes are not a direct measure of muscle activation and may be partially impacted by motor unit cycling (Vigotsky, Ogborn, & Phillips, 2015). Despite these differences in surface EMG, muscle growth at the group level was similar between the No Load condition and the High Load condition.

The lower triceps brachii EMG amplitude during the High Load condition may largely be due to the muscle action itself with an external load targeting the biceps more than the triceps. Recently, Maeo et al. (2014) measured triceps brachii EMG amplitude during elbow flexion held at 90° which produced a triceps EMG amplitude of roughly 60 %MVC. This finding may explain why they observed muscle growth in the posterior upper arm and we did not. In the present study, our triceps EMG amplitude was roughly 30 %MVC for the No Load condition, and this may be too low to meaningfully impact muscle growth. Maeo et al. (2014) suggested that amplitudes of 40-60 %MVC may need to be reached in order to impact muscle growth. However, it should also be considered that their study was 12 weeks in duration whereas ours was six.

CHAPTER 6. CONCLUSION

In conclusion, this study compared the acute skeletal muscle responses (muscle swelling, muscle fatigue and EMG amplitude) and long term muscle adaptations (size, strength and endurance) to No Load and High Load resistance exercise. In addition, we reported median ratings of perceived exertion and discomfort for each condition during all training sessions. The main research question for this study was to determine if long term muscle growth from maximally contracting a muscle through the full range of motion can increase muscle size, and if so, how does that compare to the robust stimulus of traditional High Load training.

Hypotheses

1. **The No Load condition and the High Load condition would produce a similar response in muscle swelling, muscle fatigue and muscle activation.**

   This hypothesis was partially supported by our results. There was a similar acute increase in muscle swelling, similar decrements in torque and similar biceps brachii EMG amplitudes for the first three repetitions. The biceps brachii EMG amplitudes for the last three repetitions was higher in the High Load condition than the No Load condition. In addition, the triceps brachii EMG amplitudes for the first three and the last three repetitions was higher for the No Load condition than the High Load condition.

2. **The muscle growth response would be similar between the No Load condition and the High Load condition.**

   This hypothesis was partially supported by our results. Anterior arm muscle thickness at the 50%, 60% and 70% sites increased similarly in the No Load condition and the High Load condition. The posterior arm muscle thickness remained unchanged for the 50% and 60% sites in the No Load condition but decreased in the High Load condition. The posterior arm muscle thickness at the 70% site was maintained in both conditions.

3. **The one repetition maximum (RM) strength response would increase in the No Load condition and the High Load condition, and the High Load condition's 1RM strength response would be greater in comparison to the No Load condition due to the principle of specificity.**

   This hypothesis was supported by our results. The High Load condition and the No Load condition increased 1RM strength, and the High Load condition increased more than the No Load condition.

4. **The isokinetic and isometric strength responses would be similar between the No Load condition and the High Load condition given that neither condition would be familiar with isokinetic and isometric testing.**

   This hypothesis is partially supported by our results. Isokinetic strength test at 180°/sec remained unchanged in the No Load condition and the High Load condition. Isokinetic strength test at 60°/sec increased in the High Load condition, but remained unchanged in the No Load condition. Isometric strength at 90° increased similarly in the No Load condition and the High Load condition.

5. **The muscle endurance response would increase in the No Load condition and the High Load condition, and the No Load condition would increase more than the High Load condition because the No Load condition would be completing more repetitions each training session.**

   This hypothesis was not supported by our results. The High Load condition increased repetitions completed whereas the No Load condition remained unchanged.

Significance

Skeletal muscle is necessary for all daily movements as well as being the largest disposal site within the human body for glucose; therefore increasing/maintaining skeletal muscle size is of importance. This study provides an additional method to increase muscle size through the use of No Load training, which was similar to that of traditional high load resistance training. Therefore, populations that are prone to muscle atrophy may benefit from the use of No Load training. For example, No Load training may provide a method to counteract muscle loss observed in zero gravity environments with an added benefit of not requiring an increase in pay load. In addition, No Load training may benefit those that have an injury to their wrist that limits their ability to lift an external load. While No Load training may seem valuable for bed rest populations or those that have cachexia, certain clinical populations may not be able to elicit a sufficient stimulus for muscle growth.

Future Research

Follow up studies should further investigate No Load training as well as other methodologies that may reduce the variability observed in muscle growth. Additionally, further studies could investigate No Load training during zero gravity environments and in those that have had an injury to the wrist. With respect to clinical populations, future investigations could determine if this population is able to produce a sufficient stimulus to increase muscle size. Also, future research could explore the decrease in posterior upper arm muscle size following High Load training. If this is in fact a true finding, it would suggest a need to train the triceps brachii along with the biceps brachii to ensure that no imbalances are created.

BIBLIOGRAPHY

Abe T, Kondo M, Kawakami Y, Fukunaga T. Prediction equations for body composition of Japanese adults by B-mode ultrasound. American Journal of Human Biology 1994; 6: 161-170.

Abe, T., DeHoyos, D. V., Pollock, M. L., & Garzarella, L. (2000). Time course for strength and muscle thickness changes following upper and lower body resistance training in men and women. *Eur J Appl Physiol, 81*(3), 174-180. doi:10.1007/s004210050027

Agergaard, J., Reitelseder, S., Pedersen, T. G., Doessing, S., Schjerling, P., Langberg, H., . . . Holm, L. (2013). Myogenic, matrix, and growth factor mRNA expression in human skeletal muscle: effect of contraction intensity and feeding. *Muscle Nerve, 47*(5), 748-759. doi:10.1002/mus.23667

Akima, H., Takahashi, H., Kuno, S. Y., Masuda, K., Masuda, T., Shimojo, H., . . . Katsuta, S. (1999). Early phase adaptations of muscle use and strength to isokinetic training. *Med Sci Sports Exerc, 31*(4), 588-594.

American College of Sports Medicine. (2009). American college of sports medicine position stand progression models in resistance training for healthy adults. Medicine and Science in Sports and Exercise, 41(3), 687-708. doi:10.1249/MSS.0b013e3181915670 [doi]

Bemben, D. A., Fetters, N. L., Bemben, M. G., Nabavi, N., & Koh, E. T. (2000). Musculoskeletal responses to high- and low-intensity resistance training in early postmenopausal women. *Med Sci Sports Exerc, 32*(11), 1949-1957.

Bodine, S. C., Stitt, T. N., Gonzalez, M., Kline, W. O., Stover, G. L., Bauerlein, R., . . . Yancopoulos, G. D. (2001). Akt/mTOR pathway is a crucial regulator of skeletal muscle hypertrophy and can prevent muscle atrophy in vivo. *Nat Cell Biol, 3*(11), 1014-1019. doi:10.1038/ncb1101-1014

Campos, G. E., Luecke, T. J., Wendeln, H. K., Toma, K., Hagerman, F. C., Murray, T. F., . . . Staron, R. S. (2002). Muscular adaptations in response to three different resistance-training regimens: specificity of repetition maximum training zones. *Eur J Appl Physiol, 88*(1-2), 50-60. doi:10.1007/s00421-002-0681-6

Charette, S. L., McEvoy, L., Pyka, G., Snow-Harter, C., Guido, D., Wiswell, R. A., & Marcus, R. (1991). Muscle hypertrophy response to resistance training in older women. *J Appl Physiol (1985), 70*(5), 1912-1916.

Clarkson, P. M., & Sayers, S. P. (1999). Etiology of exercise-induced muscle damage. *Can J Appl Physiol, 24*(3), 234-248.

Counts, B. R., Dankel, S. J., Barnett, B. E., Kim, D., Mouser, J. G., Allen, K. M., . . . Loenneke, J. P. (2016). Influence of relative blood flow restriction pressure on muscle activation and muscle adaptation. *Muscle Nerve, 53*(3), 438-445. doi:10.1002/mus.24756

Davies, J., Parker, D. F., Rutherford, O. M., & Jones, D. A. (1988). Changes in strength and cross sectional area of the elbow flexors as a result of isometric strength training. *Eur J Appl Physiol Occup Physiol, 57*(6), 667-6

Day, M. L., McGuigan, M. R., Brice, G., & Foster, C. (2004). Monitoring exercise intensity during resistance training using the session RPE scale. *J Strength Cond Res, 18*(2), 353-358. doi:10.1519/R-13113.1

Drummond MJ, Fry CS, Glynn EL, Dreyer HC, Dhanani S, Timmerman KL, Volpi E, Rasmussen BB. Rapamycin administration in humans blocks the contraction-induced increase in skeletal muscle protein synthesis. The Journal of Physiology 2009; 587(7): 1535-1546.

Esposito, F., Ce, E., Gobbo, M., Veicsteinas, A., & Orizio, C. (2005). Surface EMG and mechanomyogram disclose isokinetic training effects on quadriceps muscle in elderly people. *Eur J Appl Physiol, 94*(5-6), 549-557. doi:10.1007/s00421-005-1371-y

Farup, J., de Paoli, F., Bjerg, K., Riis, S., Ringgard, S., & Vissing, K. (2015). Blood flow restricted and traditional resistance training performed to fatigue produce equal muscle hypertrophy. *Scand J Med Sci Sports, 25*(6), 754-763. doi:10.1111/sms.12396

Fitts, R. H., Trappe, S. W., Costill, D. L., Gallagher, P. M., Creer, A. C., Colloton, P. A., . . . Riley, D. A. (2010). Prolonged space flight-induced alterations in the structure and function of human skeletal muscle fibres. *J Physiol, 588*(Pt 18), 3567-3592. doi:10.1113/jphysiol.2010.188508

Fry, C. S., Lee, J. D., Jackson, J. R., Kirby, T. J., Stasko, S. A., Liu, H., . . . Peterson, C. A. (2014). Regulation of the muscle fiber microenvironment by activated satellite cells during hypertrophy. *FASEB J, 28*(4), 1654-1665. doi:10.1096/fj.13-239426

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol, 10*(5), 361-374.

Housh, D. J., Housh, T. J., Johnson, G. O., & Chu, W. K. (1992). Hypertrophic response to unilateral concentric isokinetic resistance training. *J Appl Physiol (1985), 73*(1), 65-70.

Hubal, M. J., Gordish-Dressman, H., Thompson, P. D., Price, T. B., Hoffman, E. P., Angelopoulos, T. J., . . . Clarkson, P. M. (2005). Variability in muscle size and strength gain after unilateral resistance training. *Med Sci Sports Exerc, 37*(6), 964-972.

Ikai, M., & Fukunaga, T. (1970). A study on training effect on strength per unit cross-sectional area of muscle by means of ultrasonic measurement. *Int Z Angew Physiol, 28*(3), 173-180.

Ikezoe, T., Mori, N., Nakamura, M., & Ichihashi, N. (2012). Effects of age and inactivity due to prolonged bed rest on atrophy of trunk muscles. *Eur J Appl Physiol, 112*(1), 43-48. doi:10.1007/s00421-011-1952-x

Ivy, J. L., Lee, M. C., Brozinick, J. T., Jr., & Reed, M. J. (1988). Muscle glycogen storage after different amounts of carbohydrate ingestion. *J Appl Physiol (1985), 65*(5), 2018-2023.

Johns, N., Stephens, N. A., & Fearon, K. C. (2013). Muscle wasting in cancer. *Int J Biochem Cell Biol, 45*(10), 2215-2229. doi:10.1016/j.biocel.2013.05.032

Jones, D. A., & Rutherford, O. M. (1987). Human muscle strength training: the effects of three different regimens and the nature of the resultant changes. *J Physiol, 391*, 1-11.

Kosek, D. J., Kim, J. S., Petrella, J. K., Cross, J. M., & Bamman, M. M. (2006). Efficacy of 3 days/wk resistance training on myofiber hypertrophy and myogenic mechanisms in young vs. older adults. *J Appl Physiol (1985), 101*(2), 531-544. doi:10.1152/japplphysiol.01474.2005

Kraemer WJ, Staron RS, Hagerman FC, Hikida RS, Fry AC, Gordon SE, Nindl BC, Gothshalk LA, Volek JS, Marx JO, Newton RU, Hakkinen K. The effects of short-term resistance training on endocrine function in men and women. European Journal of Applied Physiology 1998; 78: 69-76.

Loenneke, J. P., Abe, T., Wilson, J. M., Thiebaud, R. S., Fahs, C. A., Rossow, L. M., & Bemben, M. G. (2012). Blood flow restriction: an evidence based progressive model (Review). *Acta Physiol Hung, 99*(3), 235-250. doi:10.1556/APhysiol.99.2012.3.1

Loenneke, J. P., Fahs, C. A., Rossow, L. M., Abe, T., & Bemben, M. G. (2012). The anabolic benefits of venous blood flow restriction training may be induced by muscle cell swelling. *Med Hypotheses, 78*(1), 151-154. doi:10.1016/j.mehy.2011.10.014

Loenneke, J. P., Kim, D., Fahs, C. A., Thiebaud, R. S., Abe, T., Larson, R. D., . . . Bemben, M. G. (2015). Effects of exercise with and without different degrees of blood flow restriction on torque and muscle activation. *Muscle Nerve, 51*(5), 713-721. doi:10.1002/mus.24448

MacKenzie, S. J., Rannelli, L. A., & Yurchevich, J. J. (2010). Neuromuscular adaptations following antagonist resisted training. *J Strength Cond Res, 24*(1), 156-164. doi:10.1519/JSC.0b013e3181bd4317

Maeo, S., Yoshitake, Y., Takai, Y., Fukunaga, T., & Kanehisa, H. (2014a). Effect of short-term maximal voluntary co-contraction training on neuromuscular function. *Int J Sports Med, 35*(2), 125-134. doi:10.1055/s-0033-1349137

Maeo, S., Yoshitake, Y., Takai, Y., Fukunaga, T., & Kanehisa, H. (2014b). Neuromuscular adaptations following 12-week maximal voluntary co-contraction training. *Eur J Appl Physiol, 114*(4), 663-673. doi:10.1007/s00421-013-2801-x

Masterson DW. The Ancient Greek Origins of Sports Medicine. British Journal of Sports Medicine 1976; (10)4: 196-202.

Matta, T. T., Nascimento, F. X., Trajano, G. S., Simao, R., Willardson, J. M., & Oliveira, L. F. (2015). Selective hypertrophy of the quadriceps musculature after 14 weeks of isokinetic and conventional resistance training. *Clin Physiol Funct Imaging*. doi:10.1111/cpf.12277

McCarthy, J. J., Mula, J., Miyazaki, M., Erfani, R., Garrison, K., Farooqui, A. B., . . . Peterson, C. A. (2011). Effective fiber hypertrophy in satellite cell-depleted skeletal muscle. *Development, 138*(17), 3657-3666. doi:10.1242/dev.068858

Michaut, A., Pousson, M., Millet, G., Belleville, J., & Van Hoecke, J. (2003). Maximal voluntary eccentric, isometric and concentric torque recovery following a concentric isokinetic exercise. *Int J Sports Med, 24*(1), 51-56. doi:10.1055/s-2003-37199

Mitchell, C. J., Churchward-Venne, T. A., West, D. W., Burd, N. A., Breen, L., Baker, S. K., & Phillips, S. M. (2012). Resistance exercise load does not determine training-mediated hypertrophic gains in young men. *J Appl Physiol (1985), 113*(1), 71-77. doi:10.1152/japplphysiol.00307.2012

Morgan, J. E., & Partridge, T. A. (2003). Muscle satellite cells. *Int J Biochem Cell Biol, 35*(8), 1151-1156.

Morton, R. W., McGlory, C., & Phillips, S. M. (2015). Nutritional interventions to augment resistance training-induced skeletal muscle hypertrophy. *Front Physiol, 6*, 245. doi:10.3389/fphys.2015.00245

Narici, M. V., Roi, G. S., Landoni, L., Minetti, A. E., & Cerretelli, P. (1989). Changes in force, cross-sectional area and neural activation during strength training and detraining of the human quadriceps. *Eur J Appl Physiol Occup Physiol, 59*(4), 310-319.

Ogasawara, R., Thiebaud, R. S., Loenneke, J. P., Loftin, M., & Abe, T. (2012). Time course for arm and chest muscle thickness changes following bench press training. *Interv Med Appl Sci, 4*(4), 217-220. doi:10.1556/IMAS.4.2012.4.7

Petrella, J. K., Kim, J. S., Mayhew, D. L., Cross, J. M., & Bamman, M. M. (2008). Potent myofiber hypertrophy during resistance training in humans is associated with satellite cell-mediated myonuclear addition: a cluster analysis. *J Appl Physiol (1985), 104*(6), 1736-1742. doi:10.1152/japplphysiol.01215.2007

Phillips, S. M. (2004). Protein requirements and supplementation in strength sports. *Nutrition, 20*(7-8), 689-695. doi:10.1016/j.nut.2004.04.009

Pipes, T. V., & Wilmore, J. H. (1975). Isokinetic vs isotonic strength training in adult men. *Med Sci Sports, 7*(4), 262-274.

Ploutz-Snyder, L. L., Convertino, V. A., & Dudley, G. A. (1995). Resistance exercise-induced fluid shifts: change in active muscle size and plasma volume. *Am J Physiol, 269*(3 Pt 2), R536-543.

Pyka, G., Lindenberger, E., Charette, S., & Marcus, R. (1994). Muscle strength and fiber adaptations to a year-long resistance training program in elderly men and women. *J Gerontol, 49*(1), M22-27.

Rennie, M. J., Wackerhage, H., Spangenburg, E. E., & Booth, F. W. (2004). Control of the size of the human muscle mass. *Annu Rev Physiol, 66*, 799-828. doi:10.1146/annurev.physiol.66.052102.134444

Rudroff, T., Staudenmann, D., & Enoka, R. M. (2008). Electromyographic measures of muscle activation and changes in muscle architecture of human elbow flexors during fatiguing contractions. *J Appl Physiol (1985), 104*(6), 1720-1726. doi:10.1152/japplphysiol.01058.2007

Senay, L. C., Jr., & Pivarnik, J. M. (1985). Fluid shifts during exercise. *Exerc Sport Sci Rev, 13*, 335-387.

Stojijkovic N, Ifnjatovic A. Savic Z, MarkovicZ, Milanovic S. History of Resistance Training. Acitvities in Physical Education and Sport 2013; 3(1): 135-138.
Todd J. From Milo to Milo: A History of Barbells, Dumbells, and Indiana Clubs. 1995; 3(6): 4-16.

Symons, T. B., Vandervoort, A. A., Rice, C. L., Overend, T. J., & Marsh, G. D. (2005). Effects of maximal isometric and isokinetic resistance training on strength and functional mobility in older adults. *J Gerontol A Biol Sci Med Sci, 60*(6), 777-781.

Todd, J. From Milo to Milo: A History of Barbells, Dumbbells, and Indian Clubs. Iron Game History 1995; 3(6): 4-16.

Vandenburgh, H., Chromiak, J., Shansky, J., Del Tatto, M., & Lemaire, J. (1999). Space travel directly induces skeletal muscle atrophy. *FASEB J, 13*(9), 1031-1038.

Vigotsky, A. D., Ogborn, D., & Phillips, S. M. (2015). Motor unit recruitment cannot be inferred from surface EMG amplitude and basic reporting standards must be adhered to. *Eur J Appl Physiol*. doi:10.1007/s00421-015-3314-6

Ward, J., & Fisk, G. H. (1964). The Difference in Response of the Quadriceps and the Biceps Brachii Muscles to Isometric and Isotonic Exercise. *Arch Phys Med Rehabil, 45*, 614-620.

Warren, G. L., Lowe, D. A., & Armstrong, R. B. (1999). Measurement tools used in the study of eccentric contraction-induced injury. *Sports Med, 27*(1), 43-59.

Wernbom, M., Augustsson, J., & Thomee, R. (2007). The influence of frequency, intensity, volume and mode of strength training on whole muscle cross-sectional area in humans. *Sports Med, 37*(3), 225-264.

West, D. W., Burd, N. A., Tang, J. E., Moore, D. R., Staples, A. W., Holwerda, A. M., . . . Phillips, S. M. (2010). Elevations in ostensibly anabolic hormones with resistance exercise enhance neither training-induced muscle hypertrophy nor strength of the elbow flexors. *J Appl Physiol (1985), 108*(1), 60-67. doi:10.1152/japplphysiol.01147.2009

Wilkinson, S. B., Tarnopolsky, M. A., Grant, E. J., Correia, C. E., & Phillips, S. M. (2006). Hypertrophy with unilateral resistance exercise occurs without increases in endogenous anabolic hormone concentration. *Eur J Appl Physiol, 98*(6), 546-555. doi:10.1007/s00421-006-0300-z

Yasuda, T., Loenneke, J. P., Thiebaud, R. S., & Abe, T. (2012). Effects of blood flow restricted low-intensity concentric or eccentric training on muscle size and strength. *PLoS One, 7*(12), e52843. doi:10.1371/journal.pone.0052843

VITAE

EDUCATION

2009-2014 Bachelor of Science, Exercise Science
West Chester University, West Chester, PA

PROFESSIONAL EXPERIENCE

2015-Present Graduate Assistant Graduate School: Send acceptance letters and denial notifications to all graduate studies, and scan/upload transcripts.

PEER REVIEWED PUBLICATIONS

1.Abe, T, **Counts, B**, Barnett B, Dankel, S, Lee, K., and Loenneke, J. Associations Between Handgrip Strength and Ultrasound-Measured Muscle Thickness of the Hand and Forearm in Young Men and Women. *Ultrasound in Medicine and Biology,* 41(8):2125-2130. (2015).

2.Barnett, B., Dankel, S., **Counts, B**., Nooe, A., Abe, T, and Loenneke, J. Blood flow occlusion pressure at rest and immediately after a bout of low load exercise. *Clinical Physiology and Functional Imaging*. doi: 10.1111/cpf.12246 (2015).

3.**Counts, B,** Dankel, S, Barnett, B, Daeyeol, K., Mouser, G, Allen, K., Thiebaud, R, Abe, T., Bemben, M., and Loenneke, J. The Influence of blood flow restriction pressure on muscle adaptation. *Muscle and Nerve*: 53(3):438-445. (2016).

4.Buckner, SL, Abe, T, **Counts, BR**, Dankel, SL, Barnet, B, and Loenneke, JP. Muscle and Fat Mapping of the Trunk: A Case Study. *Journal of Ultrasound:* 18(4): 399-405.

5.Jessee MB, Buckner, SL, Dankel, SJ. **Counts, BR**., Abe, T., Loenneke, JP. The Influence of Cuff Width, Sex, and Race on Arterial Occlusion: Implications for Blood Flow Restriction Research. *Sports Medicine (2016)*

6.Buckner SL, Dankel SJ, **Counts BR**, Barnett BE, Jessee MB, Mouser JG, Halliday TM, Loenneke JP. Are there rhythms in elbow flexor torque, oral temperature and muscle thickness during normal waking hours? *Physiology and Behavior (2016)*

7. Mattocks KT, Dankel SJ, Mouser JG, Buckner SL, Jessee MB, **Counts BR**, Laurentino GC, Loenneke JP. Periodization: What is it good for

IN REVIEW

1. Dankel S, **Counts B,** Barnett, B., Buckner, S., Abe, T., Zourdos, M., and Loenneke, J. Muscle adaptations following short term high-frequency resistance training: A case series.

2. Ingram JW, Buckner SL, Dankel SJ, **Counts BR,** Mouser G, Abe, T., Laurentino, GC., Loenneke, JP. The Influence of Time on Determining Blood Flow Restriction Pressure.

3. **Counts, BR**, Loenneke, JP, Loprinzi PD. Objectively-measured physical activity associated with heart rate recovery: NHANES.

4. Mouser G, Buckner SL, **Counts BR,** Dankel SJ, Jessee MB, Mattocks K, Laurentino GC, Loenneke JP. Venous or Arterial Blood Flow Restriction: The Impact of Cuff Width.

5. Buckner SL, Dankel SJ, **Counts BR,** Jessee MB, Mouser JG, Mattock KT, Laurentino GC, Abe T, Loenneke JP. The Influence of Cuff Material on Blood Flow Restriction Stimulus in the Upper Body.

6.Dankel SJ, Buckner SL, **Counts BR,** Jessee MB, Mouser JG, Mattocks KT, Laurentino GC, Abe T, Loenneke JP. The Acute Muscular Response to Two Distinct Blood Flow Restriction Protocols.

7.**Counts BR**, Buckner SL, Dankel SJ, Jessee MB, Mattocks KT, Mouser G, Lauretino GC, Loenneke JP. The Acute and Chronic Effects of "No Load" Resistance Training.

8.Dankel SJ, Buckner SL, Jessee MB, Mattocks KT, Mouser JG, **Counts BR**, Laurentino GC, Loenneke JP. Can Blood Flow Restriction Augment Muscle Activation During High Load Training?

9.Dankel SJ, Buckner SL, Jessee MB, Mattocks KT, Mouser JG, **Counts BR,** Laurentino GC, Loenneke JP. Post-exercise blood flow restriction attenuates muscle hypertrophy.

10.**Counts BR**, Loenneke JP, Loprinzi PD. Different exercise modalities on heart rate recovery response.

11.Buckner SL, Jessee MB, Mattocks KT, Mouser JG, **Counts BR,** Dankel SJ, Loenneke JP. Determining strength: A case for multiple methods of measurement.

12. Dankel SJ, Jessee MB, Mattocks KT, Mouser JG, **Counts BR**, Buckner SL, Loenneke JP. Training to fatigue: The answer for standardization when assessing muscle hypertrophy?

SCIENTIFC ABSTRACTS/ORAL PRESENTATIONS

1. **Counts BR**, Dankel SJ, Barnett BE, Abe T, and JP Loenneke. "High Relative Pressures Do Not Augment Changes in Early Phase Muscular Adaptations during Blood Flow Restricted Exercise" American College of Sports Medicine, San Diego California, May 2015

2. Dankel SJ, Barnett BE, **Counts BR**, Nooe AL, Abe T, and JP Loenneke. "Blood Flow Occlusion Pressure At Rest And Immediately After A Bout Of Low Load Exercise" American College of Sports Medicine, San Diego California, May 2015
3. Barnett BE, Dankel SJ, **Counts BR**, Nooe AL, Abe T, and JP Loenneke. "Predictors of Standing Upper Body Arterial Occlusion: Implications for Blood Flow Restriction Research" American College of Sports Medicine, San Diego California, May 2015
4. **Counts BR**, Buckner SL, Dankel SJ, Jessee MB, Mattocks KT, Mouser JG, Laurentino GC, and Loenneke JP. The Acute Response to No Load Exercise: Is it Sufficient? ACSM National Conference, May 2016, Boston, Massachusetts.
5. Barnett BE, Buckner SL, Dankel SJ, **Counts BR,** Jessee MB, Mouser JG, Halliday TM and Loenneke JP. Circadian Rhythms in Blood Glucose and Blood Pressure: Are they Reproducible? ACSM National Conference, May 2016, Boston, Massachusetts.
6. Mouser JG, Buckner SL, **Counts BR,** Dankel SJ, Jessee MB, Mattocks KT, Laurentino GC, and Loenneke JP. Venous versus Arterial Blood Flow Restriction: The Impact of Cuff Width. ACSM National Conference, May 2016, Boston, Massachusetts.
7. Ingram JW, Buckner SL, Dankel SJ, **Counts BR,** Mouser JG, Abe T, Laurentino GC, and Loenneke JP. The influence of time on determining blood flow restriction pressure. ACSM National Conference, May 2016, Boston, Massachusetts.
8. Mattocks KT, Buckner SL, Dankel SJ, **Counts BR**, Jessee MB, Mouser JG, Laurentinio GC, Abe T, and Loenneke JP. The Influence of Cuff Material on the Blood Flow Restriction Stimulus in the Upper Body. ACSM National Conference, May 2016, Boston, Massachusetts.
9. Laurentino GC, Mouser JG, Buckner SL, **Counts BR,** Dankel SJ, Jessee MB, Mattocks KT, Loenneke JP, Tricoli V. The influence of cuff width on regional muscle growth: Implications for Blood Flow Restriction Training. ACSM National Conference, May 2016, Boston, Massachusetts.
10. Jessee MB, Buckner SL, Dankel SJ, **Counts BR,** Abe T, and Loenneke JP. The Influence of Cuff Width and Sex on Arterial Occlusion: Implications for Blood Flow Restriction Research. ACSM National Conference, May 2016, Boston, Massachusetts.
11. Loenneke JP, Buckner SL, Dankel SJ, Jessee MB, **Counts BR**, Mouser JG, Mattocks KT, Laurentino GC, and Abe T. The Influence of Cuff Material on the Acute Muscular Response to Blood Flow Restricted Exercise in the Upper Body. ACSM National Conference, May 2016, Boston, Massachusetts.
12. Buckner SL, Dankel SJ, **Counts BR,** Barnett BE, Jessee MB, Mouser JG, Halliday TM, and Loenneke JP. The Influence of Circadian Rhythms on Upper Body Isometric Strength, Muscle Thickness and Body Temperature. ACSM National Conference, May 2016, Boston, Massachusetts.
13. Dankel SJ, **Counts BR,** Barnett BE, Buckner SL, Abe T, Zourdos MC, and Loenneke JP. Muscle adaptation to 21 Straight Days of Elbow Flexor Exercise in Trained Individuals. ACSM National Conference, May 2016, Boston, Massachusetts.

LABORATORY COMPETENCIES

1. Phlebotomist
2. Biodex Testing
3. CPR/ First Aid
4. Blood Flow Restriction with Hokanson

MENTORSHIP

2014	Jeremy P. Loenneke, PhD The University of Mississippi