THE EFFECTS OF REST PERIOD LENGTHS ON MUSCLE HYPERTROPHY AND INTRA-EXERCISE PERFORMANCE

by

Clifton J. Holmes

An Abstract
of a thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
in the Department of Nutrition and Kinesiology
University of Central Missouri

June, 2016
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The purpose of this study was to compare the effects of 1-minute versus 3-minute, between-set rest intervals on muscular hypertrophy adaptations in 12 recreationally, resistance-trained males, 18-25 years of age over a 6-week period. Week 1 consisted of dual-energy X-ray absorptiometry scans, and 1-repetition maximum (1RM) testing in the back squat and bench press. Weeks 2 through 5 consisted of four resistance training sessions per week, split between two lower-body and two upper-body workouts. The resistance training protocol started at 3 sets of 10 repetitions at 67% of 1RM and progressed from there. Week 6 consisted of follow-up body composition assessment, using DEXA scan, and 1RM testing of back squat and bench press. The findings of the study revealed no significant differences between the effects of 1-minute and 3-minute rest periods on muscle hypertrophy in recreationally strength-trained males during a 4-week training program.
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CHAPTER 1

INTRODUCTION

Strength training programs may be designed to elicit different types of muscular adaptations, such as strength, power, hypertrophy, or endurance (Baechle & Earle, 2008). When creating a strength training program, many variables must be considered and manipulated in order to achieve the proper responses. Response variables for strength training program include, but are not limited to, intensity, volume, frequency, repetition, velocity, and rest between sets (Kraemer, Noble, Clark, & Culver, 1987). In order to accurately manipulate training variables, the goals of the individual participating in the strength training program must be determined. Without proper manipulation of training variables, plateaus in progression may be reached or an overtraining syndrome could occur (Rahimi, 2005).

Strength training programs with the goal of muscle hypertrophy seek to increase the cross-sectional area (CSA) of the existing muscle fibers (Baechle & Earle, 2008). Muscle hypertrophy involves an increase in the net accretion of the contractile proteins actin and myosin within the myofibrils and an increase in the number of myofibrils within a muscle fiber (Baechle & Earle, 2008; McArdle, Katch & Katch, 2008). A major area of focus for proper hypertrophy training is the length of rest periods between sets of exercises. By viewing strength training as a form of interval training, the importance of rest periods is established. Interval training is a method that emphasizes bioenergetic adaptations for a more efficient energy transfer within the metabolic pathways by using predetermined intervals of exercise and rest periods (i.e. work-to-rest ratios) (Baechle & Earle, 2008). The body requires rest in order for the muscles to recover and properly replenish energy stores (Richmond & Godard, 2004; Willardson & Burkett, 2006).
Theoretically, when designing a strength training program, if work-to-rest intervals are properly spaced more work can be accomplished at higher exercise intensities with the same or less fatigue than during continuous training at the same relative intensity (Baechle & Earle, 2008). Within the muscle itself, there are considerable variations in metabolic recovery rates and enzyme pathways utilized, resulting in considerable differences in performance; some of these differences in performance could affect potential muscle adaptations (Richmond & Godard, 2004). In this study, performance was defined as the ability to perform the allotted number of repetitions without failing, or reaching muscular fatigue, which inhibits an individual from continuing the exercise being done. According to the National Strength and Conditioning Association (NSCA), rest periods between 30 seconds and 1.5 minutes should be taken in order to elicit the most muscle fiber hypertrophy responses (Baechle & Earle, 2008). According to the American College of Sports Medicine’s (ACSM) “Progression Model in Resistance Training for Healthy Adults,” the recommended rest period range for novice and intermediate training programs is 1-2 minutes (Ratamess et al., 2009). Willardson (2006) has shown that training protocols with shorter rest periods (≤ 2 minutes) elicit significantly greater anabolic hormone secretions within the body than protocols with longer rest periods (> 2 minutes); these increased responses in anabolic hormone levels could lead to greater muscle adaptations. Due to the greater anabolic hormone secretions obtained with short periods, greater increases lean muscle tissue will follow (Kraemer, Noble, Clark, & Culver, 1987; Kraemer et al., 1990).

Another variable affecting muscle hypertrophy, in combination with rest periods, is training volume (Schoenfeld, 2010). Training volume is a summation of the total number of repetitions performed during a training session multiplied by the resistance used (Rahimi, 2005). A training session was defined as a single bout of training which was done multiple times per
week (Baechle & Earle, 2008). Training volume has been shown to affect neural adaptations, tissue hypertrophy, metabolic mechanisms, and hormonal responses and subsequent adaptations to resistance training (Rahimi, 2005). In many studies examining varying rest period lengths, individuals assigned short rest periods performed less total volume than individuals assigned long rest periods due to the fact that with short rest periods there is not enough time for lactate accumulation to be cleared and phosphocreatine to be completely replenished (Baechle & Earle, 2008; McArdle, Katch & Katch, 2008). Theoretically, longer rest periods should lead to more total volume resulting in greater gains in muscle hypertrophy (Krieger, 2010; Lawton, 2006).

**Purpose of the Study**

The purpose of this study was to compare the effects of 1-minute versus 3-minute, between-set rest intervals on muscular hypertrophy adaptations in recreationally strength trained males over a 6-week period.

**Significance of the Study**

Little research has been done measuring lean tissue mass changes when comparing short and long rest intervals. The low number of studies that have published on this comparison have had limitations and/or additional variables, which may have skewed the results found, or had poorly designed training protocols that did not focus solely on the effects of varied rest periods. Though the relationship between rest period duration, volume, and muscle hypertrophy has been mentioned in various studies, no study has made this the primary area of focus in a research experiment.
Delimitations

This study was delimited to:

1. Only using subjects who were recreationally strength-trained college students, age 18-25, who have at least 1 year of prior strength training experience;

2. Research variables consisting of lean muscle tissue (kg), squat and bench press 1-repetition maxes (kg), total volume completed per exercise (repetitions per set);

3. Using Dual-energy X-ray absorptiometry (DEXA) scans to assess lean muscle tissue (kg) and body fat tissue (kg); 1-repetition maximum testing for bench press and back squat was used to determine maximum strength of each subject;

4. A 6-week study; and

5. An exercise protocol based on hypertrophy strength training recommendations from the NSCA (Baechle & Earle, 2008).

Limitations

The study was limited to:

1. Time duration of the study; because the subjects all have prior involvement in strength training in one form or another, significant skeletal muscle mass adaptations may not take place after 6 weeks;

2. The diet of the subjects; subjects were advised on the importance of calorie balance and nutrient timing of carbohydrates and protein in eliciting the best muscular hypertrophy results, but direct observation of each subject’s diet outside of training sessions was not possible for this study;
3. The requirement to not participate in additional resistance training programs outside of
the study, but other daily activities outside of the research study that may skew results
were not recorded or observed; and

4. No analysis of hormone levels pre- and post-training sessions being taken.

Assumptions

It was assumed that:

1. All the research participants answered the questionnaire honestly;

2. The research participants complied with the researcher’s request to give maximal effort
during each exercise session;

3. The research participants complied with the request to not participate in any other
strength training programs outside of the research study;

4. The research participants acquired adequate nutrition and sleep to fully recover between
exercise sessions.

Hypotheses

It was hypothesized that:

1. Subjects of both rest period groups would have increased lean muscle mass;

2. Subjects assigned 1-minute rest periods would have significantly greater increases in lean
muscle mass than those assigned the 3-minute rest periods;

3. Subjects assigned 3-minute rest periods would be able to complete a higher amount of
volume per training session each week for both back squat and bench press;

4. Subjects of both rest period groups would have an increased 1-repetition max in the back
squat;
5. Subjects of both rest period groups would have an increased 1-repetition max in the bench press;

6. There would be no significant difference between rest period groups in increases of 1-repetition max in the squat; and

7. There would be no significant difference between rest period groups in increases of 1-repetition max in the bench press.

**Definition of Terms**

The following terms were conceptually or operationally defined to enhance the understanding of the readers of this study:

1. *Repetition failure* - reaching muscular fatigue during an exercise set, inhibiting an individual from continuing the movement or exercise being done

2. *Interval training* - method of exercise emphasizing bioenergetic adaptations for a more efficient energy transfer within the metabolic pathways by using predetermined intervals of exercise and rest periods; also known as work-to-rest ratios (Baechle & Earle, 2008).

3. *Intensity* - the percentage of an individual’s 1-repetition maximum for a particular exercise.

4. *Performance* - the ability to perform the allotted number of repetitions without failing, or reaching muscular fatigue inhibiting an individual from continuing the movement or exercise being done.

5. *Strength training* - referring to the weight-lifting routine used to elicit specific adaptations within the skeletal muscle.
6. *Total volume* – the number of repetitions completed per set for each specific exercise by the end of a training session; repetitions completed multiplied by the number sets per exercise for each training session.

7. *Training session* - a single bout of training which can be done multiple times per week (Baechle & Earle, 2008).
CHAPTER 2

REVIEW OF LITERATURE

Muscle tissue hypertrophy is dominantly affected by the increase of protein synthesis stimulated by strength training. Various research studies have experimented with the different ways in which rest periods can be manipulated to increase protein synthesis. The specific hormones activated during bouts of exercise, the amount of volume completed per exercise during each workout session, and the ability to recover during exercise sessions are addressed in this literature review. The following sections, in this chapter, examine the research completed on the importance of rest periods between working exercise sets. In addition, a comparative analysis of the findings on short versus long rest periods is reviewed.

Hormonal Adaptations

For muscular hypertrophy to occur, protein synthesis must take place in the body, more specifically in the targeted muscle groups. Much research indicates that increasing levels of primary anabolic hormones (testosterone, growth hormone, insulin-like growth factors, etc.) will lead to high elevations in protein synthesis (McArdle, Katch & Katch, 2008).

Testosterone is the primary androgen hormone that interacts with skeletal muscle tissue. It has both direct and indirect effects that promote growth hormone responses in the pituitary gland, which can influence protein synthesis in the muscle (Baechle & Earle, 2008; McArdle, Katch & Katch, 2008). Testosterone has a high potential for interactions with other hormones which demonstrates the prominent interdependent nature of the neuroendocrine-immune system in influencing the strength and size of skeletal muscles. The role testosterone plays in changing muscle size and strength is also related to its ability to influence the nervous system.
Additionally, testosterone can interact directly with skeletal muscle itself (Baechle & Earle, 2008; McArdle, Katch & Katch, 2008).

Growth hormone, also known as somatotropin, is another important anabolic hormone which is secreted by the anterior pituitary gland (Baechle & Earle, 2008; McArdle, Katch & Katch, 2008). In association with resistance training, growth hormone enhances cellular amino acid uptake and protein synthesis in skeletal muscle, resulting in hypertrophy of both Type I and Type II muscle fibers. Growth hormone’s anabolic effects can be directly on tissues, but can also be mediated through the production of insulin-like growth factor I (IGF-I) by the liver and other cells. Growth hormone stimulates liver cell DNA to synthesize IGFs, which takes a range of 8 to 29 hours to occur. IGFs have a strong interaction with binding proteins, creating an increase in protein synthesis, especially in response to exercise stress (Baechle & Earle, 2008; Boroujerdi & Rahimi, 2008; McArdle, Katch & Katch, 2008).

Muscle fiber disruption and damage during intense resistance exercise are another major initial stimuli for the muscle growth process (Machado et al., 2011). One catabolic hormone that plays a critical role in protein degradation is cortisol. Cortisol is the main signal hormone for carbohydrate metabolism and is related to glycogen stores in the muscle. As glycogen stores become progressively low, cortisol breaks down substrates to produce energy. Though high increases of cortisol elicits protein degradation, muscle fiber disruption and damage is necessary, leading to remodeling and enlargement; acute elevations in cortisol are necessary in this process (Baechle & Earle, 2008; Bottaro, 2009). When strength training, at the proper intensity with short rest periods and high total volume, disruption of homeostasis (the body’s maintenance of a stable internal environment) leads to a cascade of molecular events that cause adaptive processes to activate and elicit system improvements in muscle size and many other factors. In order to
create the proper amount of hormonal stimulus through muscle fiber disruption and damage, short rest periods (30 seconds to 1 minute) should be used (McArdle, Katch & Katch, 2008).

Research has shown that when skeletal or cardiac muscle fiber damage occurs, elevated levels of the enzymes, creatine kinase (CK) and lactate dehydrogenase (LDH) are seen (Machado, 2011). Rodrigues et al. (2010) compared serum CK and LDH concentrations at multiple time points after resistance exercise sessions that incorporated different rest intervals between sets and exercises. Twenty untrained men performed two resistance exercise sessions, with either 1- or 3-minute rest intervals between sets and exercises, while CK and LDH concentrations were measured before exercise and 24, 48, and 72 hours post-exercise. The results indicated that CK and LDH levels were similar in both groups, with no significant differences between 1-minute or 3-minute rest intervals at any period. However, the volume load completed to induce the muscle damage was significantly greater when 3-minute rest intervals were employed, so when considered relative to the volume load completed, 1-minute rest intervals during resistance exercise may invoke greater muscle damage. In a similar study, Machado et al. (2011) determined the effects of different rest intervals between sets on serum CK and LDH activity in ten men who completed four resistance exercise sessions comprised of 4 sets of 10 repetitions, with 10RM loads for six different exercises. Each session had a certain rest interval assigned, either 60, 90, 120, or 180 seconds. The study resulted in no significant differences in CK and LDH concentrations between any of the rest periods post-exercise. It was concluded that accumulated volume or work is the main determinant of muscle damage in trained subjects.

The acute hormonal responses to different resistance exercise protocols have been compared where nine recreationally trained males performed a protocol that involved three sets of eight exercises with a 10RM load and a 1-minute rest interval between sets, and another
protocol that involved five sets of five exercises with a 5RM load and a 3-minute rest interval between sets. Blood hormone concentrations of total testosterone, free testosterone, cortisol, growth hormone and blood lactate were collected prior to the exercise session and at different time periods following the exercise session. The results showed that acute elevations in growth hormone were significantly greater for the protocol that involved 1-minute rest intervals and 10RM loads. A limitation of the study was that it did not make the difference in rest periods the main focus of the study, but instead compared two completely different protocols in regard to number of sets, intensity, and rest intervals. Another limitation was that changes in muscular hypertrophy were not examined over time, only hormone responses (Kraemer et al., 1990).

Rahimi, Qaderi, Faraji, and Boroujerdi (2010) examined the effects of three different rest periods on the acute hormonal responses to resistance exercise in ten experienced, resistance trained men. Three training sessions occurred with subjects being randomly assigned rest intervals of 60 seconds, 90 seconds, or 120 seconds. The sessions consisted of four sets of squat and bench press to failure, using 85% of 1RM. Blood draws occurred at pre-exercise, immediately post-exercise, and 30 minutes post-exercise. Serum growth hormone concentrations were significantly higher immediately post-exercise in the 60 second group when compared to the 120 second group. However, serum testosterone concentrations were significantly higher immediately post-exercise in the 120 second group when compared to the 60 second group. The results show conflicting evidence on whether shorter rest periods generate greater anabolic hormonal responses versus longer rest periods.

Goto et al. (2004) examined growth hormone responses with varying rest periods, as well as chronic adaptations to hypertrophy- and strength-oriented programs. All subjects were recreationally trained, but they had not participated in a regular training program for at least 6
months prior to commencement of the study. The strength training protocol took place over the course of four weeks with three different sessions being executed. Session 1 was nine sets at 10RM, with 30-second intervals; session 2 was five sets at 90% of 1RM and 3-min intervals; session 3 was five sets at 90% of 1RM and 3-minute intervals + one set of 10RM after 30 seconds rest. The results showed that growth hormone levels post-exercise were shown to be significantly dependent on the protocols in the following order: session 1 > session 3 > session 2. Additionally, the combined program (session 3) demonstrated significantly larger increases versus the high-intensity program in the quadriceps cross-sectional area (CSA), 1RM leg press, maximal isokinetic strength and muscular endurance for the leg extension. Although this study measured CSA, it still had the limitation of not making the main focus of the study the difference in rest periods, but instead compared three completely different protocols in regard to number of sets, intensity, and rest intervals. Finally, the six month period prior to the study, where the subjects did not participate in strength training, could have had an effect as well.

Ahtiainen et al. (2005) found hormonal responses and hypertrophic adaptations did not vary between 2- and 5-minute rest intervals in 13 recreationally strength trained men (with an experience of 6.6 ± 2.8 years of continuous strength training). This experiment involved a crossover design where two groups trained for three months utilizing both rest periods, at different points in time. The maximal strength of the leg extensors and the quadriceps CSA were assessed before and after completion of each condition. Other variables assessed included electromyography activity of leg extensor muscles, concentrations of total testosterone, free testosterone, cortisol, growth hormone and blood lactate. The results demonstrated for both conditions, acute responses and chronic adaptations were similar in terms of the hormonal concentrations, strength development and increases in quadriceps CSA. A major result of the
study demonstrated that the 5-minute rest interval allowed for the maintenance of a higher training intensity (approximately 15% higher); however, the volume of training was equalized so that the 2-minute condition required more sets at a lower intensity, while the 5-minute condition required less sets at a higher intensity. Thus, the strength and hormonal responses appeared to be somewhat independent of training intensity as long as an equal volume was performed.

Buresh, Berg, and French (2009) produced a study comparing the effects of 1-minute rest periods versus 2.5-minute rest periods on changes in hormone response, strength, arm CSA, thigh CSA, and body composition during a 10-week training period. All twelve of the untrained males engaged in the same training protocol, the only difference being in rest intervals. The results of the study indicated healthy, recently untrained males, strength training with 1-minute of rest between sets elicited a greater hormonal response than 2.5-minute rest intervals in the first week of training, but these differences diminished by week 5 and disappeared by week 10 of training. Additionally, only arm CSA increased more with long rest periods than with short rest periods, while thigh CSA and strength increases were not significantly different. As demonstrated, the available studies conflict on the impact of rest period lengths on hormonal responses, and fewer studies examine muscle hypertrophy through increases in CSA. Solely examining the hormonal responses of different resistance training protocols is not enough evidence to infer that short rest periods produce greater muscle fiber hypertrophy adaptations.

**Volume**

In order to elicit the greatest hormonal response and produce the most muscle hypertrophy increases, resistance training must have moderate to high volume of exercise, achieved with multiple sets and multiple exercises, in combination with short rest intervals. Volume refers to the total amount of weight lifted in a training session, and a set is a group of
repetitions sequentially performed before the individual stops to rest (Baechle & Earle, 2008). In a study by Gotshalk et al. (1997), hormonal responses (serum growth hormone, testosterone, cortisol and whole blood lactate) of multi-set (3S) versus single-set (1S) heavy-resistance exercise protocols were examined. Subjects consisted of eight recreationally strength trained men who completed two identical resistance exercise workouts. For growth hormone, testosterone, and whole blood lactate, the 3S protocol had significantly greater increases when compared to 1S. There were no significant differences between 1S and 3S measures in cortisol levels; both increased from pre- to post-exercise. Gotshalk et al. (1997) concluded higher volumes of total work produced significantly greater increases in circulating anabolic hormones during the recovery phase following exercise.

Although moderate to high volumes are utilized to elicit greater muscle enlargement, conflicting studies have debated whether short rest periods positively or negatively affect volume and performance. Performance refers to the ability to perform the allotted number of repetitions without stopping to rest (Richmond & Godard, 2004). Kraemer et al. (1997) experimented with the effects of 1- and 3-minute rest intervals on the total number of repetitions completed in three consecutive sets with a 10RM load on the bench press and leg press. The subjects for the study were twenty, resistance-trained American football players. The results found that resting three minutes between sets was enough time to allow for the completion of 10 repetitions of each set. Alternatively, resting one minute between sets resulted in a significant decrease in the total repetitions completed.

Rahimi, Boroujerdi, Ghaeeni, and Noori (2007) studied the effects of three different rest intervals on squat volume completed during a workout. Volume, for this study, was defined as the total number of repetitions completed over four sets for each rest condition. Twenty college-
aged men performed four sets of squat at 85% of 1RM over the course of three testing sessions. During each testing session, the squat was performed with 1-, 2-, and 5-minute rest intervals between sets. The results showed the 5-minute rest interval produced the highest volume completed, followed by the 2-minute rest condition, with the 1-minute rest condition producing the lowest volume completed. A similar study was completed by Willardson and Burkett (2005) using fifteen college-aged men, comparing the differences between 1-, 2-, and 5-minute rest intervals during four sets of eight repetitions, using 8RM over the course of three testing sessions. Results indicated that 5-minute rest condition resulted in the highest completed volume, followed by the 2-minute rest condition, and the 1-minute rest condition producing the lowest volume completed.

Mirzaei, Nia, and Saberi (2008) took the previous results a step further by comparing the differences between three different rest intervals (90, 150, and 240 seconds) on sustainability of squat repetitions with heavy versus light loads. Eighteen resistance trained males performed two testing sessions each week for three weeks. Four consecutive sets of squat were completed with the prescribed rest intervals for both sessions each week. The first session of the week included a load of 90% of 1RM, while the second session used a load of 60% of 1RM. The results indicated that for each load, a significant decline in repetition occurred between the first and fourth sets, and the sustainability of repetitions was not significantly different between loads. It was concluded that 240-second rest intervals were necessary in order to avoid significant declines in repetitions for either light or heavy loads.

The problem of short rest periods decreasing volume and exercise performance during workout sessions was addressed by a study done by Richmond & Godard (2004). The purpose was to determine the performance effects of varied rest periods required by recreational weight-
lifters for maximal recovery between sets of bench press to failure, or volitional exhaustion. The rest intervals were 1-, 3-, and 5-minutes between two sets of bench press at 75% of 1RM with a repetition range of 8-12. The results indicated there was a significant decrease in the number of repetitions performed between the second sets at all rest periods. The results also indicated that there were no significant differences in work (repetitions x work) performed during the second set with 3- and 5-minute rest conditions, but total work with a 1-minute rest interval was significantly less than the other two rest conditions (Richmond & Godard, 2004). The 8-12 repetition range is the same range for muscle hypertrophy training set by both the American College of Sports Medicine and the National Strength and Conditioning Association (Ratamess et al., 2009). The 3- and 5-minute rest interval groups were able to stay within range during the second set, while the 1-minute rest interval group was not, thereby resulting in less total work being done (Richmond & Godard, 2004).

Recovery

To fully understand the basis of comparison of various rest periods and the recovery each one allots, studies have examined the muscle fibers being recruited, the primary energy systems providing fuel and the metabolic/enzymatic pathways being utilized (De Salles, 2009; Rahimi, 2005). While performing a resistance exercise of a submaximal amount (≤ 90%), both slow- and fast-twitch muscle fibers are recruited, but the smaller, slow-twitch fibers are recruited first, according to the Henneman’s size principle (Mirzaei, Nia, & Saberi, 2008). Depending on the intensity of the activity and/or the level of fatigue reached by the slow-twitch muscle fibers, the larger fast-twitch fibers are recruited for assistance. During a set to failure, once all the muscle fibers of the targeted muscle group(s) have been fatigued and an insufficient amount of force is being produced, the set ends (Rahimi, 2005).
The type of muscle fiber recruitment has a strong relationship to the energy systems and metabolic pathways utilized, all of which are extremely dependent on exercise intensity and duration. Exercise intensity is defined as the level of muscular activity that can be quantified in terms of power (work performed per unit of time) output (Baechle & Earle, 2008). In resistance training, intensity is the percentage of 1RM. When an individual engages in an activity, like resistance training, that is of high intensity and requires high power output, energy must be produced and utilized at a rapid rate. The primary energy supplier for rapid, high intensity muscle actions is the phosphagen system. When dealing with the different energy systems, such as the phosphagen system, substrate depletion and repletion is known to play a key role (Rahimi et al., 2007; Rahimi et al., 2009; Rahimi et al. 2010). Energy substrates are the molecules that provide starting materials for bioenergetics reactions, including high-energy phosphagens (ATP and creatine phosphate), glucose, glycogen, and lactate; substrates can be selectively depleted during the performance of activities of specific intensities and durations. High-intensity, anaerobic exercise rapidly depletes high-energy phosphate concentrations in the muscle more so than aerobic exercise. Creatine phosphate can decrease by approximately 50-70% during the first 5-30 seconds of high-intensity exercise and can be almost exhausted as a result of prolonged intense exercise (Baechle & Earle, 2008). Following exercise, phosphagen repletion has been shown to occur relatively quickly; ATP completely resynthesizes within three to five minutes, while creatine phosphate completely resynthesizes within four to eight minutes (Rahimi, 2005). Though high-intensity, rapid muscle action relies primarily on the phosphagen system, studies show that its rephosphorylation of creatine is largely accomplished as a result of aerobic metabolism (McArdle, Katch & Katch, 2008).
Resistance training can cause substantial depletion of muscle glycogen anywhere from 20 to 60 percent with relatively few sets, or low total workloads. Exercise intensity dictates the rate of muscle glycogenolysis (breakdown of glycogen); as intensity increases so does the rate of glycogenolysis (Baechle & Earle, 2008). Considering the primary energy systems of high-intensity, intermittent exercise are anaerobic and make some of the greatest contributions to the total energy cost at the start of exercise, an oxygen deficit is accumulated (Mirzaei, Nia, & Saberi, 2008). When glycolysis takes the leading role as the predominant energy system, a plethora of chemical reactions occur that both benefit and hinder activity, such as resistance training. Anaerobic glycolytic reactions strip two pairs of hydrogen atoms from the glucose substrate and pass the electrons to nicotinamide adenine dinucleotide (NAD+) to form reduced nicotinamide adenine dinucleotide. During rapid anaerobic glycolysis, NAD⁺ regenerates when pairs of excess non-oxidized hydrogens combine with pyruvate to form lactate. Though many confuse the substances of lactic acid with lactate, the two are different; furthermore, lactic acid, in many cases, is blamed for muscle fatigue after intense, prolonged bouts of exercise. In reality, hydrogen ions (H⁺) cause this effect once the ions are released from the dissociation of lactic acid and its conversion to lactate. Blood lactate accumulates only when its disappearance by oxidation or substrate conversion does not match its production; this accelerates as exercise intensity increases (Baechle & Earle, 2008; McArdle, Katch & Katch, 2008). Insufficient oxygen causes an imbalance in hydrogen ion release. The buildup of H⁺ ions presents the primary problem for the body’s homeostatic mechanisms by causing the muscle pH to decrease due to insufficient buffering capacity. Discomfort and muscle fatigue occurs as the muscle becomes more acidic, impairing exercise performance (Rahimi, 2005).
Once the components of phosphagen substrate depletion and repletion, as well as the consequences of blood lactate and hydrogen ion accumulation are taken into account, the idea of shorter rest intervals being more beneficial becomes more unlikely. When the rest period duration does not match either the time it takes for ATP resynthesis, creatine phosphagen resynthesis, or blood lactate oxidation, exercise performance, especially high-intensity, rapid muscle action, such as resistance training, can be greatly inhibited (McArdle, Katch & Katch, 2008).

Finally, as mentioned in previous sections, shorter rest periods between sets of multiple repetitions fatigue the targeted skeletal muscle due to decreased phosphocreatine stores and accumulation of metabolic waste products. With each subsequent exercise set, repetition failure occurs. Research suggests that the muscle damage accumulated by reaching repetition failure leads to greater strength and muscle mass gains (Lawton et al., 2004). It is proposed that fatiguing contractions enhance strength development by: greater activation of motor units; greater contribution from synergistic and antagonistic muscles; and, fatigue-related events that trigger muscular adaptation, especially in untrained individuals (Rooney, Herbet, & Balnave, 1994). One study found training until repetition failure on the bench press induces greater strength gains than non-failure training in the bench press exercise for elite junior team sport athletes (Drinkwater et al., 2005). The utilization of shorter rest periods allows for repetition failure to be reached sooner and with lower intensities.
CHAPTER 3

METHODOLOGY

Various research experiment designs and weight-lifting programs have been used to determine whether short or long rest periods are more desirable for inducing muscle hypertrophy during strength training (sets consisting of 8-12 repetitions). The following sections of this chapter discuss the methods selected for this research study in order to examine which rest period duration is most appropriate when attempting to produce the greatest muscle tissue increases during strength training.

Selection of Participants

A total of twelve subjects participated in this study and were separated into two equal groups of six. Subjects for this study were college-aged males between the ages of 18-25 years. All subjects were classified as intermediate, recreationally strength-trained individuals, having been involved in a strength training program for at least one year with a minimum of three days per week. No collegiate or elite athletes were allowed in the study. Individuals with disabilities, diseases, or medical conditions that could inhibit exercise or skew results were excluded from the study. None of the subjects had any major surgeries within the year prior to the study.

Procedures

The study lasted six weeks. Before participating in the research study, individuals were required to sign a consent form and fill out both a questionnaire and the Physical Activity Readiness Questionnaire (PAR-Q). Week 1 consisted of body composition assessment testing, using a DEXA scan, and the determination of 1-repetition maximums (1RM) on the back squat and bench press. For the additional six exercises in the strength training program, 1RM testing
was not used. Instead of performing 1RM tests with the other six exercises, subjects were told to perform each exercise and choose the weight resistance that felt most comfortable, yet still challenging, while performing sets of ten repetitions for the first week.

Before beginning 1RM assessment, each subject completed five minutes of cycling to warm-up. After the completion of the five minutes of cycling, proper form was demonstrated for both the back squat and bench press. Following proper form demonstrations, subjects were instructed to warm-up with light resistance that easily allowed 5 to 10 repetitions. Stopwatches were operated by the tester and used to track rest periods between sets for every exercise during each session. After two-minutes of rest, the subjects estimated a load that was adequately challenging for 3 to 5 repetitions. After an additional two-minute of rest, a near-maximal load was estimated for the subjects that allowed for the completion of 2 to 3 repetitions. Subjects rested 3 to 5 minutes and the load was increased 5 to 10 kgs before attempting a 1RM. Upon success the subjects rested 3 to 5 minutes and another load increase occurred; if the subjects failed, the subject rested 3 to 5 minutes and a load decrease occurred. Once 1RM assessments were completed, subjects were randomly assigned to either the 1-or 3-minute rest period group. Subjects were divided equally into each group based on 1RM, training status, and age.

During Week 2 through Week 5, the subjects completed the prescribed exercise protocol. Sessions occurred four times per week for four consecutive weeks (Monday, Tuesday, Thursday, and Friday). There were two lower-body sessions and two upper-body sessions per week in an alternating order; lower-body sessions took place on Monday and Thursday, while upper-body sessions took place on Tuesday and Friday. Lower-body exercises were the back squat, leg press, leg curls, and leg extensions. Upper-body exercises included the barbell bench press, barbell bent-over row, barbell incline press, and lateral-pull down.
The exercise protocol was three sets of 10 repetitions at 67% of 1RM for the first training week for the back squat and bench press. The exercise protocol was based on hypertrophy strength training recommendations from the NSCA’s “Essentials of Strength and Conditioning,” which stated that intensity should be 67-85% of 1RM with 3-6 sets of 8-12 repetitions for exercises targeting large muscle groups (Baechle & Earle, 2008). The sets increased by one each week while the number of repetitions stayed the same. The load, or weight used for each exercise, was adjusted as needed as the subjects progressed through the program. The warm-up utilized prior to each training session consisted of five minutes of light cycling, using an ergometer bike, on lower-body training sessions and three minutes of light stationary rowing on upper-body training sessions. Following a warm-up, subjects performed two sets of the first/primary exercise; the back squat on lower body days and bench press on upper-body day. The first warm-up set was at 50% of 1RM, and the second warm-up set was at 60% of 1RM. Week 6 consisted of follow-up body composition assessment testing and determining the 1-repetition maximum in the back squat and bench press.

Instrumentation

The GE Healthcare Lunar Prodigy Advance dual-energy X-ray absorptiometry (DEXA) was used to measure body composition of subjects. The Befour electronic weighing scale was used to measure subjects’ body weight (kg) before each DEXA scan. The Monark Ergonmedic 828 E Stationary Bike and the Concept 2 Model E Indoor Rower were used for warm-up protocols before strength training exercises began. The YORK Power Rack, the Freemotion Epic Free Weights consisting of the Flat Bench and Incline Bench and the Freemotion Epic Resistance Machines consisting of the Leg Press, Leg Extension, Leg Flexion, and Lateral Pull-down were used to perform all the exercises required for the strength training program.
Data Collection and Analysis

Bench press and back squat 1RM s were recorded as a pretest to the study and once more as a posttest, then compared for any significantly statistical differences using a two independent groups t-test. The total volume (sets x repetitions) was recorded for the bench press and back squat for every training session throughout the study. The total volumes for the bench press and back squat of both groups were averaged and the means were compared for any significantly statistical differences. Stopwatches were operated by the researcher to track rest periods between sets for every exercise during each session. The DEXA was used to assess lean muscle tissue (kg) and body fat tissue (kg). Results for each DEXA scan were recorded during pretesting and once more as a posttest, then compared for any significantly statistical differences using a two independent groups t-test. Body weight and height were measured before each DEXA scan.
CHAPTER 4

RESULTS

The purpose of this study was to compare the effects of 1-minute versus 3-minute between-set rest intervals on muscular hypertrophy adaptations in recreationally strength-trained males over a 6-week period. The data in the study was analyzed using the Statistical Package for Social Sciences (SPSS), with the intention of reinforcing or opposing the hypotheses previously stated. The study utilized a series of both One-Sample \( t \)-Tests to estimate significant pretest and posttest differences in the subjects, as well as Two-Independent Samples \( t \)-Tests in order to determine significant differences between posttest results of the 1-minute sample group in comparison to the 3-minute sample group. This chapter presents the descriptive results and the quantitative results of each experiment group.

Descriptive Results

The selection criteria for the sample group were college-aged males, ages 18-25 years. All subjects were classified as intermediate, recreationally trained weight-lifters, having been involved in a strength training program for at least one year with a minimum of three days per week. No collegiate or elite athletes were included in the study. Individuals with disabilities, diseases, or medical conditions that could inhibit exercise or skew the results were excluded from the study. None of the subjects had any major surgeries within the year prior to the study.

A total of twelve subjects participated in the study. Subjects were separated into two equal groups of six, based on strength-training history (yrs) and then randomly assigned a rest period duration. Variables recorded during the course of the study include weight (kg), height (cm), age (yrs), lean tissue mass (kg), back squat 1RM (kg), bench press 1RM (kg), and training
history (yrs). Subjects were assigned to two groups (1-minute rest or 3-minute rest) based on their training history. Table 1 indicates the pretest descriptive statistics of the sample population for the 1-minute and 3-minute rest period groups (N = 6/6). Variables listed were compared using independent t-tests and indicate the groups were the same on all variables (see Table 1).

Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>1-Minute Mean (SD)</th>
<th>3-Minute Mean (SD)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle Mass (kg)</td>
<td>64.40 (10.38)</td>
<td>64.58 (7.36)</td>
<td>.973</td>
</tr>
<tr>
<td>Squat (kg)</td>
<td>128.03 (38.34)</td>
<td>134.47 (34.27)</td>
<td>.765</td>
</tr>
<tr>
<td>Bench (kg)</td>
<td>92.04 (22.44)</td>
<td>103.41 (26.57)</td>
<td>.442</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>82.36 (17.32)</td>
<td>90.81 (17.66)</td>
<td>.422</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>176.53 (7.42)</td>
<td>179.07 (11.05)</td>
<td>.650</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>20.00 (2.19)</td>
<td>21.00 (1.90)</td>
<td>.418</td>
</tr>
<tr>
<td>Training History (yrs)</td>
<td>4.67 (2.81)</td>
<td>4.50 (2.43)</td>
<td>.915</td>
</tr>
</tbody>
</table>

**Quantitative Results**

The first hypothesis stated that subjects of both rest period groups would experience increased lean muscle mass. Table 2 indicates the t-ratio and p-value of lean muscle mass results for all twelve subjects. The results of a One-Sample t-test for the 12 subjects demonstrate there was a statistically significant difference between the pretest and posttest lean tissue mass with all subjects, as a collective group, significantly increasing in lean muscle. Because of this significance, the null hypothesis was rejected; \( t (11) = 4.056, p = 0.002 \).
Table 2

One-Sample \( t \)-test – Lean Muscle Mass (kg) (\( N = 12 \))

<table>
<thead>
<tr>
<th>Test</th>
<th>Mean</th>
<th>±SD</th>
<th>( t )-ratio</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>64.492</td>
<td>8.58</td>
<td>4.056</td>
<td>11</td>
<td>.002*</td>
</tr>
<tr>
<td>Posttest</td>
<td>66.783</td>
<td>9.16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Difference</td>
<td>2.292</td>
<td>1.96</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* = significant at \( p < .05 \)

The second hypothesis stated that the subjects who were assigned the 1-minute rest periods would have significantly greater increases in lean muscle mass than those assigned the 3-minute rest periods. Table 3 indicates the \( t \)-test results of the comparison of the lean muscle mass increases of the 1-minute group pretest to the 1-minute group posttest. A One-Sample \( t \)-test showed no significant difference between the pretest to posttest lean muscle mass changes for the 1-minute group (\( p = .515 \)). Table 3 also indicates the \( t \)-test results of the comparison of the lean muscle mass increases of the 3-minute group pretest mean to the 3-minute group posttest mean. A One-Sample \( t \)-test showed no significant difference between the pretest to posttest lean muscle mass changes for the 3-minute group (\( p = .673 \)).
Table 3

One-Sample \( t \)-tests – Changes in Lean Muscle Mass (kg) Pretest-Posttest (N = 6/6)

<table>
<thead>
<tr>
<th>Test</th>
<th>Pretest Mean (SD)</th>
<th>Posttest Mean (SD)</th>
<th>Pretest ( t )-ratio</th>
<th>Posttest ( t )-ratio</th>
<th>Pretest ( p )</th>
<th>Posttest ( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Minute</td>
<td>64.40 (10.38)</td>
<td>67.42 (10.56)</td>
<td>.000</td>
<td>.700</td>
<td>1.000</td>
<td>.673</td>
</tr>
<tr>
<td>3-Minute</td>
<td>64.58 (7.36)</td>
<td>66.15 (8.49)</td>
<td>.000</td>
<td>.447</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4 indicates the \( t \)-ratio and \( p \)-value of the comparison of the lean muscle mass increases of both groups. The difference between pretest and posttest lean muscle mass increases from all the subjects were averaged within groups then compared to determine if there was a significant difference between them. Based on the Independent Samples \( t \)-Test, there was no significant difference between the lean muscle mass gains of the two groups. The null hypothesis is accepted due to no significant difference; \( t \) (12) = 1.327, \( p \) = .214.

Table 4

Independent Samples \( t \)-test – Comparison of Lean Muscle Mass (kg) Increases Between Groups (N = 6/6)

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean (SD)</th>
<th>Min.</th>
<th>Max.</th>
<th>R</th>
<th>( t )-ratio</th>
<th>df</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-minute</td>
<td>3.02 (2.24)</td>
<td>0.9</td>
<td>7.1</td>
<td>6.2</td>
<td></td>
<td></td>
<td>.214</td>
</tr>
<tr>
<td>3-minute</td>
<td>1.57 (1.46)</td>
<td>-0.7</td>
<td>2.8</td>
<td>3.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparison</td>
<td>1.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td>.214</td>
</tr>
</tbody>
</table>
The third hypothesis stated the 3-minute rest periods would lead to completing a higher volume per training session each week for both the back squat and bench press. Table 5 indicates the *t*-ratio and *p*-value of the Independent *t*-tests utilized in comparing the volume completed each week for back squat and for bench press for both groups. Training volume was recorded each training session for each week to analyze whether rest period length affected the amount of total repetitions completed by each group. For this study, volume was calculated by the multiplying the number of sets by the number of reps completed each training session. The completed volume for the two training sessions per week were added together for each week and then averaged for each separate group. There was no statistically significant difference between the groups from week to week for both the back squat and bench press.
Table 5

Independent Samples *t*-test – Weekly Volume (Sets x Repetitions = Total Reps per Week)

Results (N = 6/6)

<table>
<thead>
<tr>
<th>Week/Exercise</th>
<th>Group</th>
<th>Mean (SD)</th>
<th>t-ratio</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wk. 1 Bench</td>
<td>1 minute</td>
<td>57.00 (3.899)</td>
<td>.264</td>
<td>10</td>
<td>.797</td>
</tr>
<tr>
<td></td>
<td>3 minute</td>
<td>56.00 (8.414)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wk. 2 Bench</td>
<td>1 minute</td>
<td>65.67 (7.581)</td>
<td>-.173</td>
<td>10</td>
<td>.866</td>
</tr>
<tr>
<td></td>
<td>3 minute</td>
<td>67.33 (22.376)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wk. 3 Bench</td>
<td>1 minute</td>
<td>73.17 (7.278)</td>
<td>-.459</td>
<td>10</td>
<td>.656</td>
</tr>
<tr>
<td></td>
<td>3 minute</td>
<td>78.67 (28.416)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wk. 4 Bench</td>
<td>1 minute</td>
<td>81.50 (11.520)</td>
<td>-.497</td>
<td>10</td>
<td>.630</td>
</tr>
<tr>
<td></td>
<td>3 minute</td>
<td>87.83 (28.993)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wk. 1 Squat</td>
<td>1 minute</td>
<td>58.83 (2.858)</td>
<td>-1.00</td>
<td>10</td>
<td>.341</td>
</tr>
<tr>
<td></td>
<td>3 minute</td>
<td>60.00 (.000)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wk. 2 Squat</td>
<td>1 minute</td>
<td>74.83 (8.727)</td>
<td>-1.450</td>
<td>10</td>
<td>.178</td>
</tr>
<tr>
<td></td>
<td>3 minute</td>
<td>80.00 (.000)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wk. 3 Squat</td>
<td>1 minute</td>
<td>92.83 (11.215)</td>
<td>-1.448</td>
<td>10</td>
<td>.178</td>
</tr>
<tr>
<td></td>
<td>3 minute</td>
<td>99.50 (1.225)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wk. 4 Squat</td>
<td>1 minute</td>
<td>111.83 (15.420)</td>
<td>-.927</td>
<td>10</td>
<td>.376</td>
</tr>
<tr>
<td></td>
<td>3 minute</td>
<td>117.83 (3.710)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It was hypothesized that the subjects of both groups would experience increased 1-repetition maxes for the back squat and bench press. Table 6 indicates the *t*-ratio and *p*-value of 1RM for back squat and bench press results for all twelve subjects. Based on the results of a One-Sample *t*-Test for the 12 subjects, there was no statistically significant difference between
pretest and posttest 1RM for back squat ($p = .062$). There was no statistically significant
difference between pretest and posttest 1RM for bench press ($p = .425$).

Table 6

<table>
<thead>
<tr>
<th>Test</th>
<th>Mean (SD)</th>
<th>$t$-ratio</th>
<th>df</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Squat</td>
<td>131.25 (34.83)</td>
<td></td>
<td>11</td>
<td>.062</td>
</tr>
<tr>
<td>Post-Squat</td>
<td>150.76 (32.60)</td>
<td>2.073</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Pre-Bench</td>
<td>97.73 (24.19)</td>
<td></td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Post-Bench</td>
<td>103.79 (25.31)</td>
<td>.829</td>
<td>11</td>
<td>.425</td>
</tr>
</tbody>
</table>

The final hypothesis stated that there would be no significant difference between groups
in increases of 1RM for the back squat or bench press. Table 7 indicates the $t$-ratio and $p$-value
of the comparison of the 1RM for back squat and bench press increases from pretest to posttest
between the two groups. Based on the results of the Independent Samples $t$-test, there were no
significant differences between 1RM for the back squat or bench press between the 1-minute and
3-minute groups ($p = .213$).
Table 7

Independent Samples t-test – Comparison of 1-Rep Max Increases (kg) (N = 6/6)

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Group</th>
<th>N</th>
<th>Mean (SD)</th>
<th>t-ratio</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squat</td>
<td>1 minute</td>
<td>6</td>
<td>22.35 (7.53)</td>
<td>1.329</td>
<td>10</td>
<td>.213</td>
</tr>
<tr>
<td></td>
<td>3 minute</td>
<td>6</td>
<td>16.67 (7.28)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bench</td>
<td>1 minute</td>
<td>6</td>
<td>6.82 (4.77)</td>
<td>.452</td>
<td>10</td>
<td>.661</td>
</tr>
<tr>
<td></td>
<td>3 minute</td>
<td>6</td>
<td>5.31 (6.69)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 5

DISCUSSION

Strength training programs can be designed to elicit different types of muscular adaptations, such as strength, power, hypertrophy, or endurance (Baechle & Earle, 2008). An increase in muscular force with strength training provides the primary stimulus to initiate the process of skeletal muscle growth. Muscle hypertrophy reflects a fundamental biologic adaptation to increased workload independent of gender and age (McArdle, Katch & Katch, 2008). A major area of focus for proper hypertrophy training is the length of rest periods between sets of exercise. According to the National Strength and Conditioning Association, rest periods between 30 seconds and 1.5 minutes should be taken in order to elicit the most muscle fiber hypertrophy responses (Baechle & Earle, 2008). According to the American College of Sports Medicine’s (ACSM) “Progression Model in Resistance Training for Healthy Adults”, the recommended rest period range for novice and intermediate training programs is 1-2 minutes (Ratamess et al., 2009). Willardson (2006) showed that training protocols with shorter rest periods (≤ 2 minutes) elicit significantly greater anabolic hormone secretions within the body than protocols with longer rest periods (> 2 minutes); these increased responses in anabolic hormone levels could lead to greater muscle adaptations. It is thought that due to the greater anabolic hormone secretions obtained with short periods, greater increases in lean muscle tissue may follow (Kraemer, Noble, Clark, & Culver, 1987; Kraemer et al., 1990). Another aspect possibly affecting muscle hypertrophy, in combination with rest periods, is volume. Training volume has been shown to affect neural adaptations, tissue hypertrophy, metabolic mechanisms, and hormonal responses and subsequent adaptations to resistance training (Rahimi, 2005).
The purpose of this study was to compare the effects of 1-minute versus 3-minute between-set rest intervals on muscular hypertrophy adaptations in recreationally strength-trained males over a 6-week period. It was hypothesized that both rest period groups would collectively increase lean muscle mass by the conclusion of the research study. Based on the results of the One-Sample $t$-test for all twelve subjects, there was a statistically significant increase in lean tissue mass from the pretest to posttest. It was also hypothesized that despite both groups increasing lean muscle mass, the 1-minute group would have a significantly greater increase in lean muscle mass than the 3-minute group, however, based on the Independent Samples $t$-test, there was no significant difference between the lean muscle mass gains of the 1-minute group compared to the 3-minute group.

For this study, there were two outliers. One subject of the 1-minute rest period group experienced an increase in lean muscle tissue (+7.1 kg) that was well above the mean increase of the group ($M = 3.017$). One subject of the 3-minute rest period group had a decrease in lean muscle tissue (-0.7 kg) in comparison to the rest of the 3-minute group subjects, who all increased ($M = 1.567$). One possible explanation for these outliers’ results is the difference in training history between the two. The 1-minute subject had only one year of strength training background, while the 3-minute subject had six years of experience. Though many other explanations and variables could play a part in these results, the stark difference in training history and experience could have affected how each individual’s body adapted to the strength training program of the present study.

Buresh, Berg, and French (2009) produced a study comparing the effects of 1-minute rest periods versus 2.5 minute rest periods on changes in hormone response, strength, arm CSA, thigh CSA, and body composition during a 10-week training period. All twelve of the untrained males
engaged in the same training protocol, with the only difference being in rest intervals. The results of the study indicated healthy, recently untrained males, strength training with 1-minute of rest between sets elicited a greater hormonal response than 2.5-minute rest intervals in the first week of training, but these differences diminished by week 5 and disappeared by week 10 of training.

The present study used subjects who were recreationally strength-trained, as opposed to untrained, in order to mitigate the vast initial adaptations that come from novice weightlifters first participation in strength training. It can be inferred that because of the subjects’ longer training history, the increased hormone stimulation that comes from shorter rest periods might not have as great an effect as it does with individuals with a lesser training history.

As previously stated, volume has been shown to play a major part in muscle hypertrophy, with higher volume of training leading to more substantial muscle growth. Volume completed during training sessions is greatly affected by the length of intra-set rest periods and the ability of an individual to recover during said rest periods. It was hypothesized that the 3-minute group would complete a higher volume for back squat and bench press per training session each week in comparison to the 1-minute group. The Independent t-tests utilized in comparing the volume completed each week for the back squat and bench press for both groups unanimously showed that even though the 3-minute group had a higher mean volume completed, there was no statistically significant difference from week-to-week.

The process of hypertrophy involves both an increase in the synthesis of the contractile proteins actin and myosin within the myofibril and an increase in the number of myofibrils within a muscle fiber. The new myofilaments are added to the external layers of the myofibril, resulting in an increase in its diameter (Baechle & Earle, 2008; McArdle, Katch & Katch, 2008). Intense strength training stimulates the process of muscle hypertrophy through muscle fiber
disruption and damage. The process of muscle hypertrophy takes time to become evident; at the very least a few weeks is required depending on an individual’s training status and history. With the initiation of an intense strength training program, changes in the types of muscle proteins begin to take place within several workouts. However, muscle fiber hypertrophy appears to require a longer period of training time (>16 training sessions) (Baechle & Earle, 2008). The present study met that bare minimum number of training sessions within the four week program, which would explain the small increases in lean muscle mass of some of the subjects from each sample group. In order to further examine possible significant differences between the effects of varying rest period lengths on muscle hypertrophy, future research studies should extend the length of the training program or implement a higher number of training sessions per week.

Hendrick (1995) found that in order to produce the most muscle hypertrophy, high volume strength training must be accomplished using multiple sets (3 to 4) and multiple exercises (4 to 5) per body part, per training session. The present study successfully used the allotted number of sets, but only used four exercises for the lower-body. The recommended volume was not reached for the upper-body exercise regimen. Only two exercises were used to target the chest and only two were used to target the back. Both sample groups performed the same number of exercises and same number of sets per exercise, so neither group met the necessary amount of volume due to the minimal training volume of the assigned strength program. In order to further examine possible significant differences between the effects of varying rest period lengths on muscle hypertrophy, future research should increase the assigned training volume for subjects by increasing the number of exercises per body part for each training session.
1RMs were recorded and monitored during the course of this study and it was hypothesized all subjects, despite varying rest periods between groups, would increase 1RMs from pretest to posttest for the back squat and bench press. Although the means for 1RMs for both exercises for both groups increased, *t*-test results indicated no significant differences for either the back squat 1RM or the bench press 1RM. Also, it was hypothesized, despite the varying rest periods, there would be no significant difference between 1RM increases for either the back squat or bench press for either group. Independent *t*-tests showed no significant differences between 1RM for the back squat or the bench press between the 1-minute and 3-minute groups.

Previous studies (Hakkinen et al., 1996; Hakkinen et al., 1998) utilized electromyography (EMG) as a research tool to examine the magnitude of neural activation following training. An increase in EMG indicates greater neural activation. It was concluded that neural adaptation, or improved motor learning and coordination, predominate early in training without significant increases in muscle hypertrophy. Sale (1987) determined large increases in neural adaptations take place early in the training program (6 to 10 weeks). As duration of training increases (>10 weeks), muscle hypertrophy eventually occurs and contributes more to the strength and power gains observed than neural adaptations. For the present study, the 1RM back squat for both sample groups increased from pretest to posttest in the 4 week period. Due to the fact that lean muscle mass had not significantly increased, it is possible that strength increases attained during this time were predominately attributed to neural adaptations as opposed to muscle hypertrophy. In order to further examine possible significant differences between the effects of varying rest period lengths on muscle hypertrophy, future research should increase the length of the training
program to go beyond the neural adaptation phase, so muscle hypertrophy contributions can be better observed.

Conclusion

In conclusion, the findings of the present study reveal no significant differences between the effects of 1-minute and 3-minute rest periods on muscle hypertrophy in recreationally strength-trained males during a 4-week training program over the course of a 6-week research study. These findings suggest that volume, intensity, frequency, and exercise selection take precedence over rest period length when seeking to increase lean muscle mass, and that rest periods of 1 minute and 3 minutes produce the same result outcomes.

Recommendations for Future Research

Results and limitations of this study call attention to the following recommendations for future study:

1. This study should be replicated with a larger sample size.
2. Training status and training history should be more selective in subject criteria for recruitment.
3. The duration of the training program should be increased to greater than 6 weeks.
4. A higher number of training sessions per week should be implemented.
5. The training volume should be increased by increasing the number of exercises per body part for each training session.
6. Hormone secretion levels should be monitored before and after each training session.
7. Neural activation should be monitored during the course of the study using EMGs.
References


