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Recoverability of large vs small muscle groups

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RECOVERABILITY OF LARGE VS SMALL MUSCLE GROUPS

An Abstract of a Thesis

Submitted

In Partial Fulfillment

Of the Requirements for the Degree

Master of Arts

Jacob Alan Clark

University of Northern Iowa

July 2020

ABSTRACT

The purpose of this study was to assess differences in recovery between muscles with larger cross-sectional area (Quadriceps) compared to muscles with smaller cross-sectional area (Biceps). Recreationally trained male weight lifters aged 18-30 (n = 9) volunteered in this muscle recovery study. All participants were asked to attend two testing sessions in addition to an initial meeting, all of which took no more than 45-mintues per session to complete. After this initial session where the 10 RM in the biceps curl and quadricep extension were determined, participants were scheduled to perform the biceps curl and quad extension for four sets to technical failure in two separate testing sessions with no less than 48 hours in between the testing sessions. Total volume and rate of perceived exertion (RPE) measures were recorded and. The results of a dependent t-test determined there was no significant differences in the TV accumulated between T1 and T2 for the biceps brachii (T8 = -.67, p = .52). The mean biceps TV during pre-test was 2769.8 lbs (SD = 476.87, N = 9), and the post-test biceps TV was 2806.39 lbs (SD = 512.78, N = 9). Similarly, a dependent t-test determined there was no significant differences in the TV accumulated between T1 and T2 for the quadriceps (T8 = -1.449, p = .19). The average quadricep TV during pre-test was 8798.8 lbs (SD = 1669.8, N = 9), and the post-test quadriceps TV was 9290.3 lbs (SD = 1523.5, N = 9). Levene's test for equality of variances was conducted and reached significance for differences in volume accumulations between the biceps (M = 9.82lbs, SD = 1.54) and quads (M = 22.42lbs, SD = 2.01), (F (2,16) = 7.0, p = 0.18). It appears that muscle size has little impact upon the rate of recovery under the conditions of the present study. Under the same conditions, however, there was greater variation in volume accumulation 48 hours post bout in the quadriceps than in the biceps. Future research should focus on further establishing (or refuting) the connection between muscle size and recoverability while employing greater control over confounding variables

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This Study by: Jacob Alan Clark
Entitled: Recoverability of large vs small muscle groups

has been approved as meeting the thesis requirement for the

Degree of Master of Arts

Date	Dr. Jacob Reed, Chair, Thesis Committee
Date	Dr. Forest Dolgener, Thesis Committee Member
Date	Dr. Fabio Fontana, Thesis Committee Member
Date	Dr. Jennifer Waldron, Dean, Graduate College

DEDICATION

The incredible amount of time and energy that allowed this work to come to fruition is dedicated to my peers, professors, and fiancé. Nobody does it alone.

ACKNOWLEDGEMENTS

It is an impossible task to name everyone that contributed to the completion of this project. Too many individuals have lent me their support, friendship, and reassurance in the face of the most daunting academic task I have faced thus far. However, I would like to take the time to appreciate individuals who went above and beyond to help. Individuals with whom I owe my education and sincerest gratitude.

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The contribution of my fellow students must also be acknowledged as much of the framework for this study on muscle recovery was born from conversation in the psychomotor lab WRC 120. While there are well over twenty students that have contributed and have my sincerest gratitude, there are five that deserve recognition by name. Alex Long, Aubri Keesee, Sydney Cindrich, Omar Martinez, and Christy Andorf. Thank you for your time, your help, and your friendship.

Finally, I would like to acknowledge my fiancé. Without her understanding and relentless commitment, I would never have made it this far. Thank you, I love you.

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CHAPTER ONE

INTRODUCTION

Since its inception in the 1960s to prevent injury, resistance training (RT) has only grown in popularity and scope. Resistance training is currently established as a viable means to promote muscular hypertrophy, neuromuscular adaptations, and induce body composition changes (Csapo & Alegre, 2016; Judge & Burke, 2010; Schoenfeld, Grgic, & Krieger, 2019).

Of all the components contained in an effective RT program, few are debated more intensely than training frequency. Training frequency refers to the number of training sessions per body part per week. Frequency is a heavily debated topic in the professional athletics realm, but also the health and fitness world. Individuals training for recreation and athletes alike have routinely practiced training each body part once a week. This has historically been referred to as “the bro split.” As new research has emerged on training frequency, fatigue, and recovery, (DeRenne, Hetzler, Buxton, 1996; Schoenfeld, 2010; Schoenfeld et al., 2018) the idea has been postulated that this standard split may be suboptimal for promoting muscular adaptations to resistance training

Training frequency in the context of this study is not about the ability to accumulate appropriate levels of volume; but, to measure the ability of large and small muscle groups to recover in between training sessions. If different muscle groups have different speeds at which they recover from fatigue, then programming adequate rest based on that knowledge is valuable. If the biceps can fully recover from training in 48 hours, but the quads still show signs of fatigue, an individual might practice a lower frequency for quads training and a higher frequency for biceps training.

Training frequency can be refined further into frequency per muscle group. One of the hypotheses proposed in this study is that muscles with greater cross-sectional area will require greater recovery times as a result of greater amounts of absolute damage to the muscle and buildup of metabolites. The research on whether this is the case is lacking. However, the idea that there are differences in recovery between smaller and larger muscle groups is currently being invoked by several large health and wellness organizations as well as accredited fitness professionals. Some of the proposed mechanisms of variations in recovery include training status, fiber type, and mitochondrial density. One should note that the scientific evidence in support of the proposed mechanisms effect on recovery rate is lacking as well. Therefore, scientific inquiry is warranted to discern whether larger muscle groups (Quadriceps, pectorals, etc.) incur more damage and require more time to recovery from said damage than do smaller muscle groups (Biceps, wrist extensors, etc.).

Recovery is important to muscular adaptations and should be considered in any training program. Recovery is important because an individual's ability to perform in subsequent training sessions depends on how fully the individual recovers from prior training sessions. This can have a dramatic effect on accumulating optimal training volume and should be heavily considered when designing a program.

This study will concern how recovery rate pertains to muscular hypertrophy focused training. Muscle hypertrophy resulting in greater lean body mass is a precursor for other sought-after muscular adaptations like strength and body composition changes (Maughan, Watson, & Weir, 2012) and will therefore serve as the primary adaptation considered. The literature review, methodology, and discussion sections will also reflect the emphasis on hypertrophy.

Statement of the Problem

The purpose of this study is to take large and small muscle groups (quadriceps and biceps brachii) through four sets to technical failure in the biceps curl and quadricep extension and measure recovery at 48 hours post-bout in resistance trained males aged 18 to 30 years old.

Significance of the Study

In the past decade, research has been heavily focused on optimizing training volume. The evidence is clear that there are methods of accumulating volume that tend to be more effective than others. Some of the variables that are manipulated include exercise selection and sets per week. (Pareja-Blanco et al., 2018; Schoenfeld et al., 2019; Schoenfeld, Ogborn, & Krieger, 2016). However, delving deeper into optimizing training volume, training frequency becomes a manipulatable variable of interest; especially when recovery is considered. By comparing the recovery rate of small versus large muscle groups, one can obtain a further degree of refinement when optimizing training frequency, and by extension training volume.

This study will allow a more refined prescription of resistance training protocol for resistance trained individuals, aged 18-30 years. In gaining an understanding of the processes and influences of muscle recovery based on muscle group size, we will more accurately be able to prescribe training volume and frequency protocols that coincide with the ability of said muscle group to recover from fatigue; which will ultimately lead to greater muscular adaptation.

Delimitations

This study we delimited to:

1. Nine male resistance trained individuals, aged 18 to 30 years old, free of any current soft tissue injuries to the upper body.

Limitations

This study was limited to:

1. Variations in mode of resistance training experience
2. The possibility of participants not performing to absolute failure

Assumptions

This study was conducted under the following assumptions:

1. The participants complied with the researcher’s request to provide maximal effort
2. The participants were representative of the resistance trained population aged 18 to 30
3. The measuring instruments provided reliable and valid measurements
4. Participants have an adequate sleep schedule
5. Participants have acceptable nutritional practices
6. Individuals who met the inclusion criteria were familiar with the biceps curl and quad extension exercises

Hypotheses

The following were hypotheses of the study:

1. Smaller muscle groups (Biceps Brachii) will recover faster than larger muscle groups (Quadriceps).
2. A significant positive correlation will exist between muscular recovery and ability to perform close to 100 percent of control volume.
3. Training large muscle groups (Quadriceps) will result in greater subjective fatigue than training smaller muscle groups (Biceps Brachii).
4. Small muscle groups may be fully recovered within 48 hours post RT, whereas large muscle groups may take 48 hours or more.

Definition of Terms

1. Recovery – return to baseline.
2. Fatigue – the decline in the ability of a muscle to generate force, velocity, or power (Nocella et al., 2011).
3. Frequency – Rate of training sessions per muscle group per week
4. Muscular failure – inability of a muscle group to produce enough force to maintain the 8 to 12 rep range.
5. Muscular adaptations to resistance training – The changes experienced in strength, hypertrophy, power, and body composition as a result of RT
6. Training Volume – total cumulative weight lifted per muscle group per week
7. Large muscle groups – Muscles with, on average, greater cross-sectional area such as the pectorals, quadriceps, or glutes.

8. Small muscle groups – Muscles with, on average, less cross-sectional area such as the biceps brachii, wrist extensors, and triceps.
9. Recoverability – The ability of a muscle group to recover from fatigue
10. Hypertrophy – Increase in muscle cross-sectional area through increased contractile machinery, fluid retention, or both.

CHAPTER TWO

REVIEW OF THE LITERATURE

Introduction

Since RT’s inception in the 1960’s to prevent injury, RT has only grown in popularity and scope. Resistance training is currently established as a viable means to promote muscular hypertrophy, strength, power, and induce body composition changes (Csapo & Alegre, 2016; Jones, Rutherford, & Parker, 1989; Schoenfeld, 2010; Schoenfeld et al., 2016). The scientific literature surrounding RT is currently chiefly concerned with what variables contribute, and to what degree they contribute, to effective muscular adaptations.

A wide range of variables contribute to effective muscular adaptation. Some of which include tension, damage, stress, load, recovery, and fatigue management (Schoenfeld, 2010). One should note, however, that volume is the primary driver of adaptation (Schoenfeld et al., 2016). With that in mind, of all the components of effective RT, few are debated more intensely than frequency. Training frequency is a debated topic in not only the professional athletics realm, but also the health and fitness world as well. It has been a common practice for decades to train each body part once a week. This has historically been referred to as, “the bro split”. As new research has emerged on training frequency, fatigue, and recovery, the idea has been proposed that this standard split may be suboptimal when it comes to muscular adaptations.

Frequency can be broken down further into frequency per muscle group. There is speculation that smaller muscle groups can be trained more frequently than larger muscle groups. The logic behind this hypothesis often involves a smaller volume of tissue damage in smaller muscle groups accompanied by a lesser total accumulation of metabolic biproducts in smaller muscle groups as well. Differences in training adaptations and recovery between large and small muscle groups is a very sparsely studied topic. At the time of this study there was little to no research examining responses to training in large versus small muscle groups.

The purpose of this study is to take large and small muscle groups (e.g. Biceps Brachii and Quadriceps) to technical failure and measure the total volume performed for the quadricep and biceps brachii in a control session, followed by a posttest 48 hours later. Differences in the volume performed between sessions will provide insight into how recovered the individual's larger muscles were, compared to how recovered their smaller muscle groups were. This will allow the prescription of optimal training frequencies, and by extension, optimal accumulation of volume which will ultimately lead to greater muscular adaptation.

By understanding how quickly small and large muscle groups recover, training frequency can be optimized to be muscle group specific. This will allow tailoring of RT programs to suit specific muscle groups, populations, and athletic needs. It should be noted that while training frequency is the variable of interest, optimizing training frequency to the benefit of optimizing training volume will be the primary driver of muscular adaptation per week.

An understanding of fatigue and how it affects an individual's ability to perform RT is fundamental to the frequency and volume equation. This, coupled with knowledge of the recovery process from fatigue, is also crucial to understanding how training variables and fatigue affect each other. Of first consideration, however, is how does resistance training work?

Adaptations to Resistance Training

Why Resistance Train?

Whether an individual is an athlete or sedentary, RT has the potential to enrich lives through several physiological adaptations that include Hypertrophy, neuromuscular changes, and body comp changes. Of these adaptations, as stated previously, hypertrophy appears to be an important precursor for other typically sought-after resistance training adaptations. That's not to say hypertrophy is the only possible way to increase strength or improve body composition. An example of a proposed mechanism of increasing strength without an accompanied increase in muscular cross-sectional area is myofibrillar hypertrophy (Taber, Vigotsky, Nuckols, & Haun, 2019). However, the totality of evidence lends credence to the fact that, on average, a bigger muscle is a stronger muscle (Maughan et al., 2012); and therefore, hypertrophy will be the primary adaptation of concern.

Hypertrophy. Muscular hypertrophy, put simply, is the growth of muscle tissue. Some of the specific mechanisms for such growth include an increase in the components of the cellular matrix (MacDougall, Sale, Alway, & Sutton, 2017; Zatsiorsky, Kraemer, & Fry, 2020) or an increase in the number of contractile proteins actin and myosin that occur in parallel or series (Toigo & Boutellier, 2006; Vierck et al., 2000). Hypertrophy of the non-contractile components commonly referred to as "sarcoplasmic hypertrophy" can result in larger muscle size without any accompanied increase in strength (Siff, 1999). The type of muscle hypertrophy incurred is hypothesized to be a direct result of training modality. The most cited examples that occur on either end of the hypertrophy spectrum are bodybuilders and powerlifters. Bodybuilders tend to utilize higher rep lower intensity resistance training methods that result in a greater accumulation of metabolites that ultimately result in sarcoplasmic hypertrophy; whereas powerlifters tend to favor training with greater intensity and less volume that results in hypertrophy of the functional contractile machinery. A third type of hypertrophy termed "muscular hyperplasia" occurs when there is an actual increase in the number of muscle fibers; but it is not a result of resistance training adaptation (Paul & Rosenthal, 2002) and therefore will not be discussed any further. Muscular hypertrophy is desired for three primary reasons and is an area of interest for professional athletes and the common gym goer alike.

First and foremost, muscular hypertrophy is desired for aesthetic purposes. Most notably in bodybuilders and physique athletes, resistance training coupled with specific nutritional practices yields physiques that are considered aesthetic and desirable in modern culture.

Secondly, muscular hypertrophy is a considerable component of muscular strength and power. As training age increases and neuromuscular adaptation approaches a genetic limit, one of the few options to facilitate further strength increases is to increase the actual muscle size (Maughan et al., 2012). With an increase in muscle cross-sectional area, an accompanying increase in myosin-actin cross-bridges occurs, and by extension, an increase in muscular strength. Increasing base strength has an abundance of application in sport and beyond.

Of final consideration is the capacity of muscular hypertrophy to prevent sports-related injuries. In concert with increasing muscular strength and power, programs that includes RT were shown to reduce injury risk in young athletes (Faigenbaum & Myer, 2012). An important component of RT adaptation is the accompanied increase in muscular tissue and connective tissue cross-sectional area (Kraemer, Ratamess, & French, 2002). This is likely the mechanism that results in a lower instance of injury in resistance trained populations.

General hypertrophy guidelines put forth by the American College of Sports Medicine (Pescatello, Riebe, & Thompson, 2014) recommend 1 to 3 sets for novice individuals and higher volumes of 3-6 sets for more experienced individuals. Repetition ranges of 8 to 12 appear to be the most effective for muscular hypertrophy. Consideration should be lent to the fact that, with all variables accounted for, higher volume protocols will illicit more muscular growth than will low volume protocols (Schoenfeld et al., 2016).

Myogenic Pathways & Anabolic Signaling for Hypertrophy

RT induced muscular adaptations are stimulated through what are called myogenic pathways. Myogenic pathways are a series of electro-chemical signals stimulated by RT that increase protein synthesis and decrease protein breakdown (Schoenfeld, 2010). Three primary myogenic pathways will be discussed: Mammalian target of rapamycin (mTOR), Mitogen-activated protein-kinase pathway (MAPK), and calcium dependent pathways

The mTOR pathway is often framed as the "mastermind" that regulates skeletal muscle growth (Bodine et al., 2001; Jacinto & Hall, 2003). In essence, mTOR stimulates anabolic signaling and inhibits catabolic signaling (Toigo & Boutellier, 2006). There is no perfect consensus on what specific molecular processes the mTOR pathway involves, but there is speculation that mTOR is an upstream nodal point that, once stimulated, affects downstream processes that influence hypertrophy in skeletal muscle (Schoenfeld, 2010).

The MAPK pathway is a regulator of gene expression, redox status, and metabolism (Kramer & Goodyear, 2007). MAPK is the link between cellular stress and the adaptive response in myocytes that modulate cell growth (Roux & Blenis, 2004). Three primary MAPK signaling modules influence muscular hypertrophy: extracellular signal-regulated kinases, p38 MAPK, and c-Jun NH2-terminal kinase (JNK). Of these three signaling modules, JNK appears to be the most responsive to mechanical tension, muscle damage, and eccentric exercise. RT induced activation of JNK is linked to a rise in mRNA transcription that affects cell proliferation and DNA repair (Aronson, Boppart, Dufresne, Fielding, & Goodyear, 1998; Aronson, Dufresne, & Goodyear, 1997).

The calcium-dependent pathways involve a crucially important regulator in the Ca2+ signaling cascade called "Calcineurin" (Cn), a Ca2+ regulated phosphatase. Cn mediates hypertrophic effectors like myocyte enhancing factor 2, GATA transcription factors, and nuclear factor of activated cells (Michel, Dunn, & Chin, 2004). Cn-dependent signaling is apparent in every type of fiber hypertrophy. What is even more telling is that in the absence of Cn-dependent signaling, muscle growth is impaired even in the presence of muscular overload (Dunn, Burns, & Michel, 1999; Dunn, Chin, & Michel, 2000).

Training Volume

RT Volume is considered the biggest driver of muscular adaptation (Schoenfeld et al., 2016). Volume in the context of RT is calculated by taking weight lifted, multiplied by reps performed, multiplied by sets performed. Programs that utilize higher volume multiple set protocols have consistently shown to be superior to single set protocols in regard to hypertrophy (Krieger, 2010; Mulligan et al., 1996). This is most likely due to the lack of total volume accumulation over time that results from single set protocols. In fact, if volume is the biggest driver of hypertrophy, most protocols that hinder volume accumulation are likely to be suboptimal for hypertrophic adaptations.

A distinction should be made between relative and absolute volume. Absolute volume is expressible by the traditional definition of training volume sets x reps x weight. In contrast, relative volume could be expressed in sets x reps x weight (expressed as a % of 1RM). This is relevant as the quads are clearly capable of handling a greater absolute amount of training volume compared to the biceps. This is inherent as the result of a much larger area of contractile tissue. However, when expressed relatively, these differences disappear. This lends credence to the idea that all muscles, regardless of size, respond to training volume similarly.

There are crucial variables that should be considered when optimizing training volume for muscular adaptations. These include frequency, split, rest period, and intensity. Some special considerations for training volume should be considered as well, such as training to failure and repetition speed.

Frequency

In the realm of resistance training certain training variables spark debate and sometimes even ire; training frequency is one of those variables. Training frequency is defined by the number of training sessions per week. While frequency does play an important role in resistance training induced adaptations, volume is critical (Barcelos et al., 2018; Schoenfeld, 2010; Schoenfeld et al., 2019, 2016). Barcelos et al. (2018) found that training frequencies of five times per week elicited no more muscle growth than did training frequencies of three times per week when volume was equated. This suggests that for a given training volume a person may choose a frequency that fits their own lifestyle (Schoenfeld et al., 2018).

Frequency is a variable used to influence another variable, namely volume. Training more sessions in a week rather than less is not inherently helpful. For example, if an individual accumulates 100,000 lbs of total body volume in five training sessions a week, and another individual accumulates 120,000 lbs of total body volume in three sessions a week, all other variables held constant, the individual with the lower training frequency will experience greater muscular adaptation as a result of the greater accumulation of volume. Thus, understanding frequency within the context of which frequency is being applied is important.

Split

Another key variable is number of sets per body part per week. This has historically been referred to as a “split”. A growing body of research has explored how many sets per body part, per week is optimal for hypertrophy (Schoenfeld et al., 2019, 2016; Toigo & Boutellier, 2006); However, prior to the evidence suggesting one modality was better than another, individuals tended to use the “bro split’. The bro split refers to a style of training where each muscle group is trained once per week at an arbitrary amount of volume. The “bro split” is most frequently split up into chest, shoulders, legs, back, and arms.

The first, and most glaring flaw encountered with this split, is that training each muscle group once per week severely limits one’s ability to accumulate optimal volume to produce muscular adaptation . Can one accumulate enough volume in one training session to stimulate muscular adaptation? This is possible when one considers other factors, like time and intensity requirements. the “bro split” still leaves a lot to be desired. At some point, the time commitment to accumulate enough volume in a single session may become more than an individual has available. At this point, the option becomes to train with less volume per session split up into multiple sessions per week; i.e. increase frequency per muscle group, with less volume per session (Schoenfeld et al., 2019).

Schoenfeld et al. (2018) found that for a given amount of training volume, frequency was negligible. This means that frequency is a variable that can be changed based on individual preference and need. While higher frequency would be beneficial to, on average, accumulate more volume, in a practical setting this may pose an unnecessary time constraint. If the appropriate amount of volume can be comfortably completed in a 3-day training split, then one does not need to stretch into a 5-day training split. The extra time could then be devoted to other important resistance training factors like rest and recovery.

Rest Period

Rest period can be organized into three categories: Short, moderate, and long. Short is defined as 30 seconds or less, moderate ranges from 60 seconds to 90 seconds, and long is classified as 3 minutes or longer. Each category has specific effects on strength capacity and metabolite accumulation, thus affecting hypertrophic adaptations (Willardson, 2006). Short rest periods have been shown to generate a large amount of metabolic stress, thus upregulating the anabolic processes associated with metabolic buildup (Goto et al., 2004). However, less than 30 seconds of rest is insufficient to regain muscle strength and will impair performance in subsequent sets (Pincivero, Lephart, & Karunakara, 1997; Ratamess et al., 2007). The metabolite accumulation benefit gained from short rest periods is seemingly counterbalanced by the accompanied decrease in strength performance, thus making short rest periods suboptimal for hypertrophic adaptation (Miranda, Ana, Simao, & Dantas, 2007). Rest intervals of 3-5 minutes allow for more repetitions over multiple sets when using loads between 50 and 90% 1RM (de Salles et al., 2009). However, while longer rest periods allow the generation of maximal tension, metabolic accumulation is hindered; which is still an important component of hypertrophic adaptation (Kraemer et al., 1991, 1990). Moderate rest periods seem to be the ideal compromise for optimizing muscle hypertrophy. Current research suggests that the majority of an individual's capacity is recovered in the first minute after the completion of a set (Willardson, 2006).

Moderate rest periods appear to be best for hypertrophic adaptation, but rest periods of three minutes or more ensure that nearly all strength capacity is regained (Willardson, 2006). This will ensure the best performance for subsequent sets and the greatest accumulation of volume.

Special Considerations

Beyond typical variables manipulated in training such as those previously discussed, there are other variables that have not quite had their effect elucidated. These variables include repetition speed, training to failure, and pennation angle of the muscle being trained. The speculation on the magnitude of effect for these variables on muscular adaptation ranges from "somewhat" all the way to "a great deal".

Repetition speed. Training with very slow repetition speed has consistently been shown to be suboptimal for hypertrophic adaptations (Keeler, Finkelstein, Miller, & Fernhall, 2001; Neils, Uderman, Brice, Winchester, & McGuigan, 2005). As such, very slow repetition speeds should be avoided when the focus is to maximize hypertrophic adaptation. Many studies clearly show that eccentric actions, muscle lengthening exercises in particular, result in a more rapid rise in protein synthesis (Moore, Babraj, Phillips, & Smith, 2005) as well as IGF-1 mRNA expression (Shepstone et al., 2007) and thus have a greater effect on hypertrophy compared to solely concentric (shortening) exercises. There is a great amount of stress on a small number of fibers during eccentric exercise. This results in greater muscle damage when compared to concentric and isometric movements (McHugh, Eston, Connolly, & Gleim, 2000). Therefore, regardless of the speed of concentric action, the eccentric component is arguably more conducive to hypertrophy. Speed, barring it isn't hyper slow or uncharacteristically fast, is somewhat irrelevant. If loading, sets, and reps are programmed appropriately and a strict adherence to proper movement form is followed, optimal speed will likely be achieved as a result.

<u>Training to failure</u>. Muscular failure can be defined as the point within a set when the muscles cannot generate enough force to concentrically contract against a load (Schoenfeld, 2010). Like the "bro split", training to failure has been a mode of training passed on from recreational gym user to recreational gym user disguised as a standard and effective means to induce muscular hypertrophy, and ultimately, cultivate greater muscular adaptations (Willardson, 2007). According to the current body of research, this is not necessarily the case (J. J. Gonzalez et al., 2016; Pareja-Blanco et al., 2018; Stone, Chandler, Conley, Kramer, & Stone, 1996).

Pareja-Blanco et al. (2018) Found that fatiguing high volume sets until failure in the bench press and squat led to greater fatigue, slower neuromuscular recovery, an amplified hormonal response, and more signs of muscular damage. Protocols that were taken to failure incurred a decrease in performance for up to 48 hours post session. This is the most important factor to consider in protocols that incur absolute muscular failure; they inhibit performance in subsequent training sessions and may ultimately lead to less total training volume than would training methods where absolute failure is not reached. Similarly, Gonzalez et al. (2016) found that higher volume sets to failure resulted in higher autonomic, cardiovascular, and biomechanical stress, as well as greater fatigue and slower recovery than did sets with half-maximal repetitions.

Gonzalez et al. (2016) suggested that time necessary to recover may increase as repetitions approach absolute failure. This is likely due to accumulating an exponentially larger amount of fatigue as repetitions approach failure. There is speculation that there is an optimal amount of neuromuscular fatigue to facilitate adaptation. In addition, mounting evidence suggests that training to failure may not necessarily improve the magnitude of said adaptations (Drinkwater et al., 2007).

Gonzalez et al. (2016) found that training to failure via sets of 8 repetitions in the squat resulted in greater neuromuscular fatigue, much greater accumulation of prolactin and IGF-1, reductions in HRV and HRC (immediate recovery), and counter-movement jump remained reduced up to 48 hours post exercise. In contrast, the half maximal group (sets of 4) sustained a higher mean velocity on squat repetitions, lower impairment of neuromuscular performance, faster recovery, reduced hormonal response and muscle damage, and a lower reduction in HRV and HRC following exercise. This suggests that training sub maximally will allow for quicker recovery because of less muscular damage. This seems counterintuitive but this would make sense that more muscular damage would encourage greater adaptation, and ultimately, greater muscular adaptations. However, remembering that volume is critical, training to failure may impair an individual’s ability to perform a movement up to 48 hours post exercise. That hinders the ability to perform in subsequent training sessions and may negatively affect an individual’s ability to accumulate a necessary amount of volume to optimize muscular adaptation.

While training to failure does appear to result in hypertrophic benefits, one should implement it with caution due to its capacity to cause overtraining and psychological burnout (Fry & Kraemer, 1997). Training to failure resulted in the reduction of anabolic hormones including testosterone and igf-1 in a 16 week protocol. This implies that participants may have been overtrained. Although performing at or near failure is important in hypertrophy programs, failure protocol should be planned and limited in order to avoid an overtrained state (Izquierdo et al., 2008).

Training frequency also plays a role. If one is training a muscle group once per week, then training to failure may be a viable option depending on how the accompanying fatigue affects your ability to accumulate additional volume within the training session. This may be a potential argument for keeping sets to failure towards the end of a training session. However, if one has a training frequency for a given muscle group higher than once or twice a week, then training to failure may limit one’s ability to accumulate optimal volume in subsequent sessions, thus limiting the capacity for muscular adaptation.

Fatigue

An often overlooked, but vitally important component, to incurring muscular adaptations is accumulating an optimal amount of fatigue, and the subsequent recovery from said fatigue (Judge & Burke, 2010). According to Nocella et al. (2011), fatigue can be defined as the decline in the ability of a muscle to generate force, velocity, or power. This section will cover the various components of fatigue and how individuals recover from fatigue. In addition, how these variables are involved in optimizing muscular adaptation will be discussed periodically throughout the section.

Mechanisms of Fatigue

Another way to define muscular fatigue is the loss of maximum force-generating capacity (Kent-Braun, 1999). Fatigue occurs in the nervous system as well as within the muscle itself (Halson & Jeukendrup, 2004; Hargreaves, 2005; Hunter, St Clair Gibson, Lambert, Nobbs, & Noakes, 2003). An inability to produce force can occur in several places throughout the nervous system and muscular contractile machinery. Mechanisms of fatigue can be broadly separated into peripheral mechanisms and central mechanisms. There is some contention in the literature as to the best way to separate central and peripheral fatigue; how to define where on ends and the other begins. While not entirely arbitrary, for the purposes of this paper the neuromuscular junction (NMJ) will be the separating point between central factors and peripheral factors. Central factors will involve factors occurring proximal to the NMJ, while peripheral factors will include the NMJ and the contractile machinery.

Central mechanisms of fatigue.

Past research surrounding central fatigue is inconsistent at best with some studies finding little to no central fatigue (Bigland-Ritchie, Furbrush, & Woods, 1986) and others reporting statistically significant central failure during exhaustive exercise (McKenzie, Bigland-Ritchie, Gorman, & Gandevia, 1992). Reduced ability of the neuromuscular system to generate force has been reported under some fatiguing exercise conditions (Fuglevand, Zackowski, Huey, & Enoka, 1993). However, this does not appear to be a consistent finding either. Central fatigue appears to play a less important role in acute fatigue, such as what is experienced as the result of appropriately designed weekly training bouts. Kent-Braun (1999) demonstrated that in a maximum voluntary contraction (MVC) lasting four minutes in duration, only 20% of the fatigue could be traced to central factors; the remaining 80% being invoked by peripheral factors. One should also note that there are measures of chronic fatigue that involve substances generated by peripheral mechanisms of fatigue such as blood lactate (Halson & Jeukendrup, 2004). A solid consensus is yet to be confirmed, but the current state of the research does not favor central fatigue as a primary driver of acute fatigue experienced during voluntary contractions.

Peripheral mechanisms of fatigue. Peripheral mechanisms of fatigue are comprised primarily of metabolic inhibition of the contractile machinery and excitation-contraction coupling failure (Allen, Lännergren, & Westerblad, 1995; Kent-Braun, 1999; Westerblad, Allen, & Lännergren, 2002)**.** Prolonged low intensity exercise is usually accompanied by the latter form of fatigue and requires a longer recovery period (Baker, Kostov, Miller & Weiner, 1993), whereas metabolic inhibition of the contractile machinery is more common with high intensity bouts of exercise. Exactly which metabolites play a role is still a point of contention. Current research tends to lean towards hydrogen ions and inorganic phosphate as the primary driver of metabolic mechanisms of muscle fatigue (Gordon, Kraemer, Vos, Lynch, & Knuttgen, 1994; Robergs, Ghiasvand, & Parker, 2004; Westerblad et al., 2002). A study by Kent-Braun (1999) found that a fall in blood pH was very strongly correlated with a fall in muscular force. This is very much in line with other studies that have previously demonstrated the link between the generation of intramuscular energy metabolites and muscular fatigue (Cady, Jones, Lynn, & Newham, 1989; Westerblad et al., 2002). The current state of the research suggests that peripheral mechanisms of fatigue play a far more tangible role in the acute fatigue experienced during the rigors of an appropriately designed resistance training program than do central mechanisms.

Components of Fatigue

There are three components that drive the hypertrophic adaptations induced by resistance exercise: Mechanical tension, muscle damage, and metabolic stress (Jones & Rutherford, 1987; Shinohara, Kouzaki, Yoshihisa, & Fukunaga, 1997)**.** Each component has specific characteristics and can be affected by the nature of the training utilized to induce them (Toigo & Boutellier, 2006).

Mechanical tension. Mechanical tension is generated by the production of force and stretch within the muscle. This component of fatigue is crucial to hypertrophic adaptation (M. Hill & Goldspink, 2003; Hornberger & Chien, 2006). One of the most pronounced instances of the importance of mechanical tension is that in the presence of progressive overload muscle mass increases, while in contrast, during unloading muscle mass will decrease (Berg, Dudley, Haggmark, Ohlsen, & Tesch, 1991; Schoenfeld, 2010). While mechanical tension in the absence of any other factor can result in hypertrophic adaptations, it is highly unlikely that it is the only component responsible (Jones & Rutherford, 1987). On the contrary, particular resistance training practices that involve large amounts of mechanical tension are shown to primarily induce neurological adaptations without the expected accompanied hypertrophy (Vissing et al., 2008). This may be the case as a result of programs that maximize intensity neglecting the accumulation of an optimal amount of training volume. While it may not be optimal for hypertrophy, this style of training has its place; and may be particularly useful to athletes in sports that rely on, or at least heavily favor, the strong; and are constrained by weight classes.

Muscular damage. Appropriately prescribed resistance training results in local damage to muscle tissue that is theorized to generate hypertrophic adaptations (M. Hill & Goldspink, 2003). Muscular damage occurs as a result of the muscles nonuniform lengthening that results in a shearing effect on the myofibrils. This shearing process can deform membranes and lead to the disruption of calcium homeostasis thus resulting in damage to the tissue in the form of torn membranes and the opening of stretch-activated channels (Allen, Whitehead, & Yeung, 2005). The response to muscular damage is like the inflammatory responses associated with acute infection. When damage is perceived by the body, the area of interest is flooded with neutrophils and the muscles release agents that attract macrophages and lymphocytes to the area. The accompanied processes are believed to result in the release of growth factors that regulate satellite cell proliferation and differentiation (Toigo & Boutellier, 2006; Vierck et al., 2000). In addition, the area just below the myoneural junction contains high quantities of satellite cells which are strong mediators of muscle growth as well (M. Hill & Goldspink, 2003; Sinha-Hikim, Cornford, Gaytan, L., & Bhasin, 2006). This implies that nerves innervating damaged fibers might stimulate satellite cell activity thus resulting in hypertrophy (Vierck et al., 2000).

Metabolic stress. There is relatively conclusive evidence that suggests an anabolic role of exercise induced metabolic stress (Henselmans & Schoenfeld, 2014; Schoenfeld, 2013; Schott, McCully, & Rutherford, 1995). Empirical evidence examining moderate intensity training programs most frequently utilized by bodybuilders are purposefully intended to accumulate metabolite accumulation while also incurring a fair amount of muscular tension. This metabolite accumulation is the result of shorter rest periods and moderate rep schemes that relies on anaerobic glycolysis for energy production and the resulting metabolic buildup comprised of lactate, hydrogen ions, inorganic phosphate, creatine, and the like (Suga et al., 2009). The mechanisms that originate from metabolic stress that result in hypertrophic adaptation include cell swelling, ROS production, changes in hormonal milieu, and an increase in growth-oriented transcription factors (Gordon et al., 1994; Takarada et al., 2000). It is also postulated that a more acidic environment as a result of anaerobic glycolysis results in greater muscle fiber degradation and thus greater stimulation of the sympathetic nervous system that culminates as an increased hypertrophic response (Buresh, Berg, & French, 2009).

Structural Mechanisms of Fatigue

During fatigue, the reductions of force and shortening velocity contribute to the reduced power output. This is a result of the contractile machinery suffering an either acute or chronic shortage of substrate, or physical damage to the contractile unit. In addition, during repetitive movements the effectiveness of a muscle is reduced if the muscle is activated before the antagonist muscle is fully relaxed. Unless the rate of the repetitive movement is reduced, the power output and movement velocity will continue to decline. However, in a fatigued state, power output is somewhat reduced during the concentric phase; but it is the increased time it takes for the muscle to completely relax that causes stretching to occur while force is still present. This interferes with elongation of the muscle. As a result, the ability of the muscle to perform work will eventually fall below what is required for the movement (Allen et al., 1995).

For example, when an athlete performing box step-ups begins to fatigue, they may place their foot on the step-up box and begin to perform the movement by extending the right knee and hip. Before the right knee and hip reaches full extension, the athlete may place their left foot on the box and use both feet to stand up as opposed to reaching full extension solely with the right leg. Such actions will be addressed in the methods section to ensure appropriate movement standards and fatigue of the targeted muscle groups.

Overreaching & Overtraining

The rigors of a regular training stimulus, when implemented responsibly, result in adaptations with minimal fatigue. However, when the scale between training stress and recovery is disparately tipped in the direction of stress, it is postulated that overreaching and potentially overtraining may occur (Halson & Jeukendrup, 2004). Overreaching occurs as a result of an increase in training intensity and is considered a normal outcome for elite athletes given the short time needed for recovery; about 2 weeks (Halson & Jeukendrup, 2004). The time needed to recover from overtraining syndrome is considerably longer in duration lasting from months to years. As such, it may be inappropriate to compare the two physiological states. As of now, it is impossible to determine whether acute fatigue is the result of a single training session, being overreached, or being overtrained (Halson & Jeukendrup, 2004). It should be noted that there is fine line to walk when overreaching. Prolonged periods of overreaching can easily lead to an overtrained state (Halson & Jeukendrup, 2004).

Overtraining has catabolic effects on muscle tissue and is associated with a decrease in testosterone, luteinizing hormone, and an uptick in cortisol (Fry & Kraemer, 1997; Raastad, Glomsheller, Bjoro, & Hallen, 2001). The cytokine hypothesis of overtraining states that overtraining is the result of consistent musculoskeletal trauma resulting from high-intensity and high-volume training (Smith, 1999, 2004). Studies seem to reveal, however, that overtraining usually occurs because of excessive training volume rather than training intensity (Fry & Kraemer, 1997).

Recovery

Recovery after incurring fatigue is one of the most important components to stimulating muscular adaptations. The whole point of post exercise recovery is to bring the body back to a state of homeostasis. Essential fuels need replacing, Cardiovascular functioning must return to baseline, and damaged tissue must be repaired (Peake, 2019). All of these processes must take place completely, or at least in large part, before the following training session to ensure optimal muscular adaptation. The current available research reveals ways one can measure whether an athlete is recovering or not and to what extent different proposed methods of recovery impact actual recovery.

Measuring Recovery

When it comes to assessing recovery from exercise, there are several different validated methods to do so. Each method has benefits and detriments inherent to the process of gathering such data. Most assessment methods can be categorized in one of three ways: Physiological assessment methods, performance assessment methods, or psychological assessment methods (Shearer et al., 2015).

Physiological methods. Physiological methods of assessing recovery from exercise include monitoring levels of certain hormones. Hormones that have been validated as markers for muscle damage, and therefore recovery, include: plasma creatine kinase, testosterone, cortisol, and the testosterone/cortisol ratio (Elloumi, Maso, Michaux, Robert, & Lac, 2003; Mclellan, Lovell, & Gass, 2010). Takarada (2003), found that creatine kinase activity experienced an acute transient increase post rugby match; An indicator that players experienced skeletal muscle damage. What is of further interest is that the increase in creatine kinase activity is correlated to number of tackles per game. Another study found that testosterone decreases and cortisol rises as a result of a departure from homeostasis induced by competitive rugby play (Elloumi et al., 2003). Physiological markers are well-validated; However, the cost, level of expertise required, and high degree of variability of these measures are often of consideration when deciding how to quantify recovery.

Performance methods. Often the simplest measures are the most practical and consistently reliable. Performance measures frequently offer the most appropriate method of determining the extent of fatigue experienced by athletes (Twist & Highton, 2013). This can be as simple as a test retest style protocol where an individual performs a movement such as a standing long jump, vertical jump, or max reps on a movement followed by a retest between an hour to 48 hours later or more. An acute decrease in performance is a signature symptom of fatigue (Halson & Jeukendrup, 2004; Pareja-Blanco et al., 2018) and can be used to assess how an individual recovers from a given bout of exercise. For example, Judge and Burke (2010) used 1 rep max bench press strength as an assessment of recovery. Using performance as a tool for assessing recovery is a cost-effective option and does not require a high amount of technical experience to employ.

Psychological methods. Psychological methods are easy to employ and are sensitive to changes in performance; However, the fluid nature of psychological methods should be considered (Twist & Highton, 2013). Typically, psychological research has concentrated on perceived stress, behavioral symptoms of fatigue, and mood (Saw, Main, & Gastin, 2016). Mood in particular has a highly correlated dose-response relationship to training stress (Bouget, Rouveix, Michaux, Pequignot, & Filaire, 2006). In addition, mood has been studied successfully in relation to sport performance and recovery (Raglin, Koceja, Stager, & Harms, 1996). Some examples of mood assessment tools include: The Profile of Mood States (McNair, 1971) and The Brief Assessment of Mood (Dean, Whelan, & Meyers, 1990). One should note that a common issue with mood inventories is their length. Individuals tend to resent completing mood assessments that take more than a few minutes to complete, especially when it is a routine occurrence (Kellmann, 2002). This should be taken into consideration when utilizing psychological assessment methods for assessing recovery. Overall, there is an abundance of evidence supporting Psychological assessment methods as a cost-effective and valid measure of assessing fatigue and subsequent recovery.

Influences on Recovery

Apart from being able to define and measure recovery, understanding what influences recovery is paramount to maximizing post workout recovery, and by extension, hypertrophic adaptations. There are decades worth of research articles that show a trend towards several crucially important influences on recovery. The biggest influences in regard to post exercise recovery can be categorized thricely; Sleep, nutrition, and physiological interventions.

Sleep. Sleep is an extremely important component to recovery from exercise and impossible to convey the importance of sleep in a single paragraph. Having said that, the recommendation is that adults get between seven to nine hours every night to maintain optimal function (Watson et al., 2015)**.** There are a multitude of barriers that can come between individuals and optimal sleep patterns. Some of these barriers may include maladaptation to training, insomnia, and poor sleep hygiene (i.e. late-night gaming, tech before bed, and subpar sleeping environments) (Bonnar, Bartel, Kakoschke, & Lang, 2018). Removing barriers such as these is well worth the trouble as the effect of improving sleep quantity and or quality in individuals who suffer from a lack thereof is drastic. In as little as one week athletes that suffer from sleep deprivation can see improvements in physical performance, reaction time, mood, and levels of fatigue (Bonnar et al., 2018). In addition, educating individuals about proper sleep hygiene has been shown to result in improved physical performance when compared to one-off strategies like increased sleep duration (Bonnar et al., 2018). When contemplating sleep strategies for individuals, the individual should be treated as such. Sleep needs vary drastically from one person to another and therefore require a level of attention proportional to the level of impact sleep ultimately has on recovery and hypertrophic adaptation.

Nutrition. Nutrition is one of the primary influences on recovery and has a strong scientific background advocating its efficacy. Through proper nutrition individuals give their body the resources necessary to rebuild tissue, balance hormones, and provide energy. Nutrition will be referred to in such a way that reflects how nutrition influences recovery; Such as replacing fluid, replacing glycogen, and muscle protein synthesis.

Fluid replacement. Exercise causes acute changes in blood volume which in turn causes changes in the cardiovascular system. This is a deviation from homeostasis and therefore it is critical to replace lost fluids to restore cardiovascular systems function (Peake, 2019). As this study will not involve taxing the cardiovascular system in such a way that will result in acute fluid loss it will not be discussed further. For more information on fluid replacement see (Evans, James, Shirreffs, & Maughan, 2017).

Glycogen replacement. Glycogen is the primary fuel source during intense exercise (Burke, Hawley, Wong, & Jeukendrup, 2011). Some of the critical variables to consider when glycogen replenishment is of concern is how much carbohydrate should be consumed, when it should be consumed, and what type should be consumed (Peake, 2019).

The amount of carbohydrate consumed should usually reflect the amount of carbohydrate needed to replace that which is lost during exercise. 0.7 g/kg/hour is the lower end of the spectrum (Blom, Hostmark, Vaage, Kardel, & Maehlum, 1987) and no additional benefit has been shown when consuming over 1.2 g/kg/hour (Howarth, Moreau, Phillips, & Gibala, 2009).

It should be noted that glycogen depletion is a more crucial concern for endurance athletes for certain. However, glycogen depletion is still relevant, albeit to a lesser degree, to the individual focused on hypertrophy or neuromuscular adaptations. To what degree will depend on factors such as intensity level, training status, lean tissue, etc. For example, a competitive powerlifter achieves maximal exertions in a single repetition; an exertion lasting no more than a few seconds. This demand does not draw from muscle glycogen as much as it does ATP PCr (Sahlin, 2014). This is of course more reflective of competition circumstances. In training, especially during higher repetition phases of programming, replenishing muscle glycogen has potential relevance to ensure optimal volume accumulation.

Another important component to replacing muscle glycogen is nutrient timing. Completely replacing muscle glycogen can take up to 24 hours post intense exercis (Burke, Van Loon, & A., 2017). Knowing that 24 hours may pass before muscle glycogen is completely regenerated, being as efficient and as deliberate as possible when refueling is necessary. One method that is easy to implement to optimize post exercise glycogen resynthesis is getting in carbohydrate immediately post exercise. There appears to be greater muscle glycogen resynthesis when ingesting carbohydrate immediately after exercise when compared to ingesting carbohydrate two hours after exercise (Ivy, Katz, Cutler, Sherman, & Coyle, 1988). One should also note that the rate of glycogen replenishment is similar whether lower amounts of carbohydrate are ingested every hour or larger amounts are consumed every several hours (Blom et al., 1987).

A further component that is important to replenishing glycogen is the type of carbohydrate being consumed. Foods that are higher on the glycemic index tend to result in quicker glycogen replacement when compared to lower glycemic foods (Burke, Collier, & Hargreaves, 1996). There is no difference between solid and liquid carbohydrates on glycogen replenishment when glycemic index is accounted for (Reed, Brozinick, Lee, & Ivy, 1989). However, liquid carbohydrate has the added benefit of rehydration. Ingesting a combination of glucose and fructose for intakes greater than 1.2 g/kg/hour effectively enhances the rate of liver glycogen replenishment, but not muscle glycogen. Consuming the glucose and fructose in conjunction replenishes glycogen greater than either of them on their own and can mitigate gastrointestinal distress frequently associated with high glucose intakes (J. T. Gonzalez, Fuchs, Betts, & van Loon, 2017).

To briefly recap, if an athlete needs to recover quickly in between bouts, ingesting high glycemic index carbohydrate immediately post exercise is advised. Amounts of 0.7 – 1.2 g/kg/hour of carbohydrate in a mixed glucose fructose ester utilizes multiple transports and therefore is utilized more readily and may mitigate gastrointestinal distress. While it may be easier to achieve proper carbohydrate intakes through smaller more frequent meals, there is no difference when consuming larger less frequent meals when total carbohydrate and calories are equated.

Muscle protein synthesis. Whether or not an individual accrues new muscle tissue depends upon our total amount of muscle protein synthesis (MPS) and our total amount of muscle protein breakdown (MPB). Resistance training and proper nutrition tips the balance towards greater amounts of MPS than MPB (Phillips, Tipton, Aarsland, Wolf, & Wolfe, 1997), thus resulting in net muscle tissue accretion. A few important variables for keeping MPS elevated after exercise include the amount of protein consumed, the type of protein consumed, the effect of sex and aging, and the effect of other dietary factors.

Research clearly states that 20 g of whey protein during recovery from exercise nearly maximizes MPS. There appears to be a marginal increase that occurs in response to ingesting 40 g of whey protein (Witard et al., 2014). In reference to this marginal increase, a distinction should be made between protein “needs” and optimal intake for athletes. There is some evidence that suggests that the current protein RDA may not be sufficient for certain populations (Paddon-Jones, Short, Campbell, Volpi, & Wolfe, 2008). Many athletes consume protein far in excess of the RDA. There are even some anecdotal reports of athletes consuming over 4g/kg (Bilsborough & Mann, 2006). This is particularly interesting given the fact that protein needs in exercising individuals is only slightly higher (Lemon, 1997). According to the World Health Organization (WHO), the current understanding is that after hitting the minimum requirement for limiting amino acids, any further intake would plateau nitrogen retention and the excess would be excreted, thus, implying that protein intakes above requirements do not matter (WHO, 2007). This dismisses the effect that excess amino acids have on stimulating MPS. The fact that the extra amino acids are oxidized does not negate the impact they have on anabolic signaling in skeletal muscle before the oxidation (Norton & Wilson, 2009). The effect of excess amino acids are more relevant to the individual looking to maximize muscle gain, not just meet the adequate intake (Norton & Wilson, 2009).

Another crucial component to maximizing MPS is the type of protein consumed. One of the broadest categories' protein can be divided into is animal-based and plant-based. Ingestion of animal-based protein sources result in greater MPS than does ingestion of plant-based protein sources even when calories and protein are equated (Tang, Moore, Kujbida, Tarnopolsky, & Phillips, 2009). Individuals who engage in a vegetarian or vegan diet may be able to enhance MPS post exercise by eating multiple sources of plant-based protein (Tang et al., 2009). However, individuals looking to maximize muscular adaptations are encouraged to consume animal-based protein post exercise.

A further influence on MPS is the effect of body mass, sex, and aging. The effect of post-exercise protein consumption is unaffected by body mass (Macnaughton et al., 2016) and sex (West et al., 2012). Older athletes, however, may benefit from consuming greater than 20g of animal-based protein post-exercise especially those that want to maximize MPS (Tang et al., 2009). There is evidence to suggest that intakes beyond the recommended 0.8g/kg may increase anabolism and reduce the loss of muscle tissue with age (Paddon-Jones et al., 2008).

Other dietary factors that may impact MPS can be explained as the confounding effect of consuming different foods at the same time. While there is no evidence to suggest that consuming carbohydrate in conjunction with protein after exercise will increase MPS (Staples et al., 2011), there is speculation that consuming a meal high in complex carbohydrate may negatively impact digestion kinetics, thus, delaying MPS (Trommelen, Betz, & van Loon, 2019). There is no currently conclusive evidence on the effect of fat on MPS (Trommelen et al., 2019). It should also be noted that imbibing large quantities of alcohol will attenuate MPS (Parr et al., 2014).

Supplements. Supplements have historically been studied based on their anti-inflammatory and antioxidant properties, and to a lesser degree, their ability to enhance MPS (Peake, 2019). There is relatively conclusive evidence that suggest benefits for the use of: black currant extract, tart cherry juice, beet root juice, branched chain amino acids, taurine, creatine, and caffeine (Harty, Cottet, Malloy, & Kerksick, 2019; Pakise, Mihic, MacLennan, Yakasheski, & Tarnopolsky, 2001). Supplements for which there is mixed or inconclusive evidence include pineapple, pomegranate juice, watermelon juice, green tea, curcumin, L-glutamine, beta-hydroxy-beta-methyl-butyrate, vitamin D, and n-3 poly unsaturated fatty acids (Harty et al., 2019). Supplements that have little to no evidence encouraging their efficacy include green algae extract, ginseng, and ginger among others. In addition, most research demonstrates no benefits of supplementation with whey protein, vitamin E, or Vitamin C, for reducing delayed onset muscle soreness (Harty et al., 2019). Individuals should note that many studies provide these supplements in the days or weeks leading up to exercise. Less research has been conducted on these supplements during post exercise recovery. There is uncertainty surrounding the benefits these supplements may have on reducing fatigue especially when considered in conjunction with the potential detrimental effects they may have on chronic training adaptations (Owens, Twist, Cobley, Howatson, & Close, 2019).

Physiological Interventions in Recovery

Recovery methods for physical stressors have been implemented since before we had evidence that suggested they may be beneficial (i.e. stretching, massage, etc.). Other interventions have gained popularity more recently. These include practices such as neuromuscular electrical stimulation (NES), compression garments, and cryotherapy among others (Peake, 2019). In contrast to nutritional interventions, there is less conclusive physiological evidence in favor of most physical interventions to aid in recovery.

Stretching. Stretching can be categorized in several ways. This includes by form, (i.e. active, dynamic, static, ballistic, etc.) or by the nature of the mechanostimulation to various structures, (i.e. tendons, connective tissue, components of the cytoskeleton or actin myosin cross bridges, etc.) (Peake, 2019). One of the primary touted benefits of stretching is to restore strength and reduce muscle soreness during recovery from exercise (Hausswirth & Mujika, 2013, p. 55-69). However, a meta-analysis published recently stands in opposition to these anecdotally held beliefs (Dupuy, Douzi, Theurot, Bosquet, & Dugué, 2018). There is evidence to support that stretching can offer conservative benefits when used in conjunction with proven recovery strategies. Beyond this scope, it is contraindicated to use as a means of recovery.

Massage. Massage refers to manipulating muscle and fascial tissue either manually or mechanically. Manual stimulation includes use of the fingers, hands, and elbows while mechanical stimulation refers to the use of foam rollers or pneumatic compression devices (Peake, 2019)**.** Massage is proposed to increase range of motion, skin and muscle temperature, and arterial circulation (Peake, 2019). In addition, it has also been purported to reduce neuromuscular excitability, relieve muscle cramps and pain, as well as improve mood states (Hausswirth & Mujika, 2013, p. 110-134). All these effects in conjunction have the capacity to enhance recovery from exercise. Several meta-analyses link massage post-exercise to a reduction in delayed onset muscle soreness, blood markers for muscle damage and inflammation, and perceptions of fatigue (Dupuy et al., 2018). Further mounting evidence suggests that massage also aids in restoring both maximal isometric force and peak torque post exercise (Guo et al., 2017). More work is still needed to fully elucidate the exact mechanisms of such benefits as to appropriately prescribe timing and type of massage.

Hydrotherapy. Hydrotherapy is comprised of four different approaches: Thermoneutral immersion, hot immersion, cold immersion, and contrast immersion (Versey, Halson, & Dawson, 2013). There is a plethora of theoretical rationale for employing each strategy; however, it should be noted that the theoretical rationale is multifaceted, and each approach works differently under different conditions.

For example, cold immersion causes a reduction in body temperature thus affecting the release of neurotransmitters that are known regulators of fatigue. In addition, it may also increase heat storage capacity and alter brain activity in relation to alertness (Ihsan, Watson, & Abbiss, 2016). All four types of hydrotherapy result in hydrostatic pressure placed on the body that leads to shifts in fluids. This, in conjunction with a greater central blood volume as the result of vasoconstriction, may assist in the efflux of metabolites from muscle tissue (Ihsan et al., 2016). Cold immersion appears to have the greatest effect on physiological responses conducive to post-exercise recovery. Thus, the combined effect of vasoconstriction, reduced muscle temperature, increased central blood volume, and analgesic effects of cold immersion may reduce markers for inflammation, swelling and muscle soreness (Ihsan et al., 2016). More research concerning the questions of how each mode of hydrotherapy affects different modes of exercise is warranted.

As is relevant to hypertrophic adaptations, cold water immersion therapy should be used cautiously. A study by Frohlich, et al. (2014), found that there was a reduction in strength training adaptation by 1-2% after a five-week strength training regimen in athletes that participated in cold water immersion compared to athletes that did not (Frohlich et al., 2014). Emphasis should be made that the reductions were small; however, the results should still be considered especially in programs designed for muscular hypertrophy. Balancing the stimulus fatigue relationship is paramount for incurring optimal hypertrophic adaptations. Further research is warranted to reconcile the cost to benefit ration of incorporating cold water immersion into resistance training recovery protocol.

Compression garments. The utilization of compression garments for post exercise recovery is a somewhat new trend currently lacking in robust scientific evidence. There proposed benefits include enhancing recovery by means of reducing vasodilation, venous stasis, and lymphedema; and increasing venous return, microcirculation, and elimination of metabolic waste (Hausswirth & Mujika, 2013, p. 135-144). Compression garments have been validated in a meta-analysis in regards to their ability to decrease delayed onset muscle soreness and perceptions of fatigue (Dupuy et al., 2018). However, compression garment's effect on blood markers for muscular damage and inflammation show a more tempered reduction (Dupuy et al., 2018). A final consideration for the implementation of compression garments for post exercise recovery is that higher compression garments tend to result in a greater restoration of muscle function than do lower compression (J. Hill et al., 2017).

Cryotherapy. Cryotherapy involves briefly pulsing cold air or a refrigerated gas (usually CO2) between -30 C and -140 C at a high intensity and pressure, usually in dry conditions, onto the skin in the vicinity of the muscles being treated (Hausswirth & Mujika, 2013, p. 145-165). In theory, cryotherapy reduces inflammation, muscle tone (stimulates relaxation), and nerve conduction velocity (Hausswirth & Mujika, 2013, p. 145-165). Notably, reducing delayed onset muscle soreness is the most consistent benefit conveyed through cryotherapy (Dupuy et al., 2018; Hohenauer, Taeymans, Baeyens, Clarys, & Clijsen, 2015; Lombardi, Ziemann, & Banfi, 2017). In similar fashion as previous recovery strategies, the effect on blood markers of muscle damage and inflammation tend to vary more widely (Dupuy et al., 2018; Hohenauer et al., 2015; Lombardi et al., 2017). There are mixed results in terms of the effect of cryotherapy on sport performance and therefore drawing any definitive conclusions based on current evidence is suspect (Rose, Edwards, Siegler, Graham, & Caillaud, 2017). A final consideration of cryotherapy is its effectiveness relative to other recovery strategies; an important note given the cost and time it requires. Further research would benefit from elucidating such a hierarchy of importance.

Other physical interventions. Other physical interventions proposed for post exercise recovery include neuromuscular electrical stimulation, vibration therapy, and sauna. There is ample evidence to suggest that vibration therapy can reduce delayed onset muscle soreness as well as blood creatine kinase activity; however, no benefit to muscle recovery has been reported (Cochrane, 2017; Lu et al., 2019). There is an abundance of anecdotal evidence in support of using sauna's as a recovery aid amongst athlete's; however, the current research has yet to validate sauna's as an effective means of post workout recovery (Mero, Tornberg, Mäntykoski, & Puurtinen, 2015)**.**

Conclusion

Three adaptions are sought from RT: Hypertrophy, neuromuscular benefits, and body composition changes. Hypertrophy can be considered an important precursor for the other sought-after adaptations to resistance training. Myogenic pathways are the electro-chemical pathways stimulated by mechano-tension that produce the adaptations experienced as a result of RT. Training volume is the biggest driver of RT adaptation and can be manipulated through different variables such as frequency, split, and rest periods. Accumulating an optimal amount of fatigue and adequately recovering from said fatigue are two massively important variables that are sometimes overlooked in athletes and gym-goers alike. When trying to optimize RT adaptation, being able to deliver the most effective dose of volume to large and small muscle groups will depend upon the ability of each muscle group to handle acute fatigue and how quickly it can recover from fatigue. In understanding the time frame large and small muscle groups require to fully recover, a more accurate prescription of training frequency will allow for an optimized dose of volume and will subsequently lead to greater muscular adaptation.

CHAPTER THREE

METHODS

Participants

Participants were resistance trained males 18-30 years old. Qualified individuals had a history of training no less than 180 minutes per week for no less than one year upon volunteering to participate in this study. Participants were familiar with the biceps curl and quadricep extension. Familiar, in this case, refers to a basic understanding and occasional practice of the biceps curl and quadricep extension exercises. Subjects had no history or current aggravation of any soft tissue injuries to the upper limb, lower limb, or torso. Participants were instructed not to change their current resistance training, sleep, or nutrition habits for the duration of the study. This was determined by the use of a 48 hour recall questionnaire.

There were two individuals excluded from the study for the following reasons: Equipment failure as a result of a 10 RM that exceeded the structural integrity of the “Powerlift” plate-loaded quad extension, and failure to show up for testing sessions after completing the initial consent. The former participant simply was capable of moving more weight than the quad extension machine was capable of handling safely, The latter participant was present for the initial meeting and signed the informed consent paperwork but rescheduled several times and eventually decided to drop out of the study.

Instrumentation

The initial meeting was conducted in the physiology of exercise laboratory at the University of Northern Iowa (WRC 126) where the body composition testing was also done. The gathering of the 10RM's during the initial meeting was done in the public weight room (WRC 153). The testing procedures were also performed in the public weight room. These tests required a stopwatch to time rest periods, a standard EZ Curl bar, locking "CAP barbell" barbell collars, standard Olympic free-weight plates, smaller change plates, and a 'Powerlift" plate loaded quadricep extension machine.

Procedures

IRB approval was acquired followed by recruitment of participants. Once there was an adequate pool of participants, they were contacted and asked to schedule an initial meeting. During this initial meeting, the researcher began with an introduction of the study and the time commitment necessary from the participants. Before any data collection commenced, the participants were informed of the testing procedures and provided an informed consent document to sign. The participants were informed that they will be participating in a study that requires a training history of at least 180 minutes a week for at least a year and be free of any soft tissue injuries to the upper limb, lower limb, or torso. Basic demographic and population information relevant to the testing procedures was collected from participants who chose to participate in the study.

All participants were asked to attend two testing sessions in addition to the initial meeting, all of which took no more than 45-mintues per session to complete. During the initial meeting, the informed consent was administered, followed by a physical activity questionnaire, followed by a body composition analysis, as well as an initial gathering of the participant's 10 rep maxes in the biceps curl and quadricep extension. The body composition testing was used to gather fat free mass (FFM), fat mass (FM), and Lean segmental mass of the upper and lower limb. The body composition measurement required the participant to be in undergarments and stand on a conductive surface while hold two handles that also contained a conductive surface. The initial meeting also included a 48 hour recall survey that contained seven questions on sleep, training, and nutrition. The 48 hour recall was administered at the beginning of the additional two testing sessions as well. The 48 hour recall administered during the initial session was immediately followed by a five-minute standardized general warm-up that consisted of five minutes on an exercise bike at a resistance of 2 kp and 70 RPM. Immediately after, instruction of standards for technical failure in the biceps curl and quad extension were explained. This was followed by a specific warmup for the biceps that consisted of ten arm circles forward, ten arm circles backward, and three arm pulls across chest for each arm. After the biceps testing protocol and prior to the quadricep testing protocol a specific warmup for the quads was performed. This warmup consisted of ten air squats, ten second hip flexor stretch for the left and right leg, ten second groin stretch, and ten second butterfly. The specific warmup was used to take the subject through the range of motion demand that the testing procedure requires. After participants are adequately prepared, the P.I. had the participant select a weight they believe they could perform for ten repetitions and proceed to perform a set. If the participant managed to achieve ten repetitions without technical breakdown with the weight selected, the participants were asked to perform another set with more weight after a brief rest period of no less than three minutes. This process continued until the participant had found their true 10 RM. After a 10 RM was achieved for the biceps curl, a rest of no less than 5 minutes was administered, followed by a similar procedure for the quad extension. The quad extension protocol was proceeded by the aforementioned specific warmup and was performed on the “Powerlift” plate loaded quadricep extension designed to isolate knee extension as to ensure that the knee extensors (quadriceps) are the prime movers. Then, the same protocol was followed for the quad extension as used in the biceps curl. The participant selected select a weight they believe they can perform for ten repetitions and proceed to perform a set. If the participant managed to achieve ten repetitions without technical breakdown with the weight selected, the participant was asked to perform another set with more weight after a brief rest period. This process continued until the participant had found their true 10 RM. After this initial session where the 10 RM was determined, participants were scheduled to perform the biceps curl and quad extension for four sets in two separate testing sessions with no less than 48 hours in between the testing sessions. Participants utilized the same warmup protocol administered during the initial session. The participants were asked to perform four sets of maximum repetitions in the biceps curl and the quad extension separated by no less than five minutes of rest in between the movements during test session one. The participants used the 10RM they established in the initial meeting for the failure protocol. Total volume and rate of perceived exertion (RPE) measures were recorded. Forty-eight hours later, the biceps curl and quadricep extension were retested using the same protocol. Total volume and RPE measures were recorded. During the final session, the participants body composition was tested for the last time, at which point the testing concluded.

Data Analysis

Statistical analysis was performed using SPSS by IBM. A dependent T-test was applied comparing the differences in biceps TV difference between T1 and T2 as well as quad TV difference between T1 and T2. Results were considered statistically insignificant at $p \leq 0.05$. In addition, descriptive statistics were applied to assess the mass between the upper limb and lower limb. To conclude, Levene's test for equality of variances was applied and resulted in a statistically significant difference $p \leq 0.05$.

CHAPTER FOUR

RESULTS

Statistical Analysis

The results of the dependent t-test determined there was no significant differences in the TV accumulated between T1 and T2 for the biceps brachii (T8 = -.67, p = .52) as illustrated in figures 1 and 2. The mean biceps TV during pre-test was 2769.8 lbs (SD = 476.87, N = 9), and the post-test biceps TV was 2806.39 lbs (SD = 512.78, N = 9). Similarly, a dependent t-test determined there was no significant differences in the TV accumulated between T1 and T2 for the quadriceps (T8 = -1.449, p = .19). The average quadricep TV during pre-test was 8798.8 lbs (SD = 1669.8, N = 9), and the post-test quadriceps TV was 9290.3 lbs (SD = 1523.5, N = 9). Descriptive statistics were gathered to assess lean mass of the upper limb and lower limb. The upper limb contained considerably less lean mass (M = 9.82lbs, SD = 1.54, p = 0.000, N = 9) than did the lower limb (M = 22.42lbs, SD = 2.01, p = 0.000, N = 9). Finally, Levene's test for equality of variances was conducted and reached significance for differences in volume accumulations between the biceps (M = 9.82lbs, SD = 1.54) and quads (M = 22.42lbs, SD = 2.01), (F (2,16) = 7.0, p = 0.018).

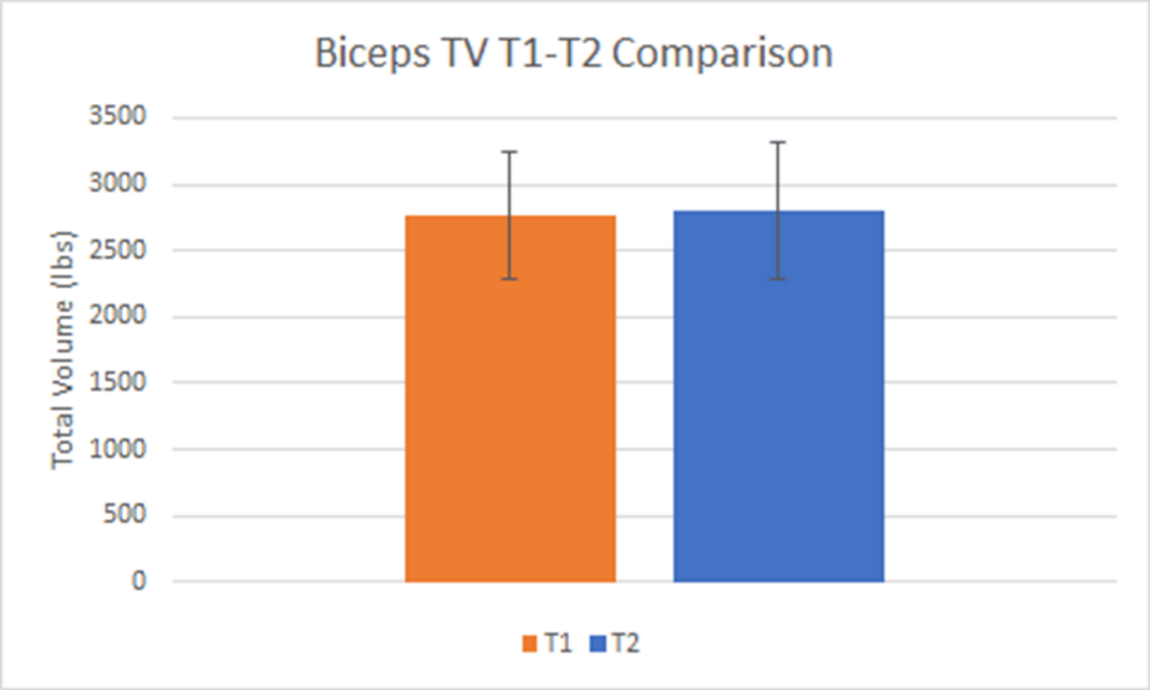

Figure 1: TV comparison between T1 and T2 for the biceps

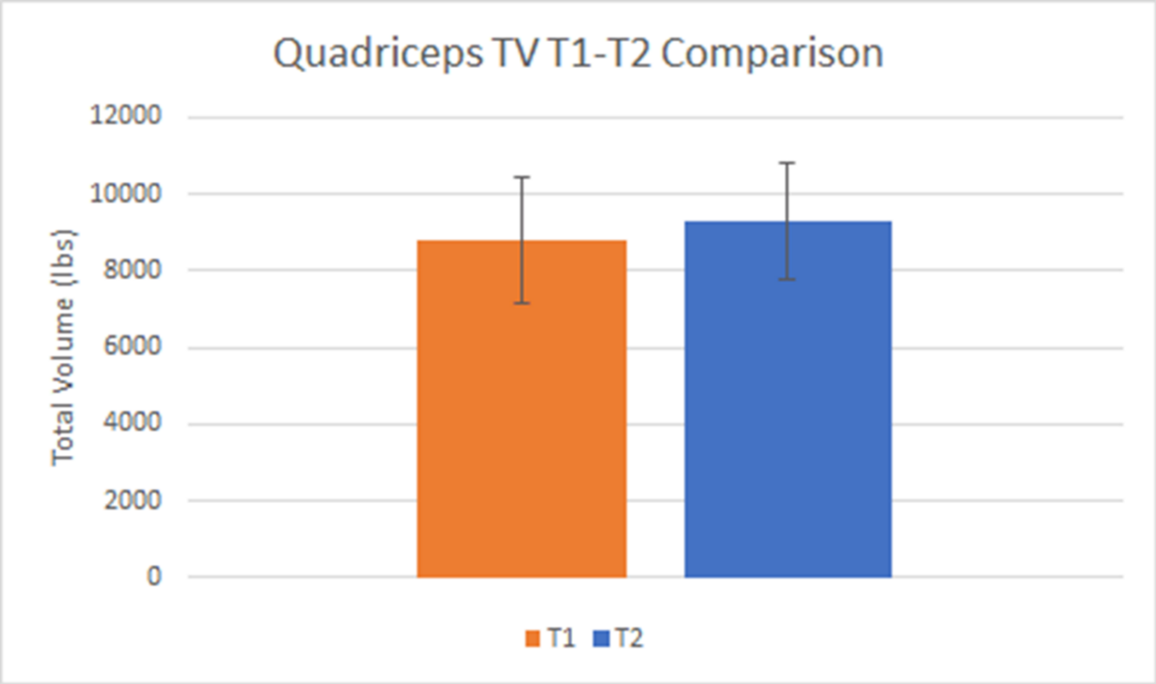

Figure 2: TV comparison between T1 and T2 for the biceps

Table 1: Individual demographics

ID #	*Height (Inches)*	*Weight (Pounds)*	*Age*	*Sex*	*FFM (Fat Free Mass in pounds)*	*FM (Fat Mass in Pounds)*
A100	70.75	228.4	23	M	173.11	55.3
A101	74	168	22	M	154.3	13,7
A102	72	216.3	25	M	188.7	27.6
A103	71.2	200.8	20	M	155.6	45.2
A104	71.3	192.7	19	M	175	17.7
A106	70	176.8	23	M	150.8	26
A107	64.6	184.3	22	M	157.8	26.5
A108	66.25	210.8	21	M	139.6	71.2
A109	67.1	166.7	19	M	125	41.7
A110	70	216	23	M	170.6	45.4
A111	70	166	23	M	151.5	14.5

ID #	*Upper limb segmental mass (pounds)*	*Lower limb segmental mass (pounds)*	*Creatine Supplementation*
A100	10.75	24.85	Yes
A101	9.3	23.8	No
A102	11.65	26.75	No
A103	9.35	22.8	Yes
A104	11.65	24.1	Yes
A106	9.1	21.95	No
A107	11.3	22.25	No
A108	8.65	20.1	No
A109	6.8	18.8	No
A110	11	24.6	No
A111	9.8	22.4	No

Table 2: Group demographics

	Height (inches)	*Weight (Pounds)*	*Age (Years)*	*Training experience (Years)*
Mean ± StDev	69.75 2.60	193.35 21.50	21.82 1.80	7.60 2.97

	Fat free mass (Pounds)	*Fat mass (Pounds)*	*Lean mass (Upper limb in pounds)*	*Lean mass (Lower limb in pounds)*
Mean ± StDev	158.36 16.94	34.98 17.48	9.94 1.43	22.95 2.13

Table 3: Relative TV difference for the biceps and quadriceps T1-T2

Participant number	*Poundage difference biceps T1-T2 (Relative)*	*Poundage difference quads T1-T2 (Relative)*	*Quads soreness T1*	*Quads soreness T2*
100	5.71	-3.77	Normal	Over
103	5.71	3.96	Normal	Normal
104	-8.11	10.28	Normal	Normal
106	4.4	0	Normal	Over
107	-1.18	-1.82	Normal	Normal
108	-6.56	-27.78	Over	Over
109	-1.05	-9.35	Normal	Normal
110	-9.3	-6.25	Normal	Normal
111	-1.39	-23.76	Normal	Over

Table 4: Absolute TV difference for the biceps and quadriceps T1-T2

Participant number	*Poundage difference Biceps T1-T2*	*Poundage difference quads T1-T2*	*Biceps soreness T1*	*Biceps soreness T2*
100	160	-405	Normal	Over
103	140	270	Normal	Over
104	-240	1127.5	Normal	Normal
106	140	0	Normal	Normal
107	-42.5	-200	Normal	Over
108	-150	-2125	Normal	Over
109	-22	-675	Normal	Over
110	-280	-495	Normal	Normal
111	-35	-1920	Normal	Over

CHAPTER FIVE

DISCUSSION

The present findings dictate that there is no statistically significant difference in recovery between the quadriceps and the biceps at 48 hours post RT bout under the utilized protocol. All individuals in the study were able to accumulate similar volume in the retest protocol as they did in the pre-test protocol. This would suggest that both the quadriceps and biceps were recovered in the 48 hours following the pre-test.

While there was no significant difference in recovery between the biceps and quads, there was significantly greater variance in the quads TV difference T1-T2 than there was in the biceps TV difference T1-T2 ($F (2,16) = 7.0$, $p = 0.18$). As illustrated in tables 1 and 2, the quadriceps do seem to show a greater variation in both a relative and absolute sense than do the biceps. Greater variance in volume accumulation between individuals for larger musculature may necessitate more attention when participating or programming RT protocols to gauge individual responses. If some individuals struggle to recover in the 48 hours following the training of large musculature, they will potentially benefit from either greater time to recover or perhaps less training volume. If followed to a logical conclusion, one would have to ask the question, “why is there greater variance in volume accumulation for larger musculature?” Further proving (or disproving) that there is in fact a greater variance in volume accumulation for larger musculature than smaller musculature would be a great place to start for further research. In addition, uncovering why that may be the case could be of significance as well.

A finding that could be considered quantitative as well as anecdotal is how individuals perceived recovery relative to their actual recovery as assessed by volume accumulation. Several participants verbally expressed feelings of soreness in both the quads and biceps. While some noted this soreness in the 48-hour questionnaire, others did not. This could be the result of poor questionnaire design or by simply being overlooked by the participants. At any rate, the results illustrated in figures 1 and 2 clearly show that individuals were recovered enough to achieve similar volumes at consistent intensities. There are several speculations that can be derived from this finding. The first and arguably most important is that within the confines of this study there is a disconnect between the perceived recovery (i.e. soreness) and actual physiological recovery (i.e. ability to accumulate volume). Individuals should not neglect the psychological component of recovery; but one should note that perceptions of soreness may not be the best indicator for recovery according to the evidence presented in this study.

Another rather novel finding that may have affected volume accumulation is differences in participants athletic and recreational resistance training backgrounds. For example, while participant A110 did in fact meet the inclusion criteria, the individual was forthcoming about a lack of direct leg work. In contrast, participant A106 competes regularly in intercollegiate rugby and accumulates appreciable amounts of direct leg work on a weekly basis. Despite a nearly 3lbs difference in lower limb lean mass in favor of participant A110 (24.6 lbs. vs 21.9 lbs.), participant A 106 performed more quad volume (17,600 lbs. vs 16,335 lbs.). Participants' athletic and recreational resistance training backgrounds may be relevant because individuals who favor one body part over another may be more adept at accumulating volume for said body part. In addition, if an individual neglects training one of the muscle groups in question at an adequate intensity, then four sets to technical failure may result in a longer recovery period on both an inter-set and chronic basis. In future research, individuals may find benefit to ensuring a greater homogeneity of participants by enforcing stricter guidelines on training status in the inclusion criteria to avoid such large differences in training status.

There is not much literature addressing the differences in recovery time between large and small muscle groups. There are, however, several studies that have compared small versus large muscle groups on training volume and frequency. There is evidence within several of these studies that allows us to make inferences on recovery between small and large muscle groups.

Schoenfeld (2018) found that both biceps and quadricep experienced statistically significant increases in hypertrophy from lower volume protocols to higher volume protocols. RT protocol consisted of seven exercises per session targeting all major muscle groups of the body. The exercises performed were flat barbell bench press, barbell military press, wide grip lateral pulldown, seated cable row, barbell back squat, machine leg press, and unilateral machine leg extension. Training for all routines consisted of three weekly sessions performed on nonconsecutive days for 8 weeks. Sets consisted of 8 to 12 repetitions carried out to the point of concentric failure. Volume was not equated between groups and therefore higher set protocols resulted in higher volume accumulation which, as expected, led to greater muscular hypertrophy. These findings are consistent with others on the effect of training volume on different musculature (Hackett et al., 2018; Ostrowski, Wilson, Weatherby, Murphy, & Lyttle, 1997; Schoenfeld et al., 2018). It can be asserted that small and large muscle groups respond similarly to increases training volumes.

Frequency also contains a similar pattern between large and small muscle groups. When sets are equated but frequency is higher, both large and small muscle groups (quads, triceps, and biceps) experience similar increases in hypertrophy (Brigatto et al., 2019; Zaroni et al., 2019). One should also not that in these studies that total volume is not equated and therefore higher frequencies resulted in greater training volume which, as previously mentioned, resulted in increased hypertrophy in both large and small muscle groups. Studies where volume is equated between different frequency protocols appears to result in the loss of this effect (Barcelos et al., 2018).

In totality, the data reveals that all muscles regardless of size respond similarly to training volume and frequency. Higher training volumes, in general, are better for hypertrophy up to the point at which recovery is not being reached in between bouts; Whereas training frequencies are not necessarily as relevant if training volume is considered. This allows the individual to select a training frequency that best suits their schedule and preferences. It may be a bit of a stretch to conclude necessarily that because all muscles respond to volume and training frequency similarly that they must recover similarly as well; However, given the interconnectedness of recovery and volume accumulation in conjunction with the findings of this study, one can certainly make the inference that small and large muscles may recovery similarly.

There were an unfortunately large number of things that could have been done more efficiently when noted in retrospect. Once testing was well underway, there were several opportunities where a greater degree of control over some variables could have been applied with minimal encumbrance to the procedures. Inter-set behavior was a big source of inter-subject variation. Whether subjects stood up, sat down, got a drink, engaged in conversation, etc. was not controlled and realistically could have had an impact on volume accumulation, albeit if only to a slight degree.

Two other extremely important variables that would have strengthened the results if they could have been tightly controlled were sleep and nutrition. However, the cumbersome nature and participant attrition rate associated with sleep and nutrition-controlled studies resulted in a simple 48 hour recall survey to assess sleep and nutrition influence. While this is not an ideal level of control, there is a certain amount of external validity in letting participants dictate their own nutrition and sleep practices.

The present study was designed to isolate the quadriceps and the biceps. However, it should be noted that it is nearly impossible to prevent the help of additional musculature even in movements that are considered “isolated”. To what degree other muscle tissue is involved is likely different from one individual to the next. In addition, it is difficult to quantify without electromyogram (EMG). The effect of recruitment of additional musculature is not controlled in this study. Individuals should consider this when interpreting the results of the present study

Another limitation that was inherent to the facilities available was the limited amount time per day that data could be gathered under the appropriate conditions. The methodology of this study was largely shaped by the limited amount of time to gather data. Data was gathered in WRC 153 between the hours of eight am and noon barring there was no class using it at the time. This severely limited the number of participants that data could effectively be gathered with.

In addition, available equipment was limited to what was contained in WRC 153. The equipment was well-suited to the demands of the present study although it should be noted that the plate loaded quadricep extension machine had a malfunction on several occasions causing one of the pulleys to slip out of alignment. On two occasions this malfunction resulted in having to regather quadriceps data for the participant and resulted in one instance of a participant being excluded from the study. The excluded participant was apparently capable of performing repetitions with a weight that the machine could not sustain.

Future Research

The results of this study suggest that at 48 hours post RT bout that the biceps and quadriceps were recovered. Future research would benefit from looking deeper into recovery of large versus small muscles. Manipulating the time between the pre-test and re-test protocol may yield an interesting result. Perhaps 24 hours or even 72 hours may result in a different outcome. Another variable that could be manipulated would be rest period. This study utilized a standardized three-minute rest because it ensured enough inter-set recovery to accumulate adequate volume and maintained a semblance of external validity. Future research might utilize rest periods anywhere between 30 seconds to five minutes. In fact, comparing the difference in recovery between shorter rest periods and longer rest periods may provide a glimpse into the effect of accumulating metabolic stress versus greater mechanical tension on recovery. A third variable that could easily be manipulated is the number of sets performed. Four sets, while not arbitrary, was utilized because it appeared to be enough sets to stimulate muscle damage without affecting participant adherence and attrition. Future research manipulating sets could perhaps see if there is diminishing returns on how many sets to failure are performed. For example, volume may be low, but recovery is high with 1-2 sets, volume and recovery are optimal around 3-5 sets, and greater than 6 sets might show a marginal increase in volume but a large increase in time to recovery.

A final note is the effect of variations in repetition speed from one participant to another. Individuals should first note that most individuals utilized what would be considered a “normal” repetition speed and cadence. This would be exemplified by similar concentric and eccentric contraction times at a rate of roughly two seconds. It was noted that seven out of the nine participants fit this definition. However, there were two instances where individuals had a fair paced concentric portion and then all but went limp on the eccentric portion. In practice for the biceps curl this looked like, as mentioned, a normal concentric phase followed by letting the weight freely drop into the bottom of the lengthening phase. For the quads this took the appearance of a normal concentric followed by allowing the weight to slam into the stopper. These two individuals did not happen to have significantly greater volume in either lift than did the individuals who had “normal” repetition speeds. However, the practice did raise questions as to the effect of less time under eccentric loading could affect volume accumulation. The lack of repetition speed standardization could potentially be a source of error.

It could be argued that the most vitally important variables were accounted for;

rest period, standardized warmup, no resistance training 48 hours before hand, etc. However, that is no excuse not to seek a greater degree of control. In future research peers would be served well by accounting for the aforementioned overlooked variables.

Conclusion

Based upon the evidence obtained from this study in conjunction with the scarce but consistent findings of prior research, it appears that muscle size has little impact upon the rate of recovery under the conditions of the present study. Under the same conditions, however, there was greater variation in volume accumulation 48 hours post bout in the quadriceps than in the biceps. Future research should focus on further establishing (or refuting) the connection between muscle size and recoverability while employing greater control over confounding variables. In addition, future research may benefit from manipulating different variables like number of sets and length of rest period. This will provide a more refined understanding of how small and large muscle groups may or may not differ.

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