INTRA-SET REST INTERVALS IN HYPERTROPHIC TRAINING: EFFECTS ON HYPERTROPHY, STRENGTH, POWER, AND MYOSIN HEAVY CHAIN COMPOSITION

A Dissertation

by

JONATHAN MICHAEL OLIVER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2012

Major Subject: Kinesiology

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ABSTRACT

Intra-Set Rest Intervals in Hypertrophic Training: Effects on Hypertrophy, Strength, Power, and Myosin Heavy Chain Composition. (August 2012)

Jonathan Michael Oliver, B.B.A., University of North Texas; M.Ed., The University of Texas at Austin

Co-Chairs of Advisory Committee: Dr. Richard B. Kreider
Dr. Stephen F. Crouse

The purpose of this study was to compare the effects of intra-set rest intervals (ALT) and traditional resistance (STD) training in hypertrophic resistance training. 22 males (25±5yrs, 179.71±5.0cm, 82.1±10.6kg, 13.6±4.3% fat, 6.5±4.5yrs training) were matched according to baseline characteristics and randomly assigned to a STD or ALT 12 week hypertrophic training protocol. Body composition, strength (1RM bench and squat); power (60% 1RM bench and squat); and vertical jump were assessed at baseline, 4, 8, and 12 weeks. Muscle biopsy for myosin heavy chain (MHC) was performed pre and post training. A 2 x 4 (Group x Time) ANOVA was used to assess changes in body composition. A 2 x 4 (Group x Time) ANCOVA covaried by baseline performance measures was used to assess differences in strength and power characteristics. A 2 x 2 (Group x Time) ANCOVA covaried for baseline percentage MHC was used to determine differences pre and post training. Both groups experienced increases in FFM with no differences between groups (62.6±7.9, 63.4±7.6, 64.2±7.4, 64.2±7.5kg; p>0.05). No time effects were noted in percent fat (13.6±4.3, 14.1±4.7, 14.0±4.6, 14.3±4.6%fat; p>0.05). Increase in FFM was associated with a decrease in MHC_{IIX}, (ALT, -37.9±24.1%; STD, -23.4±23.8%; p = 0.001) and an increase in MHC_{IIA} (ALT, 32.0±28.8%; STD, 25.4±29.1%; $p = 0.001$) with no difference between groups. A significant interaction was observed with the ALT group experiencing greater gains in both 1RM bench (STD 104.1±27.6, 102.7±29.0, 107.0±25.3, 113.2±27.3; ALT 110.9±20.1, 117.5±23.7, 120.8±22.6, 126±22.8; $p<0.05$) and 1RM squat (STD 123.3±39.3, 139.6±38.8, 160.2±36.1, 171.8±34.5; ALT 130.1±25.1, 152.6±24.8, 179.8±24.5, 193.9±24.2kg; $p<0.05$). The ALT group experienced greater gains in power in both the bench (STD 560±122, 541±105, 572±122, 593±135W; ALT 575±102, 586±123, 646±103, 658±113W; $p<0.05$) and vertical jump (STD 1378±237, 1418±214, 1452±210, 1470±215W; ALT 1389±179, 1434±152, 1470±149, 1537±150W;$p<0.05$), with gains in squat power approaching significance (STD 625±245, 704±233, 723±227, 830±232W; ALT 632±171, 734±179, 783±188, 914±207W; $p<0.10$). The use of intra-set rest intervals in programs designed to elicit hypertrophy results in greater gains in strength and power with no significant difference in lean mass or MHC composition after a 12 week resistance training program designed to elicit hypertrophy.

DEDICATION

To my parents, Larry and Denise Oliver; and my grandparents, Charlie and Betty Johnson, and Frances Oliver.

In his book, *Letters to My Son: A Father's Wisdom on Manhood, Life, and Love*, Ken Nerburn wrote, "We are born male. We must learn to be men."

I am the man I am today because of all of you. I have truly been blessed by your guidance, love, and support. Throughout my life you have supported all my endeavors and shown love abounding, and it is because of you I have been able to accomplish this milestone. You continue to strengthen my faith in God, myself and others and for that I will be forever grateful.

I love you Mom, Dad, Nannie, Papa, and Granny. Granny I wish you could have been here to see me finish, but I know you are watching from above.

ACKNOWLEDGEMENTS

I would first like to thank God for all the wonderful blessings. I know I could not have done it without Him. Dr. Richard Kreider your guidance and willingness to allow me to work in your laboratory and do the research I wanted to do, I will be forever grateful. I would also like to thank Dr. Stephen Crouse for his guidance and letting me hide out in his laboratory and conduct the sports research I believed in. As committee chairs both of you have shaped my career and I will be forever in your debt. I would also like to thank my dissertation committee: Dr. Jim Fluckey, Dr. Janet Parker, and Dr. Steve Riechman, thank you all for allowing me to learn from you, your willingness to listen, and your thought provoking conversations.

This study would not have been successful if not for a number of people who assisted in ensuring its success. First off, if it wasn't for you, Holly Meredith, I would have never been able to speak with Colonel Smith and obtain permission to use the great group of guys who volunteered for this study. I also have to thank Colonel Smith for granting approval to allow his men to participate. To Major Downing, Major Glenn, and Lieutenant Lamson, your leadership throughout the study helped in making sure your men stayed motivated. I must also thank the National Strength and Conditioning Association for funding this project in its entirety, as well as Cytosport, Inc. for providing the supplementation.

Andrew Jagim and Adam Sanchez, your assistance throughout the study was invaluable even after the training had finished. I am forever grateful for your assistance and friendship. Michelle Mardock, had it not been for you I don't know that I ever would have survived the 4 years. Between our talks and the bottles of wine and dinners, you made all of it enjoyable. I also have to thank Julie Kresta and her husband for their support and laughter throughout. To all the undergraduate assistants: Josh Adams, Sam Butler, Noah Clevenger, Joey Hall, Daniel West, and Brian Tate, all of you went the extra mile to ensure the success of this study. Corey Voges and Osmin Guevara, you both showed up to assist early morning without receiving anything in return. Your help was greatly appreciated and I wish you both great futures.

I must thank Dr. Cynthia Meininger for allowing me to work in her laboratory with Katherine Kelley on the muscle analysis. And to say thank you to you Katherine, would not even begin to express my gratitude. You not only taught me so much in the laboratory, you dealt with my relentless impatience after I headed out. Thank you both so much.

It is with great honor that I express thanks to those individuals who participated in this study from the United States Marine Corp and the Naval ROTC program at Texas A&M University. Having had the great opportunity to work with you, I have developed the highest respect for all of you and the work you do for our country. Thank you all for giving 110%.

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CHAPTER I

INTRODUCTION AND RATIONALE

Traditional resistance training programs are designed such that repetitions in a set are performed in a continuous fashion. This has direct implications on the velocity of movement, as velocity has been shown to decline over the performance of successive repetitions (40). This is counterintuitive to the principle of specificity of development of muscular power and thus researchers have attempted to develop methods for counteracting this decrease in velocity. One method for counteracting the decrease in velocity is intra-set rest intervals. Intra-set rest intervals refer to the insertion of rest within a given set thereby altering the rest to work ratio as defined in the most recent guidelines (6). Altering the rest to work ratio through the inclusion of intra-set rest intervals has been shown to result in less reduction in isometric force (62) and power (22), as well as produce significantly greater power output and velocity of contraction over the performance of a single set (34, 36). Furthermore, intra-set rest intervals have also been associated with the ability to maintain intensity over successive repetitions resulting in a greater total volume of training (21). Long term training studies have demonstrated a tendency toward greater gains in power output of the lower body musculature (27, 37) and significantly greater gains in power output of the lower body musculature in athletes (41).

Only one study has compared the effects of intra-set rest intervals utilizing

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This dissertation follows the style of the *Journal of Strength and Conditioning Research.*

intensities corresponding to hypertrophic training (27) with traditional resistance training. Folland et al. (27) reported no significant differences in isometric strength gains and a tendency toward greater high velocity strength gains in a group of recreationally trained individuals with no prior lower body strength training experience. The finding of only a tendency toward greater high velocity strength gains in the study by Folland et al. (27) may have been due to the subject population. Using a linear periodization program design over a 16 week period, Izquierdo et al. (41) demonstrated significantly greater gains in power output of the lower body musculature in trained athletes. This is in agreement with previous research in which it has been demonstrated the optimal load for the development of mechanical power is greater in trained athletes, particularly when multi-joint exercises are performed (42). Therefore, evidence suggests intra-set rest intervals may have a greater impact on muscular power in trained individuals at intensities corresponding to hypertrophy.

While the goal of hypertrophic training is an increase in lean mass, body composition was not assessed in either study. Previous studies have shown shorter rest intervals to be more important in the development of hypertrophy due to acute elevations of anabolic hormones (6, 46, 77). However, longer rest periods have been shown to have the same effect on neuromuscular and hormonal responses in long term training (2, 30) when compared to shorter rest periods. Thus, the total volume of work and corresponding intensity in which that work is performed have been implicated as the primary variables associated with optimal gains in lean mass (16). The increase in lean mass associated with hypertrophic training is accompanied by a shift in myosin heavy chain (MHC) isoforms, identified by a decrease in the percentage of MHC_{IIX} fibers with a concomitant increase in $MH_{IIA/X}$ and MHC_{IIA} fibers (16, 28, 59). These changes in MHC have been shown to vary based on type of training utilized. Liu et al. (50) recently demonstrated a shift from MHC_{slow} to MHC_{IIA}, with no change in MHC_{IIX} when ballistic exercises were performed following traditional resistance training supporting a difference in MHC shift when training at higher velocities.

To date, no studies have compared the effects of intra-set rest intervals in trained individuals utilizing loads corresponding to hypertrophy. Furthermore, studies comparing intra-set rest intervals to the performance of continuous repetitions have not evaluated changes in MHC as a result of the training intervention. Thus, the present study compared the long term effect of intra-set rest intervals and traditional resistance training utilizing loads corresponding to hypertrophy on lean mass gains, strength and power of the upper and lower body musculature as well as changes in MHC.

Statement of the Problem

Will the use of intra-set rest intervals in a program designed to elicit hypertrophy have differing effects on lean mass gains, strength and power output, and myosin heavy chain composition compared to traditional resistance training for the development of hypertrophy?

Specific Aim

The purpose of this study was to compare the effects of intra-set rest intervals and traditional resistance training in a program designed to elicit hypertrophy on changes in lean mass, strength and power output of the upper and lower body musculature and MHC content.

General Study Overview

This study will be a longitudinal comparative design to test the effects of intra-set rest intervals in a program designed to elicit hypertrophy. To contrast the effects of intra-set rest intervals, a second group performing traditional hypertrophic training will be utilized. Both groups will perform a periodized resistance training program of the same total volume over twelve weeks. Assessment of body composition, strength and power will occur at baseline, 4, 8 and 12 weeks to identify the time course of performance adaptations. Muscle biopsies for the determination of MHC content will be performed prior to initiation of training and at the conclusion to determine muscle adaptations in response to the different programs.

Hypotheses

The central hypotheses are:

Hyp1: There will be no significant difference between groups in body composition as measured by dual x-ray absorptiometry (DEXA) after 12 weeks of training.

Hyp2: There will be no significant difference between groups in strength as measured by 1RM bench press exercise after 12 weeks of training.

Hyp3: There will be no significant difference between groups in strength as measured by 1RM parallel back squat exercise after 12 weeks of training.

Hyp4: There will be a significant difference between groups in power of the upper body musculature as measured by the bench press exercise after 12 weeks of training.

Hyp5: There will be a significant difference between groups in power of the lower body musculature as measured by the parallel back squat exercise after 12 weeks of training.

Hyp6: There will be a significant difference between groups in absolute power of the upper body musculature as measured by the bench press exercise after 12 weeks of training.

Hyp7: There will be a significant difference between groups in absolute power of the lower body musculature as measured by the parallel back squat exercise after 12 weeks of training.

Hyp8: There will be a significant difference between groups in power output as measured by vertical jump after 12 weeks of training.

Hyp9: There will be a significant difference between groups in changes in MHC_{slow} percentage after 12 weeks of training.

Hyp10: There will be a significant difference between groups in changes in MHC_{IIX} percentage after 12 weeks of training.

Hyp11: There will be no significant difference between groups in changes in MHC_{IIA} percentage after 12 weeks of training.

Delimitations

These studies were conducted under the following guidelines:

1. This study will include resistance trained males age 20-35 with resistance training to include the upper and lower body musculature for at least two years.
2. Subjects will have refrained from the consumption of dietary supplements, anabolic steroids, and ergogenic aids (excluding daily vitamins and protein supplements) that are known to affect muscle mass or metabolism for at least six weeks prior to initiating testing.
3. Subjects will be advised to maintain a diet consistent with American College of Sports Medicine guidelines through the entirety of the study and will provide a four day dietary record prior to baseline testing, weeks 4, 8 and 12.
4. Subjects will have their body composition measured using dual x-ray absorptiometry (DEXA).
5. Subjects will participate in a minimum of 90% of all training sessions.
6. Subjects will refrain from strenuous upper or lower body resistance training at least 72 hours prior to baseline testing and 48 hours prior to testing in weeks 4, 8 and 12.
7. Subjects will complete strength testing and power testing separated by at least 48 hours at baseline, 4, 8 and at the conclusion of 12 weeks resistance training program.
8. Subjects will perform to their maximal ability on all testing measures.
9. Muscle biopsies of the vastus lateralis will be obtained at baseline and after 12 weeks resistance training for determination of myosin heavy chain composition.
10. All major lifts will be timed and recorded by trained personnel.

11. All supplemental lifts will be monitored for timing by trained personnel.

Limitations

1. The participants will be individuals from the Texas A & M student and military community that respond to advertisements and therefore the selection process will not be truly random.
2. There may be variations in testing times and dietary intake, all efforts will be made to conduct testing sessions at the same approximate time to account for diurnal variations. Weekly dietary analysis will be used in an effort to minimize variations in dietary intake.
3. Motivation of each individual subject to be present and put forth maximal effort.
4. There are innate limitations of the laboratory equipment that will be used for data collection and analysis. All equipment will be calibrated according to manufacturer guidelines.

Assumptions

1. Participants will follow all procedures as outlined in the familiarization and study protocol.
2. Participants accurately answered the entrance criteria screening questions and medical history questionnaire
3. Participants will adhere to the training and testing schedule throughout the duration of the study.

4. All laboratory equipment will be calibrated and functioning properly prior to all testing sessions.
5. The population, which the sample is drawn from, is normally distributed.
6. The variance among the population sample will be approximately equal.
7. The sample will be randomly assigned to the different exercise protocols.
8. Total work between groups will be equated.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Originating in Eastern Europe, the concept of periodization involves the manipulation of training variables associated with resistance training programs to achieve a specific performance outcome (32, 57). These training variables include intensity, repetitions, repetition speed/tempo, rest periods and total volume (6, 26). Scientific evidence supports the superiority of periodization, especially in trained subjects, compared to other forms of training (57). Despite the large number of possible combinations of training variables, the majority of research has been related to optimal gains in strength and power sports and thus periodization's effect on training for endurance or hypertrophy is only indirectly supported (26).

Traditional resistance training as performed in periodized programs involves the performance of repetitions in a continuous fashion resulting in a decrease in velocity in successive repetitions (40). After ten seconds of maximal exercise, power output decreases (39) and these first signs of fatigue correlate with a reduction in phosphocreatine (PCr) (66). The number of repetitions prescribed is often based on percent repetition maximum (%RM). This has direct implications on the number of repetitions performed in consecutive sets. While the capacity to generate force is rapidly restored after an isometric contraction to fatigue, the restoration of maintenance of contraction is slower and has been shown to be associated with the ability to synthesize adenine triphosphate (ATP) (63) . Evidence supports this in dynamic resistance training as well, as the number of repetitions over consecutive sets declines without sufficient rest (45, 61).

Methods for counteracting the aforementioned phenomenon include reducing the number of repetitions performed at a given %RM or the introduction of rest within a given set. Reducing the number of repetitions enables less reduction in power output over successive sets (68). However, to achieve the same volume of training this method extends the total time of training to achieve the same volume, which is often a consideration to both individuals and strength coaches. Altering the rest to work ratio through the introduction of intra-set rest intervals has been shown to produce several performance benefits in both acute (single set or training session) and long term (multiple training sessions) studies.

Methods

A number of terms have been associated with intra-set rest intervals in the scientific literature; therefore, it is necessary to define the term intra-set rest interval in resistance training. In the current context, intra-set rest intervals refer to the insertion of rest within a given set thereby altering the rest to work ratio as defined in the most recent guidelines (6). In an effort to identify all relevant investigations utilizing intra-set rest intervals, the following terms were searched: interrepetition and inter-repetition rest, interset rest, cluster training, and rest-pause. PubMed, Sport Discus, Google Scholar, and MEDLINE databases were utilized in the search. Furthermore, the authors became aware of the use of intra-set rest intervals in investigations comparing the effects of training to failure versus not to failure, and thus those studies in which intra-set rest intervals were utilized to prevent training to failure were also included. The names of authors cited in some studies were also searched.

Physiological Basis of Intra-Set Rest Intervals

Haff and coworkers (34) were the first to present a hypothetical model for the effect of intra-set rest intervals in resistance training. The term used in their investigation was cluster training, a form of intra-set rest intervals in which 15-30 second rest intervals are employed between repetitions within a set. The authors hypothesized the inclusion of 15-30 seconds or intra-set rest would allow for partial replenishment of PCr, in comparison to the performance of continuous repetitions which results in a significant decline in PCr and increased production of lactate. In support of their hypothesis, the authors' cited the work of Sahlin and Ren (65) in which it was demonstrated the performance of a maximal isometric contraction to fatigue resulted in a significant decrease in both ATP and PCr with a concomitant elevation in lactate. After a 15 second rest, isometric force had returned to 79.7% initial values. However, in contrast to the theory proposed by Haff and coworkers (34), Sahlin and Ren (65) suggested the capacity to generate force is rapidly recovered, despite high lactate concentrations. The authors further demonstrated the restoration of endurance (maintenance of contraction) is slower and may be influenced by lactate, more specifically the disassociation of hydrogen ions, acting indirectly by inhibiting adenine diphosphate (ADP) rephosphorylation by way of the glycolytic pathway. This latter hypothesis by Sahlin and Ren (65) has recently been questioned, as Bangsbo and colleagues (11) did not detect a reduction in the rate of glycolysis or glycogenolysis in acidified muscle.

There is much debate on the cause of decreased force and velocity of contraction over the performance of repeated contractions. Acidosis caused by the disassociation of hydrogen ions from lactate has often been associated with the decrease in maximal shortening velocity (4, 25). In contrast, a number of studies have demonstrated this is not the case, particularly at normal physiological temperatures. For a review see Allen et al. (3). Recently, considerable interest has focused on the possibility that the accumulation of inorganic phosphate (P_i) may affect velocity of shortening. Increases in P_i occur during muscle contraction, mainly from the breakdown of PCr. Models of cross bridge cycling propose P_i is released in the transition from low force, weakly attached states, to high force, strongly attached states (3). Westerblad et al. (75) suggested this implies that the transition to high force states is hindered by increased levels of P_i. However, research examining the effect of P_i on velocity of shortening is limited (18, 20, 56) and therefore more research must be conducted to determine the role P_i plays in reducing velocity of shortening.

Another possible metabolite contributing to the decreased velocity of shortening over the performance of repeated contractions is ADP. Increases in ADP have been suggested to occur during repeated contractions, coincident with PCr depletion (64). Westerblad et al. (76) demonstrated that in the fatigued state, the velocity of shortening was slower following a longer tetanus compared to a shorter contraction. The authors suggested this was due to transient increases in ADP. Partial recovery occurred in a matter of seconds thought to be due to rapid removal of ADP by enzyme action or diffusion. Experiments on skinned fibers have shown ADP to have a major inhibitory effect on maximal shortening velocity (18, 52). However, the determination of muscle ADP is difficult as it cannot be measured by standard biochemical methods (73), and although ^{31}P-NMR spectroscopy can measure free ADP, muscle ADP is generally difficult to detect (35).

There is no doubt some metabolic event contributes to the decreased velocity of contraction observed during the performance of repeated contractions. Unfortunately, the majority of experiments have been conducted on isolated muscle fibers. Determining the specific cause is difficult in intact muscle fibers, as this phenomenon is no doubt complex, and differences exist between fiber types which confounds the determination (3). However, while the debate on the cause of decreased velocity of contraction is ongoing, the current theories all suggest that the inclusion of intra-set rest intervals would enhance the velocity of contraction over successive repetitions.

Acute Effects of Intra-Set Rest Interval

Coincident with an investigation comparing the long term effects of training to failure vs. not to failure, Rooney and colleagues (62) performed an acute investigation to determine the magnitude of fatigue, as measured by a decline in isometric force. This was the first study to utilize intra-set rest intervals to prevent training to failure. Nine untrained subjects performed 1 set of 6 repetitions (6RM) of the elbow flexors using both continuous repetitions and intra-set rest intervals in which 30 seconds rest was employed between each repetition. Trials were separated by a two hour rest period.

After the single bout, performance of continuous repetitions resulted in a 20.2% decline in isometric force compared to a 10.4% decline utilizing intra-set rest. The authors did not associate a benefit from the observation that intra-set rest intervals resulted in a lesser decline in isometric force compared to the performance of continuous repetitions.

Haff and coworkers (34) were one of the first groups of sports research scientists to determine the effect of intra-set rest intervals on power output. Comparing three different training interventions during the performance of the clean pull, thirteen strength and power trained male athletes performed 1 set of 5 repetitions continuously or with intra-set rest of 30 seconds between each repetition; both protocols were performed at 90% and 120% 1RM. A third intra-set training intervention, undulating intensities, was included in the comparison in which intensities were increased and decreased over the set with average intensities of 90% and 120% 1RM. An intra-set rest interval of 30 seconds between each repetition was also used in undulating intensities. The intra-set rest interval without undulating intensities resulted in significantly higher average barbell velocities compared to the performance of continuous repetitions. Additionally, intra-set rest intervals resulted in higher barbell displacements when compared to continuous repetitions at 120% 1RM and approached significance at 90% 1RM. The authors hypothesized the use of intra-set rest intervals would allow for the use of higher intensities and volumes while maintaining velocity and barbell displacement resulting in an elevation in hypertrophic and neural adaptations.

Similar to Rooney and colleagues (62), Drinkwater and associates (22) conducted an acute investigation coincident with a long term training study comparing the effects of training to failure vs. not to failure. However, in contrast to Rooney et al. (62), the acute study performed by Drinkwater et al. (22) compared the effect of intra-set rest intervals on power output as measured during the bench press throw exercise. Trained male athletes performed the bench press throw for determination of power prior to the performance of either 4 sets of 6 repetitions with 260 seconds rest between sets or 8 sets of 3 repetitions with 113 seconds rest between sets; both interventions utilized a 6RM load. Bench press throw power was then assessed 3 minutes after the performance of the training intervention. The performance of continuous repetitions resulted in a 19.6% decrement in power compared to 7.8% in the intra-set rest interval intervention. The authors did not associate a benefit with the finding that intra-set rest intervals resulted in less decrease in power compared to traditional training.

A later study by Lawton and colleagues (49) comparing the effects of intra-set rest intervals on power output in the bench press exercise, twenty six elite junior male basketball and soccer players performed 1 set of 6 continuous repetitions with a load corresponding to a 6RM. Power output was measured during each repetition. After initial power assessment, subjects were randomly assigned to one of three intervention groups: 1 set of 6 repetitions with 20 seconds rest between repetitions, 3 sets of 2 repetitions with 50 seconds rest between sets, or 2 sets of 3 repetitions with 100 seconds rest between sets. All training loads corresponded to a 6RM and were thus equated by volume. Additionally, the rest to work ratio in each intervention was manipulated in such a way to allow equal time to complete all interventions. Intra-set rest intervals resulted in significantly greater power outputs (25-49%) in latter repetitions (repetitions

4-6) compared to the performance of continuous repetitions. Additionally, total power output was significantly greater in all intra-set rest interventions (21.6-25.1%).

Denton and Cronin (21) compared kinetic and kinematic variables as well as blood lactate observed after the performance of three different training interventions. Males with at least twelve months resistance training experience performed 4 sets of 6 repetitions with 302 seconds rest between sets (CONT) or 8 sets of 3 repetitions with 130 seconds rest between sets (IRR_1) of the bench press exercise. A third intervention to test the hypothesis intra-set rest intervals allow for a greater total volume of training was included in the comparison. Subjects in this intervention performed 8 sets with 130 seconds rest between sets; however, odd numbered sets consisted of three repetitions, whereas even numbered sets were performed to failure (IRR_2). A 6RM load was utilized in all training interventions which enabled the performance of equal volume in both CONT and IRR_1 while IRR_2 was equated for rest but allowed for a greater total volume of work. Kinetic and kinematic data, including duration, mean force, impulse, mean power, and work during the concentric, eccentric, and total; was collected during each intervention. Blood lactate was measured before exercise, immediately post, 5, 15 and 30 minutes post exercise. In agreement with the previous hypothesis by Haff and coworkers (34), greater kinematic and kinetic values were associated with IRR_2 as demonstrated by greater overall time under tension (~53%), total mean force (~62%), total impulse (~59%), total mean power (~63%) and total work (~65%). However, in contrast to previous studies (34, 49) no significant differences were observed between CONT and IRR_1. Blood lactate levels returned to baseline values within 5 minutes in

IRR_1, whereas, both CONT and IRR_2 did not return to baseline values until 30 minutes post. The authors hypothesized the performance of resistance training in accordance with IRR_2 would provide a superior training stimulus for the development of strength and hypertrophy while the intra-set rest parameters associated with IRR_1 would provide a superior training stimulus for the development of power. Additionally, the authors speculated the greater accumulation of lactate in IRR_2 may have been due to a greater reliance on anaerobic glycolysis and rest periods not allowing sufficient time for lactate clearance.

Most recently, Hansen and colleagues (36) compared the effect of intra-set rest intervals on the performance of the ballistic jump squat exercise in professional and semi-professional rugby union players. In a crossover design, subjects performed 4 sets of 6 repetitions with 3 minutes rest (traditional), 4 sets of 6 repetitions with 12 seconds rest between each repetition and 2 minutes between sets, 4 sets of 3 doubles with 30 seconds rest between doubles and 60 seconds rest between sets, and 4 sets of 2 triples with sixty seconds rest between triples and 2 minutes rest between each set. External load was 40 kg for all interventions. Peak power was significantly lower during repetitions 5 and 6 in traditional compared to the use of intra-set rest intervals. Peak velocity was lower during repetition six in traditional compared to all other intra-set rest interventions. There were no differences between the various intra-set rest intervals with the exception of the observation no decrease in peak velocity from repetition 1 to repetition 6 in the performance of 4 sets of 6 repetitions with 12 seconds rest between each repetition.

Long Term Effects of Intra-Set Rest Intervals

Comparing traditional circuit style resistance training and intra-set rest intervals, Byrd and colleagues (15) demonstrated intra-set rest intervals resulted in greater work capacity as measured during an arm cranking exercise. In circuit training fashion using a Universal gym machine, untrained subjects were randomly assigned to a control or one of three training interventions: performance of continuous repetitions, or one of two intra-set rest interval interventions either resting one or two seconds between repetitions. Training consisted of 3 rotations of 6-10 repetitions at six stations corresponding to approximately 75% 1RM performed 3 days a week for 10 weeks. Ninety seconds was permitted at each station to complete the required set, which included thirty seconds to adjust weight and equipment position. Loads were progressed at individual rates such that the third set resulted in repetition failure within the desired range. Strength (1RM) was measured on the bench press and leg press exercises, while work capacity was assessed during the performance of an arm cranking exercise at a heart rate of 170 beats per minute. No differences in total training volume were noted in the 7^{th} week of training, chosen randomly. After 10 weeks, the performance of continuous repetitions resulted in greater increases in the leg press with no difference in bench press exercise. Work capacity was greater in both groups using intra-set rest intervals. The authors concluded constant tension as a result of continuous repetitions constituted a limitation to the improvement in cardiovascular function, while the brief rest of intra-set rest intervals were more likely to stimulate peripheral adaptations.

One of the first studies to compare the long term effects of resistance training to failure vs. not to failure, in which intra-set intervals were utilized to prevent subjects from training to failure, was conducted by Rooney and colleagues (62) Training consisted of a 6RM elbow flexor exercise performed three times per week over a six week period. Untrained subjects were randomly assigned to either a continuous or intra-set rest group. Both groups performed only one set during each session corresponding to a 6RM. The intra-set rest group rested thirty seconds between each repetition. Rooney et al. demonstrated the performance of continuous repetitions resulted in greater increases in dynamic force; 56.3% compared to 41.2%. The acute study previously discussed conducted by Rooney et al. (62) found the performance of continuous repetitions resulted in a greater fatigue as demonstrated by a decline in isometric force compared to intra-set rest intervals. Results from the acute investigation led the authors to conclude that mechanisms responsible for fatigue contribute to gains in strength.

Contrary to the results observed in the study by Rooney et al. (62), Folland and coworkers (27) demonstrated the performance of resistance exercise to repetition failure did not result in greater gains in strength. After baseline testing, recreationally active subjects with no previous lower body strength training experience were matched according to isometric strength, body mass, and sex and randomly assigned to either a high fatigue (HF) or low fatigue (LF) training intervention. The HF training intervention involved the performance of 4 sets of 10 repetitions with 30 seconds between sets, while the LF performed 40 repetitions each separated by 30 seconds rest. Leg extension exercise was used as the training stimulus and was performed 3 times per week for 9 weeks at an intensity of 75% 1RM. Assessment of strength at intervals during the training intervention allowed progression of loads. Measurements of dynamic and isometric strength, angle-torque and torque velocity were assessed prior to and at the conclusion of the training period. Folland et al. (27) reported no significant differences in dynamic or isometric force. However, at mid-point testing (4.5 weeks), a 50% greater increase in isometric force was observed in the group performing continuous repetitions, although not significant. At the conclusion of training the mean increase in isometric force between both groups was similar, 13.3% HF; 8.9% LF. No significant differences were reported between groups in angle torque. The authors reported a non-significant tendency towards greater velocity strength gains using intra-set rest intervals ($p < 0.10$) using an isokinetic dynamometer. Folland et al. (27) theorized muscle damage attenuated further strength gains in the final few weeks of training in the HF training intervention based on observations of severe muscle soreness during the first few weeks of training. Therefore, in contrast with previous results, the authors concluded metabolite accumulation as a result of fatigue was not a necessary stimulus for strength gains.

A later investigation by Lawton and associates (48) supports the work of Rooney et al. (62). Lawton and associates (48) demonstrated the performance of continuous repetitions elicited greater improvements in strength as measured during the bench press exercise compared to intra-set rest intervals in trained male athletes. Training consisted of 3 training sessions a week for 6 weeks using the bench press exercise. Two training interventions were designed to compare the effects of training to failure vs. not to failure.

Twenty six elite male junior basketball and soccer players performed either 4 sets of 6 (6RM) repetitions with 260 seconds rest between sets or 8 sets of 3 (6RM) repetitions with 113 seconds rest between sets. Intensity was increased 5% over the last three weeks. Strength was measured by 6RM bench press and power output measured by bench press throw using loads of 20, 30, and 40 kg. After the 6 week training intervention, the performance of continuous repetitions resulted in significantly greater increases in 6RM (9.7%) compared to intra-set rest interval (4.9%). Power output increases across the loads were 5.8 – 10.9% and were not different between groups. These results were in agreement with the study by Rooney et al. (62), which led the authors to theorize metabolites associated with fatigue produce greater strength gains. Haff and coworkers (33) suggested the results observed by Lawton et al. (48) may have occurred due to measures of strength being identical to the performance of continuous repetitions. In support of their hypothesis, Haff and coworkers provided results from a study conducted Izquierdo et al. (41), in which the performance of continuous repetitions resulted in greater improvements in muscular endurance.

Results from Drinkwater and colleagues (22) are in contrast to those previously reported by Lawton et al. (48) in bench press throw power. After initial testing, twenty six elite male basketball and soccer players were divided into two training interventions identical to those previously described in the study by Lawton et al. (48) Training was performed 3 days per week for 6 weeks in which subjects also took part in whole body weight training for one hour. Intensities were increased linearly over the training period and equated between groups. Drinkwater and colleagues (22) reported a twofold greater increase in 6RM bench press in the traditional intervention (9.5%) compared to the intervention using intra-set rest intervals (5.0%). Performance of continuous repetitions also resulted in a greater improvement in bench press throw power corresponding to a 40 kg load. An average of 15.8 watt (W) difference was observed between the performance of continuous repetitions and intra-set rest intervals. Strong correlations were reported between 6RM and bench press throw power (r = 0.89). The authors concluded the high correlation supported the use of high intensity due to the dependence of strength to generate power.

Comparing the effects of training to failure vs. not to failure in a group of trained Basque athletes, Izquierdo and colleagues (41) utilized intra-set rest intervals to prevent training to failure. Across the 16 week training period, three micro-cycles corresponding to intensities associated with the development of hypertrophy, strength and power were used. During the first 6 weeks, subjects performed 3 sets of 10 (10RM) repetitions or 6 sets of 5 (10RM) repetitions corresponding to a hypertrophic phase. Strength training commenced in week 7 and lasted 5 weeks with subjects performing either 3 sets of 6 (6RM) repetitions or 6 sets of 3 (6RM) repetitions. Training concluded with both groups performing 3 sets of 2-4 repetitions with intensities corresponding to 85-90% 1RM. Approximately 2 minutes rest was allotted between sets and exercises. Measurements of strength (1RM), power output (60% 1RM), and muscular endurance (repetitions to failure at 75% 1RM) using the bench press and parallel back squat exercises were assessed at baseline, the end of each micro-cycle, and post training. Additional measures included circulating levels of specific anabolic and catabolic hormones. Both performance of continuous repetitions and intra-set rest intervals resulted in significant gains in strength, with no difference between groups observed at any time point. During the final phase of training, only intra-set rest intervals experienced an increase in power output in the parallel back squat exercise from the previous performance assessment. Performance of continuous repetitions in the bench press exercise resulted in greater muscular endurance. At 11 weeks, corresponding to the end of strength training, serum total testosterone concentration was greater in subjects performing sets with intra-set rest. However, a larger reduction was observed during the last four weeks of training compared to the performance of continuous repetitions. Similar results were observed in serum cortisol concentration between groups. Based on their results, Izquierdo et al. (41) concluded not training to failure (applying intra-set rest intervals) provides a beneficial stimulus for improving power, whereas continuous repetitions is better for the enhancement of upper body muscular endurance.

In a later study by Drinkwater and coworkers (23) investigating the effects of forced repetitions on strength and power of the bench press exercise, trained male athletes were matched according to demographics and baseline testing performance prior to being assigned to a training intervention. To determine if the performance of additional forced repetitions affected performance, three training interventions were established. Training involved the bench press exercise 3 times per week for 6 weeks in accordance with the prescribed intervention. Equated for volume, subjects in two of the interventions performed either 4 sets of 6 repetitions with 165 seconds rest between sets or 8 sets of 3 repetitions with 73 seconds between sets. Subjects in the third intervention performed 12 sets of 3 repetitions with 73 seconds rest. This allowed for a greater number of forced repetitions resulting in total greater volume in the latter intervention. Intensity was increased at similar percentages between groups based on 6RM. Subjects did participate in a whole body resistance training program lasting 60 minutes and sport specific training in addition to the intervention. The authors reported no other lifts performed by subjects targeted the musculature in a task specific way. Strength was assessed by the performance of 3RM and 6RM bench press exercise. Power output was determined during a 40 kg bench press throw. As designed, the performance of 4 sets of 6 repetitions and 12 sets of 3 repetitions resulted in significantly more forced repetitions than the rest to work ratio of 8 sets of 3 repetitions. Additionally, more total work (40%) was performed using 12 sets of 3 repetitions. All groups improved in strength and power at the conclusion of the training intervention with no differences observed between groups. These results were in contrast to the authors previous study in which greater gains in strength and power output were observed when repetitions were performed continuously (22). Drinkwater and coworkers (23) concluded the addition of a greater number of forced repetitions and volume does not result in greater strength or power gains and thus should be limited in training program design. In both studies conducted by Drinkwater et al. the training interventions were similar. However, in the two studies outlined, subjects were involved in additional resistance training and sports specific activities. Without full disclosure of the full body resistance training programs, it is difficult to interpret the results as it suggests these differences may have been impacted by other training variables.

Hansen and colleagues (37) compared traditional vs. intra-set rest intervals (cluster training) on strength and power of the lower body musculature in elite rugby union players. After baseline testing, subjects were randomly assigned to traditional resistance training in which sets were separated by 180 seconds rest or intra-set rest which involved 10-30 seconds intra-set rest with 120-180 seconds rest between successive sets. Intensity was increased over successive sets. Additionally, the first six weeks corresponded to intensities ranging from 80-95% 1RM while the last two weeks utilized heavy load jump squats (80-95% 1RM) and light to moderate ballistic jump squats performed at 0-20% 1RM. Clean pull and power clean intensities ranged from 80-95% 1RM. Intra-set rest intervals were only used in strength and power training involving squat and clean movements. In addition to the training intervention, all subjects underwent upper body strength training, conditioning and speed development, skills training and team organized practice. Training, including the intervention, occurred twice weekly over an eight week period. Results demonstrated a greater improvement in back squat 1RM in the traditional training intervention (18.3%), compared to intra-set rest intervals (14.6%). However, the training effect for both interventions was large. Peak force of the jump squat was also greater with the use of traditional training. Calculations of magnitude based inference demonstrated a likely positive effect of intra-set rest intervals in peak power and peak velocity at 40 kg, and peak velocity at bodyweight during the jump squat. The authors concluded traditional style training resulted in greater strength improvements while some evidence suggests a possible benefit for intra-set rest intervals in lower body power development.

Conclusion and Future Research Directions

Although relatively few studies have compared the acute effects of intra-set rest intervals to the performance of continuous repetitions, a number of conclusions seem warranted. First, intra-set rest intervals result in less reduction in force (62) and power (22) after the performance of a single set compared to the performance of continuous repetitions. Power output and velocity of contraction are greater over the performance of a single set compared to the performance of continuous repetitions, specifically in trained athletes (34, 36), while the results from acute studies on untrained individuals are inconclusive (21). Denton and Cronin (21) hypothesized the use of intra-set rest intervals of equal volume would result in a greater stimulus for the development of power, though no significant differences were observed in kinetic or kinematic assessments compared to the performance of continuous repetitions. The differences in results obtained by Denton and Cronin compared to others may be due to training status of the subject population. The studies in which intra-set rest intervals resulted in greater power output over a single set used trained athletes as subjects, while the investigation by Denton and Cronin used individuals with only 12 months resistance training experience. Finally, acute studies have also demonstrated the ability to maintain intensity and perform a greater total volume of training (21).

While intra-set rest intervals were used, the focus of several of the long term studies was the comparison of training to failure vs. not to failure. Therefore, whether these same results would be observed when not training to failure performing continuous repetitions compared to intra-set rest intervals is unknown. Training to failure is often used in resistance training program design using repetition number assignment based on a %1RM. Thus, for many, training to failure is a standard training program design and these conclusions are supported. In regards to strength gains, these studies have demonstrated intra-set rest intervals resulted in smaller (15, 22, 37, 48, 62) or no difference (23, 27, 41) in strength gains compared to the performance of continuous repetitions during free weight training. Studies in which strength gains have been shown to be smaller than the performance of continuous repetitions have utilized intensities corresponding to 85% or greater %1RM over the training period. The only study in which no difference in strength gains were reported with intensities at approximately 85% 1RM was conducted by Drinkwater et al. (23) These results are in conflict with others including a previous study performed by Drinkwater et al. (22) which found greater strength gains in the performance of continuous repetitions. Differences in intra-set rest interval time may explain these divergent findings. However, in both studies by Drinkwater et al. (22, 23) subjects participated in other forms of training which could contribute to the differences. Thus it appears, at loads at or above 85% 1RM, the performance of continuous repetitions results in superior strength gains compared to the use of intra-set rest intervals, at least over a 6 week training cycle.

Folland et al. (27) reported no difference in strength gains when intensities of 75% 1RM were utilized. Additionally, the training period was longer than reported in other studies. Folland et al. (27) did report at mid-point testing 50% greater gains in strength in the use of continuous repetitions, although not significant. By 9 weeks, there were no differences observed. Therefore, changes in strength gains due to the performance of continuous repetitions may be time and intensity dependent. In support of the finding intra-set rest intervals results is smaller strength gains, many authors have suggested the repeated submaximal contractions to failure in the performance of continuous repetitions result in a greater recruitment of motor units than intra-set rest intervals, based on previous research (51). At the intensities investigated, this may well be the case. EMG activity has been shown to increase leading up to the sixth repetition in a 6RM (43). On the other hand, Burd et al. (14) demonstrated maximal EMG activity occurred half way through (i.e. repetitions 5-6) the performance of continuous repetitions at an intensity of 70%1RM. These results suggest the use of intra-set rest intervals at intensities lower than 85% may not influence strength gains, which would explain the differing results observed by others (27, 41). However, in the study by Izquierdo et al.(41), different intensities were used throughout the 16 week training program making these results difficult to interpret. Thus the results from long term training suggest an intensity range in which strength gains are not impacted by the use of intra-set rest intervals. Future research comparing intra-set rest intervals at different intensities relative to %1RM may provide insight to this unanswered question.

Long term studies on intra-set rest intervals have demonstrated a tendency toward greater gains in measures of power output of the lower body musculature in both recreationally trained (27) and elite athletes (37), as well as significantly greater gains in power output of the lower body musculature compared to the performance of continuous repetitions in athletes (41). Studies demonstrating only a tendency toward greater gains in power output utilized loads corresponding to the development of strength and power, whereas, the study demonstrating significantly greater gains utilized intensities corresponding to hypertrophy, strength and power over a 16 week training period. Unique in design, the study by Izquierdo et al. (41) demonstrated the effectiveness of intra-set rest intervals over a typical periodized program for athletes. While no differences were noted in power output until the conclusion of the training intervention, it is possible different physiological adaptations occurred during the initial few weeks of training, as there were no differences in training intervention during the final 5 weeks of training. Research indicates peak power output of the bench press occurs between 40-60% 1RM and between 50-70% 1RM in the parallel back squat (69). The intensity during the initial 5 weeks of training in the study by Izquierdo et al. (41) corresponded to loads similar (10RM ~ 75%1RM) to those which have been reported for peak power output of the parallel back squat. However, whether this was responsible for the improvement in power output at the end of the training intervention is unknown. Future research should determine if improvements in power are intensity dependent with the use of intra-set rest intervals.

Intra-set rest intervals do not appear to provide a benefit in upper body power output at loads greater than or equal to 85%1RM. However, the results are conflicting with studies demonstrating the use of intra-set rest intervals results in smaller improvements in power output (22) or no difference in power output (23, 41, 48) compared to the performance of continuous repetitions. The finding that intra-set rest intervals results in less improvement in power output of the upper body musculature by Drinkwater et al. (22) is difficult to interpret. Baseline subject demographic data suggests the same subject pool was used in the study by Drinkwater et al. (22) as was used in the previous study by Lawton et al. (48) in which no differences in power output were reported. No differences in baseline subject demographics suggest these studies were performed at the same time, as differences would have been observed in baseline subject data if only slight. Furthermore, the training interventions were identical. The only difference reported was a slight difference in intensity and the inclusion of a whole body resistance training program in the study by Drinkwater et al. (22) Thus, the differing results reported by Drinkwater et al. in contrast to others, may be attributed to the inclusion of the whole body resistance training and not the training intervention. When this study is excluded, it appears there is no difference between intra-set rest intervals and continuous repetitions in power output of the upper body musculature.

Denton and Cronin demonstrated intra-set rest intervals allow for maintenance of intensity and greater total volume (40%) over a single set (21). These observations have led researchers to hypothesize intra-set rest intervals would allow for individuals to train at a higher intensity and volume resulting in greater adaptations. Drinkwater et al. demonstrated intra-set rest intervals allowed for maintenance of intensity and greater total volume (40%) over multiple sessions. However, no significant differences in strength or power were observed after six weeks compared to the performance of continuous repetitions. Whether the greater volume resulted in greater lean mass gains is unknown as measures of body composition were not assessed. This is yet another unexplored opportunity for future research.

Several opportunities exist for future research to be conducted on both the acute and long term effects of intra-set rest intervals compared to continuous repetition training. To date, studies investigating the acute effects of intra-set rest intervals have mainly focused on intensities corresponding to the development of strength and power. The effect of intra-set rest intervals on intensities associated with hypertrophy has not been studied in a trained population. Intensities corresponding to hypertrophic training are utilized in classic linear (26), reverse linear (58) and undulating periodization models (8, 9). In comparison to strength and power training, hypertrophic training is characterized by the performance of a number of repetitions continuously and often to failure. The total volume of work and corresponding intensity in which that work is performed have been implicated as the primary variables associated with optimal gains in lean mass (16). As such, the finding intra-set rest intervals results in the maintenance of intensity over successive sets resulting in a greater total volume suggests a possible benefit for the use of intra-set rest intervals in training designed to elicit hypertrophy.

The physiological mechanism of action responsible for the greater velocity of contraction and maintenance of intensity is as of yet unknown. While studies on isolated muscle preparations offer some insight (see Allen et al. (3)), this warrants further investigation. The results from Denton and Cronin (21) suggest less reliance on glycolytic metabolism with the use of intra-set rest intervals as evidenced by the return of blood lactate to baseline values 5 minutes post exercise. However, further research is needed to determine if this is responsible for the maintenance of strength, power, and greater power output associated with intra-set rest intervals. A determination of muscle metabolites may offer insight in the differences observed in acute investigations. Additionally, supplementation with creatine may enhance the benefits of intra-set rest intervals as oral supplementation has been shown to increase total muscle creatine (PCr + creatine) by up to 10-20% (38), as well as increase performance during high intensity exercise (31).

Practical Applications

From a practical perspective, the use of intra-set rest intervals provides another novel stimulus to introduce into a training program to enhance performance. The research suggests this would be optimally used in programs targeting lower body muscular power. Research supports the use of intra-set rest intervals in the development of power specifically in long term periodized training programs in athletes. However, if the goal of the training program is strength gains, the use of intra-set rest intervals may be counterproductive, especially at loads at or above 85% 1RM. While intra-set rest intervals are not known to effect upper body strength gains, strength and conditioning professionals may be better served using continuous repetitions for the optimal development of strength and using intra-set rest intervals when power output is the primary goal.

CHAPTER III

METHODS

Experimental Design and Approach to Problem

A longitudinal research design was employed to compare the effects of intra-set rest intervals and traditional resistance training to elicit hypertrophy. Measurements included body composition, strength and power of the upper and lower body musculature and myosin heavy chain content. In order to eliminate any possible confounding factors, type of exercise, exercise order, intensity and volume were equated. This was critical to the design of the study as previous studies have shown these factors to influence changes in the measured variables (16, 29).

After baseline testing, participants were matched according to age, height, body composition, training experience, and strength and power of the upper and lower body musculature. Groups were then randomly assigned to an intra-set rest interval group (ALT, 60 second rest interval performing 8 sets of 5 repetitions) or a traditional training group (STD, 120 second rest interval performing 4 set of 10 repetitions). Body composition, strength and power of the upper and lower body musculature were assessed at baseline, 4, 8 and 12 weeks of training. Muscle biopsies for determination of myosin heavy chain content occured at baseline and at the conclusion of training (12 weeks).

Subjects

Twenty-eight males aged 20-35 years were recruited from the Texas A & M University community as well as from the Naval military community on campus.

Participants were required to have been actively involved in a resistance training program for at least two years consisting of training of upper and lower body musculature at least once per week. Participants completed a medical history questionnaire to eliminate those with any contraindications to resistance training. Additionally, participants were required to have not taken any nutritional supplements and/or ergogenic aids in the previous 6 weeks leading up to baseline testing, excluding daily vitamin and/or protein supplementation.

Familiarization

Prior to testing, participants were required to participate in a familiarization session in which guidelines of study participation were outlined. During familiarization participants completed a medical history questionnaire. Participants meeting entry criteria were asked to grant consent to continuation in the study by signing a consent form as approved by the Institutional Review Board of Texas A & M University. Once consent was granted, participants were familiarized with the study protocol including description of exercises and testing, training protocol, body composition testing, muscle biopsy procedures, as well as information related to dietary recording. Prior to baseline testing, participants meeting entry requirements and having signed consent forms participated in a nutrition seminar provided by a registered dietitian outlining current macronutrient requirements for individuals participating in strength training as described by the American College of Sport Medicine (7) as well as instruction on completing accurate dietary records. In the week prior to baseline testing, participants also participated in an exercise demonstration session in which there were required to demonstrate proficiency of all lifts tested and trained throughout the duration of the study. Exercise demonstration was led by a National Strength and Conditioning Certified Strength and Conditioning Specialist.

Dietary Recording and Analysis

After familiarization and prior to baseline testing, participants completed a dietary record to include 3 weekdays and 1 weekend day. Dietary recording then took place prior to each successive testing session corresponding to weeks 3, 7, and 11. All food logs were entered and analyzed using dietary analysis software (ESHA food Processor Version 8.6, Salem, OR). Analysis was then subsequently reviewed by a registered dietitian. Post workout supplementation (20 g protein, 45 g carbohydrates, 3.5 g fat) was provided on training days (Muscle Milk Collegiate, Cytosport, Benicia, CA).

Body Composition Testing

Body composition testing took place at baseline, in weeks 4, 8 and 12 of training. Participants reported to the Exercise and Sports Nutrition Laboratory (ESNL) on the assigned day for body composition testing. Prior to testing, participants were asked to fast for at least 10 hours as well as vacate their bowels. Height and weight were recorded to the nearest .02 kg and .02 cm respectively using a self-calibrating digital scale (Bridgeview, IL) in socks or bare feet. Body composition was then determined using dual x-ray absorptiometry (DEXA) technology (Hologic Discovery W DXA software version 12.1, Waltham, MA). Previous studies indicate DEXA to be an accurate and reliable means to assess changes in body composition (5). For determination of body composition, subjects removed all metal objects that are known to interfere with measurement. Subjects were then positioned in the supine position based on manufacturer's guidelines by a trained technician. DEXA measurement was then performed, taking approximately 6-8 minutes. Analysis of body composition was immediately performed by a trained technician to determine body composition.

Strength Testing

Participants' upper and lower body strength was assessed using one repetition maximum (1RM) parallel back squat ($1RM_{BS}$) and bench press ($1RM_{BP}$) exercises. On the day of strength testing, participants reported to the laboratory having refrained from any exercise outside of daily living for at least 72 hours prior to baseline testing and at least 48 hours prior to testing in weeks 4, 8 and 12. Baseline 1RM of both exercises was estimated from self-reported workout logs. After baseline, all 1RM estimations were based on training logs kept throughout the study. A dynamic warm up lasting approximately 8-10 minutes was performed prior to 1RM determination. The dynamic warm up included four minutes on a stationary cycle followed by dynamic stretches of the upper and lower body musculature. Strength testing for both $1RM_{BS}$ and $1RM_{BP}$ commenced with two warm up sets of 5 repetitions at 40-60% 1RM separated by two minutes rest. After a three minute rest period, one to two sets of 2-3 repetitions at a load corresponding to 60-80% 1RM were performed. Participants then began performing sets of 1 repetition of increasing weight for 1RM determination. Three to five minutes rest was provided between each successive attempt. All 1RM determinations were made within 3-5 attempts. Participants were required to reach parallel in the $1RM_{BS}$ for an attempt to be considered successful as determined by a CSCS certified individual providing an "up" command. $1RM_{BP}$ was considered successful if the participant remained in contact with the bench during the entire concentric phase of the lift. $1RM_{BS}$ testing was conducted prior to $1RM_{BP}$ separated by a five minute rest period. The same 1RM testing procedure was utilized for both exercises. All strength testing was performed on an Optima Smith Machine (LifeFitness, Schiller Park, IL) without counterbalance technology. Foot placement was recorded during baseline $1RM_{BS}$ testing; hand placement was recorded at baseline $1RM_{BP}$ testing. These measurements were then used in all subsequent testing procedures for strength and power output. All testing sessions were supervised by two CSCS certified individuals to determine success during each attempt. The intra-class correlation coefficient for the $1RM_{BS}$ and $1RM_{BP}$ testing procedures was established at 0.99 and 0.99, respectively.

Power Testing

Power testing commenced at least 48 hours post 1RM testing. Participants performed the same warm up prior to the initiation of power testing as was performed prior to strength testing. Weight and reach height were recorded for calculation of power as determined by vertical jump. Two countermovement vertical jumps (CMJ) using less than maximal effort were allowed prior to testing. Three maximum effort vertical CMJ were then recorded separated by two minutes rest. If the third attempt was greater than the first three, another attempt was allowed until a decrease in jump height was observed. No more than five maximum vertical CMJ were allowed. Reach height and jump height were recorded using a commercially available Vertec system (Sports

Imports, Columbus, OH). The maximum attempt of record was later converted to power in watts (PWR_{VJ}) using previously described procedures (71).

After vertical jump testing, power output was assessed during the concentric phase of the parallel back squat (PWR_{BS}) and bench press (PWR_{BP}) exercises using a relative load of 60% 1RM. PWR_{BS} was determined preceding PWR_{BP} separated by five minutes rest. All testing was performed on the same smith machine used for 1RM testing. A warm-up of 3 sets of 5 repetitions at 40-50% 1RM was provided on both exercises prior to power output assessment. Participants were instructed to perform the concentric phase of each lift as explosively as possible. Participants then began performing single repetitions at 60% 1RM for power determination. During the parallel back squat rubber tubing was placed at the parallel point. This position was determined during strength testing ensuring subjects reached the appropriate parallel position for the attempt to be a success. Three attempts were allowed with the best recorded for further analysis. Again, if the third attempt was greater than the first two, another attempt was recorded until power output declined. No more than five attempts were recorded with the highest average power output being used for statistical analysis. Three minutes rest was utilized between successive maximal power attempts. Power output was measured using a Tendo Fitrodyne (Sorinex, Irmo, SC). During post training (12 weeks) power output was assessed on both parallel back squat ($APWR_{BS}$) and bench press ($APWR_{BP}$) using loads corresponding to 60% baseline 1RM followed by 60% post training 1RM. The test retest reliability of the PWR_{BS} and PWR_{BP} was determined to be 0.97 and 0.98, respectively.

Training

Participants were provided the option for morning or evening training sessions. Training consisted of 4 supervised workouts a week in the following sequence; two days on, one day off, two days on, two days off. Morning workouts were held between the hours of 5:30 am and 8:00 am on Monday, Tuesday, Thursday and Friday. Evening workouts were held between the hours of 5:30 pm and 8:00 pm on Sunday, Monday, Wednesday and Thursday. The training intensity was structured into four week micro cycles concluding with strength and power assessment in the final week of the cycle. Intensity was increased weekly in a linear fashion corresponding to 65%, 70%, and 75% 1RM followed by a two day unloading period during the week of testing corresponding to 60% 1RM with reduced volume. All sessions were supervised by trained staff with at least 1 – 2 CSCS certified personnel leading sessions.

Throughout the training program, both groups performed the same exercises, in the same order and intensity. All major lifts tested for strength and power output were performed on the same apparatus used for determination of 1RM and power output. Additionally, all lifts derived from major lifts tested were performed on the same equipment used for testing. Therefore, all squat, front squat, bench and incline presses were performed on the smith machine in which testing was performed. Participants were instructed to perform the concentric phase of all major lifts in an explosive manner. Verbal encouragement was provided throughout training. To compare the effect of intra-set rest intervals, groups differed on the sets, repetitions and rest in all major lifts performed. Participants in the STD group performed 4 sets of 10 repetitions for all major lifts involving multi-joint movements with 2 minutes rest between sets, while the ALT group performed 8 sets of 5 repetitions for all major lifts with 1 minute rest between sets. All assistive lifts single joint exercises were performed in a 3 sets by 10 repetitions with 1.5 minutes rest fashion. Loads were reduced if subjects are unable to perform the required number of repetitions. Intensity was increased if participants were able to achieve at least 85% of total volume on major lifts. Timing of rest was performed using stop watches on all lifts by trained personnel. The total sum of work (weight x reps x sets) was grouped according to lifts utilizing the upper and lower body for main lifts and push and pull exercises for assistive exercises for later analysis. Workout logs were maintained and verified throughout the 12 week period. Compliance throughout the entire 12 week study was set at 90%.

Biopsy

A muscle biopsy of the vastus lateralis was obtained from the participant's right leg before the initiation of testing and training and within 72 hours of the last testing session. Prior to entering exam room, the participant was shaved in the area in which the biopsy was taken. The participant was then asked to lie in the supine position and flex the muscles of the quadriceps so the actual site could be identified. The actual site, midway between the patella and greater trochanter at the anterior border of the iliotibial band, was marked and the participant was again asked to relax in this position. The surrounding area (4 x 4 inches) was cleansed with alcohol and then sterilized with iodine.

After sterilization procedures, the area was numbed using 3 ml local anesthetic (1% Xylocaine HCl) injected approximately 1.5 cm under the skin and muscle fascia. A sterile bandage was then placed over the area for approximately 10 minutes to allow sufficient time for anesthetic to cause its effect. The bandage was then removed and an approximate 1/3 incision was made through the skin and into the fascia of the muscle. A sterile 5mm biopsy needle (Pelomi Industries, Denmark) was used to obtain the approximate 100-200 mg of muscle using a modification of Bergstrom's technique (12) as described by Evans et al. (24) All muscle samples were cleansed of visible fat, connective tissue and blood and immediately frozen in liquid nitrogen (-190°C), and then transferred and stored at -80°C until analyzed.

Immediately following the biopsy procedure, pressure was applied to the area to prevent any unwarranted bleeding. Once no visible signs of bleeding were present, a bandaid was applied followed by a gauze roll and secondary bandage to supply pressure for the remainder of the day. Participants were provided with a biopsy care kit including multiple bandaids and contact information for the study coordinator and biopsy personnel.

Myosin Heavy Chain Analysis

Refrigerated homogenization buffer (250 mM sucrose, 100 mM KCl, 5 mM EDTA, 20 mM Tris, pH 6.8) was added to the frozen muscle samples. The muscle samples were then homogenized on ice with a micropestle, followed by centrifugation in the cold (5°C) at 10,000 x g for 10 minutes. The resultant supernatant was discarded and the myofibril pellet was resuspended in 100 µL of wash buffer (175 mM KCl, 2 mM EDTA, 0.5% Triton X-100, 20 mM Tris, pH 6.8). Centrifugation was then repeated and the resultant supernatant discarded , and the myofibril pellet resuspended in 100 µL of final resuspension buffer (150 mM KCl, 20 mM Tris, pH 7.0) (10, 72). Centrifugation was again repeated and 50 μL Lysis buffer (1% Sodium Deoxycholate, 1% NP-40, 0.1% SDS, 10mM Tris, pH 8, .14M NaCl, 10 mM EDTA, protease inhibitor cocktail – 10 μL/ml(Calbiochem, Darmstadt, Germany)) was added followed by protein assay determination. Total protein was assayed according to the bicinchoninic acid (BCA) method using a commercially available BCA Protein Assay Reagent (Thermo Scientific, Rockford, IL).

The separating gel was poured into a 140 x 160 x 0.75-mm gel cast 4 cm from the top of the glass plate The separating gel consisted of 35% v/v glycerol, 8% w/v acrylamide-N,N'-methylenebisacrylamide (Bis) (99:1), 0.2 M Tris-HCl (pH 8.8), 0.1 M glycine, 0.4% w/v SDS, 0.1% w/v ammonium persulfate, and 0.05% v/v/ N,N,N'N'-tetramethylethylenediamine (TEMED). After pouring, the separating gel was allowed to polymerize overnight. The stacking gel was poured the following day and consisted of 30% v/v glycerol, 4% w/v acrylamide-Bis (50:1), 70 mM Tris-HCl (pH 6.7), 4 mM EDTA, 0.4% w/v SDS, 0.1% w/v ammonium persulfate, and 0.05% v/v TEMED (54).

Samples were then diluted with sample buffer (.16M Tris-Cl, pH 6.8, 43% glycerol, 100 mM DTT, .005 Bromophenol blue, 5% SDS) prior to loading. The lower running buffer consisted of 0.05M Tris (base), 75 mM glycine, and 0.05% w/v SDS, while the upper running buffer was two times the concentration of the lower running buffer and β-ME was added (final concentration: 0.12v/v) (44, 54). After samples were loaded (15 μL) electrophoresis was performed at a constant voltage of 200 V for 22 h in a gel system (R.Shadel, San Franscisco,CA). For stacking gel penetration, the first hour, the voltage was kept at 160V. During electrophoresis, the gel system was kept in a temperature controlled ventilated hood. Throughout electrophoresis, the lower running buffer was stirred gently with a magnetic stirrer.

After the electrophoresis run, the gels were stained with a silver staining kit (Bio-Rad, Hercules, CA) according to manufacturer's instructions. The protein bands of each MHC isoform on the silver-stained acrylamide gel were then densitometrically digitalized using a digital camera (Fugi LAS 4000, Fujifilm Life Sciences, Wayne, NJ). The densitometric values were then derived as an integral of the band density and band area. This procedure was performed using a software package (MultiGauge 3.0, Fujifilm Life Sciences, Wayne, NJ). The amount of each isoform was expressed as a percentage calculated as (IntegProtein/IntegAll) * 100%. Where IntegProtein is the densitometric integral of the corresponding protein band, and the IntegAll is the densitometric integral of all isoforms in the sample.

Statistical Analysis

All statistical analysis was performed using SPSS Version 16.0 (Chicago, IL). One way ANOVA was used to determine baseline differences in age, height, body mass, years training, days training, $1RM_{BP}$, $1RM_{BS}$, PWR_{BP}, PWR_{BS}, and PWR_{VJ}. A 2 x 4 (group x time) ANOVA was utilized to determine differences in body mass, lean mass, and percent body fat. Macronutrient content was analyzed in a 2 x 4 (group x time) ANOVA. Overall training volume was analyzed by independent student t-test. A 2 x 4 (group x time) ANCOVA covaried for baseline values was utilized to determine changes over the training period in $1RM_{BP}$, $1RM_{BS}$, PWR_{BP}, PWR_{BS}, and PWR_{VJ}. These variables were also analyzed relative to body weight and lean mass in a 2 x 4 (group x time) ANCOVA covaried for absolute baseline values to determine differences at each time point. Independent student t-tests were used to determine the difference between pre- and post- $APWR_{BP}$ and $APWR_{BS}$. A 2 x 2 (group x time) repeated measure ANCOVA covaried for baseline values was used to determine changes in percentage of total myosin heavy chain content of MHC_{slow}, MHC_{IIA} and MHC_{IIX}. The effect size (difference between 12 weeks and baseline divided by the standard deviation of baseline) was used in accordance with the scale proposed by Rhea (60) to determine the treatment effect of both strength training programs. Where necessary, post hoc analysis was performed. Statistical significance was defined as $p \leq 0.05$.

CHAPTER IV

GREATER GAINS IN STRENGTH AND POWER AFTER A 12 WEEK RESISTANCE TRAINING PROGRAM DESIGNED TO ELICIT HYPERTROPHY USING INTRA-SET REST INTERVALS

Introduction

Resistance training programs designed to elicit hypertrophy are characterized by the performance of multiple sets and repetitions using moderate to high intensity loads with short rest intervals (6). The total volume of work and corresponding intensity in which that work is performed have been implicated as the primary variables associated with optimal gains in lean mass (16). This type of training is utilized in both the classical linear (26), reverse linear (58) and undulating periodization models (8, 9). These models of periodization in which volume and intensity are manipulated have been utilized predominantly in training for strength and power type sports (26).

While performing moderate to high volume utilizing moderate to high intensities produces significant gains in lean mass, the speed at which repetitions are performed in this type of training is contrary to the principle of specificity, especially in sports in which the ability to generate power is a necessary aspect of performance. The average velocity of repetitions declines significantly when the number of repetitions exceeds 34% and 48% of total repetitions performed in the bench press and parallel back squat exercises, respectively; utilizing loads corresponding to hypertrophic training (40). One method for maintaining velocity, and thus power output, throughout a set of repetitions involves the use of intra-set rest intervals, also referred to as interrepetition rest intervals and cluster training (33). Intra-set rest intervals refer to the insertion of rest within a given set thereby altering the rest to work ratio as defined in the most recent guidelines (6). Acute strength training with a 6RM load incorporating intra-set rest intervals resulted in a significant improvement in power output when compared to continuous repetitions (49). However, the use of intra-set rest intervals in a six week resistance training program designed to elicit strength, failed to demonstrate an increase in power output over the performance of continuous repetitions (48). The optimal intensity for the development of strength is greater than that performed during hypertrophic training. In trained subjects, performing multi-joint exercises, the optimal load for the development of maximum muscular power corresponds to the optimal intensity for the development of hypertrophy (42). Despite the congruence in intensity between hypertrophy and the development of muscular power, the effects of intra-set rest intervals in a hypertrophic training program have yet to be determined. Furthermore, the authors are unaware of any studies determining the effects of intra-set rest intervals on myosin heavy chain (MHC) composition compared to traditional resistance training.

It is well established, resistance training results in a shift in MHC composition, primarily an increase in percentage of MHC_{IIA} and $MHC_{IIA/X}$ hybrids, with a concomitant decrease in MHC_{IIX} (16, 59). However, the changes in MHC composition have been shown to vary based on type of training utilized. Liu et al. (50) recently compared the effects of performing traditional resistance training and combination training to include traditional resistance training followed by ballistic exercise on MHC composition. Their results for traditional resistance training were congruent with previous studies, demonstrating a shift in MHC_{IIX} to MHC_{IIA}. However, the combination group demonstrated a shift in MHC_{slow} to MHC_{IIA} with no change in MHC_{IIX}. Results from this study provide evidence that the velocity of contraction results in a shift in MHC isoforms different from that experienced with traditional resistance training.

Therefore, the purpose of our investigation was to test the hypothesis that the use of intra-set rest intervals in hypertrophic training produces differing results in performance variables and MHC composition compared with traditional resistance training when total volume is equated. A secondary purpose was to identify the time course of changes in performance over the training period. We hypothesized training with intra-set rest intervals would result in a greater power output, with no differences in strength or lean mass over time. We further hypothesized utilizing intra-set rest intervals would result in less reduction in MHC_{IIX} isoform compared with traditional hypertrophic training.

Methods

Experimental Design and Approach to Problem

A longitudinal research design was employed to compare the effects of intra-set rest intervals and traditional resistance training in a program designed to elicit hypertrophy. To eliminate any possible confounding factors, the type and order of exercises performed as well as intensity and volume were equated between groups. This was critical to the design of the study as others have shown variations in these variables to impact training adaptations (16, 29). Testing included measurements of body composition, strength and power output of the upper and lower body musculature and MHC content. Dietary intake was not controlled, but a nutrition education session was provided and dietary intake analyzed.

After baseline testing, subjects were matched according to age, height, body composition, training experience, strength and power output of the upper and lower body musculature and randomly assigned to either a standard (STD) training group or an alternate (ALT) training group. Body composition, strength and power output of the upper and lower body musculature was assessed at baseline, after 4, 8, and 12 weeks of training. Dietary intake recording and analysis was conducted prior to each testing session. Muscle biopsies for MHC content were performed prior to initiation of training (baseline) and at the conclusion of the training program (12 weeks).

Subjects

Twenty eight males were eligible for participation. Selection criteria included 1) males between the ages of 20 and 35, 2) having at least 2 years resistance training experience to include training of the upper and lower body musculature weekly, and 3) reporting not having consumed any nutritional or ergogenic supplements excluding protein supplementation and/or a daily vitamin for the previous 6 week period leading up to baseline testing. Those meeting entry criteria were asked to fill out a medical history questionnaire to eliminate those with any possible contraindications to exercise. Subjects meeting all criteria were informed of the experimental procedures and asked to sign an informed consent approved by the Institutional Review Board of Texas A & M

University (College Station, TX). Twenty two subjects were included in final analysis. A consort diagram is provided in Figure 1 outlining reasons for drop out and/or exclusion. Baseline characteristics for the final 22 subjects (n = 22) are presented in Table 1. No significant differences were noted in any of the baseline variables prior to group assignment.

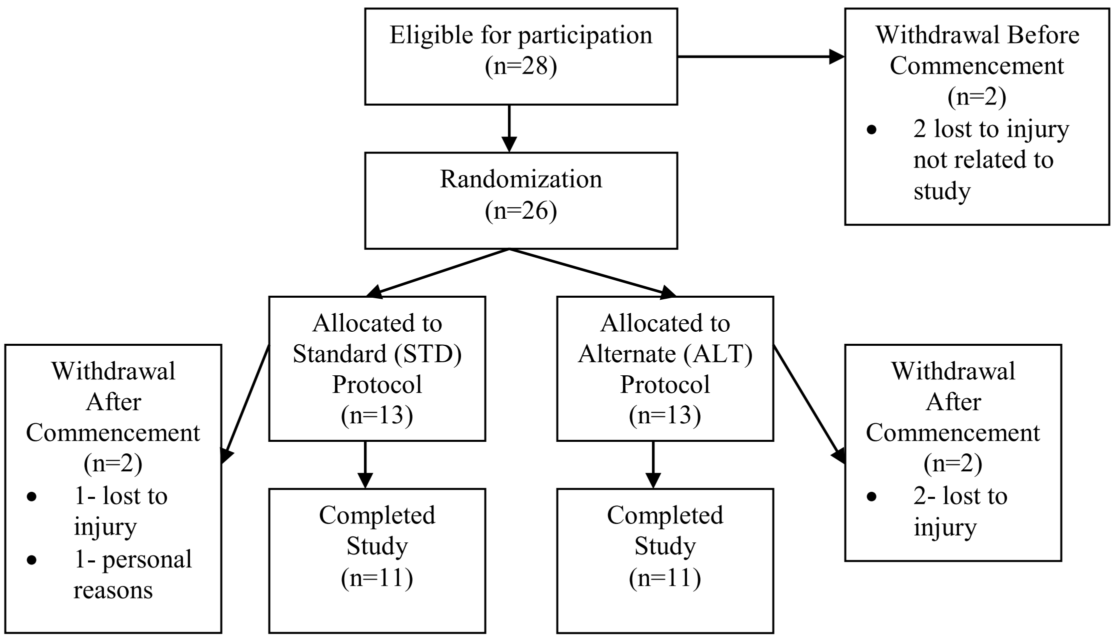


Figure 1. Consort diagram for participation.

Table 1. Baseline group characteristics. Data are means ± SD.

	STD			ALT			COMBINED			P Value
Age (yr)	25	±	5	25	±	4	25	±	5	0.790
Height (cm)	179.71	±	6.18	179.71	±	3.90	179.71	±	5.04	1.000
Weight (kg)	81.7	±	11.6	82.5	±	10.0	82.1	±	10.6	0.878
Lean Mass (kg)	61.9	±	8.9	63.3	±	7.0	62.6	±	7.9	0.689
Fat Percentage (%)	14.3	±	2.7	12.9	±	5.5	13.6	±	4.3	0.466
Years Trained (yrs)	6.5	±	4.0	6.0	±	5.0	6.5	±	4.5	0.815
# Days Trained (days)	3.5	±	2.0	3.5	±	2.0	3.5	±	2.0	1.000

Data are means ± SD. STD, standard group; ALT, alternate group.

Testing Sessions

Figure 2 provides a summary of testing and training procedures. Prior to baseline testing, subjects underwent an exercise familiarization session led by a Certified Strength and Conditioning Specialist (CSCS). Proficiency in all lifts utilized for training and testing was required. During the same week, a nutrition seminar outlining current macronutrient guidelines for athletes involved in a resistance training program was also provided by a registered dietitian (7) including instruction on proper dietary intake recording. Preceding baseline testing, subjects completed a four day dietary record to include three week days and one weekend day. Thereafter, subjects completed a four day dietary recording one week prior to subsequent testing sessions. The same protocol was followed prior to each testing session. Every effort was made to schedule follow up testing sessions at the same approximate time to reduce any diurnal variations. Subjects were tested at baseline, in weeks 4, 8 and 12 of the exercise intervention. In the week of testing sessions, subjects were weighed, had their body composition determined using dual-energy x-ray absorptiometry (DEXA), and had their strength and power output assessed according to standardized procedures outlined below. Muscle biopsies were obtained prior to baseline testing and at the conclusion of the exercise intervention.

<table>
<tr><td colspan="2">Familiarization, Nutrition Seminar, and Muscle Biopsy (1 week prior to baseline)</td></tr>
<tr><td colspan="2">Body Composition, Strength and Power Testing Baseline</td></tr>
<tr><td>Standard Training Group (STD)</td><td>ALT Training Group (ALT)</td></tr>
<tr><td>4 x 10 with 2 min rest compound lifts
3 x 10 with 1.5 min rest assistive lifts
Week 1 – 65% 1RM (4 days • wk^{-1})
Week 2 – 70% 1RM (4 days • wk^{-1})
Week 3 – 75% 1RM (4 days • wk^{-1})
Week 4 – 60% 1RM (2 days • wk^{-1})</td><td>8 x 5 with 1 min rest compound lifts
3 x 10 with 1.5 min rest assistive lifts
Week 1 – 65% 1RM (4 days • wk^{-1})
Week 2 – 70% 1RM (4 days • wk^{-1})
Week 3 – 75% 1RM (4 days • wk^{-1})
Week 4 – 60% 1RM (2 days • wk^{-1})</td></tr>
<tr><td colspan="2">Body Composition, Strength and Power Testing Week 4</td></tr>
<tr><td>4 x 10 with 2 min rest compound lifts
3 x 10 with 1.5 min rest assistive lifts
Week 5 – 65% 1RM (4 days • wk^{-1})
Week 6 – 70% 1RM (4 days • wk^{-1})
Week 7 – 75% 1RM (4 days • wk^{-1})
Week 8 – 60% 1RM (2 days • wk^{-1})</td><td>8 x 5 with 1 min rest compound lifts
3 x 10 with 1.5 min rest assistive lifts
Week 5 – 65% 1RM (4 days • wk^{-1})
Week 6 – 70% 1RM (4 days • wk^{-1})
Week 7 – 75% 1RM (4 days • wk^{-1})
Week 8 – 60% 1RM (2 days • wk^{-1})</td></tr>
<tr><td colspan="2">Body Composition, Strength and Power Testing Week 8</td></tr>
<tr><td>4 x 10 with 2 min rest compound lifts
3 x 10 with 1.5 min rest assistive lifts
Week 9 – 65% 1RM (4 days • wk^{-1})
Week 10 – 70% 1RM (4 days • wk^{-1})
Week 11 – 75% 1RM (4 days • wk^{-1})
Week 12 – 60% 1RM (2 days • wk^{-1})</td><td>8 x 5 with 1 min rest compound lifts
3 x 10 with 1.5 min rest assistive lifts
Week 9 – 65% 1RM (4 days • wk^{-1})
Week 10 – 70% 1RM (4 days • wk^{-1})
Week 11 – 75% 1RM (4 days • wk^{-1})
Week 12 – 60% 1RM (2 days • wk^{-1})</td></tr>
<tr><td colspan="2">Body Composition, Strength and Power Testing, and Muscle Biopsy Week 12</td></tr>
</table>

Figure 2. Testing and training program design.

Dietary Recording and Analysis

Prior to each testing sessions subjects completed a dietary record to include 3 weekdays and 1 weekend day. Dietary recording was completed one week prior to baseline and in weeks 3, 7, and 11 corresponding to the highest volume of training during each four week cycle (Figure 2). All food logs were entered and analyzed using dietary analysis software (ESHA food Processor Version 8.6, Salem, OR). Analysis was subsequently reviewed by a registered dietitian. Post workout supplementation (20 g protein, 45 g carbohydrates, 3.5 g fat) was provided on training days (Muscle Milk Collegiate, Cytosport, Benicia, CA).

Body Composition Testing

Body composition testing occurred at baseline; in weeks 4, 8 and 12 coincident with testing of strength and power output (Figure 2). Subjects reported to the laboratory having fasted for at least 10 hours prior to body composition measurement. Height and weight were recorded to the nearest .02 kg and .01 cm respectively using a self-calibrating digital scale (Bridgeview, IL) in socks or bare feet. Body composition was then determined using DEXA (Hologic Discovery W DXA software version 12.1, Waltham, MA) calibrated according to manufacturer's guidelines and performed by a trained technician. Previous studies indicate DEXA to be an accurate and reliable means to assess changes in body composition (5).

Strength Testing

Upper and lower body strength was assessed using 1RM parallel back squat ($1RM_{BS}$) and bench press ($1RM_{BP}$) exercises. On the day of strength testing, subjects reported to the laboratory having refrained from any exercise outside of daily living for at least 72 hours prior to baseline testing and at least 48 hours prior to testing in weeks 4, 8 and 12. Baseline 1RM of both exercises was estimated from self-reporting. After baseline, all 1RM estimations were based on training logs kept throughout the study. A dynamic warm up lasting approximately 8-10 minutes was performed prior to determination 1RM. Strength testing for both $1RM_{BS}$ and $1RM_{BP}$ commenced with two warm up sets of 5 repetitions at 40-60% 1RM separated by two minutes rest. After a three minute rest period one to two sets of 2-3 repetitions at a load corresponding to 60-80% 1RM were performed. Subjects then began performing sets of 1 repetition of increasing weight for 1RM determination. Three to five minutes rest was provided between each successive attempt. All 1RM determinations were made within 3-5 attempts. Subjects were required to reach parallel in the $1RM_{BS}$ for an attempt to be considered successful as determined by a CSCS certified individual providing an "up" command. $1RM_{BP}$ was considered successful if subject remained in contact with the bench during the entire concentric phase of the lift. $1RM_{BS}$ testing was conducted prior to $1RM_{BP}$ after a five minute rest period. The same 1RM testing procedure was utilized for both exercises. All strength testing took place on an Optima Smith Machine (LifeFitness, Schiller Park, IL) without counterbalance technology. Foot placement was recorded during baseline $1RM_{BS}$ testing; hand placement was recorded at baseline

$1RM_{BP}$ testing. These measurements were then used in all subsequent testing procedures for strength and power output. All testing sessions were supervised by two CSCS certified individuals to determine success during each attempt.

Power Testing

Power testing commenced at least 48 hours post 1RM testing. Subjects performed the same warm up prior to initiation of power testing. Weight and reach height were recorded for calculation of power as determined by vertical jump. Two countermovement vertical jumps (CMJ) using less than maximal effort were allowed prior to testing. Three maximum effort vertical CMJ were then recorded separated by two minutes rest. If the third attempt was greater than the first three, another attempt was allowed until a decrease in jump height was observed. No more than five maximum vertical CMJ were allowed. Reach height and jump height were recorded using a commercially available Vertec system (Sports Imports, Columbus, OH). The maximum attempt of record was later converted to power in watts (PWR_{VJ}) using previously described procedures (71).

After vertical jump testing, power output was assessed during the concentric phase of the parallel back squat (PWR_{BS}) and bench press (PWR_{BP}) exercises using a relative load of 60% 1RM. PWR_{BS} was determined preceding PWR_{BP} separated by five minutes rest. All testing was performed on the same smith machine used for 1RM testing. A warm-up of 3 sets of 5 repetitions at 40-50% 1RM was provided on both exercises prior to power output assessment. Subjects were instructed to perform the concentric phase of each lift as explosively as possible. After warm up sets, subjects began performing single repetitions at 60% 1RM for determination of mean power output. During the parallel back squat, rubber tubing was placed at the parallel point. This position was determined during strength testing and ensured subjects reached the appropriate parallel position for the attempt to be a success. Three attempts were allowed with the best recorded for further analysis. Again, if the third attempt was greater than the first two another attempt was recorded until power output declined. No more than five attempts were recorded with the highest mean power output being used for statistical analysis. Three minutes rest was utilized between successive maximal power attempts. Power output was measured using a Tendo Fitrodyne (Sorinex, Irmo, SC). During post training (12 weeks) power output was assessed on both parallel back squat ($APWR_{BS}$) and bench press ($APWR_{BP}$) using loads corresponding to 60% baseline 1RM followed by 60% post training 1RM.

Reliability of Strength and Power Testing

Ten resistance trained males age 25±5 yrs, 181.48±11.21 cm, 91.3±14.0 kg with 8±5 years 5±1 days per week resistance training experience having signed consent forms approved by the Institutional Review Board of Texas A & M University performed strength and power output assessment according to previously described procedures to determine reliability of measurement. After one week, subjects returned to perform the same testing procedures. Table 2 provides the reliability statistics for strength and power output measurements.

Table 2. Intraclass correlation coefficients (ICC) and Pearson product-moment coefficient (r) between trials for strength and power testing procedures.

	Day 1			Day 2			ICC	r
Bench Press 1RM								
	135.4	±	28.6	137.0	±	28.0	0.99	0.001
Back Squat 1RM								
	171.9	±	47.4	173.5	±	47.6	0.99	0.001
Bench Press Power (60% 1RM)								
	657	±	147	665	±	140	0.98	0.001
Back Squat Power (60% 1RM)								
	860	±	295	868	±	275	0.97	0.001

Day 1 and Day 2 values are means ± SD.

Training

All training sessions commenced with a dynamic warm up identical to that used for strength and power testing. Training consisted of 4 supervised workouts a week in the following sequence; two days on, one day off, two days on, two days off. The training program intensity was structured into four week cycles with increasing intensity as described in Figure 2 providing an unload week during each week of testing. All sessions were supervised by trained staff with at least 1 – 2 CSCS certified personnel leading sessions.

Throughout the training program, both groups performed the same exercises, in the same order and intensity (Figure 2). Table 3 provides the exercises performed as well as the order in which they were performed. All major lifts tested for strength and power output were performed on the same apparatus used for determination of 1RM and power output. Additionally, all derivations of major lifts tested were also performed on the same apparatus used for strength and power testing. Therefore, all squat, front squat, bench and incline presses were performed on the smith machine in which testing was performed. Subjects were instructed to perform the concentric phase of all major lifts in an explosive manner. Verbal encouragement was provided throughout training. To determine differences between training programs, groups differed on the sets, repetitions and rest in all major lifts performed (Figure 2). Briefly, the STD group performed 4 sets of 10 repetitions for all major lifts with 2 minutes rest between sets, while the ALT group performed 8 sets of 5 repetitions for all major lifts with 1 minute rest between sets. All assistive lifts were performed 3 sets of 10 repetitions with 1.5 minutes rest. The load was reduced if subjects were unable to complete the prescribed number of repetitions. Intensity was increased if subjects were able to achieve at least 85% of total volume on major lifts. Timing of rest was performed using stop watches on all lifts by trained personnel. The total sum of work (weight x reps x sets) was grouped according to lifts utilizing the upper and lower body for main lifts and push and pull exercises for assistive exercises for later analysis. Workout logs were maintained and verified throughout the 12 week period. Compliance throughout the entire 12 week study was 95%.

Table 3. Exercises performed during training.

Day 1 (Upper Body Push)	**Day 2 (Lower Body + Upper Body Pull)**	**Day 3 (Upper Body Push)**	**Day 2 (Lower Body + Upper Body Pull)**
Bench Press*‡	Squats*‡	Incline Press*‡	Front Squat*‡
Incline DB Press*	Leg Press*	DB Bench*	DB RDL*
Seated DB Military Press*	Partial DL to Power Shrug	Push Press*	DB Step Up*
DB Flat Flies	Pull-ups†	DB Incline Flies	Pull-ups†
Front DB Raises	One Arm DB Row	DB Rear Delt	Close Grip Lat Pulldowns
Side DB Raises	Hamstring Curl	Side DB Raises	T Bar Row
Straight Bar Skull Crusher	EZ Bar Curls	EZ Bar Skull Crusher	Straight Bar Curl
Dips†	DB Curl	Dips†	DB Curl

* Main lift exercises performed according to group (STD or ALT), concentric phase explosively as possible. †exercise performed 3 sets of maximum repetitions with 1.5 minute rest. ‡exercise performed on Smith Machine. DB = Dumbbell, DL = Deadlift, RDL = Romanian Deadlift.

Biopsy and Myosin Heavy Chain Analysis

Prior to baseline testing and within 72 hours of post strength and power testing, a muscle biopsy of the vastus lateralis was obtained from the participant's right leg. A 4 x 4 inch area was cleansed and numbed using a local anesthetic (1% Xylocaine HCl). An approximate 1/3 inch incision was made after additional anesthetic was injected subcutaneously. A sterile 5mm biopsy needle (Pelomi Industries, Denmark) was used to obtain the approximate 100-200 mg of muscle using a modification of Bergstrom's technique (12) as described by Evans et al. (24) All muscle samples were cleansed of visible fat, connective tissue and blood and immediately frozen in liquid nitrogen (-190°C), and then transferred and stored at -80°C until analyzed.

Refrigerated homogenization buffer (250 mM sucrose, 100 mM KCl, 5 mM EDTA, 20 mM Tris, pH 6.8) was added to the frozen muscle samples. The muscle samples were then homogenized on ice with a micropestle, followed by centrifugation in the cold (5°C) at 10,000 x g for 10 minutes. The resultant supernatant was discarded and the myofibril pellet was resuspended in 100 µL of wash buffer (175 mM KCl, 2 mM EDTA, 0.5% Triton X-100, 20 mM Tris, pH 6.8). Centrifugation was then repeated and the resultant supernatant discarded , and the myofibril pellet resuspended in 100 µL of final resuspension buffer (150 mM KCl, 20 mM Tris, pH 7.0) (10, 72). Followed by centrifugation, 50 µL Lysis buffer (1% Sodium Deoxycholate, 1% NP-40, 0.1% SDS, 10mM Tris, pH 8, .14M NaCl, 10 mM EDTA, protease inhibitor cocktail – 10 µL/ml(Calbiochem, Darmstadt, Germany)) was added followed by protein assay determination. Total protein was assayed according to the bicinchoninic acid (BCA) method using a commercially available BCA Protein Assay Reagent (Thermo Scientific, Rockford, IL).

The separating gel was poured into a 140 x 160 x 0.75-mm gel cast 4 cm from the top of the glass plate The separating gel was made of 35% v/v glycerol, 8% w/v acrylamide-N,N'-methylenebisacrylamide (Bis) (99:1), 0.2 M Tris-HCl (pH 8.8), 0.1 M glycine, 0.4% w/v SDS, 0.1% w/v ammonium persulfate, and 0.05% v/v/ N,N,N'N'-tetramethylethylenediamine (TEMED). After pouring, the separating gel was allowed to polymerize overnight. The stacking gel was poured the following day and consisted of 30% v/v glycerol, 4% w/v acrylamide-Bis (50:1), 70 mM Tris-HCl (pH 6.7), 4 mM EDTA, 0.4% w/v SDS, 0.1% w/v ammonium persulfate, and 0.05% v/v TEMED (54).

Samples were then diluted with sample buffer (.16M Tris-Cl, pH 6.8, 43% glycerol, 100 mM DTT, .005 Bromophenol blue, 5% SDS) prior to loading. The lower running buffer consisted of 0.05M Tris (base), 75 mM glycine, and 0.05% w/v SDS, while the upper running buffer was two times the concentration of the lower running buffer and β-ME was added (final concentration: 0.12v/v) (44, 54). After samples were loaded (15 μL) electrophoresis was performed at a constant voltage of 200 V for 22 h in a gel system (R.Shadel, San Franscisco,CA). For stacking gel penetration, the first hour, the voltage was kept at 160V. During electrophoresis, the gel system was kept in a temperature controlled ventilated hood. Throughout electrophoresis, the lower running buffer was stirred gently with a magnetic stirrer.

After the electrophoresis run, the gels were stained with a silver staining kit (Bio-Rad, Hercules, CA) according to manufacturer's instructions. The protein bands of each

MHC isoform on the silver-stained acrylamide gel were then densitometrically digitalized using a digital camera (Fugi LAS 4000, Fujifilm Life Sciences, Wayne, NJ). The densitometric values were derived as an integral of the band density and band area. This procedure was performed using a software package (MultiGauge 3.0, Fujifilm Life Sciences, Wayne, NJ). The amount of each isoform was expressed as a percentage calculated as (IntegProtein/IntegAll) * 100%. Where IntegProtein is the densitometric integral of the corresponding protein band, and the IntegAll is the densitometric integral of all isoforms in the sample.

Statistical Analysis

All statistical analysis was performed using SPSS Version 16.0 (Chicago, IL). One way ANOVA was used to determine baseline differences in age, height, body mass, years training, days training, $1RM_{BP}$, $1RM_{BS}$, PWR_{BP}, PWR_{BS}, and PWR_{VJ}. A 2 x 4 (group x time) ANOVA was utilized to determine differences in body mass, lean mass, and percent body fat. Macronutrient content was analyzed in a 2 x 4 (group x time) ANOVA. Overall training volume was analyzed by independent t-test. A 2 x 4 (group x time) ANCOVA covaried for baseline values was utilized to determine changes over the training period in $1RM_{BP}$, $1RM_{BS}$, PWR_{BP}, PWR_{BS}, and PWR_{VJ}. These variables were also analyzed relative to body weight and lean mass in a 2 x 4 (group x time) ANCOVA covaried for absolute baseline values to determine differences at each time point. Independent t-tests were used to determine the difference between pre- and post-$APWR_{BP}$ and $APWR_{BS}$. A 2 x 2 (group x time) repeated measure ANCOVA covaried by baseline value was used to determine changes in percentage MHC_{slow}, MHC_{IIA} and

$MHC_{IIX.}$ The effect size (difference between 12 weeks and baseline divided by the standard deviation of baseline) was used in accordance with the scale proposed by Rhea (60) to determine the treatment effect of both strength training programs. Where necessary, post hoc analysis was performed using the Bonferroni correction. Statistical significance was defined as $p \leq 0.05$.

Results

Baseline Characteristics

No significant differences were observed at baseline in age, height, body mass, or lean mass. Additionally, no significant differences were observed in training status (training years or days training) between subjects (Table 1).

Macronutrient Intake

Absolute macronutrient intake, as well as percent total calories and intake relative to body weight are presented in Table 4. No significant between group differences were observed in any of the macronutrients measured. Caloric intake did not change over the course of the study in absolute terms or relative to body weight. Protein intake increased significantly from baseline to 3 weeks with no further increase observed. Protein intake as a percent of total calories increased over time with the greatest increase observed from baseline to 3 weeks and a slight increase being observed from week 3 to week 11. Protein intake relative to body weight followed the same pattern as absolute protein intake increasing from baseline to 3 weeks with no further increase observed.

Carbohydrate intake decreased over the course of the experimental period decreasing from week 3 to week 7, with a continued decrease in week 11. Percentage carbohydrate from total calories as well as g•kg^{-1} experienced a decrease from 3 weeks to 7 weeks and again from week 7 to week 11. No significant changes were observed in absolute fat intake, as a percentage of total calories or relative to body weight.

Training Volume

Total volume of main lifts (upper and lower body) and assistive exercises (push and pull) is provided in Table 5. There were no significant differences between groups for total volume of main lifts or assistive exercises.

Table 4. Kcalories, protein, carbohydrate and fat intake, percent of total kcalories, and relative intake at baseline, 3, 7, and 11 weeks of training.

	Baseline			3 Weeks			7 Weeks			11 Weeks			P Value
Overall													
Kcalories	2620	±	581	2918	±	601	2923	±	573	2793	±	481	T = 0.084
Protein (g)	147	±	39	196	±	50†	191	±	34†	201	±	40†	T = 0.001
Carbohydrate (g)	261	±	94	270	±	63	231	±	85‡	182	±	69†‡§	T = 0.001
Fat (g)	101	±	33	109	±	32	110	±	32	101	±	26	T = 0.517
Percent Total Kcal													
Protein (%)	22.7	±	4.6	26.8	±	3.5†	27.2	±	8.0†	29.1	±	5.8†‡	T = 0.001
Carbohydrate (%)	40.1	±	13.3	37.4	±	6.9	31.0	±	9.0†‡	26.0	±	8.5†‡§	T = 0.001
Fat (%)	34.4	±	8.0	33.5	±	4.7	33.8	±	5.6	32.7	±	7.2	T = 0.754
Relative to Bodyweight													
Kcalories (g•kg^{-1})	32.3	±	7.9	35.5	±	8.2	35.7	±	9.5	33.6	±	6.8	T = 0.128
Protein (g•kg^{-1})	1.8	±	0.5	2.4	±	0.7†	2.3	±	0.5†	2.4	±	0.5†	T = 0.001
Carbohydrate(g•kg^{-1})	3.3	±	1.3	3.3	±	0.8	2.8	±	1.1†‡	2.2	±	0.8†‡§	T = 0.001
Fat (g•kg^{-1})	1.2	±	0.4	1.3	±	0.4	1.4	±	0.5	1.2	±	0.4	T = 0.424

Data are means ± SD. STD, standard group; ALT, alternate group. T = time effect. †significantly different than baseline. ‡significantly different from 3 weeks. § significantly different from 7 weeks.

Table 5. Total training volume for STD and ALT over 12 weeks of training.

	STD			ALT			P Value
Major Lifts (kg)							
Upper Body	102,711.67	±	25,484.80	119,728.80	±	22,587.40	0.113
Lower Body	220,811.80	±	35,827.50	235,807.10	±	35,002.30	0.333
Assistive Lifts (kg)							
Push	34,041.40	±	9,085.40	37,356.70	±	10,251.40	0.432
Pull	58,978.80	±	7,697.00	60,791.90	±	11,089.70	0.661

Data are means ± SD. STD, standard group; ALT, alternate group. Major lifts performed according to group assignment. Assistive lifts all performed same rest to work ratio.

Muscular Strength

The results of strength testing are presented in Table 6. There were no significant differences between groups observed at baseline in either $1RM_{BP}$ or $1RM_{BS}$. Both groups experienced a significant improvement in $1RM_{BP}$ after 12 weeks of training. A significant difference was observed between groups at 4, 8 and 12 weeks. The ALT group experienced an increase at 4, 8 and 12 weeks of which all three time points corresponded to values greater than the STD group. The STD group decreased at 4 weeks and then increased at 8 and 12 weeks for an overall improvement in $1RM_{BP}$ from baseline. Significant differences were observed in absolute changes from baseline in weeks 4, 8 and 12. From baseline to week 4, the ALT group experienced a 6.5±6.6 kg increase while the STD group experienced a -1.4±6.2 kg decrease (p= 0.008). The ALT group continued to experience significantly greater increases from baseline at week 8 (9.9±6.8 kg) and week 12 (15.1±8.3 kg) compared to the STD group (week 8, 2.9±5.8 kg; week 12, 9.1±3.7 kg; $p = 0.018$ and 0.041; respectively). In evaluating $1RM_{BP}$ in relationship to body weight, both groups experienced a significant improvement from baseline with the ALT group increasing to a greater degree at 4, 8 and 12 weeks. $1RM_{BP}$ relative to lean mass did not show a time or group effect, but showed a significant interaction which when analyzed post hoc showed again that the ALT group experienced greater increase at all testing points after baseline compared with STD group.

Both groups experienced significant increases in $1RM_{BS}$ which showed continued increase from baseline to 4 weeks, 4 to 8 weeks and 8 to 12 weeks. The ALT group experienced greater increases at both 8 (ALT, 49.7±13.8 kg; STD, 36.9±13.5 kg; $p = 0.040$) and 12 (ALT, 63.8±12.0 kg; STD, 48.5±17.4 kg; $p = 0.026$) weeks compared to the STD group. $1RM_{BS}$ relative to body weight and lean mass showed the same pattern of improvement over time in both groups with the ALT group showing greater increases in $1RM_{BS}$ at both 8 and 12 weeks. The results demonstrated herein lead to rejecting our initial hypotheses stating no significant differences in strength of the bench press and parallel back squat exercises after 12 weeks of training.

Table 6. Strength measures (1RM) at baseline, 4, 8, and 12 weeks of training.

	STD	ALT	COMBINED	P Value
Bench Press 1RM (kg)				
Baseline	104.1 ± 27.6	110.9 ± 20.1	107.5 ± 23.8	T = 0.027
4 Weeks	102.7 ± 29.0	117.5 ± 23.7*	110.1 ± 26.9	G = 0.013
8 Weeks	107.0 ± 25.3	120.8 ± 22.6*	113.9 ± 24.5†‡	T X G = 0.017
12 Weeks	113.2 ± 27.3	126.0 ± 22.8*	119.6 ± 25.4†‡§	
Bench Press to Bodyweight Ratio				
Baseline	1.27 ± 0.22	1.35 ± 0.23	1.31 ± 0.22	T = 0.010
4 Weeks	1.22 ± 0.24	1.42 ± 0.24*	1.32 ± 0.26	G = 0.035
8 Weeks	1.26 ± 0.18	1.45 ± 0.23*	1.36 ± 0.23†‡	T X G = 0.001
12 Weeks	1.33 ± 0.19	1.51 ± 0.22*	1.42 ± 0.22†‡§	
Bench Press to Lean Mass Ratio				
Baseline	1.67 ± 0.27	1.75 ± 0.26	1.71 ± 0.26	T = 0.090
4 Weeks	1.61 ± 0.29	1.84 ± 0.30*	1.73 ± 0.31	G = 0.066
8 Weeks	1.66 ± 0.22	1.88 ± 0.29*	1.77 ± 0.28	T x G = 0.004
12 Weeks	1.75 ± 0.25	1.95 ± 0.29*	1.85 ± 0.28	
Back Squat 1RM (kg)				
Baseline	123.3 ± 39.3	130.1 ± 25.1	126.7 ± 32.3	T = 0.001
4 Weeks	139.6 ± 38.8	152.6 ± 24.8	146.1 ± 32.4†	G = 0.016
8 Weeks	160.2 ± 36.1	179.8 ± 24.5*	170.0 ± 31.7†‡	T X G = 0.006
12 Weeks	171.8 ± 34.5	193.9 ± 24.2*	182.8 ± 31.2†‡§	
Back Squat to Bodyweight Ratio				
Baseline	1.50 ± 0.34	1.59 ± 0.30	1.54 ± 0.32	T = 0.001
4 Weeks	1.66 ± 0.34	1.85 ± 0.27	1.76 ± 0.31†	G = 0.038
8 Weeks	1.90 ± 0.30	2.17 ± 0.25*	2.03 ± 0.30†‡	T X G = 0.001
12 Weeks	2.03 ± 0.30	2.33 ± 0.27*	2.18 ± 0.32†‡§	
Back Squat to Lean Mass Ratio				
Baseline	1.97 ± 0.42	2.05 ± 0.30	2.01 ± 0.36	T = 0.001
4 Weeks	2.19 ± 0.41	2.40 ± 0.27	2.30 ± 0.35†	G = 0.045
8 Weeks	2.49 ± 0.35	2.79 ± 0.26*	2.64 ± 0.34†‡	T X G = 0.001
12 Weeks	2.67 ± 0.36	3.02 ± 0.26*	2.84 ± 0.35†‡§	

Data are means ± SD. STD, standard group; ALT, alternate group. T = time effect, G = group effect, T x G = time x group interaction effect. *significantly different from STD. † significantly different from baseline. ‡ significantly different from 4 weeks. § significantly different from 8 weeks.

Power Output

Data from power output assessments are presented in Table 7. There were no significant differences between groups noted in any power variable (PWR_{BP}, PWR_{BS}, or PWR_{VJ}) measurements at baseline. No significant time effect was noted in PWR_{BP}, however, group and interaction effects were both noted. Post hoc analysis revealed significant differences between groups at 8 and 12 weeks with the ALT group showing an overall greater increase over time in PWR_{BP} compared to the STD group. Compared to baseline, the ALT group experienced significantly greater increases in weeks 4 (11.1±46.6 W), 8 (71.4±40.2 W), and 12 (83.0±49.9 W), compared to STD which decreased in week 4 (-19.2±49.3 W, $p = 0.155$), then increased in weeks 8 (11.3±38.4 W, $p = 0.002$) and 12 (32.8±53.4 W, $p = 0.034$). In evaluating power relative to body weight and lean mass, the same pattern emerged with the ALT group showing significant improvements over time while the STD experienced no significant increase. Based on results, the original hypothesis is proven stating intra-set rest intervals would result in significantly greater power output of the bench press exercise after 12 weeks of training.

Both groups showed an increase in PWR_{BS}. A significant interaction was observed with post hoc analysis revealing no significant differences. However, the difference between groups at both 8 and 12 weeks approached significance ($p = 0.084$ and $p = 0.064$, respectively) with the ALT group showing a greater increase. This was also reflected in changes from baseline at 8 (ALT, 151.0±74.0 W; STD, 97.5±60.9 W; $p = 0.085$) and 12 (ALT, 282.1±104.1 W; STD, 204.9±70.2 W; $p = 0.059$). The magnitude of effect was also greater in the ALT group (Table 7). In relationship to body weight, both groups experienced a significant increase over time. Significant differences between groups were noted when evaluating PWR_{BP} relative to body weight. While both groups showed improvement the ALT group showed a greater improvement at 8 weeks with significance almost being reached at 12 weeks ($p = 0.057$). A significant difference was noted at both 8 and 12 weeks between groups with the ALT group showing a greater increase when evaluating PWR_{BS} relative to lean mass. Contrary to the original hypothesis, no significant differences were found in parallel back squat power output leading to rejection of the original hypothesis.

Changes in $APWR_{BP}$ and $APWR_{BS}$ are presented in Figure 3. The ALT group experienced a significantly greater improvement in $APWR_{BP}$, 71.0 W compared to 13.5 W for STD ($p = 0.048$). No significant differences were observed in $APWR_{BS}$ between groups. However, the magnitude of effect size was greater for the ALT group (Table 7). Failure to reject the original hypothesis stating a significant difference in absolute bench press power after 12 weeks of resistance training with a rejection of the hypothesis stating significant difference in absolute parallel back squat power after 12 weeks of training is warranted based on these results.

Increases in PWR_{VJ} were observed in both groups at 4, 8 and 12 weeks with improvement noted from each testing period to the next. A significant difference was observed at 12 weeks with the ALT group showing a greater increase over time compared with the STD group (ALT, 147.7±52.0 W; STD, 91.6±59.8 W; $p = 0.034$). Evaluation of PWR_{VJ} relative to body weight and lean mass showed the same pattern of differences over time and between groups. Based on these results the original hypothesis was proven leading to a failure to reject" our initial hypothesis stating intra-set rest intervals would result in greater power output in the vertical jump after 12 weeks of training.

Table 7. Power measures at baseline, 4, 8, and 12 weeks of training.

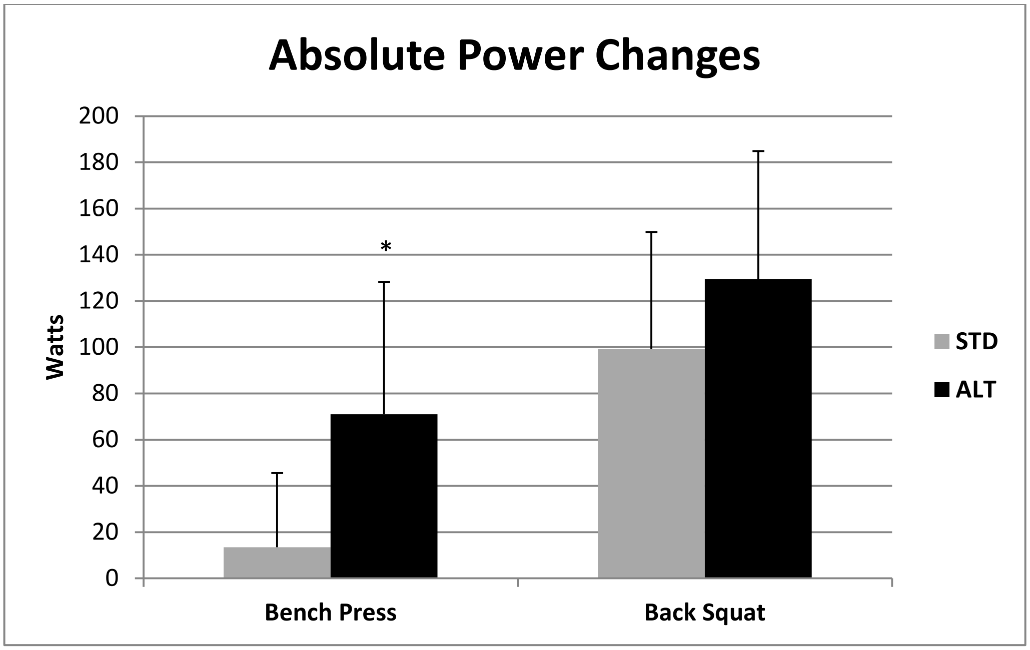
	STD			ALT			COMBINED			P Value
Bench Press Power (W)										
Baseline	560	±	122	575	±	102	568	±	110	T = 0.568
4 Weeks	541	±	105	586	±	123	564	±	114	G = 0.011
8 Weeks	572	±	122	646	±	103*	609	±	116	T X G = 0.020
12 Weeks	593	±	135	658	±	113*	626	±	126	
Bench Press Power to Bodyweight Ratio										
Baseline	6.84	±	0.96	6.99	±	1.10	6.92	±	1.01	T = 0.627
4 Weeks	6.46	±	0.91	7.09	±	1.28	6.78	±	1.13	G = 0.056
8 Weeks	6.77	±	0.92	7.77	±	0.92*	7.27	±	1.03	T X G = 0.003
12 Weeks	6.96	±	0.96	7.90	±	1.24*	7.43	±	1.18	
Bench Press Power to Lean Mass Ratio										
Baseline	9.01	±	1.14	9.07	±	1.21	9.04	±	1.15	T = 0.793
4 Weeks	8.56	±	1.24	9.18	±	1.32	8.87	±	1.29	G = 0.066
8 Weeks	8.88	±	1.11	10.02	±	0.96*	9.45	±	1.17	T X G = 0.006
12 Weeks	9.20	±	1.39	10.21	±	1.17*	9.70	±	1.35	
Back Squat Power (W)◊										
Baseline	625	±	245	632	±	171	628	±	208	T = 0.001
4 Weeks	704	±	233	734	±	179	718	±	205†	G = 0.081
8 Weeks	723	±	227	783	±	188	751	±	206†‡	T X G = 0.053
12 Weeks	830	±	232	914	±	207	870	±	219†‡§	

Data are means ± SD. STD, standard group; ALT, alternate group. T = time effect, G = group effect, T x G = time x group interaction effect. *significantly different from STD. † significantly different from baseline. ‡ significantly different from 4 weeks. § significantly different from 8 weeks. ◊ One subject was excluded from analysis of lower body power due to failure to accurately follow protocol during T1 and T3.

Table 7. Continued.

	STD			ALT			COMBINED			P Value
Back Squat Power to Bodyweight Ratio◊										
Baseline	7.57	±	2.23	7.83	±	2.33	7.69	±	2.23	T = 0.001
4 Weeks	8.37	±	2.14	9.09	±	2.42	8.71	±	2.25†	G = 0.101
8 Weeks	8.53	±	1.94	9.57	±	2.35*	9.02	±	2.16†‡	T X G = 0.015
12 Weeks	9.78	±	2.03	11.11	±	2.64	10.41	±	2.38†‡§	
Back Squat Power to Lean Mass Ratio◊										
Baseline	9.96	±	2.77	10.19	±	2.62	10.07	±	2.63	T = 0.001
4 Weeks	11.04	±	2.57	11.83	±	2.65	11.41	±	2.57†	G = 0.068
8 Weeks	11.15	±	2.31	12.41	±	2.63*	11.75	±	2.49†	T X G = 0.017
12 Weeks	12.86	±	2.49	14.45	±	2.87*	13.62	±	2.73†‡§	
Vertical Jump Power (W)◊										
Baseline	1378	±	237	1389	±	179	1383	±	206	T = 0.001
4 Weeks	1418	±	214	1434	±	152	1426	±	183†	G = .205
8 Weeks	1452	±	210	1470	±	149	1461	±	179†‡	T X G = 0.036
12 Weeks	1470	±	215	1537	±	150*	1502	±	185†‡§	
Vertical Jump Power to Bodyweight Ratio (W)◊										
Baseline	17	±	1	17	±	2	17	±	2	T = 0.001
4 Weeks	17	±	1	18	±	2	17	±	2†	G = 0.243
8 Weeks	17	±	1	18	±	2	18	±	2†‡	T X G = 0.001
12 Weeks	17	±	1	19	±	2*	18	±	2†‡§	
Vertical Jump Power to Lean Mass Ratio (W)◊										
Baseline	22	±	1	22	±	2	22	±	2	T = 0.001
4 Weeks	22	±	1	22	±	2	23	±	1†	G = 0.141
8 Weeks	23	±	1	23	±	1	23	±	1†	T X G = 0.004
12 Weeks	23	±	1	24	±	1*	24	±	1†‡§	

Data are means ± SD. STD, standard group; ALT, alternate group. T = time effect, G = group effect, T x G = time x group interaction effect. *significantly different from STD. † significantly different from baseline. ‡ significantly different from 4 weeks. § significantly different from 8 weeks. ◊ One subject was excluded from analysis of lower body power due to failure to accurately follow protocol during T1 and T3.



Data are means ± SD. STD, standard group; ALT, alternate group. *significantly different from STD.

Figure 3. Absolute power changes.

Effect Size and Magnitude

The ALT group displayed greater size magnitudes in all performance variables excluding $1RM_{BS}$ compared to the STD group (Table 8). The ALT group magnitude of effect sizes were all moderate or large, while the STD group was found to have small magnitudes as defined by Rhea (60) for highly trained individuals in $1RM_{BP}$, PWR_{BP}, PWR_{VJ}.

Table 8. Effect size and magnitude in strength and power variables.

	STD		ALT	
Bench Press 1RM	0.33	(small)	0.75	(moderate)
Back Squat 1RM	1.22	(large)	2.54	(large)
Bench Press Power	0.27	(small)	0.81	(moderate)
ABS Bench Press Power	0.11	(trivial)	0.69	(moderate)
Back Squat Power	0.84	(moderate)	1.65	(large)
ABS Back Squat Power	0.41	(small)	0.76	(moderate)
Vertical Jump Power	0.39	(small)	0.83	(moderate)

Body Composition

Results of body composition testing over the course of the training period are presented in Table 9. A significant increase in body mass was observed over the course of the 12 week training program. While a time x group interaction was observed, post hoc analysis revealed no significant differences between groups at any time point. Lean mass increased in both groups from baseline to 4 weeks and showed a continued increase at 8 weeks. No further increases were noted in lean body mass from 8 to 12 weeks. No between group differences were identified. When evaluating percentage change from baseline, a significant time effect was noted ($p = 0.001$) with no significant time x group interaction or group effect. Determination of effect size magnitude showed a small (0.25) and trivial (0.14) for STD and ALT groups, respectively. There were no significant changes in percent body fat as measured by DEXA during the twelve week training. Failure to reject the original hypothesis is warranted based on results demonstrating no significant differences in lean mass gains after 12 weeks of training.

Table 9. Body composition at baseline, 4, 8, and 12 weeks of training.

	STD	ALT	COMBINED	P Value
Weight (kg)				
Baseline	81.7 ± 11.6	82.5 ± 10.0	82.1 ± 10.6	T = 0.001
4 Weeks	83.6 ± 10.0	82.7 ± 9.7	83.2 ± 9.6†	G = 0.898
8 Weeks	84.1 ± 10.7	83.1 ± 9.2	83.6 ± 9.7†	T X G = 0.018
12 Weeks	84.7 ± 10.9	83.6 ± 9.2	84.1 ± 9.9†‡	
Lean Mass (kg)				
Baseline	61.9 ± 8.9	63.3 ± 7.0	62.6 ± 7.9	T = 0.001
4 Weeks	63.2 ± 8.2	63.5 ± 7.3	63.4 ± 7.6†	G = 0.869
8 Weeks	64.0 ± 8.3	64.3 ± 6.9	64.2 ± 7.4†‡	T X G = 0.227
12 Weeks	64.2 ± 8.5	64.3 ± 6.8	64.2 ± 7.5†‡	
Percent Fat (%)				
Baseline	14.3 ± 2.7	12.9 ± 5.5	13.6 ± 4.3	T = 0.126
4 Weeks	15.0 ± 3.3	13.3 ± 5.9	14.1 ± 4.7	G = .445
8 Weeks	14.7 ± 3.5	13.2 ± 5.5	14.0 ± 4.6	T X G = 0.892
12 Weeks	15.1 ± 3.5	13.5 ± 5.6	14.3 ± 4.6	

Data are means ± SD. STD, standard group; ALT, alternate group. T = time effect, G = group effect, T x G = time x group interaction effect. † significantly different from baseline. ‡ significantly different from 4 weeks. § significantly different from 8 weeks.

Myosin Heavy Chain Composition

Studentized t-tests of baseline MHC demonstrated a significantly higher percentage of MHC_{IIX} in the ALT group (p = 0.023) compared to STD. No significant differences were observed at baseline in percentage MHC_{IIA} or MHC_{slow}. Results from myosin heavy chain analysis are presented in Table 10. Both groups experienced a significant reduction in MHC_{IIX} after 12 weeks of training, with a concomitant increase in $MHC_{IIA.}$ No interaction or between group effects were noted in either MHC_{IIX} or MHC_{IIA}. Evaluating percentage change from baseline, a significant time effect (p = 0.001) was noted with both ALT and STD groups experiencing a decrease in MHC_{IIX}, -37.9±24.1% and -23.4±23.8% respectively, with no differences noted between groups.

A time effect was also noted in percentage change from baseline in MHC_{IIA} for both ALT and STD groups, with both showing an increase 32.0±28.8% and 25.4±29.1% ($p = 0.001$). Again, no interaction or group effect was noted. A small but significant decrease in percentage MHC_{slow} was observed in both groups. However, when evaluating percent change from baseline, this did not reach significance ($p = 0.164$). These results are in contrast to the original hypothesis, therefore, the hypothesis is rejected.

Table 10. Myosin heavy chain isoform in percentage total at baseline and 12 weeks of training.

	STD	ALT	COMBINED	P Value
MHC_{IIX}				
Baseline	11.1 ± 4.2	16.5 ± 5.7	13.9 ± 5.7	T = 0.020
12 Weeks	7.9 ± 2.5	9.8 ± 4.5	8.9 ± 3.7†	G = 0.649
				T X G = 0.649
MHC_{IIA}				
Baseline	35.6 ± 7.7	34.5 ± 7.6	35.0 ± 7.5	T = 0.001
12 Weeks	43.2 ± 7.5	43.9 ± 6.2	43.6 ± 6.7†	G = 0.756
				T X G = 0.756
MHC_{slow}				
Baseline	53.3 ± 7.9	49.0 ± 7.6	51.1 ± 7.9	T = 0.002
12 Weeks	48.9 ± 5.9	46.2 ± 7.1	47.5 ± 6.5†	G = 0.568
				T X G = 0.568

Data are means ± SD. STD, standard group; ALT, alternate group. T = time effect, G = group effect, T x G = time x group interaction effect. † significantly different from baseline. ◊ One subject was excluded from analysis due to lack of sufficient sample.

CHAPTER V

SUMMARY

In the current study, we compared the effects of 12 weeks of intra-set rest intervals in a program designed to elicit hypertrophy and traditional hypertrophic training on performance measures and MHC composition. The ability to generate force and power output is a necessary requirement for a number of sports. Manipulation of the variables within a resistance training program in which performance is optimized is important to the strength and conditioning professional, while the adaptations that occur as a result of resistance training are significant to the applied researcher. Results of the current study demonstrate the effectiveness of intra-set rest intervals in programs designed to elicit hypertrophy as evidenced by the greater gains in both strength and power output. The major findings of this study were that after 12 weeks of training 1) intra-set rest intervals resulted in greater increases in strength in the bench press and back squat exercises, 2) intra-set rest intervals resulted in greater power output in the bench press exercise and vertical jump, 3) power output as measured during parallel back squat approached significance compared to traditional hypertrophic training, and 4)when normalized to body weight and lean mass, intra-set rest intervals were superior in increasing power output during parallel back squat, 5) absolute power difference in the bench press was greater in the bench press exercise with the use of intra-set rest intervals. Additionally, similar gains in lean mass were experienced between traditional and intra-set rest which resulted in similar changes in MHC isoforms in both groups.

Macronutrient Intake

It is well established that rates of protein synthesis are elevated following an acute bout of resistance training and the consumption of amino acids (i.e., protein) provides a synergistic effect to this response (13, 53). Therefore, protein requirements for individuals involved in a strength training program are higher than for sedentary individuals (7). Dietary intake was not controlled over the duration of the study, however, a nutrition seminar conducted by a registered dietitian was provided prior to the initiation of training. Additionally, subjects were advised to follow the prescribed dietary guidelines and dietary records were obtained throughout the study. The subjects utilized in the current study reported having been actively performing resistance training 3.5±2.0 days per week for the previous 6.5±4.5 years. Baseline dietary analysis demonstrated protein intake to be within the current guidelines (1.8 $g \cdot kg^{-1}$). However, protein intake increased prior to the second dietary analysis with no further increases observed. Total calories and dietary fat intake did not demonstrate any changes from initial recordings. Carbohydrate intake did progressively decline over the course of the 12 week training period. The loss of calories from carbohydrate intake was made up by the high intake of protein over the duration of the training program.

Training Volume

The use of intra-set rest intervals in a program designed to elicit hypertrophy is a novel aspect of the current study. Few studies have reported on the effects of intra-set rest intervals in long-term training (15, 22, 23, 27, 37, 41, 48, 62) and none of these studies have reported on changes in body composition. In order to effectively compare intra-set rest intervals to traditional hypertrophic training, it was necessary to equate total volume as well as intensity throughout the training as manipulation of these factors have been previously shown to affect training adaptations (16, 29). This was accomplished as no differences in total training volume were observed between groups in main lifts or assistive exercises (Table 4).

Strength

In contrast to our original hypothesis, intra-set rest intervals resulted in greater increases in bench press and parallel back squat strength from baseline compared to traditional resistance training. These differences appeared as early as 4 weeks with the ALT group showing a 6.6 kg increase compared to a decrease of -1.4 kg in the STD group ($p = 0.008$). The trend of greater increases from baseline was also observed at 8 and 12 weeks with the ALT group demonstrating an increase of 9.9 kg and 15.1 kg, respectively; compared to the STD group increase of only 2.9 kg and 9.1 kg ($p = 0.018$ and 0.041, respectively). Similar to bench press strength, intra-set rest intervals resulted in greater increases in parallel back squat strength. By 4 weeks ALT showed an increase over baseline of 22.5 kg compared to 16.3 kg in the STD group ($p = 0.084$), with a significant difference being observed by week 8 (ALT, 49.7 kg; STD, 36.9 kg; $p = 0.040$) and continuing through the conclusion of training (ALT, 63.8 kg; STD, 48.5 kg; $p = 0.026$).

Resistance training for the development of hypertrophy is characterized by the performance of repetitions to the point of fatigue, or failure, as evidenced by the need to decrease the load over consecutive sets. While the comparison of intra-set rest intervals to traditional resistance training to elicit hypertrophy was the primary goal of the current study, the performance of continuous repetitions in hypertrophic training to failure warrants a comparison to those studies in which intra-set rest intervals were used to prevent training to failure. Few studies have determined the effect of training to failure on strength gains in a longitudinal periodized program (22, 27, 41, 62). Results from those studies have shown that performance of repetitions to failure increases (22, 62) or has no effect on strength gains (27, 41). However, no studies have determined that not training to failure provided superior strength gains when compared to training to failure.

Lawton et al. (48) reported greater strength gains in the bench press exercise when performing continuous repetitions compared to intra-set rest intervals in a six week strength training program. Differences between our study and that of Lawton et al. (48) may at least partially explain our divergent findings. First, the intensity in our study corresponded to that used for the development of hypertrophy (65-75%1RM), while the intensity of the study conducted by Lawton et al. (48) corresponded to that used for the development of strength (6RM or 85%1RM). Additionally, the 6RM strength testing procedures performed in the study conducted by Lawton et al. (48) were identical to the performance of continuous repetitions. Greater muscular endurance has been reported in the performance of repetitions to failure (41). As Haff et al. (33) suggested, the results from Lawton et al. (48) on strength improvements in those performing continuous repetitions should be expected after the continued performance of successive 6RM over a six week period when compared to intra-set rest intervals in which repetitions were not performed continuously.

Izquierdo et al. (41) demonstrated similar results comparing resistance training to failure and not to failure. In agreement with Lawton et al.(48) they found training to failure resulted in a greater number of repetitions performed; however, they found no significant difference in strength gains as determined by 1RM strength measures. The study by Izquierdo et al. (41) was unique in design as it allowed for multiple comparisons over a 16 week periodized training period to include a peaking phase. The intensities utilized during the first six week cycle corresponded to the intensities used in the current study. In contrast to the results obtained by Izquierdo et al. (41), in the current study strength gains were greater with the use of intra-set rest intervals after only four weeks in the bench press exercise and approached significance after four weeks in the parallel back squat exercise while reaching significant difference by week 8. While both studies utilized the same relative intensities, it is possible the difference in training experience, as well as rest between sets (1 minute vs. 2 minutes) may account for the differing results. Although Izquierdo et al. (41) reported no difference in strength gains; we demonstrate the efficacy of not only intra-set rest intervals but not training to failure in eliciting strength gains suggesting fatigue is not a necessary stimulus for improved strength.

The rationale for training to failure suggests the performance of repetitions to failure results in a progressive recruitment of muscle fibers in accordance with the size principle as the muscle fatigues (67). Increased recruitment of muscle fibers would result in greater stimulation, particularly in the fast MHC_{IIX} fibers, which may be measured using electromyography (EMG) techniques. While the current study did not measure EMG activity, Burd et al. (14) recently demonstrated peak EMG amplitude occurred at 50% of set completion utilizing loads corresponding to 70% 1RM. Additionally, EMG activity was significantly reduced by the third set, compared to the first. Those results suggest when performing successive repetitions with loads corresponding to hypertrophic training, maximal recruitment occurs at approximately 50% completion during the initial set, and performance of repetitions past this point results in reduced activation of fibers which are considered quick to fatigue, primarily MHC_{IIX}. This is not the case when performing with loads corresponding to a 6RM, as Keogh et al. (43) demonstrated EMG activity increased linearly to the last repetition. While EMG is unable to detect fiber type differences, it is well established fast MHC are recruited last and fatigue very quickly. Intra-set rest intervals in the current study divided the number of repetitions performed in traditional hypertrophic training by 50%. This may have resulted in greater neuromuscular activation over the performance of consecutive sets compared to continuous repetitions. The repetitive maximum activation may have resulted in the greater strength gains as demonstrated in the current study. However, further research is needed to answer this question conclusively.

Power

Our original hypothesis stating intra-set rest intervals would result in greater power output of the upper and lower body musculature after 12 weeks of training was supported in part. Intra-set rest intervals resulted in greater increases in power output over traditional hypertrophic training at the conclusion of the training cycle in both the bench press exercise and vertical jump, with an almost significant difference in parallel back squat. In the bench press, the time course of these changes showed the ALT group increased after only 4 weeks (11.1 W), while the STD group demonstrated a decrease (-19.2 W); although not significant ($p = 0.155$). By 8 weeks of training a significant difference was achieved with ALT group increasing 71.4 W compared to 11.3 W in STD ($p = 0.002$). The ALT group demonstrated an 83.0 W increase compared to the relatively moderate increase in the STD group of 33.8 ($p = 0.034$) over the entire training period. Additionally, when power output was evaluated using the initial load from baseline, the ALT group increased 71.0 W compared to a 13.5 W increase in the STD group ($p = 0.046$).

Power output of the parallel back squat followed the same trend as that of the bench press exercise demonstrating a 151.0 W increase in the ALT group by week 8 compared to 97.5 W increase in the STD group ($p = 0.085$). At the conclusion of training the change from baseline in power output of the parallel back squat exercise reached 282.1 W in the ALT group, while the STD group only achieved a 204.9 W increase ($p = 0.059$). We suggest our original hypothesis was supported only in part due to the fact the power difference in the parallel back squat exercise only approached significance. However, the effect size in the ALT group was large compared to the moderate effect size in the STD group according to the magnitude of effect size developed by Rhea (60). When power output was evaluated using baseline loads, there was no significant difference between the ALT and STD groups (129.5 W and 99.3 W; respectively). Again, the magnitude of effect size was moderate for the ALT group and only small in the STD group.

In contrast to the trends observed in both bench press and parallel back squat exercises, the difference between the two training paradigms in power output of the vertical jump took the full 12 week training phase to manifest. Once demonstrated, the difference in change from baseline and magnitude of effect size were both greater in the ALT group where an improvement of 147.7 W was produced compared to 91.6 W in the STD group ($p = 0.034$).

Haff et al. (34) originally proposed that intra-set rest intervals (termed cluster training in the original study) would allow each prescribed repetition of a set to be performed with the highest quality. Previous studies in isolated frog muscle have shown that a decrease in force is closely correlated with an increase in muscle metabolites, primarily H^+ and adenine diphosphate (ADP) (19). Similar studies have demonstrated comparable results in humans (74). In contrast to these results, Sahlin and Ren (63) demonstrated that force is not limited by high H^+ concentration, but the ability to maintain an isometric contraction, or endurance, is diminished possibly due to impaired capacity to resphosphorylate ADP. Recent investigations have demonstrated acidosis is not responsible for the decrease in force or velocity observed over the performance of continuous contractions. For a review see Allen et al. (3) A number of investigations have suggested the accumulation of inorganic phosphate (P_i) may affect velocity of shortening. Increases in P_i occur during muscle contraction, mainly from the breakdown of PCr. Models of cross bridge cycling propose P_i is released in the transition from low force weakly attached states to high force strongly attached states (3). Westerblad et al. suggested this implies that the transition to the high force states is hindered by increased levels of P_i (75). However, research examining the effects of Pi on velocity of shortening are limited (18, 20, 56).

Still another possible metabolite contributing to the decreased velocity of shortening over the performance of repeated contractions is ADP. Increases in $[ADP]_i$ have been suggested to occur during repeated contractions, coincident with PCr depletion (64). Westerblad et al. (76) demonstrated that in the fatigued state, the velocity of shortening was slower following a longer tetanus compared to a shorter contraction. The authors suggested this was due to transient increases in ADP. Partial recovery occurred in a matter of seconds thought to be due to rapid removal of ADP by enzyme action or diffusion. While the exact cause of reduced velocity of shortening is still debated (75), the current study suggests the use of intra-set rest intervals allows for a superior ability to generate power. It is therefore possible, intra-set rest intervals allowed for a partial reduction of either P_i or ADP by enzyme action or diffusion. Furthermore, the intra-set rest interval may have allowed for an almost complete resynthesis of PCr, as after a fatiguing maximum voluntary contraction lasting approximately 54 seconds PCr has been shown to be resynthesized to 67% original concentration in just 2 minutes and 87% after 4 minutes (63). The truncated number of repetitions performed per set, 5 in the current study, would utilize less PCr and result in less metabolite accumulation than more traditional hypertrophic training. While not recorded, it was observed the time to complete the 5 repetitions performed by the ALT group to be approximately 10-15 seconds, while it took almost twice the time for the STD group to complete the desired number of repetitions (20-25 seconds).

Support for the superiority of intra-set rest intervals on power output of the upper and lower body musculature has been provided by acute studies in which greater power output (21.6-25.1%) in the bench press exercise compared to the performance of continuous repetitions has been demonstrated (49), as well as higher peak velocity in the power clean utilizing intra-set rest intervals (34). While these results support the use of intra-set rest intervals in chronic training, long term studies have demonstrated a tendency toward greater gains in power output of the lower body musculature (27, 37), as well as significantly greater gains in power output of the lower body musculature compared to the performance of continuous repetitions in athletes (41). The results of intra-set rest intervals on upper body power output is controversial, with some reporting no difference (23, 27, 41, 48) and one reporting less (22) improvement in power output of the upper body musculature. In the current investigation, we report greater gains in power output of both the upper and lower body musculature after 12 weeks of training.

Differences between the current study and those reporting no difference or less improvement in power output of the bench press exercise may at least partially explain the divergent findings. The intensity used in the current study corresponded to loads for the development of hypertrophy (65-75%). The optimal load for the development of power has been widely studied, however, it has been demonstrated peak power occurs between 40-60% 1RM in the bench press utilizing a Smith machine (69) which was the apparatus used in the currents study. Loads in the current study were greater than those prescribed for bench press power; however, they fall closer to the desired range than intensities used in previous investigations in which no difference or less improvement was observed. Previous studies utilized loads corresponding to a 6RM or approximately 85% 1RM.

The only study to date that has utilized loads similar to the current study was conducted by Izquierdo et al.(41); however, the authors failed to demonstrate differences in power output in the initial phase of training utilizing loads corresponding to10 RM (~75% 1RM) for the bench press. While intra-set rest intervals were not the comparative goal in the study by Izquierdo et al. (41), intra-set rest intervals were utilized to prevent training to failure. Differences between the current study and that by Izquierdo et al. (41) may at least partially explain the different findings. Greater improvements in power output were not completely realized in the current study until 8 weeks of training. The initial phase in which intensity of the two studies was similar lasted only 6 weeks. Therefore, the differences in power output may not have had an opportunity to be realized. Additionally, assessment of power output by Izquierdo et al. (41) involved only the concentric action beginning from a stop position, compared to our determination which allowed a descent phase corresponding to an eccentric component.

In agreement with previous studies, we demonstrated intra-set rest intervals to be superior in the development of lower body power output compared to the performance of intra-set rest intervals. While back squat power only approached significance, the magnitude of effect size was greater for intra-set rest intervals, and when evaluated relative to lean mass significance was reached. Additionally, power output as determined by vertical jump was also greater using intra-set rest intervals. Folland et al. (27) were the first to report a tendency towards greater velocity strength gains using intra-set rest intervals in lower body exercises. Additionally, Hansen et al. (37) recently compared traditional vs. intra-set rest intervals (cluster training) on strength and power of the lower body musculature in elite rugby union players. During the first six weeks intensities corresponded to 80-95% 1RM while the last two weeks utilized heavy load jump squats (80-95% 1RM) and light to moderate ballistic jump squats performed at 0-20% 1RM. Clean pull and power clean intensities ranged from 80-95% 1RM. Intra-set rest intervals were only used in strength and power training involving squat and clean movements. Calculations of magnitude-based inference demonstrated a likely positive effect of intra-set rest intervals in peak power and peak velocity at 40 kg, and peak velocity at bodyweight during the jump squat. The authors concluded traditional style training resulted in greater strength improvements while some evidence suggests a possible benefit for intra-set rest intervals in lower body power development.

It has been demonstrated peak power occurs between 50-70% in the parallel back squat exercises utilizing a Smith machine (69). The loads in the current study fall within this range (65-75%). Izquierdo et al. (41) have been the only group to demonstrate significantly greater gains in lower body power output after long term training. Unique in design, the study by Izquierdo et al. allowed multiple comparisons in a 16 week training period corresponding to three micro-cycles using intensities associated with the development of hypertrophy, strength and power. During the first 6 weeks, subjects performed 3 sets of 10 (10RM) repetitions or 6 sets of 5 (10RM) repetitions corresponding to a hypertrophic phase. Strength training commenced in week 7 and lasted 5 weeks with subjects performing either 3 sets of 6 (6RM) repetitions or 6 sets of

3 (6RM) repetitions. Training concluded with both groups performing 3 sets of 2-4 repetitions with intensities corresponding to 85-90% 1RM. Differences in power output were not observed until the last testing session. This is unique as there were no differences in training intervention during the last 5 weeks. Based on the current results and those from other studies, adaptations may have occurred during the initial few weeks of training and not been realized until the end of training.

Abdessemed et al. (1) compared the effects of different intra-set rest intervals utilizing 70% 1RM loads. The authors utilized 10 sets of 6 repetitions with the corresponding load with 1, 3 and 5 minutes rest. Results demonstrated no difference in power output between 3 and 5 minute intra-set rest intervals, while 1 minute intra-set rest interval was associated with reduced mean power output. While these results favor greater rest periods in intra-set rest intervals, they did not compare these to the traditional hypertrophic training model. The use of 1 minute intra-set rest interval in the current study provides for greater increases in power output compared to traditional hypertrophic training. Abdessemed et al. (1) have demonstrated an even greater power output can be obtained by increasing the intra-set rest interval time. However, from a practical standpoint, the use of 1 minute intra-set rest interval in the current study allowed the training time to be similar in length, whereas while greater intra-set rest interval length may provide superior results, the time to complete the training would be sufficiently extended. The length of time is of importance when designing resistance training programs, particularly to the collegiate strength and conditioning professional as time with athletes may be limited by rules and regulations.

Hypertrophy

As previously stated, few studies have reported on the effects of intra-set rest intervals in long-term training (15, 22, 23, 27, 37, 41, 48, 62) and none of these studies have reported on changes in body composition. In support of our original hypothesis, training with traditional and intra-set rest intervals resulted in similar increases in lean mass over the duration of the 12 week training program. Increases in lean mass were observed in week 4 (0.73 kg) and week 8 (1.5 kg); with no significant increase observed over the final 4 weeks (1.6 kg). In the current study, rest intervals were short and congruent with current recommendations for the development of hypertrophy (6). The use of shorter rest intervals using moderate intensities has been associated with greater acute elevations in growth hormone when compared to longer rest periods using higher intensity loads (47). However, Ahtiainen et al. (2) demonstrated that hormonal and hypertrophic response did not vary when short (2 minutes) or long (5 minutes) rest intervals were utilized in a chronic training program when volume was equated. There were no differences in total volume over the 12 week training period in either the multi-joint upper or lower body major lifts or single joint assistive lift exercises ($p > 0.05$). These data support the previous work by Ahtiainen et al. (2) demonstrating similar hypertrophic response regardless of rest intervals when volume and intensity are equated.

Contrary to our original hypothesis, no significant differences were observed between groups in changes in myosin heavy chain isoforms after 12 weeks of resistance training. Both groups experienced a significant increase in MHC_{IIA} with a concomitant reduction in MHC_{IIX}. Furthermore, a small decrease in MHC_{slow} was also observed, although when evaluating percentage change from baseline this did not reach significance. It is well established; the increase in lean mass associated with hypertrophic training is accompanied by a shift in MHC isoforms, identified by a decrease in the percentage of MHC_{IIX} fibers with a concomitant increase in $MH_{IIA/X}$ and MHC_{IIA} fibers (16, 28, 59). However, Liu et al. (50) previously reported strength training combined with ballistic exercise lead to a differential effect on MHC shifts after 12 weeks of training, shifting from percentage MHC_{slow} to MHC_{IIA}. While the training protocol in the current study did not explicitly include ballistic movements, the use of intra-set rest intervals has been shown to result in greater velocity of contraction compared to traditional resistance training (34, 36).

The differences in intensity and length of time of the current protocol and that of Liu et al. (50) may at least partially explain our divergent findings. Liu et al. (50) utilized loads corresponding to a much higher intensity than the one used in the current protocol, 93% 1RM vs. 65-75% 1RM. Additionally, the length of training of the current study was twice that of the study by Liu et al. (17), 12 weeks vs. 6 weeks, respectively. Both protocols fall within the time course of adaptations as have been previously reported, occurring in as little as 4 weeks in males (70). However, Claflin et al. (17) recently suggested that an alternative explanation must be responsible for the enhanced fiber function as a result of high-velocity training as that group did not find any differences at the single fiber level in size, force or power of type II fibers after 14 weeks of training with high-velocities. While Claflin et al. (17) did not directly assess changes in MHC_{IIA} and MHC_{IIX}, the results from the current study and that of Claflin et al. (17)

suggest that the increased performance evidenced as a result of high-velocity contractions may in fact result from neural adaptations (55) rather than physiological adaptations.

Practical Applications

The results from the current study support the use of intra-set rest intervals during training for muscle hypertrophy. Intra-set rest intervals resulted in greater gains in strength and power output when compared to traditional hypertrophic training. Furthermore, intra-set rest intervals produced similar gains in lean mass over the course of the training period. The length of time prescribed in the current study for intra-set rest intervals did not impact the total training time. This is of importance to coaches and strength and conditioning professionals who have rules and regulations dictating the time allowed for training. Based on these results, it could be suggested the incorporation of intra-set rest intervals in the hypertrophic phase of a traditional or non-traditional periodized training program would allow for greater improvements in strength and power. Whether these improvements would result in greater gains in strength and power output over an entire mesocycle is unknown, but hypothetically entering the strength and power phases of a training mesocycle at higher performance ability (strength and power) would allow a continued improvement above that achieved during traditional training models.

Conclusions

The purpose of this dissertation study was to determine the effects of intra-set rest intervals on performance measures and MHC adaptations after a 12 week resistance training program designed to elicit hypertrophy. The results obtained herein suggest intra-set rest intervals are superior to traditional resistance training for hypertrophy as evidenced by the greater gains in both strength and power output of the upper and lower body musculature when intra-set rest intervals were utilized. Furthermore, intra-set rest intervals resulted in the same physiological adaptation in MHC and body composition, further demonstrating the advantage of using intra-set rest intervals in hypertrophic training.

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APPENDIX A

CONSENT FORM

CONSENT FORM

Effects of Altering Rest to Work Ratio in a Hypertrophic Training Program

Introduction

The purpose of this form is to provide you information that may affect your decision as to whether or not to participate in this research study. If you decide to participate in this study, this form will also be used to record your consent.

You have been asked to participate in a research project studying the effect of altering the rest to work ratio in a standard hypertrophic resistance training protocol. The purpose of this study is to determine if altering the rest to work ratio as well as sets and repetitions impacts strength, power, and muscle mass. You were selected to be a possible participant because you informed the researchers you were a healthy male between the ages of 20 and 40 and have been resistance training for at least 2 years and have informed researchers that you:

1. Do not have any metabolic disorders including known electrolyte abnormalities; heart disease, arrhythmias, diabetes, thyroid disease, or hypogonadism;
2. Do not have a history of hypertension, hepatorenal, musculoskeletal, autoimmune, or neurologic disease;
3. Do not have any bleeding disorders
4. Are not taking thyroid, anti-hyperlipidemic, hypoglycemic, anti-hypertensive, anti-inflammatory (these include any corticosteroids, i.e. cortisone, or any over the counter non steroidal anti-inflammatory medications which includes medications containing aspirin, ibuprofen contained in Advil and Motrin, or naproxen contained in Aleve) or androgenic medications;
5. Have not taken ergogenic levels of nutritional supplements that may affect muscle mass (e.g., creatine, HMB), insulin-like substances, or anabolic/catabolic hormone levels (DHEA, etc.) within six months prior to the start of the study and/or creatine naïve ideally.

This study is being sponsored/funded by the National Strength and Conditioning Association.

What will I be asked to do?

If you agree to participate in this study, you will be asked to record all food ingestion on food record forms for four days (4-d) for the entire duration of the study. You will be asked to attend a familiarization session in which you will be shown exercises that you will be asked to complete during testing and training.

Baseline Testing

You will be weighed, have your body composition measured using dual energy x-ray absorptiometry, and have your one repetition maximum determined on a smith machine for both the back squat and bench press. You may then be asked to participate in a pilot study looking at the muscle activity during two different training sessions. If you are asked to participate in pilot testing, you will return to the laboratory after strength testing and perform the back squat and bench press at a percentage of your maximum while having your muscle activity recorded via electrodes placed on your skin. One week later you will be asked to return to the laboratory and do the same workout again with a different set and repetition scheme.

After pilot testing, you will be asked to participate in strength and power testing as well as body weight and body composition testing. Testing will take place over two days and will be separated by at least 48 hours. You will also be asked to provide a muscle sample from your leg muscle for us to determine your fiber composition. Muscle biopsies will be obtained using the Bergstroem technique (2 biopsies during the study), which involves a ¼ incision on the skin and the use of a 5mm biopsy needle. Local anesthetic will be used prior to incision and biopsy. Percutaneous muscle biopsies (50-70 mg) will be obtained from the middle portion of the vastus lateralis muscle (thigh muscle covering the outermost portion of the front of the leg) of one leg at the midpoint between the knee and hip joint at a depth between 1 and 2 cm. For the remaining biopsy, attempts will be made to extract tissue from approximately the same depth and area as the initial biopsy by using the pre-biopsy scar, depth markings on the needle, and a successive incision that will be made approximately 0.5 cm to the former from medial to lateral. All these procedures will be conducted again at the conclusion of the training program. Prior to beginning training, you will also have a small amount of blood drawn (approximately 20 ml).

Training Program

You will then be asked to participate in a training program designed to increase lean mass. You will be asked to train four times a week for 12 weeks. Your training sessions will be supervised by trained personnel. You will have your body composition, strength and power tested every fourth week of the study for a total of 4 times (including pre and post). You will also be asked to drink a nutritional supplement that is commercially available at the end of every workout.

You will also have a small amount of blood drawn from your arm (approximately 20 ml) three times during the 3rd, 7th, and 11th week corresponding to 24, 48 and 72 hours after your last workout to test for markers of muscle damage. Training will last approximately 1 hour 4 times per week. The total time involved in this study is approximately 14 weeks.

What are the risks involved in this study?

The risks associated with this study are you will be in contact with a very low level of radiation during body composition testing. This is a standard procedure for the measurement of body composition and the level of radiation is similar to that experienced in a flight from Houston to Dallas on a commercial airline. The exercise tests that will be performed may cause symptoms of fatigue, shortness of breath, and/or muscular fatigue/discomfort. The exercise tests may also cause short-term muscle soreness and moderate fatigue for several days following the tests. The exercise tests will be performed by trained personnel and monitored to ensure appropriate compliance. Risks associated with blood sampling include minor discomfort at puncture site and possible bruising. There is a slight risk of contracting an infection, however, only trained phlebotomist will be performing blood sampling using previously approved sterilization procedures.

The biopsy procedure carries the risk of the following complications which include sores (100%), infection (<1%), and permanent numbness (<<1%). Additional risks include discomfort, bleeding and possible scarring at biopsy site. If problems occur as a result of biopsy procedure please contact Jonathan Oliver (214)649-3887 24 hours a day.

What are the possible benefits of this study?

The possible benefits of participation are you will receive a comprehensive body composition analysis, dietary analysis, as well as an assessment of your current strength and power based on standard athletic testing procedures. You will also receive information regarding your current muscle status and composition as well as a training program known to increase muscle size.

Do I have to participate?

No. Your participation is voluntary. You may decide not to participate or to withdraw at any time without your current or future relations with Texas A&M University being affected.

Will I be compensated?

You will receive $25 for each biopsy obtained. Disbursement will occur at the conclusion of individual testing.

Who will know about my participation in this research study?

This study is confidential. The records of this study will be kept private. No identifiers linking you to this study will be included in any sort of report that might be published. Research records will be stored securely and only researchers within the Exercise and Sports Nutrition Laboratory will have access to the records.

Whom do I contact with questions about the research?

If you have questions regarding this study, you may contact Jonathan Oliver, (214)649-3887, joliver@hlkn.tamu.edu .

Whom do I contact about my rights as a research participant?

This research study has been reviewed by the Human Subjects' Protection Program and/or the Institutional Review Board at Texas A&M University. For research-related problems or questions regarding your rights as a research participant, you can contact these offices at (979)458-4067 or irb@tamu.edu.

Signature

Please be sure you have read the above information, asked questions and received answers to your satisfaction. You will be given a copy of the consent form for your records. By signing this document, you consent to participate in this study.

Signature of Participant: ______________________________ Date: ____________

Printed Name:
____

Signature of Person Obtaining Consent: ______________________Date: _____________

Printed Name:
____

APPENDIX B

PERSONAL INFORMATION WORKSHEET

PERSONAL INFORMATION WORKSHEET

Texas A&M University
EXERCISE & SPORT NUTRITION LABORATORY

Personal Information

Name: ____

Address: ____

City: __________________ State: ______ Zip Code ______ SS# ____________________

Home Phone: (___) _____________________ Work Phone: (___) _____________________

Beeper: (___) _____________________ Cell Phone: (___) _____________________

Fax: (___) ______________ E-mail address:__________________________

Birth date: _____ / _____ / ______ Age: ______ Height: __________ Weight: __________

Exercise History/Activity Questionnaire

1. Describe your typical occupational activities.

2. Describe your typical recreational activities

3. Describe any exercise training that you routinely participate.

4. How many days per week do you exercise/participate in these activities?

5. How many hours per week do you train?

6. How long (years/months) have you been consistently training?

APPENDIX C

MEDICAL HISTORY QUESTIONNAIRE

MEDICAL HISTORY QUESTIONNAIRE

Texas A&M UNIVERSITY

EXERCISE & SPORT NUTRITION LABORATORY

Medical History Inventory

Directions. The purpose of this questionnaire is to enable the staff of the Exercise and Sport Sciences Laboratory to evaluate your health and fitness status. Please answer the following questions to the best of your knowledge. All information given is **CONFIDENTIAL** as described in the **Informed Consent Statement.**

Name:______________________________ Age _____Date of Birth_______________

Name and Address of Your
Physician:____

MEDICAL HISTORY

Do you have or have you ever had any of the following conditions? (Please write the date when you had the condition in the blank).

____Heart murmur, clicks, or other cardiac findings?
____Asthma/breathingdifficulty?
____ Frequent extra, skipped, or rapid heartbeats?
____Chest Pain of Angina (with or without exertion)?
____High cholesterol?
____Diagnosed high blood pressure?
____Heart attack or any cardiac surgery?
____Leg cramps (during exercise)?
____Chronic swollen ankles?
____Varicose veins?
____Frequent dizziness/fainting?
____Muscle or joint problems?
____High blood sugar/diabetes?
____Thyroid Disease?
____Low testosterone/hypogonadism?
____Glaucoma?
____Bleeding Disorders

____Bronchitis/Chest Cold?
____Cancer, Melanoma, or Suspected Skin Lesions?
____Stroke or Blood Clots?
____Emphysema/lung disease?
____Epilepsy/seizures?
____Rheumatic fever?
____Scarlet fever?
____Ulcers?
____Pneumonia?
____Anemias?
____Liver or kidney disease?
____Autoimmune disease?
____Nerve disease?
____Psychological Disorders?

Do you have or have you been diagnosed with any other medical condition not listed?

____

____

Please provide any additional comments/explanations of your current or past medical history.

____

____

Please list any recent surgery (i.e., type, dates etc.).

____

____

List all prescribed/non-prescription medications and nutritional supplements you have taken in the last 3 months.

____

____

What was the date of your last complete medical exam?

____

____

Do you know of any medical problem that might make it dangerous or unwise for you to participate in this study? (including strength and maximal exercise tests) ____ If yes, please explain: __________________

____

____

Recommendation for Participation (for ESNL use only):

_____ No exclusion criteria presented. Subject is ***cleared*** to participate in the study.
_____ Exclusion criteria is/are present. Subject is ***not cleared*** to participate in the study.

Signed: ______________________________________ Date: ________________________

APPENDIX D

POWER TESTING FORM

TIMEPOINT: (circle)

Name: ______________________ **1 2 3 4**

NOTE: USE FEET AND HAND PLACEMENT TAKEN AT T1 FROM STRENGTH FORM

Procedure: Have subject perform warm up and vertical jump test. Followed by 3 sets 5 reps 40-50% 1RM, then test 3 sets for maximum power with 2 min rest between. If 3rd average power greater than set 1 and 2, another set is allowed.

BS1RM (lbs)	400
40% (lbs)	160
50% (lbs)	200
60% (lbs)	240
60% (kgs)	109
T1 BS1RM	245
60% ABS	145
60% ABS (kgs)	66

Relative (60% 1RM)	**Set 1**	**Set 2**	**Set 3**	**Set 4**	**Set 5**
average power (watts)	______	______	______	______	______
average velocity (m/s)	______	______	______	______	______
peak power (watts)	______	______	______	______	______
peak velocity (m/s)	______	______	______	______	______

Absolute (60% T1 1RM)	**Set 1**	**Set 2**	**Set 3**	**Set 4**	**Set 5**
average power (watts)	______	______	______	______	______
average velocity (m/s)	______	______	______	______	______
peak power (watts)	______	______	______	______	______
peak velocity (m/s)	______	______	______	______	______

BP1RM (lbs)	220
40% (lbs)	90
50% (lbs)	110
60% (lbs)	130
60% (kgs)	59
T1 BP1RM	205
60% ABS	125
60% ABS (kgs)	57

Relative (60% 1RM)	**Set 1**	**Set 2**	**Set 3**	**Set 4**	**Set 5**
average power (watts)	______	______	______	______	______
average velocity (m/s)	______	______	______	______	______
peak power (watts)	______	______	______	______	______
peak velocity (m/s)	______	______	______	______	______

Absolute (60% T1 1RM)	**Set 1**	**Set 2**	**Set 3**	**Set 4**	**Set 5**
average power (watts)	______	______	______	______	______
average velocity (m/s)	______	______	______	______	______
peak power (watts)	______	______	______	______	______
peak velocity (m/s)	______	______	______	______	______

APPENDIX E

STRENGTH TESTING FORM

Name: ____________________

Squat feet placement (measured at T1 only)

left foot heel (measured from right)	16.5
right foot heel (measured from right)	16.5
left foot outside (measured from top)	35.5
right foot outside (measured from top)	10
90 degrees	13

Bench hand placement (measured at T1 only)

distance between hands	24

	T1	**T2**	**T3**	**T4**
Date:	________	________	________	________

Estimate 1RMBS	405
Estimate 1RMBP	265
Estimate 1RMLP	0

Back Squat

Reps	Resistance	%Old 1RM	Achvd Reps
5	162	40%	________
5	203	50%	________
5	243	60%	________
(2-3)	284	70%	________
(2-3)	324	80%	________
1	365	90%	________
1	385	95%	________

Leg Press

Reps	Resistance	%Old 1RM	Achvd Reps
5	0	40%	________
5	0	50%	________
5	0	60%	________
(2-3)	0	70%	________
(2-3)	0	80%	________
1	0	90%	________
1	0	95%	________

Bench Press

Reps	Resistance	%Old 1RM	Achvd Reps
5	106	40%	________
5	133	50%	________
5	159	60%	________
(2-3)	186	70%	________
(2-3)	212	80%	________
1	239	90%	________
1	252	95%	________

APPENDIX F

VERTICAL JUMP FORM

TIMEPOINT: (circle)

Name: ______________________________ **1 2 3 4**

Procedure: Have subject perform warm up and vertical jump test. Three attempts, if third is better than first and second, then they get another go. Max of 5 jumps.

Weight (lbs) ____________

Weight (kgs) ____________

Reach Height (in) ____________

Jump Height (in)

1st Attempt ____________

2nd Attempt ____________

3rd Attempt ____________

4th Attempt ____________

5th Attempt ____________

Best Jump (Jump height - Reach height)

____

VITA

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