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Block Periodization Programming: Efficacy in Subjects of Differing Strength Levels

Paul Moquin
East Tennessee State University

Block Periodization Programming: Efficacy in Subjects of Differing Strength Levels

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by

Paul A. Moquin

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Dr. Michael Stone, Chair

Dr. Andrew Fry

Dr. Guy Hornsby

Dr. Kevin Carroll

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ABSTRACT

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Physiological muscle adaptations due to resistance training are still not fully known. The rate and area of hypertrophy could drastically help or hinder athletic performance. The purpose of this study was to observe the changes in lean body mass (and related factors), relative allometrically scaled strength and absolute strength through an 11-week block periodized resistance training program. The subjects (n = 15) realized an increase in total body water (pre = 49.77Kg; post = 51.70Kg), lean body mass (pre = 67.98Kg; post = 70.63Kg), adjusted lean body mass (pre = 20.35Kg; post = 21.03Kg) and cross-sectional area (pre = 32.73 cm^2; post = 36.33cm^2). Subjects (n= 15) were divided into either a strong (1 RM ≥ 1.75x body weight), moderate (1 RM = ≥ 1.25-1.74x body weight), or weak (1 RM < 1.25x body weight) group and data were analyzed in pre-post training. While all subjects showed gains in LBM and related factors, initial strength levels altered these adaptations. Subjects with a lower initial maximum strength level tended to make greater gains. However, due to the increase in total body water and relatively small increases in adjusted LBM, it appears, among this group, that little myofibrillar hypertrophy occurred during this short training period. These data suggest that greater accuracy for measures of alterations in LBM and related factors may require measures of total body water.

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My first NSCA conference, I was filming Adam Feit (you both aren’t supposed to know who that is) at 7:30am. He was presenting on becoming a strength coach and things you can expect. He was explaining the type of humble beginnings you might experience and if you are in it for the money then you chose the wrong profession. He also spoke on being excited for little victories such as buying your first bed frame and moving you bed off the floor.

Not even 5 months earlier, you both helped me move to Colorado to intern with NSCA. I remember renting all of my furniture and dad saying he had a foldable bed frame in the crawl space I could bring with me in the car. Before he attempted to crawl around for 20 minutes looking for it, I said it wasn’t a big deal and I could just put the mattress on the floor. He looked at me and just said no. He didn’t want me sleeping on the floor (even if it was still on a mattress) and he could help me if I was just patient.

It’s the little things like this I remember and am reminded how much you both have helped me along the way. I am not ashamed to say I am not self-made and without my parents I would not have been able to move to D.C, interned with the Wizards, graduated with my Masters and now my Doctorate. Thank you both and I hope I am able to do the same for my children when the day comes.

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CHAPTER 1

INTRODUCTION

Research concerning training methods and philosophies in order to improve athlete performance has been around since the days of ancient Greece, Rome and China (Cunanan et al., 2018). While the concept of periodization has a long history, Nadori and Matveyev were able to study and summarize findings concerning periodization with Hungarian and USSR athletes during the 1950's and early 1960's. It would take almost two decades until meticulous investigation of periodization would make its way to the USA with studies by O'Bryant, Garhammer and Stone (Stone et al., 1981; Stone et al., 1982). Since that time, periodization has continued to evolve and currently two types of periodization models are recognized, traditional (classic) and block periodization (Cunanan et al., 2018; DeWeese et al., 2015a, 2015b).

Today, several studies and critical analyses indicate block periodization to be superior when attempting to increase strength, power and athletic performance compared to non-periodized or traditional periodization (Carroll et al., 2018; Cunanan et al., 2018; DeWeese et al., 2015a, 2015b; Fleck et al., 1999; Issurin, 2008; Issurin, 2014; O'Bryant et al., 1988; Painter et al., 2012; Painter et al., 2018; Rhea et al., 2004; Rhea et al., 2005; Scala et al., 1987; Stone et al., 1981; Stone et al., 1982; Stone et al., 1983; Williams et al., 2017).

A basic tenet of block periodization deals with the sequential fitness phase paradigm in which one phase theoretically potentiates the next through residual effects. For optimum increases in strength, explosive strength and power, the general conceptual paradigm is increase muscle cross-sectional area (and work capacity), then work on basic strength, then work on power (Cunanan et al., 2018; DeWeese et al., 2015a, 2015b); a paradigm with considerable theoretical mechanistic underpinning (Minnetti, 2002; Zampero et al., 2002).

Despite the vast array of studies and reviews dealing with the process of training using subjects with a variety of training backgrounds, several questions still remain unclear. One such question is the timeline in which edema of the muscle subsides and true myofibrillar hypertrophy occurs. Another unanswered question is that of inhomogeneous hypertrophy. These basic questions could have considerable impact on the block periodization conceptual paradigm. For example, although development of work capacity is still a factor, if the initial development of CSA is largely a result of sarcoplasmic hypertrophy (i.e. edema) then that initial high volume phase may be unnecessary. While considerable evidence has indicated block periodization to be a superior method of training, there are still questions concerning adaptations of the muscle that remain unanswered.

Recent studies have shown the initiation of resistance training may cause an increase in sarcoplasmic hypertrophy of the muscle (edema) (Damas, 2018; DeFritas et al., 2010). Indeed, Myofibrillar hypertrophy may not occur until several weeks after resistance training has been initiated (Damas, 2018; DeFritas et al., 2010; Haun et al., 2019). Thus, tracking body water may be quite valuable in estimating the time-frame until true myofibrillar hypertrophy is engaged.

Studies examining inhomogeneous hypertrophy have typically done so via seated leg extension (Ema et al., 2013; Matta et al., 2014; Narici et al., 1989). These studies have shown hypertrophy occurring at the distal portion of the quadriceps muscles to a greater extent than the proximal aspect. Abe et al., (2003) examined hypertrophy of the vastus lateralis via complex squatting movements and discovered a greater extent of hypertrophy to the proximal vastus lateralis. Importantly, the geometry of the hypertrophy could play a role in difference between success and failure in the sports world.

The aim of the current study was to examine specific physiological adaptations in lean body mass (LBM) and muscle hypertrophy of subjects during an 11-week block periodized resistance training program. By measuring the subjects' muscle thickness and cross-sectional areas via ultrasound and their lean body mass and total body water via bioimpedance spectroscopy, the investigators attempted to estimate the degree of sarcoplasmic hypertrophy (edema) non-evasively.

These physiological adaptations were also examined across differing strength levels. Investigators attempted to examine the relationship between different initial strength and changes after each block of training in terms of lean body mass, muscle cross-sectional area, muscle thickness, total body water, relative strength and absolute strength.

This study is important to sport science because it may help to optimize the conceptual paradigm of block periodization. If sport scientists and coaches are only tracking athlete anthropometric changes via skin folds or girth measurements, they are not examining the whole picture. Initial alterations in LBM (and muscle hypertrophy) could be due to edema. Furthermore, hypertrophy creating non task specific geometries of the muscle or limb might also lead to decrements in the athlete's performance by altering moment arms in a less beneficial manner. It is import that the strength and conditioning coach understands the requirements of the sports they are coaching and is conscience of potentially hindering their athlete's performance based on their training methods.

CHAPTER 2

LITERATURE REVIEW

Periodization, LBM, muscle CSA and alterations in muscle function (maximum strength)

Training Methodology

Block Periodization

Periodization is not a unique term to sport and training and is typically used to identify repeating time intervals often with similar characteristics (Cunanan et al., 2018). In sport, the term has been used to portion specific segments of time throughout the competitive and non-competitive season; each segment contains different fitness characteristics. Thus “periodization” represents a conceptual paradigm for sport management in order for the athlete to train and compete at optimum or peak levels. Thus, conceptually, periodization emphasis establishes a training timeline and sequences of fitness and performance goals rather than establishing a training program or certain philosophy (Cunanan et al., 2018; DeWeese et al., 2015a, 2015b).

Again, it should be noted that “periodization” is a conceptual paradigm that deals with timelines compatible with the implementation of specific sequential fitness phases. For most athletes, there are two basic (general) premises concerning the sequencing of the periodization concept: 1. less task specific to more task specific and 2. higher volume to lower volume (Carroll et al., 2018; Cunanan et al., 2018; DeWeese et al., 2015a, 2015b). Basically there are two types of periodization, Traditional or Classical (Matveyev, Nadori) and Block (Issurin, Stone, Verkoshansky). Traditional periodization allows for simultaneous alterations in a variety of fitness characteristics whereas block periodization (single factor) takes a more consecutive approach in which one or a few compatible characteristics are developed before emphasizing a different set of characteristics (DeWeese et al., 2015a, 2015b; Suchomel, 2018a).

For resistance training and its integration into other sport training activities, many different methods and hypothetical paradigms to train athletes have been created. For example: some coaches believe in a triphasic training paradigm (Dietz, 2012) while others feel undulating periodization is the superior paradigm (Zourdas et al., 2016). However, several studies and reviews have indicated block periodization to be a superior training paradigm for improving athletic performance (Carroll et al., 2018; Cunanan et al., 2018; DeWeese et al., 2015a, 2015b; Issurin, 2008; Issurin, 2016; O'Bryant et al., 1988; Painter et al., 2012; Painter et al., 2018; Stone et al., 1982; Stone et al., 1983).

Indeed, a basic tenet of block periodization (and appropriate programming) for strength-power athletes is the initial alterations in body composition, and an increase in muscle mass (DeWeese et al., 2015a, 2015b; Minetti et al., 2002; Stone et al., 1982; Zampero et al., 2002). The increase in muscle CSA both contributes to force production and potentiates further increases in strength and power when training is altered to emphasize strength and power gains (DeWeese et al., 2015a, 2015b; Minetti et al., 2002; Stone et al., 1982; Zampero et al., 2002). These alterations potentially increase the ability of muscle to produce maximum force (strength) and eventually power (Balshaw et al., 2017a, 2017b; Hornsby et al., 2018; Minetti et al., 2002; Taber et al., 2019; Zampero et al., 2002). This conceptual paradigm of initial alterations in LBM and muscle hypertrophy has recently been criticized as being unnecessary as muscle hypertrophy resulting from resistance training will not contribute to strength gains and that training induced increases in maximum strength are largely neural in nature (Buckner et al., 2016; Mattocks et al., 2016). The indication of these papers is that hypertrophy generated by resistance training is largely sarcoplasmic (including edema). In effect the conceptual and mechanistic paradigms of periodization do not work according to these authors (Buckner et al., 2016; Mattocks et al., 2016). Thus, the relationship of variables, among resistance trained subjects, associated with alterations in LBM and their relationship to increased force production is not completely clear, especially in trained versus untrained subjects. These variables include the type of exercise (inhomogeneous hypertrophy), total body water, muscle cross-sectional area (CSA) and actual estimates of lean body mass (LBM).

Closed Kinetic Chain vs Open Kinetic Chain Movements

Studies examining changes in muscle physiology and body composition rely on either closed kinetic chain (i.e. back squat, dead lift, and push press) or open kinetic chain movements (i.e. seated leg extension machine, seated leg curl machine, and bicep curls). Open and closed kinetic chain exercises do not activate muscle in the same manner. Exercises using closed kinetic chain have been shown to promote a more balanced activation than open kinetic chain exercises. This may be of importance in designing training programs aimed toward control of joints, particularly those surrounded by a large muscle mass such as the patellofemoral joint (Stensdotter et al., 2003). Furthermore, while both variations will elicit adaptations of the muscle, performance alterations may not occur to the same extent or at the same rate (Augustsson et al., 1998; Prokopy et al., 2008; Stone et al., 2002).

For example: Augustsson et al., (1998) and Prokopy et al., (2008) investigated the use of open kinetic chain movements vs closed kinetic chain movements on performance variables, while Stone et al. (2002) reviewed previous studies pertaining to the same topic. Augustsson et al. (1998) found closed kinetic chain movements elicited a greater increase in lower body performance measures (vertical jump) and Prokopy et al. (2008) observed better CKC adaptation for upper body performance (Throwing). Stone et al. (2002) found closed kinetic chain movements (free weights) produced superior vertical jump results (vertical jump height, velocity and power output) in five of seven studies. The other two studies produced equivalent results.

Paoli et al. (2017) also found closed kinetic chain movements (multi-joint) improved VO_{2max} to a greater degree than open kinetic chain movements (single joint). Similar to the findings of Stone et al. (2002), Paoli et al. (2017) also investigated changes in maximal strength and noted a statistically significant greater increase in 1-RM bench and back squat for the multi-joint group.

Another significant reason for closed kinetic chain movements increasing athletic performance to a greater degree has to deal with inhomogeneous hypertrophy. Previous studies have shown closed kinetic chain movements and open kinetic chain movements will cause hypertrophy in different portions of muscle groups (i.e. the quadriceps) and even the same muscle (proximal vs distal vastus lateralis).

Studies dealing with different types of exercises have shown the seated leg extension machine to promote hypertrophy in the distal portions of the quadriceps (Ema et al., 2013; Matta et al., 2014; Narici et al., 1989) as opposed to the back squat which promotes greater hypertrophy in the proximal or middle portion of the quadriceps (Abe et al., 2003).

Depending on the sport of the athlete, indiscriminant hypertrophy might hinder the athlete’s performance. Certain sports, such as track cycling, seem to benefit from greater hypertrophy along the length of the quadriceps, including close to the knee joint, but for many sports that rely on sprinting (i.e. track, football, etc.) the athletes generate their power from the hip region (Abe et al., 2003). For these athletes, adding mass further down the moment arm could not only hinder performance from a biomechanics perspective but, potentially, also lead to increased risk of injury.

Training History

Untrained

As was previously noted, Minetti and Zampero, using review of the literature and mathematical modeling, provide a theoretical framework indicating increases in muscle CSA contributes to force production and potentiates increases in strength and power when training is altered to emphasize strength and power gains (DeWeese et al., 2015a, 2015b; Minetti et al., 2002; Stone et al., 1982; Zampero et al., 2002). However, considerable evidence indicates that individuals respond to resistance training differently depending upon their training status and history. Indeed, as a result of differences in the initial trained state, the outcome of comparative research may be quantitatively quite different.

Based on previous research, it is widely understood untrained subjects will adapt at a faster rate than trained subject under the same stimulus (Ahtiainen et al., 2003; Mangine et al., 2018; Rhea et al., 2004). When an untrained individual begins to resistance train, gains in strength are mostly due to adaptations of the nervous system (Jeffreys et al., 2016; Moritani et al., 1979; Phillips et al., 2000; Staron et al., 1994; Stone et al., 2007). Due to the introduction of resistance training, changes in neural drive are thought to be accomplished through cortical and peripheral alterations including: increase synchronization of the motor units, reduced activity of the agonist muscle, myelination and increased rate coding (Moritani et al., 1979; Phillips et al., 2000; Stone et al., 2007).

Researchers examining novice lifters found the subjects to improve strength levels while not experiencing any significant gain in lean body mass (Kamen et al., 2004; Moritani et al., 1979; Sale, 1988). Kamen et al. (2004) found untrained subjects improved maximal force output after one week of resistance training along with a 19% increase in maximal discharge rate of the vastus lateralis motor unit. The research of Moritani and deVries (1979) also suggest that neural adaptations account for the majority of gains in strength and power when resistance training is first introduced. For first 3-5 weeks of resistance training, neural adaptations account for the largest portion of gains in strength in initially untrained individuals. Hypertrophy of the muscle becomes the more dominant component to continued gains in strength and power with continued resistance training (Moritani et al., 1979). Narici et al. (1989) reported similar findings with regards to the nervous system being the main factor in early strength development for untrained individuals. After examining changes in maximum voluntary contraction (MVC), integrated electromyographic activity (iEMG) and quadriceps cross-sectional area (CSA) of trained and untrained limbs, they found an increase in both iEMG (24.%) and MVC (8.7%) with no significant change in CSA of the quadriceps (Narici et al., 1989). For the trained limb, after a few weeks, Narici et al. (1989) suggest that hypertrophy contributed approximately 40% to the increase in force, while approximately 60% appears to be contributed by increased neural drive and, potentially, small changes in muscle and connective tissue architecture. These findings are supported by Damas et al. (2018) and DeFritas et al. (2010) who’s research suggest early onsets of hypertrophy are likely due to edema and swelling of the muscle and non-contractile proteins (sarcoplasmic hypertrophy). True hypertrophy (myofibrillar) may not occur for the first 15-18 resistance training sessions. Thus, early increases in strength should be primarily attributed to neural adaptations.

Studies indicated untrained subjects can experience increases in strength to a greater degree than their trained counterparts (Ahtiainen et al., 2003; Mangine et al., 2018). Ahtiainen et al. (2003) examined the response to 21 weeks of resistance training of both trained and untrained subjects. While both groups improved maximum isometric leg extension strength, the untrained group improved by 20.9% compared to 3.9% for the trained group. Examining the response of novice and advanced lifters, Mangine et al. (2018) demonstrated similar findings. After an 8-week intervention, the novice lifters experienced a greater increase in 1-RM squat and bench press (maximum strength) (12.5%) compared to their more advanced counterparts (1.3%). While both weak and strong groups improved in these studies, clearly, those with less (or zero) experience were able to improve their maximum strength at a greater rate.

Novice Athletes

Novice athletes are distinguished from untrained subjects in that the novice athlete may be using different or more complex exercises in order to optimize training specificity and transfer of training effect for a sport. A primary goal for a novice athlete would be the relatively early enhancement in work capacity, muscle CSA and the nervous system. Part of the neural adaptation concerns the acquisition of lifting (and other exercises) technique. Creating a high degree of skill for a given technique is typically a goal that should be accomplished at the beginning of a training program; this lays the appropriate foundation for long-term improvement and adaptation (Andren-Sandberg, 1998; Issurin, 2009). High levels of fatigue can inhibit the acquisition of skill and the skill deficit may persist long-term (Branscheidt et al., 2019). Thus, large workloads creating a large accumulative fatigue state can inhibit learning and becoming skillful. Thus, in the early stages of training, fatigue must be managed so that an emphasis on skill acquisition is optimized. This can be accomplished through basic methods and stimuli that may not be suitable for advanced lifters (Plisk and Stone, 2003). The use of relatively low loading and relatively flat work-loads prescribed over the course of several weeks can reduce accumulative fatigue and promote skill acquisition (Plisk and Stone, 2003). While this type of programming may not be optimal for strength (and related characteristics development), the novice is able to learn new skills while experiencing reasonable neural and muscle adaptations as well (Plisk and Stone, 2003).

As the athlete continues to improve and skill level is stabilized, the annual plan will evolve as well. It is during this period, after technique has been sufficiently acquired and stabilized, that an emphasis on altering body composition and muscle hypertrophy should be emphasized. The athlete should introduce additional variation into their meso- and micro-cycles for continued improvements. The athlete can also vary their exercise selection to a greater degree in order to experience different stimuli to decrease monotony and potentially increase performance (Plisk and Stone, 2003).

Advanced Athletes

Moving from untrained to the advanced level requires that the overload be relatively constant. It also requires periodic but relatively consistent increases in training load. This progression of training from untrained to advanced levels also creates a narrower window for adaptation and likely requires considerably more variation in order to provide the necessary stimuli for further adaptation (Pierce and Stone, 2017; Smith, 2003). Advanced/elite athletes require greater stimulus variation and novelty, and fatigue management especially at the micro-cycle level (Plisk and Stone, 2003). Indeed, the overall complexity of the periodization/programming model is likely to be altered substantially as the athlete progresses to the advanced level. An important aspect of the programming for advanced athletes is the realization phase which often contains a taper. The type and extent of the taper may translate to a substantial effect on performance (Mujika, 2010; Mujika, 2014). For competitive athletes, the concept of a functional overreach followed by a taper may enhance the performance outcome (Mujika, 2014; Thomas and Busso, 2004). Part of the reason that the overreach may enhance performance when coupled with a taper, especially among strength power athlete, is maintenance of LBM (Suarez et al., 2019). As training volume is decreased, muscle CSA tends to decrease. The addition of a planned overreach, in conjunction with the taper, may help preserve LBM (Suarez et al., 2019).

Mujika (2010, 2014) examined the importance of maintaining intensity during the taper following an overreach. There is a need to reduce the training load during the taper to allow for recovery by the athlete. This can be accomplished via reduction in intensity, volume and/or frequency (Mujika, 2010; Mujika, 2014). Mujika concludes a reduction in volume will not hinder the athlete's performance leading into competition and maintaining the intensity from the overreach can help maintain or further enhance training-induced adaptations (Mujika, 2010).

Muscle Physiology Measures

Total Body Water

Recent studies have demonstrated substantial edema following the introduction of resistance training (Damas et al., 2018; DeFritas et al., 2010). Due to the potential influx of fluid into the muscle, potentially due to damage, investigators should measure more than just muscle thickness or cross-sectional area via ultrasound or magnetic resonance imaging. Although acute alterations in muscle fluid (edema) were well known, Damas et al. (2018) found the first 15-18 resistance training sessions could result in sarcoplasmic hypertrophy with substantial edema persisting in the muscle. It appears that after the introduction of resistance training, muscle damage must attenuate before true, meaningful (myofibrillar) hypertrophy can take place (Damas et al., 2016).

An increase in strength and power shortly after the initiation of resistance training is not uncommon. While improved neural drive has a part in this improvement, the phenomenon, turgor pressure, may also play a part in the increase of strength and power. As fluid in the cell is increased both intracellularly and extracellularly, the increased pressure during muscle contraction allows for the increase in force transmission and contractile force production (Sleboda and Roberts, 2019).

Lean Body Mass

Lean body mass (LBM) is the combination of muscle, connective tissue and bone. Resistance training will have an impact on all three of these areas but the adaption of muscle through resistance training has been vastly studied. It appears that the greatest resistance trained alterations in LBM occur as a result of muscle hypertrophy.

Multiple studies have indicated high volume resistance training can lead to increased LBM and positive changes (decreased body fat) in body composition (Kraemer et al., 2000; Kraemer et al., 2002; Radaelli et al., 2015; Stone et al., 1991). Reviews of the literature indicate that alterations in body composition with increases in LBM, particularly muscle, are essential for optimum enhancement of maximum strength and power and strength-power performance in general (DeWeese et al., 2015a, 2015b; Morehouse and Miller, 1976; Sale and McDougall, 1981; Stone et al., 1991; Taber et al., 2019). Alterations in LBM are typically accompanied by alterations in muscle cross-sectional area.

Cross-Sectional Area and Muscle Thickness

Cross-sectional area (CSA) and muscle thickness (MT) measurements of the vastus lateralis (VL) are commonly measured at the mid femur and have been widely used for monitoring hypertrophy in resistance training studies (Abe et al., 1999; Abe et al., 2003; Ema et al., 2013; Hug et al., 2006; Matta et al., 2014; Narici et al., 1989; Suarez et al., 2019; Wagle et al., 2017).

Studies conducted by Ema et al., (2013), Matta et al., (2014) and Narici et al. (1989) investigated hypertrophy via resistance training using a seated leg curl machine. This method of resistance training has been known to increase hypertrophy primarily in the distal aspect of the quadriceps muscle group.

Fewer studies have investigated hypertrophy of the VL through multi-joint movements (back squat, lunges, deadlift, etc.) (Abe et al., 2003; Suarez et al., 2019; Wagle et al., 2017). Increased hypertrophy at the proximal or mid aspect of the quadriceps muscle was evident in these studies.

Depending on the sport of the athlete, performance could be helped or hindered depending on training methods and where hypertrophy occurs (Abe et al., 2003; Augustsson et al., 1998; Hug et al., 2006; Paoli et al., 2017; Stone et al., 2002). Therefore, it is important to measure not only hypertrophy or atrophy during resistance training but also the area in which hypertrophy (or atrophy) is taking place. By performing measurements at several locations along the femur, investigators can be more accurate with their inferences as to how resistance training might positively (or negatively) impact performance of an athlete.

It should be noted that alterations in LBM, particularly muscle, do appear to influence the outcome changes of performance measures (maximum strength) from resistance training (Hornsby et al., 2018; Stone et al., 1991; Taber et al., 2019). Importantly, strength performance can be assessed in both absolute and relative terms.

Maximum Strength Measures

Maximum strength can be measured dynamically and isometrically. Dynamic measurements can be single or multiple-joint tests. Isometric exercises (tests) reduce the reliance on technique/skill but reduce inference for training derived transferability to other activities. As a result of task specificity, training with multi-joint dynamic exercises and testing with the same exercise are often used (Stone et al., 2002). Strength can also be measured in absolute or relative terms. Absolute maximum strength is the maximum amount of force exerted under a specific set of conditions, independent of muscle or body size. Greater absolute maximum strength is associated with greater muscle mass, body mass and, in general, larger individuals (Stone et al., 2005). Greater absolute strength will improve relative strength capabilities provided muscle or body size is not substantially increased. Relative maximum strength is an attempt to scale or normalize maximum strength in relation to another variable. Thus maximum strength can be scaled as a percent of maximum capabilities (i.e. 1 RM) or more typically in relation to a measure of body size. While all scaling methods, particularly those attempting to obviate body size, have some built in error it appears that allometric (exponent 0.67) scaling best obviates differences in body mass (Stone et al., 2005; Suchomel 2018b).

<u>Absolute Strength</u>

Generally, studies investigating the relationship of resistance trained alterations in absolute strength indicate that as LBM or CSA of tested muscle increases so does absolute maximum strength. This relationship has been observed isometrically and dynamically with single fiber analysis (Shoepe et al., 2003; Widrick et al., 2002), with isometric and dynamic single-joint (Schantz et al., 1983; Shoepe et al., 2003; Trezise and Blazevich, 2019) and isometric and dynamic multi-joint tests (Carroll et al., 2018; Hakkinen et al., 1981; Kraemer, 1997; Stone et al., 1981). Recently, many investigators have used the multi-joint isometric mid-thigh pull test (IMTP). The mid-thigh pull has strong relationships with other dynamic measures (i.e. 1-RM back squat, snatch and power clean) (Painter et al., 2012). Importantly, previous research investigating 11 weeks of block periodization programming among well-trained subjects resulted in increases in absolute maximum strength using both dynamic multi-joint (1RM squat) and multi-joint IMTP tests (Carroll et al., 2018). Carroll et al., (2019) also demonstrated concomitant increases in muscle size (ultrasound and biopsy), however, exact relationships between strength and muscle size were not presented. Considering the evidence as a whole, the concomitant increase in muscle size and maximum force production, particularly the single fiber data, suggest that myofibrillar hypertrophy is contributing to the increase in absolute maximum force production (Maden-Wilkinson et al., 2020).

Relative Strength

Because maximum strength is substantially effected by body size, comparison of subjects and athletes of different sizes becomes problematic. The use of a relative maximum strength tests is an attempt to obviate body size differences so that the size bias is at least partially obviated (Stone et al., 2005; Suchomel et al., 2018b). While size and muscle CSA increases often show strong correlations with absolute maximum strength measures, relative measures do not always show this relationship in single fiber (Meijer et al., 2015; Shoepe et al., 2003; Widrick et al., 2002) or isometric and dynamic single-joint or multi-joint measures (Ikegawa et al., 2008; Suarez et al., 2019). It can be hypothesized, assuming no change in MHCs, that hypertrophy dependent increases in relative maximum strength is a function of the relative ratio of myofibrillar hypertrophy versus sarcoplasmic hypertrophy (Figure 2.1) in the muscle fiber (Haun et al., 2019; Roberts et al., 2018).

Figure 2.1: Effect of Myofibrillar versus Sarcoplasmic Hypertrophy

Myofibrillar < Sarcoplasmic = little or no change in absolute strength - decrease in relative maximum strength

Myofibrillar = Sarcoplasmic = increase in absolute strength – no change in relative maximum strength

Myofibrillar > Sarcoplasmic – increase in absolute strength – increase in relative maximum strength

Other factors impacting gains in absolute strength resulting from resistance training induced LBM and muscle CSA adaptations include the possibility of alterations in myofibrillar packing density, specific muscle fiber selectively (i.e. increased II:I CSA ratio) and altered tissue stiffness (Suchomel et al., 2016). Although, these factors deserve additional study they are beyond the scope of this review.

While, reviews and previous studies have presented data indicating superior efficacy for block periodization and appropriate programming for attaining gains in strength-power performance (Carroll et al., 2018; Carroll et al., 2019; Cunanan et al., 2019; DeWeese, et al., 2015a, 2015b; Painter et al., 2012; Painter et al., 2018; Plisk and Stone, 2003; Stone et al., 1999; Stone et al., 1999), the exact relationship between alterations in LBM and strength gains remains unclear. One important aspect in studying this relationship(s) would be to differentiate absolute and relative strength gains and their relationship to alterations in LBM and muscle CSA. A testing procedure to aid in ensuring that strength gains are independent of LBM and muscle CSA adaptations is allometric scaling. The scaling method providing the most reliable results appears to be: absolute/body mass$^{0.67}$ (Suchomel et al., 2018b).

The equation aids in ensuring potential increases or decreases in strength and power are weighted evenly for all subjects by at least partially obviating body mass differences. This calculation also aids in minimizing potential error when calculating pre-post differences between subjects and between strength training groups.

Summary

While evidence does exist indicating that resistance training induced alterations in LBM and muscle hypertrophy do impact gains in maximum strength (and other performance variables), the exact association and time frames of this relationship are unclear. It is known that resistance training can induce both myofibrillar and sarcoplasmic (including edema) alterations (Dams et al., 2018; DeFietas et al., 2010; Haun et al., 2019; Maden-Wilkinson, 2019; Philippe et al., 2019). Understanding how these two types of hypertrophy impact maximum strength (and other variables) is largely unknown. Furthermore, it is not clear exactly how these potential relationships would behave during a commonly used training protocol in which volume and intensity of training are altered over time. Thus, following alterations in LBM, while accounting for total body water during a block periodization programming model, would aid in understanding these relationships.

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CHAPTER 3

Body Composition and Muscle CSA Adaptations among Strong, Moderate and Weak College Age Males across 11 weeks of Block Periodized Programed Resistance Training

Paul A. Moquin[1], Alex B. Wetmore[1], Andrew C. Fry[2], W.G. Hornsby[3], Kevin M. Carroll[1] and Michael H. Stone[1]

1. Department of Sports, Exercise, Recreation and Kinesiology

Center of Excellence for Sport Science and Coaches Education

East Tennessee State University,

Johnson City, TN 37614

2. Health, Sport, & Exercise Sciences

University of Kansas

Lawrence KS, 66045

3. College of Physical Activity and Sport Sciences,

West Virginia University

Morgantown WV, 26505

Department of Sport, Exercise, Recreation, and Kinesiology, Center of Excellence for Sport Science and Coach Education, East Tennessee State University, Johnson City, United States of America

moquin@etsu.edu

Body Composition and Muscle CSA Adaptations among Strong, Moderate and Weak College Age Males across 11 weeks of Block Periodized Programed Resistance Training

Abstract

The block periodization training paradigm has been shown to produce enhanced gains in strength and power compared to other training methodologies. Certain adaptations of resistance training still are not fully known. The purpose of this study is to assess resistance training induced alterations in lean body mass and cross-sectional area using a block periodization training model among individuals of differing strength levels (strong, moderate and weak). Several correlations (n = 15) were calculated to analyze the relationship between strength levels at the beginning of the study (relative and absolute) and values of several variables (cross-sectional area, lean body mass, lean body mass adjusted and total body water) at the beginning of the study, as well. Additionally, subjects were divided into three separate training groups based upon relative strength, absolute strength and training history. A 3x5 mixed-design ANOVA examined within-and between-subject changes in cross-sectional area, lean body mass, lean body mass adjusted and total body water over an 11-week resistance training program. The correlations (n = 15) revealed a moderate relationship between initial lean body mass and initial strength (relative and absolute) ($r = 0.591$; $r = 0.584$ respectively). There was a strong relationship between initial strength (relative and absolute) and initial lean body mass ($r = 0.652$; $r = 0.611$ respectively). The ANOVA revealed no statistically significant between-group differences in any independent variable ($p > 0.05$). Within-group effects showed statistically significant increases in cross-sectional area ($p < 0.001$), lean body mass ($p < 0.001$), lean body mass adjusted ($p < 0.001$) and total body water ($p < 0.001$) from baseline to post intervention: CSA: 32.73cm^2 ± 8.64; 36.33cm^2 ± 7.22, LBM: 67.98Kg ± 9.46; 70.63Kg ± 9.43, $LBM_{adjusted}$: 20.35Kg ± 3.14; 21.03Kg ± 3.29 and TBW: 49.77Kg ± 6.92; 51.70Kg ± 6.90. In conclusion, the results of this study suggest initial strength and lean body mass level can influence gains in lean body mass and lean body mass adjusted through resistance training.

Keywords: LBM, TBW, CSA, block periodization, strength

Introduction

Theoretical considerations, particularly for periodized programming, indicate that for optimum enhancement of maximum strength and power, initial training should emphasize body composition (lean body mass and fat) alterations and metabolic/work capacity enhancement (DeWeese et al., 2015a, 2015b; Morehouse and Miller, 1976; Sale and McDougall, 1981; Stone et al., 1991; Taber et al., 2019). Evidence indicates that alterations in body composition, gains in lean body mass (LBM) and loss of fat are better-accomplished using higher volumes of resistance training (Kraemer et al., 2000; Kraemer et al., 2002; Radaelli et al., 2015; Stone et al., 1991). LBM largely consists of muscle, connective tissue and bone. Although resistance training can effect alterations in all of these constituents, muscle hypertrophy is largely responsible for increases in measured LBM (Tesch, 1988).

Several factors likely effect the degree to which hypertrophy impacts strength and power development. These include the type of hypertrophy and the initial strength and LBM values. Hypertrophy potentially takes two forms, sarcoplasmic and myofibrillar (Haun et al., 2019; Rasch, 1955; Roberts et al., 2018). Increased sarcoplasmic proteins, glycogen and sarcoplasm (including fluid) characterize sarcoplasmic hypertrophy; whereas myofibrillar hypertrophy is characterized by an increase in contractile proteins (Roberts et al., 2018). Recent evidence (Damas et al., 2018; DeFritas et al., 2010) indicates that initial hypertrophy is largely sarcoplasmic in nature and depends upon a large influx of fluid (edema) in response to damage and inflammation.

Although there can be individual variation (Haun et al., 2019), meaningful contractile related hypertrophy (myofibrillar) likely does not occur for several weeks after training is initiated (Damas et al., 2018; DeFritas et al., 2010). While the impact on strength and power can be relatively small, particularly in early phases of training, compared to other factors such as neurological adaptations, tissue stiffness etc., reviews of the literature indicate that hypertrophy (myofibrillar) resulting from long-term resistance training does appear to substantially contribute to strength development (Andersen and Aagaard, 2010; Maden-Wilkinson et al., 2019).

Indeed it should be noted that there is evidence from both early muscle activation and cross-sectional area (CSA) studies (Hakkinen et al., 1983; Moritani and deVries, 1979) and later studies of CSA (Damas et al., 2018; DeFritas et al., 2010) indicating that the initial gains (up to 6-8 weeks) in hypertrophy (myofibrillar) are negligible to small and likely do not contribute markedly to increased strength, power, etc. However, this evidence also suggests that later (after ≈ 8 wks) alterations in CSA (myofibrillar) can begin to contribute to alterations in strength, power and related characteristics.

Indirect evidence suggests it is also possible that consistent bodybuilding type resistance training (high repetitions per set, training to failure) may result in greater sarcoplasmic hypertrophy (Haun et al., 2019; Meijer et al., 2015). Perhaps this hypertrophic difference partially explains observations indicating that bodybuilders are not as strong or as powerful as other strength-power athletes in multi-joint absolute (DiNasso et al., 2012), relative (Ikgegawa et al., 2008) or single fiber (Meijer et al., 2015) measures.

There is evidence to understand why initial resistance trained increases in LBM and muscle CSA do not always associate with gains in strength and related characteristics, particularly among untrained and minimally trained subjects. Some evidence indicates that initial maximum strength levels and initial CSA can influence subsequent adaptation in CSA and LBM (Anderson and Aagaard, 2010). Furthermore, most resistance training programs, particularly those using periodization programming, alter several factors over time including volume and intensity. Variation appears to produce enhanced gains in strength and power and perhaps muscle CSA (Anderson and Aagaard, 2010; DeWeese et al., 2015a, 2015b; Thompson et al., 2019).

It is not clear to what extent training program alterations in resistance training volume and intensity impact alterations in muscle CSA and LBM. Additionally it is not clear as to the impact of initial maximum strength levels, muscle CSA and LBM on alterations in muscle CSA and LBM.

Thus, the purpose of this study was assess the degree of resistance training induced alterations in CSA and LBM by examining the effect of:

- Volume and intensity variation using block periodization programming over an 11 week period.
- Initial maximum strength levels, using isometric mid-thigh pulls (IMTP) and the one repetition maximum back squat (1-RM)
- Initial LBM and total body water values, using bioimpedance spectroscopy
- Initial CSA of the vastus lateralis using ultrasound techniques

Methods

Subjects

Fifteen males of varying strength levels volunteered to participate and completed the study (age = 24.07 ± 3.43 yrs, body mass = 89.08 ± 16.96 kg, BMI = 28.15 ± 5.26). Those who volunteered and did not finish the study failed to report to baseline testing (n = 1), reported personal reasons (n= 3), reported an issue of time commitment (n = 2) or reported an injury due to training (n= 1).

It was noted that there was a strong statistically significant relationship between initial strength and initial LBM. It was also noted that relationships between the initial values for maximum strength and LBM and the change scores, although generally non-significant and relatively weak, were consistently negative (Tables 3.5, 3.6, 3.7, 3.8 and 3.9). These consistent negative relationships suggests that weaker subjects or those with a lower initial LBM adapted at a different rate than stronger subjects or those with a relatively higher LBM. Based on these results, it appears that initial maximum strength and LBM may influence training outcomes. Therefore, the subjects were divided into the three strength groups (strong, moderate and weak) in accordance with Suchomel et al., (2018) to investigate potential group differences over the 11-week training intervention. This review (Suchomel et al., 2018) of the literature reported strong individuals to be able to back squat at least 1.75x their body weight and weaker (untrained) individuals to be unable to back squat at least 1.25x their body weight (Suchomel et al., 2018). Those with at least one year of resistance training experience and able to back squat between 1.26 and 1.74x their body weight were considered moderate in strength.

Table 3.1 highlights the three group characteristics. All subjects read and signed an informed consent document prior to participating in the study, as approved by the university's Institutional Review Board.

Table 3.1 Subject Characteristics

Strength Level	Age (years)	BM (kg)	BMI
Strong (n = 4) 1-RM ≥ 1.75x BW	24.25 ± 2.22	87.68 ± 10.01	28.24 ± 4.90
Moderate (n = 4) 1-RM ≥ 1.25-1.74x BW	25.25 ± 3.20	100.18 ± 17.93	30.98 ± 5.63
Weak (n = 7) 1-RM < 1.25x BW	23.29 ± 4.27	83.54 ± 18.48	26.49 ± 5.31

Note: 1-RM = 1 repetition maximum back squat; BW = body weight; BM= body mass

Dietary Food Logs

Subjects were asked to fill out a 3-day dietary food log during the end of each training block. They were asked to maintain their regular diet and to continue using any supplements/medications in use the month prior to the start of the study. Food logs were analyzed for total kilocalorie intake and macronutrient intake (carbohydrates, proteins and fats) using Nutritionist Pro Diet Analysis Software (Axxya Systems, Stafford, Tx, USA).

Training

The training program consisted of resistance training (RT) 3days/wk and sprint training 2days/wk. RT occurred Monday, Wednesday and Friday while sprints occurred every Tuesday and Thursday each week.

The sprint program consisted of 3 sets of 2x20m sprints with a 2-minute rest between each repetition and a 4-minute rest between each set (Carroll et al., 2018). Often strength power athletes, such as throwers, use sprint training in addition to resistance training, therefore a basic sprint protocol was used to mimic real world training.

The groups followed a three phased programming emphasis (strength-endurance, maximal strength and power). This progression included a three-week taper at the end of the last block following a functional overreach. Heavy and light intensity days were included each week. The training program is shown in Table 3.2 (based on Carroll et al., 2018).

Table 3.2 Resistance Training Program

Training Block	Week	Sets x Reps	Day 1 and 2	Day 3
SE	1	3x10	80%	70%
SE	2	3x10	85%	75%
SE	3	3x10	90%	80%
MS	4	3x5 (1x5)*	85%	70%
MS	5	3x5 (1x5)*	87.5%	72.5%
MS	6	3x5 (1x5)*	92.5%	75%
MS	7	3x5 (1x5)*	80%	65%
FOR	8	5x5	85%	75%
SS	9	3x3 (1x5)*	87.5%	67.5%
SS	10	3x2 (1x5)*	85%	65%
SS	11	2x2 (1x5)*	65% & 60%	---------

Note: SE = strength endurance, MS = maximal strength, FOR = functional overreach, SS = speed-strength, Day 1 and 2 = heavy intensity days, Day 3 = light intensity day, * signifies down set at 60% of working weight after major exercise (squats, bench, MTP)

The exercise selection is shown in Table 3.3. Day 1 and 3 consisted of push days while Day 2 was a pull day (Carroll et al., 2018). Prior to all training sessions (RT and sprints) all subjects completed a dynamic warm-up consisting of two or three 10-15 m walking stretches, multi-directional lunge movements, leg swings, squatting patterns and three to four sprint build ups (10 M) (Carroll et al., 2018).

Table 3.3 Resistance Training Exercise Selection

Training Block	Day 1	Day 2	Day 3
Strength-Endurance	Back Squat, Overhead Press, Bench Press, DB Triceps Ext.	CG MTP, CG SLDL, BB Bent Over Row, DB Bent Lateral Raise	Back Squat, Overhead Press, Bench Press, DB Triceps Ext.
Max Strength	Back Squat, Push Press, Incline Bench Press, Wtd. Dips	CG MTP, Clean Pull, SG SLDL, Pull Ups	Back Squat, Push Press, Incline Bench Press, Wtd. Dips
Overreach	Back Squat, Push Press, DB Step Ups, Bench Press	CG CM Shrug, Clean Pull, CG SLDL, SA DB Bent Over Row	Back Squat, Push Press, DB Step Ups, Bench Press
Speed-Strength	Back Squat + Rocket Jumps, Push Press, Bench press + Med Ball Chest Pass	CG MTP, CG CM Shrug, Vertical Med Ball Toss	Back Squat + Rocket Jumps, Push Press, Bench press + Med Ball Chest Pass

Note: DB = dumbbell, CG = clean grip, MTP = mid-thigh pull, BB = barbell, Ext = extension, Wtd = weighted, SG = snatch grip, SLDL = stiff-legged deadlift, SA = single arm, CM = counter-movement

Hydration

Prior to all bioimpedance spectroscopy (BIS), ultrasound (US) testing and strength testing (relative and absolute) subjects provided a urine sample to estimate their hydration level. Hydration was tested using a refractometer (Atago, Tokyo, Japan). Dehydration has been shown to have a negative effect on performance, cognitive abilities and ultimately testing results (Judelson et al., 2007). The participants were deemed to be dehydrated if their urinary specific gravity (USG) was ≥ 1.02 and they continued to hydrate until they reach USG levels < 1.02 before testing could begin.

Bioimpedance Spectroscopy

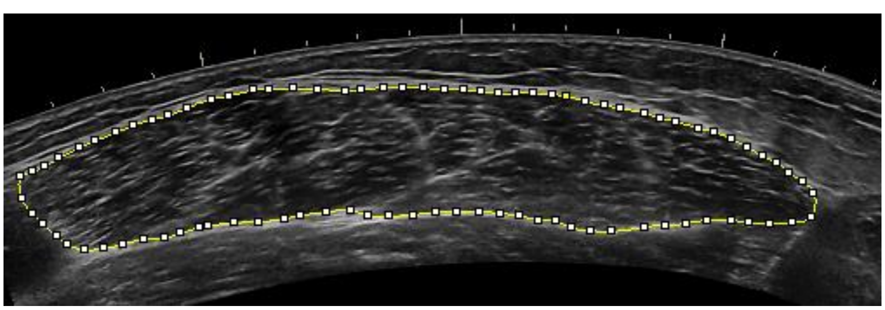
An SFB7 bioimpedance spectroscopy (BIS) device (ImpediMed Limited, Queensland, AU) was used to measure total body water (TBW) according to the methods used by Moon et al.

(2008). The test began by the subject resting supine on a table for 5-10 minutes. Their arms were separated from their torso (≥ 30°) and their legs were separated as well (Haun et al., 2018; Moon et al., 2008). Two electrodes were placed five centimeters apart on the wrist and ankle. Two more electrodes were placed five centimeters above the top of the subject's patella and the anterior portion of the femur in line with the greater trochanter. Two readings were averaged together for the measurement of TBW.

Ultrasonography

A 7.5 MHz ultrasound (US) probe (LOGIQ P6, General Electric Healthcare, Wauwatosa, WI, USA) was used to measure cross-sectional area (CSA) of the vastus lateralis (VL). Two CSA images were attained using panoramic image sweep perpendicular to the VL from the mid-point of the femur while the subject was standing and the measured leg unweighted to better reflect the functional architecture of the muscle in sporting activities (Wagle et al., 2017). The CSA was then analyzed by selecting the best image that displayed the VL and using an image processing software (ImageJ 1.52a, National Institutes of Health, Bethesda, MD, USA) to trace the intermuscular area as shown in Figure 3.1. The ultrasound technician and researcher analyzing the data remained the same throughout the entire study.

Figure 3.1. Cross-Sectional Area Measurement



1-Repeition Maximum Back Squat

For dynamic strength, the subjects performed a 1-RM test for the back squat. Prior to the lift, a standardized warm-up was performed (Wagle et al., 2017). The warm up procedure is shown in Table 3.4.

Table 3.4: 1-RM Back Squat Warm-Up Protocol

5x30% of 1-RM*	3x50% of 1-RM*	2x70% of 1-RM*	1x80% of 1-RM*	1x90% of 1-RM*
1 minute	1 minute	2 minutes	3 minutes	3 minutes

Note: 1-RM weight for untrained subjects will be based on the participant’s estimated 1-RM weight and the trial and error method

The testing percentages were based on a subject’s estimated 1-RM and the trial and error method for the untrained subjects (Kraemer et al., 1995). If the projected 1-RM was successful, the subject continued to attempt progressively heavier loads until a true 1-RM was reached. The back squat was deemed acceptable if the participant was able to squat to parallel (determined by a line from the top of the knee to the hip-crease) with the floor or below. Squat depth was determined by two experienced certified strength and conditioning specialists.

Isometric Mid-Thigh Pull

Isometric strength (isometric peak force) was determined via isometric mid-thigh pull (IMTP) using dual force plates (2 x 91cm x 45.5cm) sampling at 1000Hz (Rice Lake Weighing Systems, Rice Lake, WI). Each subject performed at least two IMTP following a standardized warm-up (Kraska et al., 2009). The subjects were positioned in a custom-built power rack using a fixed bar. Initial knee angle was $125° \pm 5°$ degrees and hip angle $145 \pm 5°$ degrees (Hornsby et al., 2018; Kawamori, et al., 2006). Subjects then performed two warm-up pulls at 50% and 75% intensity. Upon completion of the first warm-up pull, the subject was secured to the bar using wrist straps and athletic tape to eliminate grip strength as a confounding variable during testing (Carroll et al., 2018). The data was analyzed using a commercially available software (LabView National Instruments, Upper Saddle River, NJ).

Volume Load Displacement

Volume load displacement (VLd = sets · repetitions · vertical displacement) was measured to estimate work throughout the study (Bazyler et al., 2016; Carroll et al., 2018; Hornsby et al., 2018). Vertical displacement was measured using a standard measuring tape by the same investigator each block.

Lean Body Mass Adjusted

An equation was created in an attempt to investigate the potential difference between sarcoplasmic hypertrophy (edema) and myofibrillar hypertrophy (contractile elements), equation 5.1. The TBW of each subject was subtracted from LBM. Adipose tissue consists of approximately 10% water (Marieb et al., 2008). The total fat mass of the subject was multiplied by 0.1. This product was subtracted from the subject's TBW prior to calculating the subject's LBM adjusted for water in fat, equation 5.2.

Equation 3.1 Lean body mass adjusted for water content

$$LBM_{adjusted} = LBM - TBW_{adjusted}$$

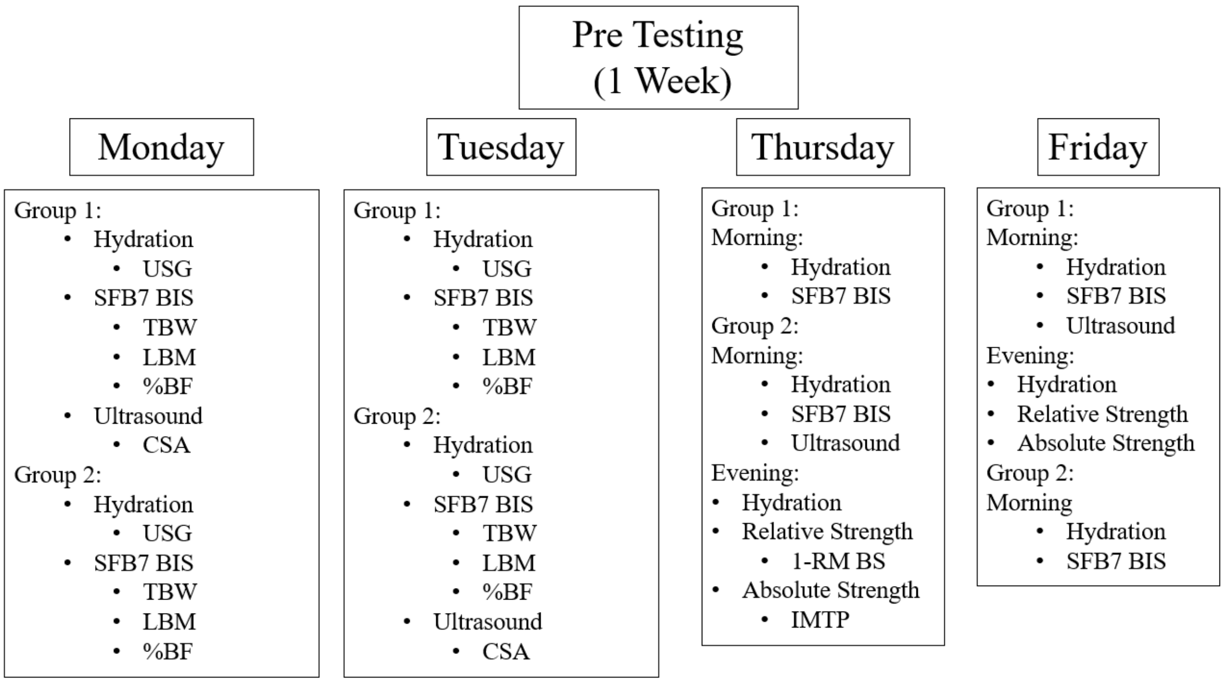
Equation 3.2 Total body water adjusted for water in fat

$$TBW_{adjusted} = TBW - [(\text{Body mass}*\text{percent body fat})*0.1]$$

Testing Timeline

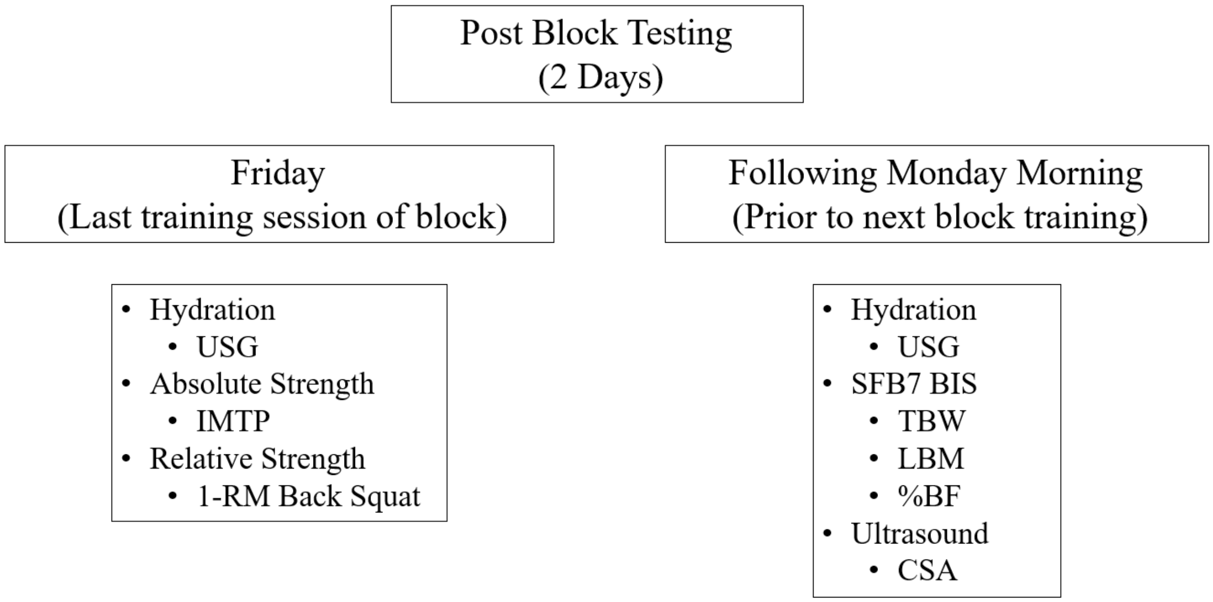
Pre-intervention testing was held the week prior to the start of the intervention. All subjects were split into two separate groups for ease of testing. The testing included hydration, body composition via BIS, muscle size via US, absolute strength via IMTP and relative strength via 1-RM. Both groups performed hydration and BIS testing Monday, Tuesday, Thursday and Friday. Group 1 performed hydration and US measurements for CSA on Monday and Friday while group 2 was tested on Tuesday and Thursday. Group 2 performed strength measurements Thursday evening while group 1 was tested Friday evening. The pre testing schedule is shown in Figure 3.2.

Figure 3.2. Pre-testing Timeline and Procedures



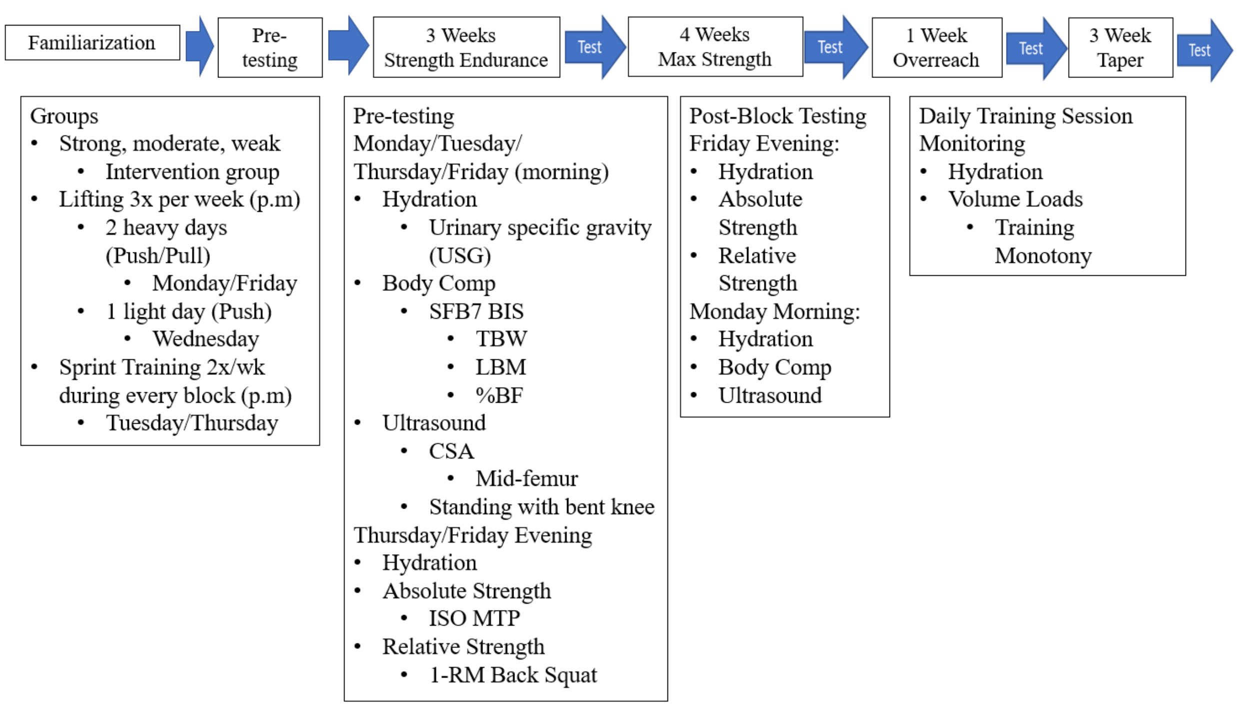
Post block testing occurred the Friday of the last training session that block and the following Monday morning after the last block was completed and prior to the new block beginning that same day. Friday post block testing consisted of all subjects completing hydration, absolute strength measures and relative strength measures that evening. Monday post block testing consisted of all subjects completing hydration, BIS and US testing that morning. Each subject was tested after the 3-week strength endurance block, 4-week maximum strength block, 1-week functional overreach and the 3-week taper. The post block testing is shown in Figure 3.3.

Figure 3.3. Post Block Testing Timeline and Procedures



After each training session, Daily work was estimated by VLd. The testing scheme for the entire research project is shown in Figure 3.4.

Figure 3.4. Research Testing Scheme



Statistical Analysis

All data have been recorded as mean ± standard deviation. Demographics were analyzed using Microsoft Excel 2013 (Microsoft Corporation, Redmond, WA, USA). G*Power was used to calculate the necessary sample size (alpha = 0.05, f = 0.9, number of groups = 3, number of measurements = 5) for an ANOVA repeated measures, between factors statistical analysis (n = 15) (Franz Faul, Universität Kiel, Germany, version 3.1.9.2).

To examine the relationships between dependent variables (1-RM, 1-RM_a, IPF, IPF_a, Δ1-RM and Δ1-RM_a) and independent variables (LBM, $LBM_{adjusted}$, ΔLBM and ΔLBM_a), Pearson correlations were conducted using a commercially available statistical software (JASP version 0.10.1).

Pearson's r and 95% confidence intervals (CI) were calculated to infer practical and meaningful changes (JASP version 0.10.1). The following scale was used to interpret these outcomes: 0.1-0.20 (small), 0.21-0.60 (moderate), 0.61-1.20 (large), 1.21-2.0 (very large), 2.01-4.0+ (extremely large) (Hopkins et al., 2009).

To examine within- and between-subject difference for body mass, total calorie intake, protein intake, percent body fat, total body water, lean body mass, lean body mass adjusted for water and cross-sectional area at 50% of the femur, a 3x5 (group x time) mixed-design analysis of variance (ANOVA) was conducted using a commercially available statistical software (JASP version 0.10.1). Tests for homogeneity of variance (Levene's Test) and Mauchly test of sphrecity were calculated prior to performing ANOVA tests. If sphrecity was violated, the Greenhouse-Geisser correction was used. The alpha level was set at $p \leq 0.05$. Significant main effects were followed by post-hoc tests using Holm-Bonferroni adjustment.

To examine the shared variance between changes in both relative (1-RM) and absolute (IPF) strength and change in CSA, LBM and $LBM_{adjusted}$ a multiple linear regress model using the enter method was conducted using a commercially available statistical software (JASP version 0.10.1).

Effect size (Cohen's d) and 95% confidence intervals were calculated to infer practical and meaningful changes (Lenhard & Lenhard, 2016). The following scale was used to interpret these outcomes: 0.01-0.19 (very small), 0.2-0.49 (small), 0.5-0.79 (medium), 0.8-1.19 (large), 1.2-1.99 (very large), 2.0+ (huge) (Sawilowsky, 2009).

Intraclass correlation (ICC) and coefficient of variation (CV) were used to analyze reliability of US and BIS measures were performed using Microsoft Excel and SPSS 26.0 (IBM Corp., Armonk, NY, USA).

Results

Correlation

Bioelectrical Impedance Measures

Pearson's r for correlation between initial variables (1-RM, 1-RM_a, IPF, IPF_a, LBM and LBM_a) are shown in Table 3.5. The correlations revealed a large statistically significant relationship between initial 1-RM and initial LBM ($p < 0.01$; [95% CI = 0.21 – 0.87]), initial isometric IPF and initial LBM ($p < 0.02$; [CI = 0.14 – 0.86]) and initial 1-RM and initial IPF ($p = 0.01$; [CI = 0.16 – 0.86]).

Pearson's r for correlations between the change in 1-RM and initial variables are shown in Table 3.6. The correlations revealed a large statistically significant relationship between change in 1-RM (D-E) and a moderate statistically significant relationship between initial LBM ($p = 0.011$; [CI = 0.18 – 0.87]) and change in 1-RM (D-E) and initial $LBM_{adjusted}$ ($p = 0.02$; [CI = 0.11 – 0.85]).

Pearson's r for correlations between the change in 1-RM_a and initial variables are shown in Table 3.7. The correlations revealed a large statistically significant relationship between change in 1-RM_a (D-E) and initial LBM ($p < 0.01$; [CI = 0.23 – 0.88]) and change in 1-RM_a (D-E) and initial $LBM_{adjusted}$ ($p < 0.02$; [CI = 0.14 – 0.85]).

Pearson's r for correlations between the change in LBM and initial variables are shown in Table 3.8. The correlations revealed a moderate statistically significant relationship between change in LBM (C-D) and initial IPF ($p = 0.03$; [CI = -0.05 - -0.83]).

Pearson's r for correlations between the change in $LBM_{adjusted}$ and initial variables are shown in Table 3.9. The correlations revealed a moderate statistically significant relationship between change in $LBM_{adjusted}$ (C-D) and initial IPF ($p = 0.04$; [CI = -0.26 - -0.82]).

ANOVA

Food Logs and Anthropometrics

The ANOVA (n = 15) showed a statistically significant interaction effect for body mass (BM) (p <0.001). The ANOVA did not reveal a statistically significant interaction effect on total caloric intake ($p = 0.39$) or protein intake ($p = 0.55$). No statistically significant between-subject differences were observed in BM ($p = 0.28$), caloric intake ($p = 1.00$) or protein intake ($p = 0.52$) over the 11-wk intervention. Overall, from A to E, there was a statistically significant moderate increase in BM ($p = 0.03$; $d = 0.81$, [CI = 0.04 - 1.53]). Results for change in BM for each block are shown in Table 3.10.

Bioelectrical Impedance Measures

The ANOVA revealed a statistically significant interaction effect on TBW ($p < 0.001$), LBM ($p < 0.001$) and $LBM_{adjusted}$ ($p < 0.03$). The ANOVA did not indicate a statistically significant interaction effect on percent body fat ($p = 0.30$) (Table 3.10). The ANOVA did not show any statistically significant differences between-subject interaction effect but did reveal very large effect sizes on TBW ($p = 0.07$; $d = 1.67$, [CI = 0.80 - 2.45]), LBM ($p = 0.07$, $d = 1.67$, [CI = 0.80 - 2.45]) and $LBM_{adjusted}$ ($p = 0.09$, $d = 1.59$, [CI = 0.73 - 2.36]). Overall from A to E there was a statistically significant very large increase in TBW ($p < 0.01$; $d = 1.37$, [CI = 0.54 - 2.12]), LBM ($p < 0.01$; $d = 1.37$, [CI = 0.54 - 2.12]), and $LBM_{adjusted}$ ($p < 0.01$; $d = 1.22$, [CI = 0.41 - 1.97]). Results for change in BM, TBW, LBM and $LBM_{adjusted}$ after each block for the entire subject pool and each group are shown in Table 3.10. Change in the independent variables (LBM and TBW) over the course of the intervention for the strong, moderate and weak groups are shown in figures 3.5 and 3.6, respectively.

TBW using dilution techniques has been found to be 58 ± 8% for young males (Watson et al., 1980) and ranges from about 50 to 70 % (Yashushi et al., 2018). The percentage of TBW for the current study was approximately 56% (n=15) across all 11 weeks and corresponds well with the literature. Within session intraclass correlation coefficient (ICC) and coefficient of variation (CV) for each variable were: %BF (ICC = 0.99, CV = 8.5%), TBW (ICC = 0.99, CV = 3.03%), LBM (ICC = 0.99, CV = 3.03%) and $LBM_{adjusted}$ (ICC = 0.99, CV = 2.54%) (Table 3.11).

Ultrasonography Measures

The ANOVA revealed a statistically significant interaction effect on CSA (p < 0.01) (Table 3.10). The ANOVA did not reveal any statistically significant differences between-subject effects of time but did show a large effect size for CSA ($p = 0.14$; $d = 1.26$, [CI = 0.45 – 2.01]). Overall from A to E there was a statistically significant large increase in CSA ($p < 0.01$; $d = 1.22$, [CI = 0.41 - 1.96]). Results for change CSA after each block for the entire subject pool and each group are shown in Table 3.10. Change of CSA over the course of the intervention for the strong, moderate and weak groups are shown in Figure 3.7.

Within session intraclass correlation coefficient (ICC) and coefficient of variation (CV) for CSA (ICC = 0.98, CV = 6.83%) (Table 3.11).

Multivariate Linear Regression

A multivariate linear regression analysis revealed a statistically significant relation between initial relative strength and initial CSA and LBM (*adjusted* R^2 = 0.36; p = 0.03) and between change in relative strength and initial $LBM_{adjusted}$ (*adjusted* R^2 = 0.25; p = 0.03). A non-statistically significant relation between initial absolute strength and initial CSA and LBM (*adjusted* R^2 = 0.23; p = 0.08) and between initial absolute strength and initial $LBM_{adjusted}$ over the 11 week RT intervention (*adjusted* R^2 = 0.18; p = 0.06). Large effect sizes were calculated for initial CSA (d = 0.97, [CI = 0.19 - 1.70]), initial LBM (d = 0.95, [CI = 0.17 - 1.68]) and $LBM_{adjusted}$ (d = 1.42, [CI = 0.59 - 2.18]) with regards to their relationship with initial relative strength. Large effect sizes were calculated for initial LBM (d = 1.50, [CI = 0.65 - 2.26]) and $LBM_{adjusted}$ (d = 1.29, [CI = 0.47 - 2.03]) and a small effect size was calculated for CSA (d = 0.18, [CI = -0.54 - 0.89]) with regards to their relationship with initial absolute strength.

A multiple regression analysis revealed a statistically significant relation between change in relative strength and change in $LBM_{adjusted}$ (*adjusted* R^2 = 0.52; p = 0.001). A multivariate linear regression analysis revealed a non-statistically significant relation between change in relative strength and change in CSA and LBM (*adjusted* R^2 = 0.13; p = 0.17), change in absolute strength and change in CSA and LBM (*adjusted* R^2 = -0.08; p = 0.62) and change in absolute strength and change in $LBM_{adjusted}$ (*adjusted* R^2 = -0.08; p = 0.876). Large effect sizes were calculated for change in CSA (d = 0.88, [CI = 0.11 - 1.60]) and change in $LBM_{adjusted}$ (d = 1.96, [CI = 1.04 - 2.77]) while change in LBM (d = 0.73, [CI = -0.03 - 1.45]) had a moderate effect size with regard to their relationship with relative strength. A moderate effect size was calculated for change in LBM (d = 0.73, [CI = -0.03 - 1.45]) while both change in CSA (d = -0.48, [CI = -

1.19 - 0.26]) and change in $LBM_{adjusted}$ (d = 0.19, [CI = -0.53 - 0.90]) had a small effect size with regard to their relationship with absolute strength.

Table 3.5 Pearson r for Initial Variables

	Initial 1-RM	Initial 1-RM_a	Initial IPF	Initial IPF_a	Initial LBM
Initial 1-RM					
Initial 1-Rm_a	0.90*				
Initial IPF	0.62*	0.76*			
Initial IPF_a	0.47	0.76*	0.91*		
Initial LBM	0.65*	0.64*	0.61*	0.48	
Initial LBM_a	0.67*	0.62*	0.49	0.37	0.95*

Note: 1-RM= one repetition maximum back squat; 1-Rm_a = allometrically scaled one repetition maximum back squat; IPF = isometric peak force of isometric mid-thigh pull; IPF_a = allometrically scaled isometric peak force of isometric mid-thigh pull; LBM= lean body mass; LBM_a= allometrically scaled lean body mass. * Statistically significant ($p \leq 0.05$).

Table 3.6 Pearson r for Initial Variables and Change of 1-RM for Each Time Point

	Δ1-RM (A-B)	Δ1-RM (B-C)	Δ1-RM (C-D)	Δ1-RM (D-E)	Δ1-RM (A-E)
Initial 1-RM	-0.16	-0.12	-0.33	0.36	-0.18
Initial 1-Rm_a	-0.01	-0.34	-0.20	0.25	-0.22
Initial IPF	0.000	-0.06	-0.20	0.13	-0.08
Initial IPF_a	0.13	-0.26	-0.13	0.01	-0.12
Initial LBM	0.35	-0.16	-0.27	0.67*	0.29
Initial $LBM_{adjusted}$	0.28	-0.15	-0.137	0.59*	0.29

Note: $LBM_{adjusted}$ = lean body mass adjusted for water; Δ1-RM = change in one repetition maximum back squat. * Statistically significant ($p \leq 0.05$).

Table 3.7 Pearson r for Initial Variables and Change of Allometrically Scaled 1-RM for Each Time Point

	Δ1-RM$_a$ (A-B)	Δ1-RM$_a$ (B-C)	Δ1-RM$_a$ (C-D)	Δ1-RM$_a$ (D-E)	Δ1-RM$_a$ (A-E)
Initial 1-RM	-0.12	-0.17	-0.33	0.33	-0.16
Initial 1-Rm$_a$	0.07	-0.33	-0.22	0.26	-0.09
Initial IPF	0.09	-0.05	-0.14	0.16	0.04
Initial IPF$_a$	0.24	-0.22	-0.01	0.06	0.08
Initial LBM	0.39	-0.14	-0.25	0.66*	0.36
Initial LBM$_{adjusted}$	0.31	-0.14	-0.14	0.61*	0.33

Note: Δ1-RM$_a$ = change in allometrically scaled one repetition maximum back squat. * Statistically significant ($p \leq 0.05$).

Table 3.8 Pearson r for Initial Variables and Change of LBM for Each Time Point

	ΔLBM (A-B)	ΔLBM (B-C)	ΔLBM (C-D)	ΔLBM (D-E)	ΔLBM (A-E)
Initial 1-RM	-0.03	0.10	-0.21	-0.02	-0.21
Initial 1-Rm$_a$	-0.07	0.30	-0.31	-0.04	-0.17
Initial IPF	-0.05	0.44	-0.55*	0.03	-0.22
Initial IPF$_a$	-0.07	0.53*	-0.51	0.01	-0.10
Initial LBM	0.36	0.06	-0.34	-0.06	0.03
Initial LBM$_{adjusted}$	0.33	-0.04	-0.30	0.08	0.10

Note: ΔLBM = change in lean body mass. * Statistically significant ($p \leq 0.05$).

Table 3.9 Pearson r for Initial Variables and Change of Allometrically Scaled LBM for Each Time Point

	ΔLBM_a (A-B)	ΔLBM_a (B-C)	ΔLBM_a (C-D)	ΔLBM_a (D-E)	ΔLBM_a (A-E)
Initial 1-RM	-0.08	0.08	-0.22	-0.15	-0.29
Initial 1-Rm_a	-0.09	0.25	-0.31	-0.17	-0.25
Initial IPF	0.01	0.48	-0.53*	-0.07	-0.06
Initial IPF_a	-0.01	0.51	-0.49	-0.07	-0.03
Initial LBM	0.32	0.18	-0.38	-0.05	0.12
Initial $LBM_{adjusted}$	0.31	0.08	-0.33	0.08	0.17

Note: ΔLBM_a = change in allometrically scaled lean body mass. * Statistically significant ($p \leq 0.05$).

Table 3.10 Independent Variables at Each Time Point for Strong, Moderate, Weak and Entire Subject Pool

Group	Variable	A	B	C	D	E
Strong Subject Pool	BM (kg)	87.68 ± 10.01	89.63 ± 9.42	90.33 ± 9.68	90.50 ± 9.35	88.58 ± 9.17
	%BF	19.41 ± 8.26	18.98 ± 7.90	17.40 ± 8.23	18.51 ± 7.77	17.41 ± 6.77
	TBW (kg)	51.65 ± 4.73	52.91 ± 5.02	54.34 ± 4.61	53.74 ± 4.98	53.27 ± 3.36
	LBM (kg)	70.56 ± 6.46	72.28 ± 6.86	74.23 ± 6.30	73.42 ± 6.82	72.77 ± 4.59
	$LBM_{adjusted}$ (kg)	20.65 ± 1.81	21.11 ± 1.80	21.51 ± 1.68	21.39 ± 1.78	21.08 ± 1.48
	CSA (cm^2)	32.99 ± 6.31	36.45 ± 5.95	36.32 ± 6.78	36.10 ± 4.59	36.91 ± 3.36
Moderate Subject Pool	BM (kg)	100.18 ± 17.93	102.48 ± 20.49	105.40 ± 22.03	105.40 ± 21.52	104.08 ± 21.98
	%BF	25.52 ± 6.43	24.60 ± 7.60	24.93 ± 7.91	25.74 ± 7.51	26.14 ± 7.30
	TBW (kg)	54.36 ± 8.14	56.20 ± 10.81	57.35 ± 10.29	56.76 ± 9.87	55.67 ± 9.44
	LBM (kg)	74.27 ± 11.12	76.77 ± 14.77	78.35 ± 14.05	77.54 ± 13.49	76.05 ± 12.89
	$LBM_{adjusted}$ (kg)	22.51 ± 3.53	23.15 ± 4.34	23.70 ± 4.36	23.57 ± 4.23	23.18 ± 4.22
	CSA (cm^2)	38.87 ± 11.96	39.80 ± 9.95	42.57 ± 9.84	42.65 ± 9.85	42.34 ± 9.94
	BM (kg)	83.54 ± 18.48	85.26 ± 18.68	86.27 ± 17.94	86.50 ± 17.93	86.07 ± 18.40
	%BF	22.69 ± 9.65	21.38 ± 10.07	21.67 ± 10.09	21.22 ± 10.95	21.66 ± 9.38
	TBW (kg)	46.06 ± 5.92	47.96 ± 5.51	48.46 ± 5.84	48.66 ± 4.85	48.54 ± 6.10

Weak Subject Pool	LBM (kg)	62.92 ± 8.09	65.53 ± 7.53	66.21 ± 7.97	66.48 ± 6.63	66.32 ± 8.34
	$LBM_{adjusted}$ (kg)	18.94 ± 3.11	19.53 ± 3.07	19.75 ± 3.03	19.81 ± 2.80	19.77 ± 3.21
	CSA (cm^2)	29.08 ± 6.49	30.79 ± 6.98	32.13 ± 6.77	32.03 ± 5.93	33.07 ± 5.28
Entire Subject Pool	BM (kg)	89.08 ± 16.96	91.01 ± 17.70*	92.45 ± 18.17*#	92.61 ± 17.95*#	91.54 ± 18.14#
	%BF	22.57 ± 8.29	21.60 ± 8.59	21.40 ± 8.93	21.70 ± 9.17	21.72 ± 8.35
	TBW (kg)	49.77 ± 6.92	51.48 ± 7.52*	52.40 ± 7.59#	52.17 ± 7.01#	51.70 ± 6.90#
	LBM (kg)	67.98 ± 9.46	70.33 ± 10.28*	71.58 ± 10.37#	71.28 ± 9.58#	70.63 ± 9.43#
	$LBM_{adjusted}$ (kg)	20.35 ± 3.14	20.92 ± 3.34*	21.27 ± 3.39*#	21.23 ± 3.23*#	21.03 ± 3.29#
	CSA (cm^2)	32.73 ± 8.64	34.71 ± 8.10*	36.03 ± 8.37#	35.95 ± 7.81#	36.33 ± 7.22#

Note: BM= body mass; %BF= percent body fat; TBW= total body water; LBM= lean body mass; $LBM_{adjusted}$= lean body mass adjusted for water; CSA = Cross-sectional Area. * Statistically different from the previous time point ($p \leq 0.05$). # Statistically different from time point A ($p \leq 0.05$).

Table 3.11 Intraclass Correlation and Coefficient of Variation for BIS and US Measures

Dependent Variable	%BF	LBM	TBW	$LBM_{adjusted}$	CSA
Intraclass Correlation (ICC)	0.99	0.99	0.99	0.99	0.98
Lower Confidence Limit	0.98	0.98	0.99	0.99	0.96
Upper Confidence Limit	1.00	1.00	1.00	1.00	0.99
Coefficient of Variation (CV) (%)	8.50%	3.03%	3.03%	2.54%	6.83%

Figure 3.5 Change of LBM over Time

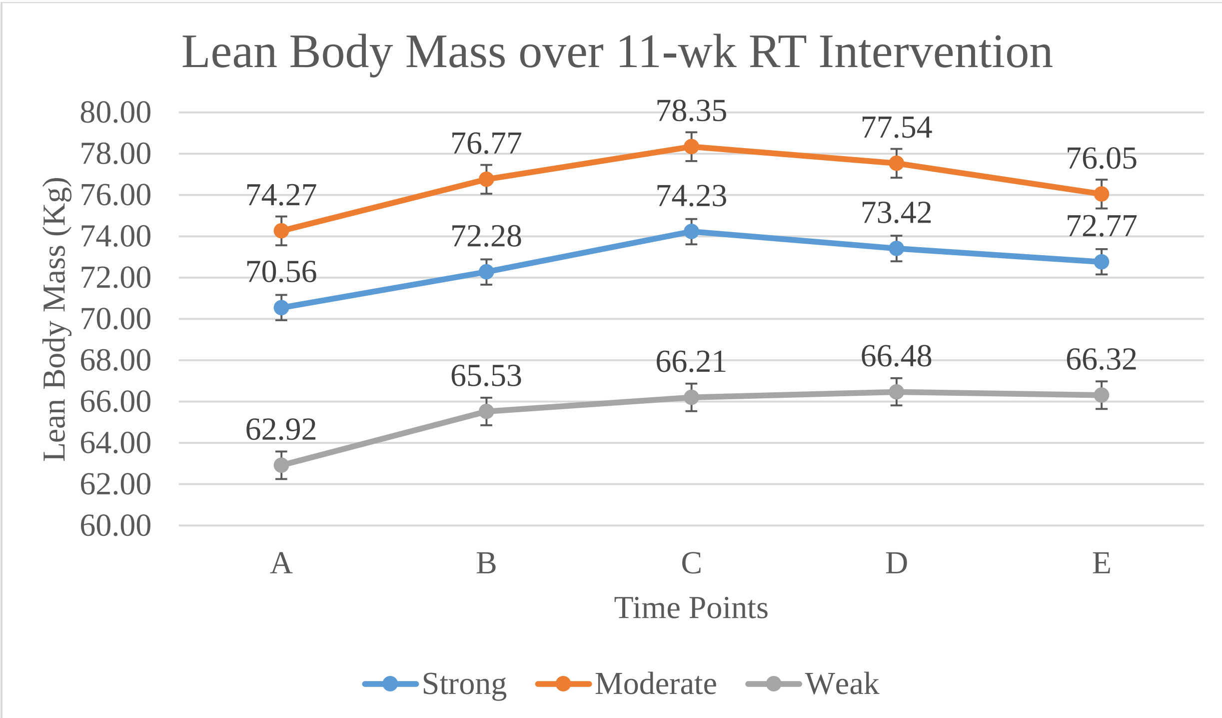


Figure 3.6 Change of TBW over Time

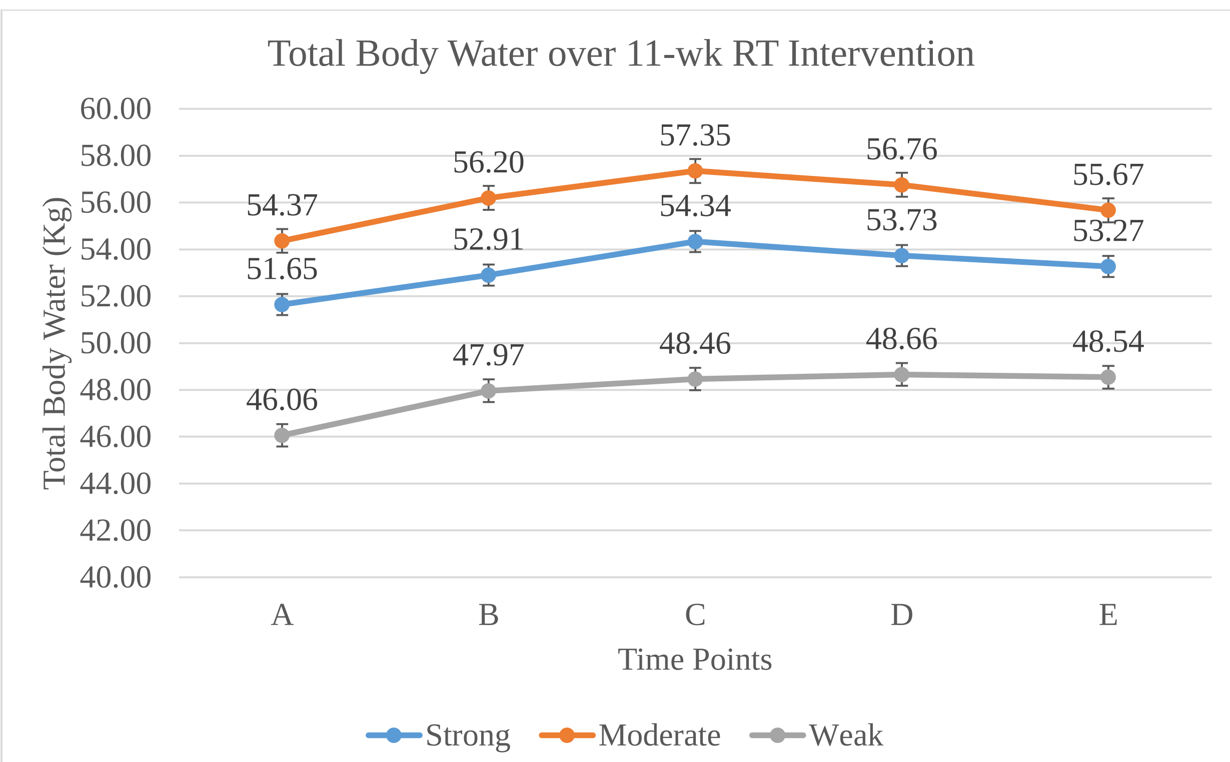
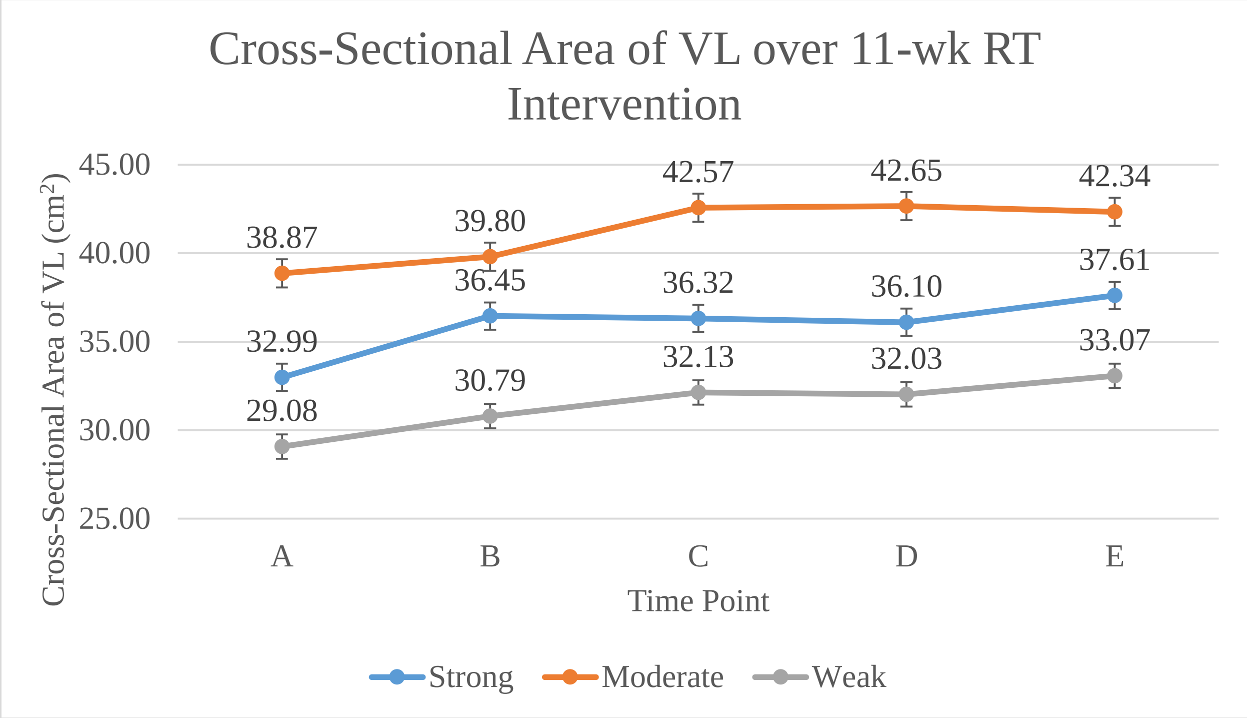


Figure 3.7 Change of CSA over Time



Discussion

The primary purpose of this study was to examine alterations in LBM and muscle CSA over the 11-week resistance training program in college age males. As a first step to more clearly delineate the composition of alterations in LBM, TBW adjustments were made. An assumption made is that the resulting $LBM_{adjusted}$ value reflect primarily protein alterations as a result of training.

The results indicate $LBM_{adjusted}$ increased over time ($p < 0.03$; $d = 1.22$), even with a statistically significant increase in TBW ($p < 0.001$; $d = 1.37$). The increase in TBW is at least partially explained by fluid retention in muscle, perhaps resulting from damage (Damas et al., 2015; Damas et al., 2016; DeFrietas et al., 2010). The greatest increase in TBW and $LBM_{adjusted}$ occurred during the initial high volume phase (A – B). A similar trend for CSA (n = 15) was also noted. This observation may simply result from a relatively novel stimulus causing more damage and edema than occurred later in the program. Damas et al. (2018) found similar results, increases in CSA and CSA echo intensity, following the first three weeks of a high volume resistance training intervention among untrained subjects. Following their 10 week intervention, Damas et al. (2018) found a statistical increase in CSA but not a statistical difference in CSA echo intensity; inferring initial muscular swelling at the initiation of high volume resistance training (sarcoplasmic hypertrophy). The findings presented in this experiment support early edema followed by sustained muscular growth throughout the training program.

However, this initial large alteration in $LBM_{adjusted}$ occurred regardless of trained state or training background suggesting that a higher volume of training stimulates protein accretion to a greater extent than lower volumes. Additionally, a drop in training volume, especially D to E, showed a loss of $LBM_{adjusted}$ indicating that training volume has a marked effect on protein accretion and maintenance. These observations agree with previous indications of the effect of volume on muscle hypertrophy (Schoenfeld et al., 2019). However, the exact makeup of the protein accretion cannot be ascertained using this method (BIA and ultrasound).

Interestingly, the presence of increased TBW is not necessarily detrimental to muscle performance. While increased TBW at the beginning of a resistance training program could mean edema and muscle damage, increased muscle fluid content could theoretically improve muscle force production. Fluid pressure within muscle acts as an intermediary between contractile proteins operating at molecular scales and extracellular matrix elements present throughout the tissue (Sleboda and Roberts, 2019). Thus alterations of muscle internal fluid pressure could alter contractile force. Sleboda and Roberts (2019) present evidence that increased intra and inter fiber fluid could enhance force transmission and potentially produce more contractile force through an increase in force transmitted to the extracellular matrix. Thus, increased TBW could potentially improve performance of the muscle. This could partially explain (along with the nervous system) an initial increase in maximum strength with little indication of myofibrillar hypertrophy occurring. Regardless, the net effect of the training program increased $LBM_{adjusted}$ over 11 weeks by approximately 0.68 kg.

Importantly, initial levels of LBM, $LBM_{adjusted}$ and maximum strength levels did appear to influence the gains in LBM and $LBM_{adjusted}$, thus the degree of protein accretion. The negative correlations, though generally weak, indicated that weaker subjects with lower initial values had greater gains in these variables. For example: $LBM_{adjusted}$ showed a net (A-E) improvement of: Strong = 0.43 kg (2.1%), *d* = 0.79, (CI = -0.74 - 2.11); Moderate 0.67 kg (3.0 %), *d* = 0.79, (CI = -0.74 - 2.11) and Weak 0.83 kg (4.4%), *d* = 2.16, (CI = 0.72 - 3.29).

Although the multivariate linear regression analysis revealed a non-statistically significant relationship of ΔCSA and ΔLBM with the change in relative strength (1-RM back squat, A-E), effect size magnitudes suggest that at least some of the gains in LBM contributed to alteration in maximum strength. Both ΔCSA (*d* = 0.88, (CI = 0.11 - 1.60)) and ΔLBM (*d* = 0.73 (CI = -0.03 - 1.45)) had an effect on the change of relative 1RM strength. The same suggestion can be made between the relationship of change in absolute strength (A-E) and LBM (*d* = 0.73, (CI = -0.03 - 1.45)). The multivariate regression analysis revealed a strong and statistically significant relationship of $\Delta LBM_{adjusted}$ with the change in relative strength over the 11-week resistance training intervention (*d* = 1.96, (CI = 1.04 - 2.77)). These findings suggest that if subjects were able to increase either the CSA of the VL, LBM or $LBM_{adjusted}$, they were able to increase their relative and absolute strength.

Lastly, the subjects were divided into three separate groups based on pre-testing relative strength level. While the weak strength group consisted of mostly untrained subjects (7 untrained and 1 trained), the moderate and strong group each consisted of four trained subject (based on resistance training for at least the past 12 months). In terms of physiology, the moderate group had higher pre-intervention levels of both LBM (moderate = 74.27Kg; strong = 70.56Kg) and $LBM_{adjusted}$ (moderate = 22.51Kg; strong = 20.65Kg) than the strong group; however, the strong group had a higher percentage of $LBM_{adjusted}$ compared to BM (strong = 23.6%; moderate = 22.5%) pre-intervention.

Although, it is well known that heredity influences physical and performance characteristics (Stone et al., 2007), it is also well known resistance training influences these factors (Mangine et al., 2018). Further research will be needed to determine to what degree each of these factors (heredity versus previous training) affect training induced alterations. Regardless initial strength levels affect the adaptations.

Conclusion

Potential sarcoplasmic/edema based hypertrophy at the onset of a RT program and a continued increase in LBM and CSA with drop in volume should continue to be examined, particularly with very well trained subjects. If this pattern holds true for athletes, an increase in muscle edema with an increase in RT volume might lead to adverse effects in performance if introduced at the wrong point in time.

The results of this study suggests that subjects' initial strength and LBM level can influence the gain in LBM and $LBM_{adjusted}$ through RT and likely play a role in maximum strength (1-RM) alterations. While subjects experienced an increase in hypertrophy after the introduction of RT, there should be consideration for the possibility of edema occurring in muscle. True myofibrillar hypertrophy may not occur until several weeks after the start of a new

RT program. In conclusion, hypertrophy should be monitored not only through CSA measures but also using TBW measures. By only monitoring LBM or CSA, the researcher (and coaches) may be misled as to what is actually occurring in terms of protein accretion.

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CHAPTER 4

Inhomogeneous Hypertrophy among Strong, Moderate and Weak College Age Males across 11 weeks of Block Periodized Programed Resistance Training

Paul A. Moquin[1], Alex B. Wetmore[1], Andrew C. Fry[2], W.G. Hornsby[3], Kevin M. Carroll[1] and Michael H. Stone[1]

1. Department of Sports, Exercise, Recreation and Kinesiology

Center of Excellence for Sport Science and Coaches Education

East Tennessee State University,

Johnson City, TN 37614

2. Health, Sport, & Exercise Sciences

University of Kansas

Lawrence KS, 66045

3. College of Physical Activity and Sport Sciences,

West Virginia University

Morgantown WV, 26505

Department of Sport, Exercise, Recreation, and Kinesiology, Center of Excellence for Sport Science and Coach Education, East Tennessee State University, Johnson City, United States of America

moquin@etsu.edu

Inhomogeneous Hypertrophy among Strong, Moderate and Weak College Age Males across 11 weeks of Block Periodized Programed Resistance Training

Abstract

Skeletal muscle hypertrophy is a well-studied outcome following resistance training. However, research examining inhomogeneous (i.e. regional) hypertrophy is sparse, particularly as it pertains to multi-joint resistance training. The purpose of this study was to investigate muscle thickness changes of the vastus lateralis at different regions. A secondary purpose was to examine whether differing initial strength levels (relative and absolute) affect the amount of change in muscle thickness during an 11-week block periodized resistance training program. Fifteen (n = 15) college aged males consisting of strong (n = 4), moderate (n = 4) and weak (n = 7) initial strength levels volunteered. Statistical analysis consisted of correlations between starting strength (relative and absolute) and muscle thickness of the vastus lateralis (25%, 50% and 75% of the femur). A 3x5 mixed-design ANOVA was also calculated to examine within-and between-subject changes of muscle thickness over the 11-week resistance training program. Correlations (n = 15) revealed a strong statistically significant relationship between initial 1-RM back squat and initial 50% muscle thickness (r = 0.518), initial 50% muscle thickness and change of 50% muscle thickness (r = -0.804) and initial 75% muscle thickness and change of 75% muscle thickness (r = -0.750). There was a statistically significant increase in 50% muscle thickness from time point C (2.90cm ± 0.51) and time point D (2.89cm ± 0.51) compared to baseline (2.64cm ± 0.64) for the entire subject pool. There were no statistically significant group differences for any measurement of muscle thickness. In conclusion, inhomogeneous hypertrophy appears to occur in the vastus

lateralis when performing multi-joint resistance training exercises during a block periodized training program.

Keywords: MT, Inhomogeneous hypertrophy, hypertrophy block periodization

Introduction

Adaptations of the muscle due to resistance and sport training are necessary for athletes to succeed in sport. One important adaptation is skeletal muscle hypertrophy (Haun et al., 2019; Maden-Wilkinson et al., 2019; Trezise et al., 2016). Not all lower body resistance training exercises will create the same amount of hypertrophy in a muscle nor will it create hypertrophy in the same area of the muscle. For example, it has been shown the seated leg extension machine will lead to greater hypertrophy of the distal vastus lateralis (VL) (Ema et al., 2013; Matta et al., 2014; Narici et al., 1989) while complex squatting movements lead to greater hypertrophy of the proximal VL (Abe et al., 2003).

Previous research illustrates instances of inhomogeneous hypertrophy; however, there appears to be a paucity of studies involving multi-joint resistance exercises. In the context of training athletes, there is evidence indicating the use of multi-joint exercises have a greater transfer to sport performance tests and sport performance compared to single joint training (Augustsson et al., 1998; Stone et al., 2002). As the training of athletes should transfer to testing and performance as much as possible, multi-joint exercises have been the primary mode of training (Paoli et al., 2017; Stone et al., 2002). Furthermore, indiscriminant (inappropriate) hypertrophy as a result of exercises producing inhomogeneous hypertrophy could reduce performance; for example: Sprinters and sprint cyclists both need to generate as much power as possible to be successful in their sport but the moment arms for their sport differ (Earp et al., 2015). Sprint cyclists tend to have substantial hypertrophy along the total thigh and comparatively more in the distal region of the thigh (Hug et al., 2006) while sprint runners have their greatest hypertrophy near the hip region (Abe et al., 1999). Exercises producing extra muscle in the “wrong” area could alter moment arms and reduce performance (Earp et al., 2015). Thus, hypertrophy in the incorrect region for either athlete could mean the difference between winning and losing.

Due to these reasons, research is necessary to examine where hypertrophy occurs after the introduction of multi-joint movements. Furthermore, it is important to understand the effects of a typical training program similar to that which may be used by athletes (Carroll et al., 2018; DeWeese et al., 2015a, 2015b; Painter et al., 2012). It is still unclear how the same muscle will adapt to multi-joint resistance training at differing points of the training program. The primary purpose of this study was to examine muscle thickness changes of the vastus lateralis at different regions during an 11-week resistance training program. A secondary purpose was to examine how different strength training backgrounds and different initial levels of maximum strength (relative and absolute) relate to inhomogeneous hypertrophy.

Methods

Subjects

Twenty two males of varying strength levels initially volunteered to participate in the study. Those who volunteered and did not finish the study failed to report to baseline testing (n = 1), reported personal reasons (n = 3), reported an issue of time commitment (n = 2) or reported an injury due to training (n = 1). Fifteen subjects finished the study (age = 24.07 ± 3.43 yrs, body mass = 89.08 ± 16.96 kg, BMI = 28.15 ± 5.26) based on the relationship of initial strength levels with alterations in body composition (Moquin et al., 2020). After initial relative strength (1-repetition maximum back squat) and absolute strength (isometric mid-thigh pull) testing, the subjects were grouped into three varying strength levels. The groupings were based on the consistent negative correlations between initial maximum strength and LBM levels and the change in these variables (Moquin et al., 2020). If the subject was unable to back squat at least 1.25x their body weight, they were considered weak. If the subject was able to back squat between 1.26 – 1.74x their body weight, they were considered moderate. If the subject was able to back squat at least 1.75x their body weight or greater, they were considered strong. These thresholds were in accordance with the findings of Suchomel et al. (2018). Table 4.1 highlights the three groups' physical characteristics. All subjects read and signed an informed consent document prior to participating in the study, as approved by the university's Institutional Review Board.

Table 4.1 Subject Characteristics

Strength Level	Age (years)	BM (kg)	BMI
Strong (n = 4) 1-RM ≥ 1.75x BW	24.25 ± 2.22	87.68 ± 10.01	28.24 ± 4.90
Moderate (n = 4) 1-RM ≥ 1.25-1.74x BW	25.25 ± 3.20	100.18 ± 17.93	30.98 ± 5.63
Weak (n = 7) 1-RM < 1.25x BW	23.29 ± 4.27	83.54 ± 18.48	26.49 ± 5.31

Note: 1-RM = 1 repetition maximum back squat; BW = body weight; BM= body mass

Dietary Food Logs

Subjects were asked to fill out a 3-day dietary food log during the end of each training block. They were asked to maintain their regular diet and to continue using any supplements/medications in use the month prior to the start of the study. Food logs were analyzed for total kilocalorie intake and macronutrient intake (carbohydrates, proteins and fats) using Nutritionist Pro Diet Analysis Software (Axxya Systems, Stafford, Tx, USA).

Training

The training program consisted of resistance training (RT) 3days/wk and sprint training 2days/wk. RT occurred Monday, Wednesday and Friday while sprints occurred every Tuesday and Thursday each week.

The sprint program consisted of 3 sets of 2x20m sprints with a 2-minute rest between each repetition and a 4-minute rest between each set (Carroll et al., 2018). Often strength power athletes, such as throwers, use sprinting in addition to resistance training, therefore a basic sprint protocol was used to mimic real world training.

The groups followed a three phased programming emphasis (strength-endurance, maximal strength and power). This progression included a three-week taper at the end of the last block following a functional overreach. Heavy and light intensity days were included each week. The training program is shown in table 4.2 (Carroll et al., 2018).

Table 4.2 Resistance Training Program

Training Block	Week	Sets x Reps	Day 1 and 2	Day 3
SE	1	3x10	80%	70%
SE	2	3x10	85%	75%
SE	3	3x10	90%	80%
MS	4	3x5 (1x5)*	85%	70%
MS	5	3x5 (1x5)*	87.5%	72.5%
MS	6	3x5 (1x5)*	92.5%	75%
MS	7	3x5 (1x5)*	80%	65%
FOR	8	5x5	85%	75%
SS	9	3x3 (1x5)*	87.5%	67.5%
SS	10	3x2 (1x5)*	85%	65%
SS	11	2x2 (1x5)*	65% & 60%	---------

Note: SE = strength endurance, MS = maximal strength, FOR = functional overreach, SS = speed-strength, Day 1 and 2 = heavy intensity days, Day 3 = light intensity day, * signifies down set at 60% of working weight after major exercise (squats, bench, MTP)

The exercise selection is shown in table 4.3. Day 1 and 3 consisted of push days while Day 2 was a pull day (Carroll et al., 2018). Prior to all training sessions (RT and sprints) all subjects completed a dynamic warm-up consisting of two or three 10-15 m walking stretches, multi-directional lunge movements, leg swings, squatting patterns and three to four sprint build ups (10 M) (Carroll et al., 2018).

Table 4.3 Resistance Training Exercise Selection

Training Block	Day 1	Day 2	Day 3
Strength-Endurance	Back Squat, Overhead Press, Bench Press, DB Triceps Ext.	CG MTP, CG SLDL, BB Bent Over Row, DB Bent Lateral Raise	Back Squat, Overhead Press, Bench Press, DB Triceps Ext.
Max Strength	Back Squat, Push Press, Incline Bench Press, Wtd. Dips	CG MTP, Clean Pull, SG SLDL, Pull Ups	Back Squat, Push Press, Incline Bench Press, Wtd. Dips
Overreach	Back Squat, Push Press, DB Step Ups, Bench Press	CG CM Shrug, Clean Pull, CG SLDL, SA DB Bent Over Row	Back Squat, Push Press, DB Step Ups, Bench Press
Speed-Strength	Back Squat + Rocket Jumps, Push Press, Bench press + Med Ball Chest Pass	CG MTP, CG CM Shrug, Vertical Med Ball Toss	Back Squat + Rocket Jumps, Push Press, Bench press + Med Ball Chest Pass

Note: DB = dumbbell, CG = clean grip, MTP = mid-thigh pull, BB = barbell, Ext = extension, Wtd = weighted, SG = snatch grip, SLDL = stiff-legged deadlift, SA = single arm, CM = counter-movement

Hydration

Prior to all ultrasound (US) and strength (relative and absolute) testing, subjects provided a urine sample to test their hydration level. Hydration was tested using a refractometer (Atago, Tokyo, Japan). Dehydration has been shown to have a potential negative effect on performance, cognitive abilities and ultimately testing results (Judelson et al., 2007). The participants were deemed to be dehydrated if their urinary specific gravity (USG) was ≥ 1.02 and must continue to hydrate until they reach USG levels < 1.02 before testing could begin.

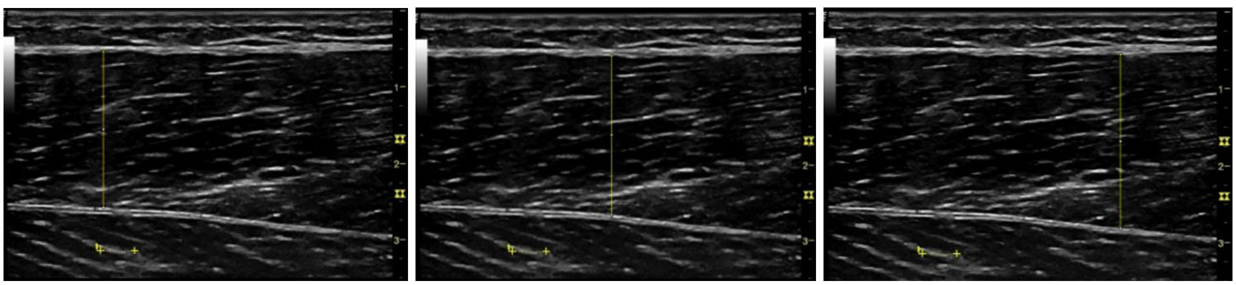
Ultrasonography

A 7.5 MHz ultrasound probe (LOGIQ P6, General Electric Healthcare, Wauwatosa, WI, USA) was used to measure muscle thickness (MT) of the vastus lateralis (VL). MT measurements occurred on the subject’s vastus lateralis at 25%, 50%, and 75% of the distance between the greater trochanter and the lateral epicondyle of the femur. Measurements were taken while the subject was standing and the measured leg unweighted. This posture was chosen to better reflect the functional architecture of the muscle in sporting activities (Wagle et al., 2017). Three MT images were then collected five centimeters anteromedial to the three femur marks. The best image was selected and the mean MT of the first quarter, midway and third quarter of the image was calculated as shown in Figure 4.1 (Suarez et al., 2019).

Figure 4.1. Muscle Thickness Calculation

(2.116cm (A) + 2.271cm (B) + 2.058cm (C))/3 = 2.148cm

(A) (B) (C)



Note: A: 1st quarter of the muscle thickness measurement for 50% of the femur; B: midway of the muscle thickness measurement for 50% of the femur; C: 3rd quarter of the muscle thickness measurement for 50% of the femur

1-Repeition Maximum Back Squat

For dynamic strength, the subjects performed a 1-RM test for the back squat. Prior to the lift, a standardized warm-up was performed (Wagle et al., 2017). This standardized warm up is shown in Table 4.4 below.

Table 4.4: 1-RM Back Squat Warm-Up Protocol

5x30% of 1-RM*	3x50% of 1-RM*	2x70% of 1-RM*	1x80% of 1-RM*	1x90% of 1-RM*
1 minute	1 minute	2 minutes	3 minutes	3 minutes

Note: 1 RM weight for untrained subjects will be based on the participant's estimated 1 RM weight and the trial and error method

The testing percentages were based on a subject's estimated 1-RM and the trial and error method for the untrained subjects (Kraemer et al., 1995). If the projected 1-RM was successful, the subject continued to attempt progressively heavier loads until a true 1-RM was reached. The back squat was deemed acceptable if the participant was able to squat parallel (determined by a line from the top of the knee to the hip-crease) with the floor or below. Squat depth was determined by two experienced certified strength and conditioning specialists.

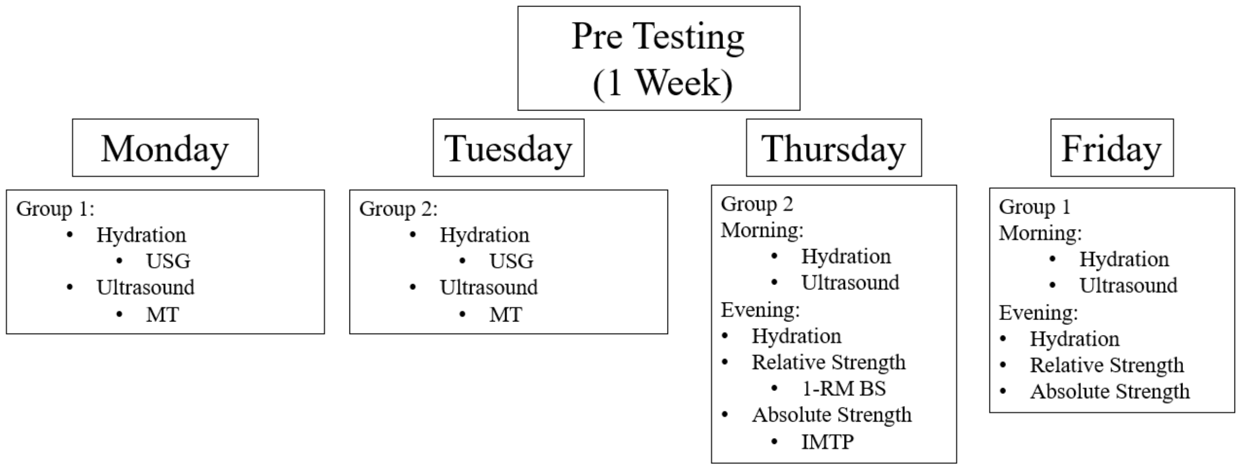
Isometric Mid-Thigh Pull

Isometric strength was determined via isometric mid-thigh pull (IMTP) using dual force plates (2 x 91cm x 45.5cm) sampling at 1000Hz (Rice Lake Weighing Systems, Rice Lake, WI). Each subject performed at least two IMTP following a standardized warm-up (Kraska et al., 2009). The subjects were positioned in a custom-built power rack using a fixed bar. Initial knee angle was between $125° \pm 5°$ degrees and hip angle between 145 ± 5 ° degrees (Hornsby et al., 2018; Kawamori et al., 2006). Subjects then performed two warm-up pulls at 50% and 75% intensity. Upon completion of the first warm-up pull, the subject was secured to the bar using wrist straps and athletic tape to eliminate grip strength as a confounding variable during testing (Carroll et al., 2018). The data was analyzed using a commercially available software (LabView National Instruments, Upper Saddle River, NJ).

Testing Timeline

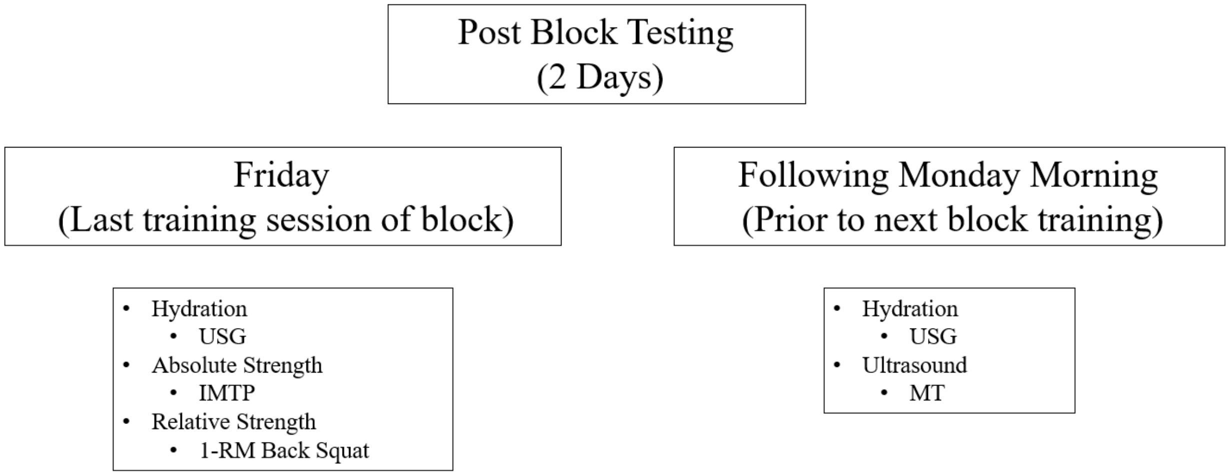
Pre-intervention testing was performed the week prior to the start of the intervention. All subjects were split into two separate groups for ease of testing. The testing included hydration, muscle size via US and strength (relative and absolute). Group 1 performed hydration and US measurements for CSA on Monday and Friday while group 2 was tested on Tuesday and Thursday. Group 1 also tested for strength measures on Friday while group 2 tested for strength measures on Thursday. The pre testing schedule is shown in Figure 4.2.

Figure 4.2. Pre-testing Timeline and Procedures



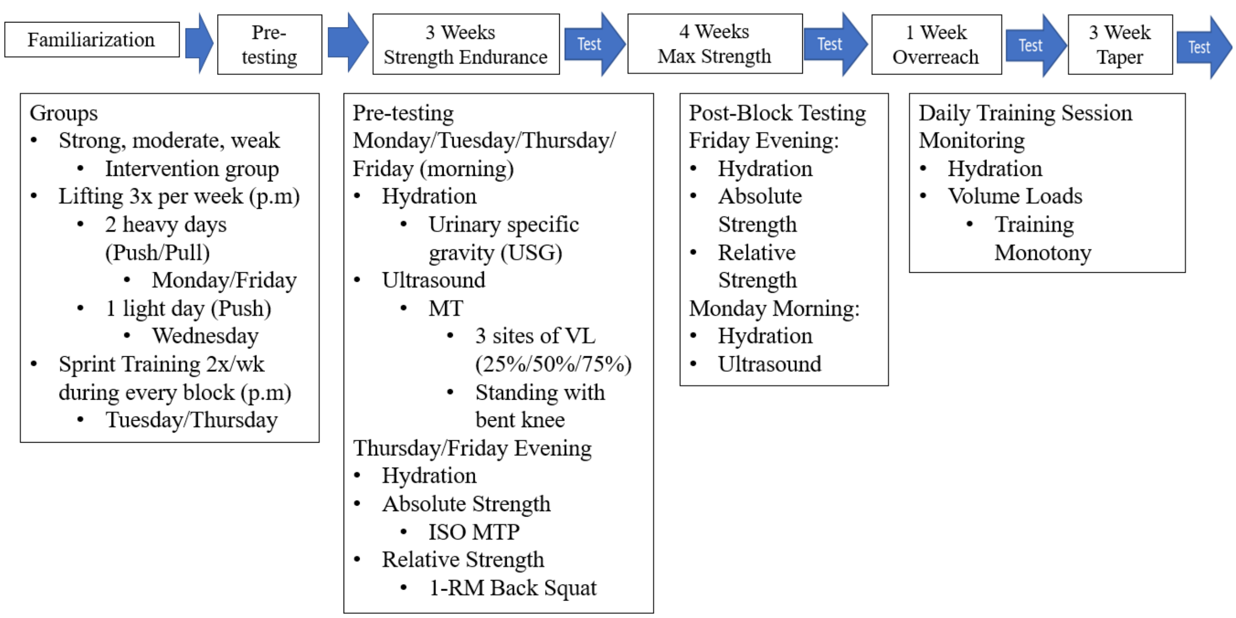
Post block testing occurred the Friday of the last training session that block and the following Monday morning after the last block was completed and prior to the new block beginning that same day. Friday post block testing consisted of all subjects completing hydration, absolute strength measures and relative strength measures that evening. Monday post block testing consisted of all subjects completing hydration and US testing that morning. Each subject was tested after the 3-week strength endurance block, 4-week maximum strength block, 1-week functional overreach and the 3-week taper. The post block testing is shown in Figure 4.3.

Figure 4.3. Post Block Testing Timeline and Procedures



After each training session, Daily work was estimated by volume load displacement (Hornsby, 2018). The testing scheme for the entire research project is shown in Figure 4.4.

Figure 4.4. Research Testing Scheme



Statistical Analysis

All data have been recorded as mean ± standard deviation. Demographics were analyzed using Microsoft Excel 2013 (Microsoft Corporation, Redmond, WA, USA). To examine the relationships between two dependent variables (initial relative strength (1-RM) and initial absolute strength (IMTP)) and three independent variables (25% MT, 50% MT and 75% MT), twelve correlations (1-RM and 25% MT_a; IMTP and 25% MT_a; 1-RM and Δ25% MT; IMTP and Δ25% MT; 1-RM and 50% MT_a; IMTP and 50% MT_a; 1-RM and Δ50% MT; IMTP and Δ50% MT; 1-RM and 75% MT_a; IMTP and 75% MT_a; 1-RM and Δ75% MT; IMTP and Δ75% MT) were conducted using a commercially available statistical software (JASP version 0.10.1). To examine the relationship between change in the same independent variables (Δ25% MT, Δ50% MT and Δ75% MT) three correlations were conducted using a commercially available statistical software (JASP version 0.10.1).

Pearson's r and 95% confidence intervals were calculated to infer practical and meaningful changes (JASP version 0.10.1). The following scale was used to interpret these outcomes: 0.1-0.20 (small), 0.21-0.60 (moderate), 0.61-1.20 (large), 1.21-2.0 (very large), 2.01-4.0+ (extremely large) (Hopkins et al., 2009).

To examine within- and between-subject difference for body mass and MT at 25%, 50% and 75% of the femur a 3x5 (group x time) mixed-design analysis of variance (ANOVA) was conducted using a commercially available statistical software (JSAP version 0.10.1). Tests for homogeneity of variance (Levene's Test) and Mauchly test of sphrecity were calculated prior to performing ANOVA tests. If sphrecity was violated, the Greenhouse-Geisser correction was used. The alpha level was set at $p \leq 0.05$. Significant main effects were followed by post-hoc tests using Holm-Bonferroni adjustment.

Effect size (Cohen's d) and 95% confidence intervals were calculated to infer practical and meaningful changes (Lenhard & Lenhard, 2016). The following scale was used to interpret these outcomes: 0.01-0.19 (very small), 0.2-0.49 (small), 0.5-0.79 (medium), 0.8-1.19 (large), 1.2-1.99 (very large), 2.0+ (huge) (Sawilowsky, 2009).

Intraclass correlation (ICC) and coefficient of variation (CV) were used to analyze reliability of US measures were performed using Microsoft Excel and SPSS 26.0 (IBM Corp., Armonk, NY, USA).

Results

Correlation

Ultrasonography Measures

The correlation matrix revealed no statistical significant relationship between the change in 25% MT, 50% MT or 75% MT from time point A to B (Table 4.5).

Correlations revealed a moderate non-statistically significant relationship between initial relative strength and initial 25% MT (p = 0.08; r = 0.47, [95% CI = -0.05 - 0.79]), initial absolute strength and initial 25% MT (p = 0.12; r = 0.42 [CI = -0.12 - 0.77]), initial absolute strength and change in 25% MT (p = 0.24; r = 0.32 [CI = -0.23 - 0.72]) and a weak non-statistically significant correlation between initial relative strength and change in 25% MT a (p = 0.28; r = 0.30 [CI = -0.25 - 0.70]).

Correlations revealed a strong statistically significant relationship between initial relative strength and initial 50% MT (p = 0.05; r = 0.52, [CI = 0.01 - 0.81]), initial 50% MT and change in 50% MT (p < 0.001; r = -0.80 (CI = -0.93 - -0.50]) and weak non-statistically significant correlations between initial absolute strength and initial 50% MT (p = 0.52; r = 0.18 [CI = -0.37 -

0.63]), initial relative strength and change in 50% MT (p = 0.28; r = -0.30 [CI = -0.70 - 0.26]) and absolute strength and change in 50% MT (p = 0.61; r = 0.14 (CI = -0.40 - 0.61]).

Correlations revealed a strong statistically significant correlation between initial 75% MT and change in 75% MT (p = 0.001; r = -0.75 [CI = -0.91 - -0.39]) and weak non-statistically significant correlations between initial relative strength and initial 75% MT (p = 0.49; r = 0.19, [CI = -0.34 - 0.64]), initial absolute strength and initial 75% MT (p = 0.93; r = 0.02 [CI = -0.49 - 0.53]), relative strength and change in 75% MT (p = 0.56; r = 0.15 [CI = -0.39 - 0.62]) and initial absolute strength and change in 75% MT (p = 0.47; r = 0.20 [CI = -0.34 - 0.65]).

ANOVA

Food Logs and Anthropometrics

The ANOVA (n = 15) indicated a statistically significant interaction effect for BM (p < 0.001) and a statistically non-significant interaction effect for total caloric intake (p = 0.39) or protein intake (p = 0.55). No significant between-subject differences were observed in BM (p = 0.28), caloric intake (p = 1.00) or protein intake (p = 0.52) over the 11-wk intervention. Overall from A to E there was a statistically significant moderate increase in BM (p = 0.03; d = 0.81, [CI = 0.04 - 1.53]).

Ultrasonography Measures

The ANOVA did not reveal a statistically significant interaction effect but did reveal a moderate effect size at 50% MT (p = 0.21; d = 0.60, [CI = -0.14 - 1.32]) and small effect sizes for 25% MT (p = 0.05; d = 0.36, [CI = -0.37 - 1.08]) and 75% MT (p = 0.70; d = 0.24, [CI = -0.49 - 0.95]) (Table 4.6). The ANOVA did not reveal any statistically significant differences between-subject effects of time but did reveal large effect sizes on 25% MT (p = 0.31; d = 0.93, [CI = 0.15 - 1.65]), 50% MT (*p* = 0.25; *d* = 1.01, [CI = 0.23 - 1.74]) and a moderate effect size on 75% MT (p = 0.56; d = 0.64, [CI = -0.11 - 1.36]).

There was not a statistically significant change in 50% MT during the SE phase (A-B) (*p* = 0.09; *d* = 0.74, [CI = -0.02 - 1.46]), the MS phase (B-C) (*p* = 0.22; *d* = 0.56, [CI = -0.19 - 1.27]), the FOR (C-D) (*p* = 0.66; *d* = -0.12, [CI = -0.83 - 0.60]) or during the taper (D-E) (*p* = 0.22; *d* = -0.57, [CI = -1.28 - 0.17]); however, 50% MT remained significantly higher at both C and D than A. Overall (A-E) there was not a statistically significant difference but effect sizes indicate a moderate effect occurred at 50% MT (*p* = 0.21; *d* = 0.60, [CI = -0.14 - 1.32]). All changes in variables for the entire subject pool and each strength group are shown in Table 4.6.

Change in the independent variables (25% MT, 50% MT and 75% MT) over the course of the intervention for the strong, moderate and weak groups are shown in Figures 4.5, 4.6 and 4.7 respectively.

Within session intraclass correlation coefficient (ICC) and coefficient of variation (CV) for each variable were: 25% MT (ICC = 0.945 CV = 9.05%), 50% MT (ICC = 0.984, CV = 5.93%) and 75% MT (ICC = 0.869, CV = 18.83%) (Table 4.7).

Table 4.5 Correlation Matrix for Independent Variables between A and B

		Δ25 MT	**Δ50 MT**	**Δ75 MT**
Δ25 MT	Pearson's r	-		
	p-value	-		
Δ50 MT	Pearson's r	-0.10	-	
	p-value	0.72	-	
Δ75 MT	Pearson's r	0.02	0.12	-
	p-value	0.95	0.66	-

Note: MT = muscle thickness.

Table 4.6 Independent Variables at Each Time Point for Strong, Moderate, Weak and Entire Subject Pool

Group	Variable	A	B	C	D	E
Strong Subject Pool	BM (Kg)	87.68 ± 10.01	89.63 ± 9.42	90.33 ± 9.68	90.50 ± 9.35	88.58 ± 9.17
	25% MT (cm)	2.58 ± 0.26	2.64 ± 0.21	2.76 ± 0.37	3.00 ± 0.39	2.79 ± 0.22
	50% MT (cm)	2.46 ± 0.83	2.76 ± 0.36	2.81 ± 0.39	2.69 ± 0.44	2.69 ± 0.43
	75% MT (cm)	1.77 ± 1.13	1.63 ± 1.27	2.09 ± 0.81	2.06 ± 0.82	2.15 ± 0.70
Moderate Subject Pool	BM (Kg)	100.18 ± 17.93	102.48 ± 20.49	105.40 ± 22.03	105.40 ± 21.52	104.08 ± 21.98
	25% MT (cm)	2.80 ± 0.70	2.99 ± 0.85	2.87 ± 0.68	3.14 ± 0.59	3.16 ± 0.56
	50% MT (cm)	3.05 ± 0.77	3.19 ± 0.81	3.28 ± 0.72	3.26 ± 0.71	3.13 ± 0.65
	75% MT (cm)	2.27 ± 0.74	2.21 ± 0.51	1.78 ± 1.32	2.27 ± 0.59	2.17 ± 0.63
Weak Subject Pool	BM (Kg)	83.54 ± 18.48	85.26 ± 18.68	86.27 ± 17.94	86.50 ± 17.93	86.07 ± 18.40
	25% MT (cm)	2.42 ± 0.59	2.46 ± 0.53	2.63 ± 0.48	2.58 ± 0.56	2.39 ± 0.69
	50% MT (cm)	2.50 ± 0.41	2.67 ± 0.36	2.74 ± 0.36	2.79 ± 0.37	2.65 ± 0.29
	75% MT (cm)	1.63 ± 0.39	1.80 ± 0.40	1.76 ± 0.32	1.72 ± 0.44	1.86 ± 0.25
Entire Subject Pool	BM (Kg)	89.08 ± 16.96	91.01 ± 17.70*	92.45 ± 18.17*#	92.61 ± 17.95*#	91.54 ± 18.14#
	25% MT (cm)	2.56 ± 0.54	2.65 ± 0.58	2.73 ± 0.49	2.84 ± 0.55	2.70 ± 0.62
	50% MT (cm)	2.64 ± 0.64	2.83 ± 0.52	2.90 ± 0.51#	2.89 ± 0.51#	2.79 ± 0.46

75% MT (cm)	1.84 ± 0.73	1.86 ± 0.72	1.85 ± 0.76	1.95 ± 0.60	2.02 ± 0.49

Note: BM = body mass; MT = muscle thickness. * Significantly different from the previous time point ($p \leq 0.05$). # Significantly different from T1 ($p \leq 0.05$).

Table 4.7 Intraclass Correlation and Coefficient of Variation for US Measures

Dependent Variable	25% MT	50% MT	75% MT
Intraclass Correlation (ICC)	0.945	0.984	0.869
Lower Confidence Limit	0.885	0.966	0.724
Upper Confidence Limit	0.979	0.994	0.950
Coefficient of Variation (CV) (%)	9.05	5.93	18.83

Figure 4.5 Change of Muscle Thickness at 25% of the Vastus Lateralis over Time

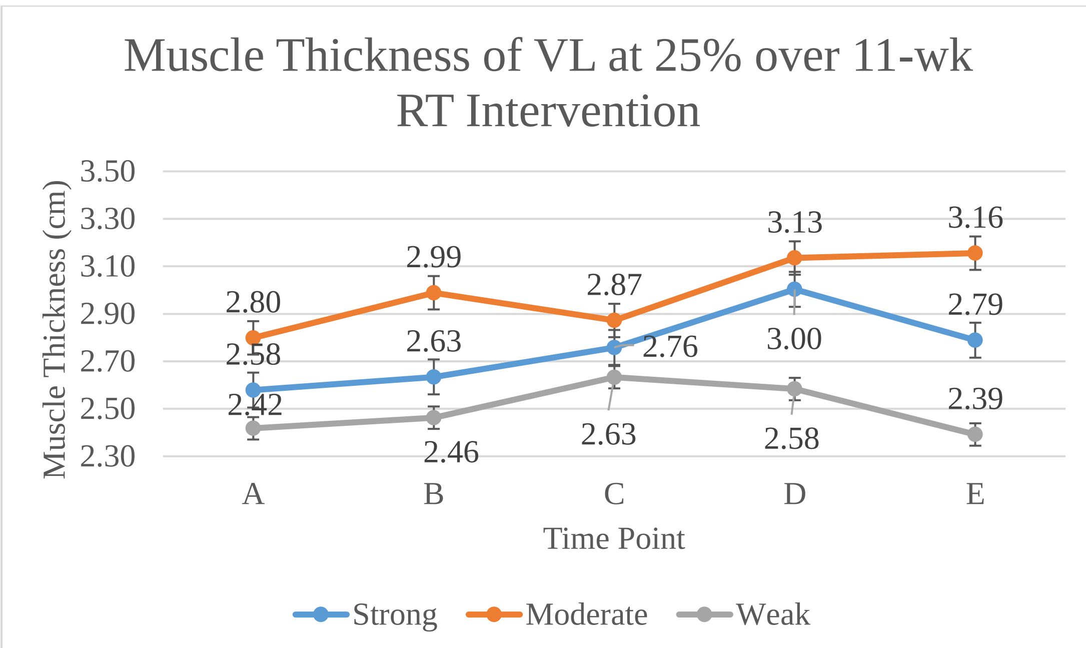


Figure 4.6 Change of Muscle Thickness at 50% of the Vastus Lateralis over Time

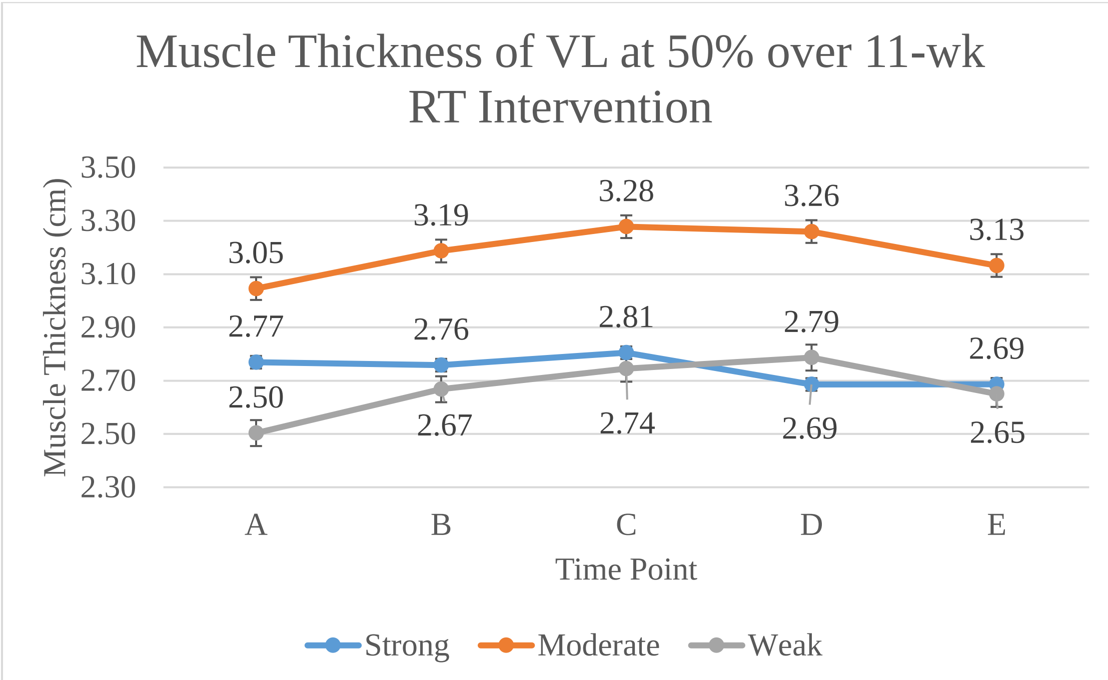
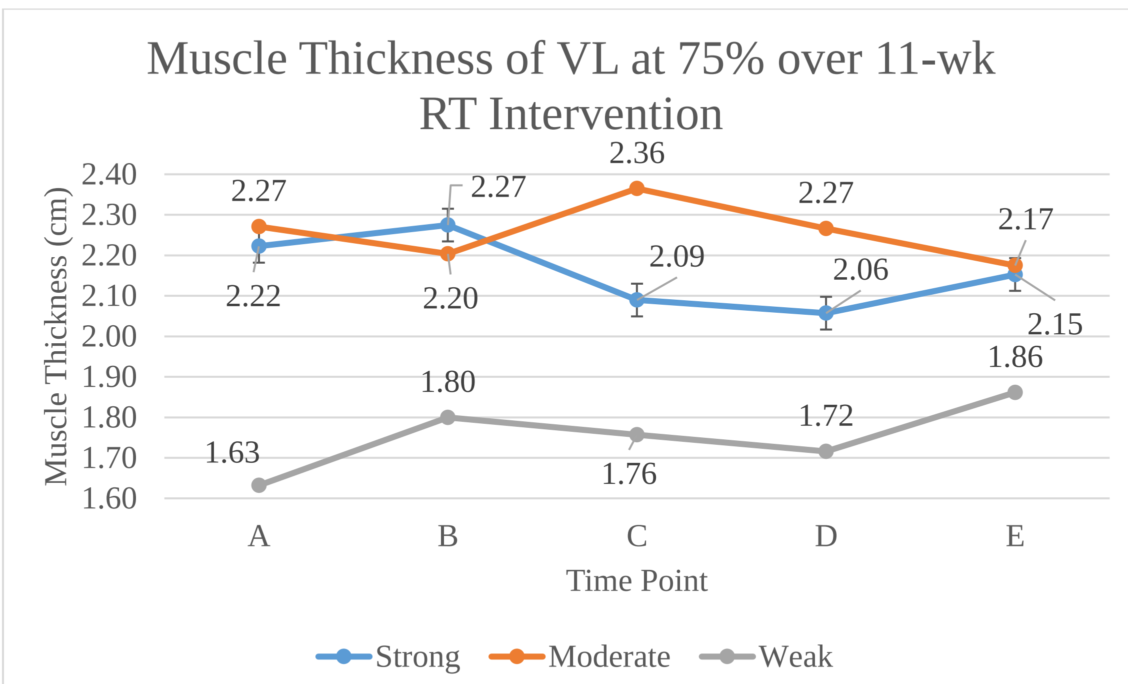


Figure 4.7 Change of Muscle Thickness at 75% of the Vastus Lateralis over Time



Discussion

The intent of this investigation was to answer questions concerning inhomogeneous hypertrophy. Depending on the sport of the athlete, the location of hypertrophy could negatively impact performance by altering moment arms. While it is often the intention of an athlete to increase their muscle mass through resistance training (RT), the athlete (and coach) must also ensure adaptations will not hinder their performance. Certainly, from a coach/athlete perspective, creating hypertrophy in an area that might hinder performance is an unwanted effect. As a result, it is important to understand where hypertrophy occurs when conducting RT for athletes.

In the present study, subjects exhibited hypertrophy in all three sectors of the VL but only the 50% MT hypertrophy was statistically significant between time point A and time points C and D. While studies by Ema et al. (2013) and Matta et al. (2014) found the occurrence of distal hypertrophy to occur to a greater extent than proximal hypertrophy, their subjects used a single joint exercise device (leg extension) for training. The findings of the present study are consistent with those of Baz-Valle et al., (2019), Housh et al., (1992) and Narici et al. (1996).

For example: Baz-Valle et al. (2019) conducted an intervention using more athletic complex movements (i.e. back squat, leg press and dead lift). Although only a 50% MT was measured, the subjects of this study exhibited a statistically significant increase in the VL (Baz-Valle et al., 2019). The present study, with varying exercise selection, is more in line with the findings of Baz-Valle et al. (2019).

As a result of task specificity, inter muscle differences are also possible (Abe et al., 2003). Mangine et al. (2018) examined muscle adaptations following an eight week resistance training intervention consisting of multi-joint lifts. While no intra-muscle inhomogeneity was observed between regions (proximal, middle and distal) for MT or cross-sectional area of the VL, there was a larger increase in the VL compared to the rectus femoris (RF), suggesting intermuscular inhomogeneous hypertrophy occurred. However, Mangine et al. (2018) noted that Ema et al. (2013) and Narici et al. (1996) found the RF to hypertrophy to a greater extent than VL. This difference between studies may be explained by task specificity. Mangine et al. (2018) examined multi-joint closed kinetic chain lifts (i.e. back squat, leg press, etc.) while both Ema et al. (2013) and Narici et al. (1996) examined single joint open kinetic chain lifts (i.e. leg extension). Although intermuscular homogeneity of hypertrophy was not examined in the present study, this possibility underscores the need to understand the CSA outcomes of task specificity. This can have considerable implications for sport performance.

Appropriately training an athlete requires varying volume loads, training intensities and exercise selection (Anderson and Aagaard, 2010; Carroll et al., 2018; DeWeese et al., 2015a, 2015b; Thompson et al., 2019). Training programs using relatively non-specific tasks (little transfer to performance) such as single joint exercises would likely have smaller transfer effect (Augustsson et al., 1998; Gordon et al., 2019; Paoli et al., 2017; Stone et al., 2002). More studies should be conducted using various exercise selections when examining muscle adaptations.

Conclusion

Inhomogeneous hypertrophy appears to occur in the VL when conducting block periodized resistance training emphasizing multi-joint exercises. The VL could experience training induced hypertrophy at differing points in the muscle which may benefit or hinder certain athletes. Depending on the type of exercise used, sport performance could be hindered as a result of indiscriminate hypertrophy. Before creating an annual plan, coaches and sport scientists need to understand their athlete's sport and how exercise selection may help or hurt their performance.

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CHAPTER 5

SUMMARY AND FUTURE DIRECTIONS

In conclusion, all subjects in this study experienced statistically similar trends in physiological muscle adaptations due to resistance training. The first two blocks of training (7 weeks) contained an increase in both lean body mass (LBM) and total body water (TBW) (LBM = 3.6Kg; TBW = 2.63Kg). This suggests a greater increase in sarcoplasmic hypertrophy (including edema) at the onset of resistance training. When the volume is decreased and intensity increased in later blocks (Over-reach and taper) TBW decreased while LBM and $LBM_{adjusted}$ were still elevated, indicating, potentially, true (myofibrillar) hypertrophy. The subjects of this study also experienced a statistically significant increased muscle thickness of the vastus lateralis (VL) at 50% of the length of the femur after the maximum strength and functional over-reach block of training. The other two femur placements (25% and 75%) did not show statistically significant increased muscle thickness at any point of testing. It appears multi-joint movements tend to hypertrophy the VL closer to the proximal aspect of the muscle than the distal aspect of the muscle. This finding is very important depending on the needs and demands of the athlete and their specific sport. Increased mass at the “incorrect” portion of a movement arm could mean decreased power output or even increased risk of an injury. Therefore, it is suggested that strength and conditioning coaches track total body water along with lean body mass. Multi-joint lifts are also recommended during resistance training for most team sports based on their sport’s need and athletic requirements.

Furthermore, a better understanding of the relative contribution of sarcoplasmic and myofibrillar protein accretion to resistance trained hypertrophy can lead to a clearer picture to the extent of their relative contribution to performance aspects, such as strength and power. A greater understanding of these alterations can lead to more efficacious training programs. It is clear that further research exploring the nature of protein accretion using biopsy, proteomics and advanced ultrasound techniques etc. are necessary. Additionally, these types of investigations should be designed such that physiological and performance differences between different levels of training are better identified.

Of interest in relation to this study, recently, several researchers have contended resistance training induced hypertrophy (and periodization as a whole) is not an important component to improve strength and power in strength-power athletes (Buckner et al., 2018; Kiely et al., 2018; Mattocks et al., 2016; Mattocks et al., 2017). This is largely based on recent observations, (Dankel et al., 2015; Mattocks et al., 2017) using relatively untrained subjects, indicating initial alterations in muscle cross-sectional area did not contribute to gains in muscle maximum strength. However, upon closer examination of these studies, several questions have arisen about the authors' findings including several flaws in the experimental implementation and interpretation of their data (Hornsby et al., 2018; Taber et al., 2019).

However, based on the results of the current and previous studies their results (Dankel et al., 2015; Mattocks et al., 2017) should not be surprising (Jeffreys et al., 2016; Mortiani et al., 1979; Narici et al., 1989; Phillips et al., 2000; Staron et al., 1994; Stone et al., 2007). As these two studies were both short-term and used relatively untrained subjects, the initial alterations in CSA would not be expected to have a great impact on strength performance.

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Appendix: Data Collection Sheets

Hydration						
Date:						
Subject	Trial 1		Trial 2		Trial 3	
	1.	1.	1.	1.	1.	1.
	1.	1.	1.	1.	1.	1.
	1.	1.	1.	1.	1.	1.
	1.	1.	1.	1.	1.	1.
	1.	1.	1.	1.	1.	1.
	1.	1.	1.	1.	1.	1.
	1.	1.	1.	1.	1.	1.
	1.	1.	1.	1.	1.	1.
	1.	1.	1.	1.	1.	1.
	1.	1.	1.	1.	1.	1.
	1.	1.	1.	1.	1.	1.
	1.	1.	1.	1.	1.	1.
	1.	1.	1.	1.	1.	1.
	1.	1.	1.	1.	1.	1.

BIA Measureables (Date)

Name	Date	D.O.B	Age	Gender	Height (cm)	Weight (Kg)	Ankle -Patella Length (cm)	Trochanter-Patella Length (cm)	Full Leg Length (cm)

BIA Measurables (Date)

Full Rc 1	Full Rad 1	Full Rc 2	Full Rad 2	Leg Rc 1	Leg Rad 1	Leg Rc 2	Leg Rad 2	Upper Rc 1	Upper Rad 1	Upper Rc 2	Upper Rad 2

Ultrasound Measurements					
Subject	Femur (cm)	25% Depth	50% Depth	75% Depth	CSA depth

ISO Rack			Date:				
Subject	Bar Height (m)	Knee Angle	Pull 1	Pull 2	Pull 3	Pull 4	Pull 5

1-RM Squat Weight												
Date:												
Subject	30%x5	50%x3	70%x2	80%x1	90%x1	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7
	1min	1min	2min	3min	3min	3min	3min	3min	3min	3min	3min	3min

Day 1 and 3 Displacement										
		Subject	Subject	Subject	Subject	Subject	Subject	Subject	Subject	Subject
Lift	Top									
	Bottom									
	Displacement	**0.0**	**0.0**	**0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Lift	Top									
	Bottom									
	Displacement	**0.0**	**0.0**	**0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Lift	Top									
	Bottom									
	Displacement	**0.0**	**0.0**	**0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Lift	Top									
	Bottom									
	Displacement	**0.0**	**0.0**	**0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Day 2 Displacement										
		Subject	Subject	Subject	Subject	Subject	Subject	Subject	Subject	Subject
Lift	Top									
	Bottom									
	Displacement	**0.0**	**0.0**	**0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Lift	Top									
	Bottom									
	Displacement	**0.0**	**0.0**	**0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Lift	Top									
	Bottom									
	Displacement	**0.0**	**0.0**	**0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Lift	Top									
	Bottom									
	Displacement	**0.0**	**0.0**	**0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Daily and Weekly Volume Displacement Day 1 and 3						
Subject						
Lift	WU	Vld	Work	Vld	Total Vld	Weekly total
W1 D1						
W1 D3						
W2 D1						
W2 D3						
W3 D1						
W3 D3						
Lift						
W1 D1						
W1 D3						
W2 D1						
W2 D3						
W3 D1						
W3 D3						
Lift						
W1 D1						
W1 D3						
W2 D1						
W2 D3						
W3 D1						
W3 D3						
Lift						
W1 D1						
W1 D3						
W2 D1						
W2 D3						
W3 D1						
W3 D3						

Daily and Weekly Volume Displacement Day 2						
Subject						
Lift	WU	Vld	Work	Vld	Total Vld	Weekly total
W1 D2						
W2 D2						
W3 D2						
Lift						
W1 D2						
W2 D2						
W3 D2						
Lift						
W1 D2						
W2 D2						
W3 D2						
Lift						
W1 D2						
W2 D2						
W3 D2						

Subject ID:																Date:					
Day 1- Intensity:																					
Exercise	1 RM	Warm-Ups						Reps	Suggested Load			Set 1		Set 2		Set 3		Set 4		Set 5	
												Weight	Reps	Weight	Reps	Weight	Reps	Weight	Reps	Weight	Reps
Lift	0	Load:							0	-	0										
		Reps:																			
Lift	0	Load:							0	-	0										
		Reps:																			
Lift	0	Load:							0	-	0										
		Reps:																			
Lift	0	Load:							0	-	0										
		Reps:																			
Lift	0	Load:							0	-	0										
		Reps:																			
Lift	0	Load:							0	-	0										
		Reps:																			
Lift	0	Load:							0	-	0										

VITA

PAUL A. MOQUIN

Education:	Ph.D. Sport Physiology and Performance, East Tennessee State University, Johnson City, TN 2020 M.S. Exercise Science, The George Washington University, Washington D.C 2015 B.S. Exercise Science, University of Pittsburgh, Pittsburgh, Pa 2012 Parkland High School, Allentown, Pennsylvania 2008
Professional Experience:	Men's Basketball Assistant Coach, Milligan University, 2019-2020 Men's Basketball Head Strength and Conditioning Coach, Milligan University, 2018-2020 Doctoral Fellow, East Tennessee State University, 2018-2020 Women's Basketball Assistant Strength and Conditioning Coach, Milligan University, 2017-2018 Assistant Strength and Conditioning Coach, Shippensburg University, 2017-2017 Strength and Conditioning Intern, National Strength and Conditioning Association, 2015-2016 Strength and Conditioning Intern, Washington Wizards 2014-2015 Graduate Assistant, The George Washington University, 2013-2015
Publications:	Moquin, P. A., Walters, J., Wetmore, A. B., Flynn, A. I., Lang, H. M., & Stone, M. (2018). Consideration for Using Multi-Joint, Large Muscle Mass Exercises and One-Repetition Maximums: A Case Study. ETSU Coaches and Sport Science College, 4. Abbott, J., Hierholzer, K.M, Moquin, P., Bursais, A., Kirkpatrick, J., Cogniglio, C.L & Gentles, J.A (2017). The Relationship Between Accelerometry Derived Training Loads and sRPE In Women's Collegiate Soccer. ETSU Coaches and Sport Science College, 5. Walters, J., Travis, K. S., Flynn, A., Moquin, P., & Smith, A. (2017). Time-Series Forecasting: A Theoretical Model for Predicting Performance Potential. ETSU Coaches and Sport Science College, 5.