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Effect Of Load Reductions Over Consecutive Sets On Repetition Performance

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EFFECT OF LOAD REDUCTIONS OVER CONSECUTIVE

SETS ON REPETITION PERFORMANCE

(TITLE)

BY

MAUREEN KHAIRALLAH

THESIS

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ABSTRACT

In order to achieve specific muscular adaptations, repetitions need to be maintained within a certain repetition range throughout consecutive sets; however, maintaining repetition performance can be difficult when using short rest intervals (i.e. ≤ 1-minute). Therefore, purpose of this study was to determine whether a 0%, 5%, 10%, or 15% decrease in resistance would be the most effective in maintaining repetitions over consecutive sets in the squat, leg curl, and leg extension. Eleven male college students volunteered to participate in the seven week study. Each participant was tested over the first three weeks, with one testing session each week. During these testing sessions, a 10-RM was assessed for the free weight parallel squat, leg curl, and leg extension. The last four weeks were used to assess which condition (0%, 5%, 10%, 15%) enabled each subject to maintain repetitions over three sets of each exercise using the 10-RM that was established during the first three weeks. The subjects were randomly assigned to each condition. Participants completed one condition each week. During conditions 2, 3, and 4 (i.e. 5%, 10%, 15% decrease in load) the resistance was lowered after the first and second sets of each exercise; however, the weight was held constant for all three sets in each exercise during condition 1. Subjects were only given 1-minute of rest between each set and 2-minutes of rest between exercises.

Post hoc pairwise comparisons indicated that when averaged across sets, significantly fewer repetitions were accomplished for the back squat and leg curl in condition 1 versus 4 ($p < 0.05$). Conversely, for the leg extension, there were no significant differences in the repetitions accomplished between conditions ($p > 0.05$).

Post hoc pairwise comparisons also indicated that for set 3, significantly fewer repetitions (across exercises) were accomplished for conditions 1, 2, and 3 versus condition 4 ($p < 0.05$). Overall, subjects were able to maintain a 10-RM range for all three sets with the use of a 15% drop in resistance after the first and second set in the back squat and leg curl. Results also indicated that the load could be kept constant over all three sets for the leg extension. Hypertrophy occurs in skeletal muscles in response to specific types of resistance training. According to previous studies, individuals will experience the greatest gains in muscle size when repetitions are maintained around ten with short rest intervals between sets (e.g. 60-seconds). In summary, the current study demonstrated that a 10-RM could be maintained over three sets by dropping the resistance 15% after the first and second sets.

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I would like to thank my parents, Maroun and Eugenie Khairallah, for providing me with the opportunity to receive an education. They have sacrificed their time and lives and set their own interests aside to put my sisters and me first, and I am very grateful. I know I will never be able to repay them for everything they have done, but I hope one day I will be able to give back at least a fraction of it.

Maureen Khairallah

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CHAPTER I

INTRODUCTION

When designing any type of resistance training program, it is important to establish a training goal. Muscles will adapt differently according to the type of training stimulus imposed. This is known as the concept of specificity. By manipulating variables such as exercise mode, intensity, volume, frequency, velocity, and rest between sets, participants can emphasize certain outcomes such as absolute muscular strength, localized muscular endurance, muscular hypertrophy, or power (Miranda et al., 2007). One factor that has been studied less frequently is the rest interval between sets.

A one repetition maximum is the absolute maximum load an individual can lift one time in a certain exercise. Absolute strength can be achieved by using heavy resistance (e.g. >90% of 1RM) with low repetitions per set (e.g. 1-5) and taking long rest periods between sets (e.g. 2-3 minutes). Conversely, muscular endurance is attained by using low resistance (e.g. <70% of 1RM) with higher repetitions (e.g. >12) and short rest periods between sets (e.g. 30 seconds-1 minute).

By maintaining repetitions in a specific target range throughout consecutive sets, individual's can attain a specific training goal or muscular adaptation. Hypertrophy occurs when short rest intervals are utilized between sets (i.e. $\leq$ 1 minute); however, maintaining repetitions over two or three sets is difficult with a short amount of rest. In order to maintain repetitions within these conditions, another variable is altered. Often, that variable is intensity; however, no study has been conducted that addresses the amount of load reduction that might be necessary to maintain consistency in repetition performance at a specific intensity.

It is difficult to maintain repetitions with short rest intervals. Numerous studies have addressed various rest interval lengths on maintenance of repetitions at a given repetition maximum. One, for example, was conducted by Willardson & Burkett (2005). The study demonstrated that there was a direct relationship between rest interval length and number of repetitions completed per set. Longer rest intervals resulted in more repetitions. The fifteen subjects completed four sets of the squat and bench press using an 8 repetition maximum (RM). Each exercise was performed with a 1-, 2-, or 5-minute rest interval between sets. The results from the study indicated that the 5-minute rest interval produced the highest volume.

Therefore, the purpose of this study is to determine how much percentage drop is necessary in order to maintain repetitions throughout three sets in three different lower body exercises (squat, prone leg curl, seated leg extension) with the use of short rest intervals.

Hypothesis

It is hypothesized that a 15% reduction in resistance after the first and second set would enable recreational lifters to maintain ten repetitions throughout consecutive sets and exercises.

CHAPTER II

REVIEW OF THE LITERATURE

The studies incorporated into this literature review focused on the effects of different rest intervals between sets, the effects of different repetition ranges on the work accomplished, and acute and chronic physiological outcomes. The rest interval between sets and the repetition range maintained over consecutive sets are key variables in any resistance training program. Manipulating the rest interval and/or repetition range can alter the adaptations associated with a training regimen. Although other variables (e.g. velocity, training frequency) can also affect the outcome, this literature review focused on the rest interval and repetition range.

Rest Interval: Maintaining Repetitions/Volume

Bodybuilders and Power-lifters are infamous for changing their intensity and rest intervals between sets to achieve desired outcomes. Bodybuilders' main goal is to increase muscle size, not necessarily absolute strength. Increases in muscle size are accomplished through the use of moderate loads (e.g. 80-85% of 1RM) and shorter rest intervals between sets (e.g. 1-2 minutes). Conversely, Power-lifters' utilize greater intensities (e.g. >90% RM) and longer rest intervals between sets (e.g. 3-5 minutes) to build absolute muscle strength.

One of the challenges in utilizing shorter rest intervals between sets, as in bodybuilding style training, is a decrease in the repetitions performed over consecutive sets. Willardson & Burkett (2005) demonstrated that the total number of repetitions increased as the rest interval between sets increased from 1-minute to 5-minutes. Four sets of the squat and bench press were completed using an 8 repetition maximum (8-RM). Fifteen college-aged men performed each exercise with a 1-, 2-, or 5-minute rest interval between sets. The men were considered experienced recreational lifters in that they performed three strength workouts per week during the previous three years.

One testing session took place each week (Willardson & Burkett, 2005). The first week was used to assess each participant's 8-RM. Four sets of the squat and bench press were tested each week for three weeks using the different rest intervals. The repetition cadence was consistent at 3-seconds for the eccentric phase and 1-second for the concentric phase. This was monitored using a hand held stop-watch.

Overall, Willardson & Burkett (2005) demonstrated that the 5-minute rest interval between sets resulted in the highest total repetitions completed over four sets when training with an 8-RM load. However, a key finding was the lack of significant differences in volume between the 1- and 2-minute rest conditions for the squat, which indicated that these men possessed greater endurance when performing the squat versus the bench press. This may be due to the greater use of the lower body muscles during activities of daily living.

Based on previous research (Wier et al. (1994), Matuszak et al. (2003), Todd et al. (2001), Kraemer (1997), Willardson & Burkett (2005, 2006B), and Richmond and Godard (2004)), the maintenance of repetitions is related to the load lifted. Variations in the load lifted and the resulting time under tension emphasizes different energy systems. Willardson & Burkett (2005) demonstrated that participants were able to accomplish more repetitions for the squat than for the bench press when utilizing the same rest interval and relative load. This may indicate a greater amount of muscular endurance in the lower body versus the upper body. Therefore, resting 1-minute for lower body exercises (e.g. squat) and 2-minutes for the upper body exercises (e.g. bench press) might be sufficient to maintain repetitions over consecutive sets performed to failure.

In 2006(A), Willardson & Burkett demonstrated that the decline in repetitions was similar whether utilizing 50% or 80% of a 1-RM load over five consecutive sets with 1-, 2-, or 3-minute rest intervals between sets. Sixteen recreationally trained men volunteered to participate in this study. Data was collected over four weeks. Week one was used to assess each participant's 1-RM in the bench press. Testing took place two days per week on weeks 2, 3, and 4. During each week, the first testing session consisted of performing five sets to failure at 80% 1-RM and five sets to failure at 50% 1-RM during the second testing session. The two testing days were separated by 72 hours. The results demonstrated that the sustainability of repetitions over five consecutive sets were similar for the 50% and 80% of 1-RM loads and the total repetitions increased linearly as the length of the rest interval between sets increased.

In similarly designed studies, Wier et al. (1994), Matuszak et al. (2003), and Todd et al. (2001) demonstrated that 1- to 2-minute rest intervals between sets were sufficient to maintain repetitions when training with loads greater than 90% of 1 RM. Conversely, when training with loads less than or equal to 80% of 1 RM, Kraemer (1997), Willardson & Burkett (2005), and Richmond and Godard (2004), all found that 3- to 5-minute rest intervals were necessary to prevent drastic declines in repetitions.

Todd et al. conducted a study that assessed bench press repetitions at 85% of 1-RM. Results demonstrated that 3- to 6-minute rest intervals resulted in similar repetitions when working at that intensity level (as cited in Todd et al., 2001). Ratamess et al. (2007) also demonstrated that when training with 75% and 85% of a 1-RM, participants were able to maintain consistent repetitions throughout 4 of the 5 sets in the bench press exercise when using a 5-minute rest interval between sets.

Another study conducted by Todd et al. (2001) focused on the bench press exercise; participant's completed three sets to failure using 1-, 2-, 3-, 4-, 5-, and a "preferred" minute rest interval between sets. Todd et al. (2001) wanted to address if resting 3- to 6-minutes between sets applies to other intensities; therefore, twenty-two recreationally trained men were tested using 60% and 90% of their 1-RM for the bench press. Results demonstrated a significant difference in optimum rest interval length between the two intensities. At 60% of 1-RM, bench press repetitions were highest when resting 4- to 5-minutes between sets. Conversely, at 90% of 1-RM, bench press repetitions peaked with only 2-minutes rest between sets. Interestingly, the "preferred" rest interval was measured to be approximately between 4- to 6-minutes.

As shown in these various studies, rest interval between sets and intensity can alter an individual's performance in certain exercises. According to Weiss, when training at intensities greater than 90%, two minutes of rest is sufficient because the body relies more upon intramuscular adenosine triphosphate and phosphocreatine (PCr) energy stores for muscular contraction (as cited in Willardson and Burkett, 2006 B). Restoration of PCr occurs very quickly. Approximately half of the used PCr is replenished within 30 seconds of recovery (Harris et al. as cited in Willardson and Burkett, 2006B). When training with sub-maximal loads (i.e. >80% of 1RM), greater rest is needed. They body is now dependent upon anaerobic glycolysis to supply the energy needed for muscular contraction (Weiss as citied in Willardson and Burkett, 2006B). During anaerobic glycolysis, the fast twitch fibers are recruited. Large amounts of hydrogen ions accumulate within these fibers during low- to moderate-intensity resistance exercises performed to failure. An increase in hydrogen ions lowers the intracellular pH which in turn causes muscle fatigue (Larson and Potteiger, 1997). According to Larson and Potteiger (1997), the time needed for the removal of hydrogen ions and peak cellular lactate from the contracting muscles has been shown to be 4-10 minutes. This gives reason as to why bench press repetitions were highest when resting 4- to 5-minutes between sets when training at 60% of 1-RM.

Kraemer (1997) assessed the consistency in repetition performance when performing three sets to failure with a 10-RM in the bench press and leg press exercises. Twenty Division I football players completed the same workout for these exercises with 1-minute or 3-minutes rest intervals between sets. This study demonstrated that each player was able to complete 3 sets of 10 repetitions with the 3-minute rest interval for both the bench press and leg press. Repetitions were greatly decreased when the 1-minute rest interval was utilized.

When 1-minute rest intervals are used (when training with non-maximal loads, < 90% 1-RM), it is important to realize that blood lactate concentrations tend to increase greatly when resistance exercises are performed to failure. Hydrogen ions accumulate causing the pH within the muscles to decrease. The increase in hydrogen ions in the muscles inhibits the muscles from contracting due to reduced release of calcium from the sarcoplasmic reticulum, which in turn results in a decrease in performance of repetitions (Kraemer, 1997; Willardson & Burkett, 2005, 2006 A, 2006 B; Larson & Potteiger, 1997). According to Larson & Potteiger, it takes 4-10 minutes to transport hydrogen ions out of the contracting muscle tissue (as cited in Willardson & Burkett, 2006 B).

Numerous studies have demonstrated that when performing multi-joint exercises such as the bench press and squat, the number of repetitions completed per set tends to decrease when rest intervals are shortened. Garcia-Lopez et al. (2007) examined whether this also occurred in single-joint exercises (i.e. arm-curl machine). They also looked at the changes in mean velocity over a moderate-intensity set to failure. In order to assess the changes in mean velocity, the resistance was set at 60% of the pre-training maximum voluntary isometric contraction (MVIC). In order to obtain the MVIC, each participant performed two maximal 5-second isometric bilateral elbow flexions at a 90° joint angle. Three minutes of rest was given between each attempt. Each individual's highest force output determined the resistance utilized in the study. The angular velocity of elbow flexion was measured for each subject. Angular velocity was assessed by performing a maximal repetitive high-power output set to failure with a sub-maximal load of approximately 60% of the subject's MVIC. The arm-curl machine was also used in this test.

The second purpose of the study was to examine the neuromuscular adaptations that occurred by the two different rest period training protocols. Twenty-one untrained participants were divided evenly into three groups: short rest (SR) between sets (i.e. 1 minute), long rest (LR) between sets (i.e. 4 minutes) and a non-training control group (CG). Two days per week for five weeks, the SR and LR group trained using the arm-curl machine. Both groups completed 3 sets to failure at 60% of their MVIC for the first two weeks of training. The intensity increased to 65%, 70%, and 75% during weeks 3, 4, and 5, respectively. This study demonstrated that participants that rested 4-minutes between sets were able to maintain repetitions for the first two sets. Participants that rested only 1-minute were not able to maintain repetitions for any of the sets. The LR group completed 31.6% more repetitions than the SR group (448 ± 86 vs. 343 ± 72 repetitions). Although training with shorter rest intervals may not result in a greater number of repetitions completed, these participants also experienced less fatigue and were able to maintain repetition velocity throughout the five weeks of training. This may be due to the body's adaptation to the short rest interval training and its efficiency in removing hydrogen ions. The results from the study demonstrated that resting 1-minute between sets allows individuals to maintain a higher repetition velocity, delays the rate at which velocity decreases over a set of repetitions to failure, and is more efficient for improving local muscular endurance.

In their study, Richmond & Godard (2004) concluded that 3-minutes of rest between sets was sufficient to maintain an 8-12 repetition range over two sets; however, regardless of the rest interval used, recreational lifters will find it more difficult to maintain repetitions compared to highly trained participants such as Bodybuilders or Power-Lifters. Research has even shown that Power-Lifters and Bodybuilders were able to maintain performance in repeated sets of the bench press when a 3-minute rest interval was used (Kraemer; Kraemer, Adams et al.; Kraemer, Noble et al.; Pearson, Feigenbaum et al., as cited in Richmond & Godard, 2004). As stated by Abdessemed et al., highly trained participants are capable of repeating performance with shorter rest intervals because enzymatic activity is enhanced which in turn results in a greater energy restoration capacity (as cited in Richmond & Godard, 2004). Therefore, it is important to not overlook the participants training history when determining the length of the rest interval between sets.

Larson and Potteiger (1997) compared three different methods of recovery when performing squat sets to failure: 1) a post-exercise heart rate, 2) a fixed 3-minute interval, and 3) a fixed 1:3 work:rest ratio. Participants performed four sets to failure with 85% of their 10-RM. Results from this study demonstrated that each method was equally effective as a means of recovery. However, the post-exercise heart rate recovery condition resulted in a slightly greater volume (43.0 +/- 1.8 total repetitions for the 4 sets) than the other two conditions. The 1:3 work:rest ratio recovery condition was the second best (41.6 +/- 2.3 repetitions) followed by the 3-minute timed interval (40.9 +/- 1.8 repetitions). Although the post-HR recovery condition produced the best results, the total number of repetitions completed did not differ significantly among conditions. These results indicated that using various recovery methods can be equally effective when conducting any type of research that involves resistance training. Also, participants wanting to make the best use of their time in the weight room can revert to these types of recovery methods rather than sticking to the traditional 3-minute rest interval between sets.

Another study conducted by Willardson & Burkett (2006 B) focused on the relationship between muscular endurance and rest interval length. The purpose was to determine how much rest was needed in order to sustain 15 repetitions over five sets of the squat and bench press. Fifteen college-aged men volunteered to participate in this study. All participants were considered recreational lifters, having at least one year of experience performing the squat and bench press.

Participants were tested once a week for four weeks (Willardson & Burkett, 2006 B). The first week was used to assess each participant's 15-RM in the squat and bench press. During the following three weeks, each participant performed five sets of the squat and five sets of the bench press with a 30-second, 1-minute, or 2-minute rest interval between sets. Each set was performed to voluntary exhaustion. Five minutes of rest was allowed between each exercise. The repetition cadence consisted of a 3-second eccentric phase and a 1-second concentric phase. Results indicated a greater decrease in repetitions per set for the 30-second rest condition versus the 2-minute rest condition. Regardless of the rest interval length, participants were unable to maintain 15 repetitions per set over five sets; however, the 2-minute rest condition resulted in the highest total repetitions.

However, Anderson and Kearney (1982), Kraemer et al. (1987), and Stone et al. (1994) all found that greater muscular endurance adaptations occur when the rest interval between sets was shorter (i.e. 30-seconds – 1-minute). An important point is that Willardson & Burkett (2006 B) addressed acute repetition performance in certain exercises rather than chronic muscular endurance adaptations. Although Willardson & Burkett (2006 B) study did not focus on chronic muscular endurance adaptations, it is important to note that short rest intervals can be utilized while maintaining high repetitions per set. In order to maintain repetitions at a specific target, variables such as intensity or volume need to be altered.

Long-term strength gains for the squat exercise were examined by Willardson & Burkett (2008) utilizing different rest intervals (e.g. 2- and 4-minutes) between sets. Fifteen men volunteered to participate in the study. Each participant was a former high school or collegiate football player that had at least four years of experience performing the squat for the purpose of gaining maximal strength. The study was divided into three, four week cycles. The first week of each cycle was used to test each participant's 1-RM in the squat. The 1-RM was used to determine the load for the following three weeks of each cycle. One "heavy" and one "light" squat workout was completed each week. The heavy workouts consisted of eight sets of 11-15 repetitions at 70% of 1-RM for week 2; seven sets of 6-10 repetitions at 80% of 1-RM for week 3; and six sets of 3-5 repetitions at 90% of 1-RM for week 4. Each light workout consisted of five sets of 8 repetitions at 60% of 1-RM.

The heavy and light squat workouts were separated by 72 hours each week (Willardson & Burkett, 2008). Participants were assigned to either a 2-minute or a 4-minute rest interval group. A major finding of this study was that there was no significant difference in squat strength gains between the groups that rested 2-minutes versus 4-minutes between sets. Although the 4-minute group had a higher total volume per workout and greater repetitions performed per set, this did not produce larger strength gains. Knowing this, researchers concluded that resting at least 2-minutes between sets was more time efficient. This finding is beneficial information for participants that have little time to spend working-out.

Willardson & Burkett (2008) hypothesize that every participant has a different "training age". Those that have trained less than 6 months may respond differently to an exercise program versus participants that have trained consistently for more than one year. Longer rest intervals (e.g. 4-5 minutes) may be necessary in the beginning of a program until that participant has adapted physiologically and is able to maintain a certain volume/intensity with shorter rest intervals (e.g. 2-3 minutes).

Miranda's et al. (2007) study also supports the notion that longer rest intervals increase total number of repetitions that can be completed over the course of a workout. However, unlike other studies that examined the squat and bench press, this study focused on a sequence of exercises that involved the same muscle groups (i.e. wide grip lat pull-down, close grip lat pull-down, machine seated row, barbell row lying on a bench, dumbbell seated arm curl, and machine seated arm curl). Fourteen men with at least two years of resistance training experience volunteered to participate in this study. Using the participant's predetermined 8-RM load, three sets of each exercise were completed to failure. Participants completed the exercises on two separate occasions; one time with a 1-minute rest interval between sets, and another time with 3-minutes of rest. Each training session was separated by 48-72 hours.

Results indicated that participants were able to complete a greater total number of repetitions for each exercise with a 3-minute rest interval compared to a 1-minute rest interval between sets (Miranda et al., 2007). Although the number of repetitions decreased in each consecutive set of each exercise in both rest intervals, the 1-minute rest interval demonstrated a greater decrease.

Rest Interval: Physiological/Metabolic Responses

Different types of training have different effects on the body. The body will respond to short rest interval training much differently than it does to longer rest intervals (e.g. 30 seconds vs. 5 minutes). Often times, beginners are unconditioned and need longer rest intervals in order to maintain repetitions over consecutive sets. According to Ratamess et al. (2007), participants that were training at 85% of their 1-RM experienced greater post-exercise oxygen consumption during the 30-second and 1-minute rest intervals versus the 2-, 3-, or 5-minute rest intervals.

They also reported an inverse relationship between rest interval length and metabolic response (Ratamess et al., 2007). In this study, absolute and relative oxygen consumption (VO2), ventilation (V_E), respiratory exchange ratio (RER), as well as post-exercise V_E and RER responses were used to measure the metabolic responses. "Fatigue rate [resistance/volume of set 1 – set 5/set 1 (x100)] was calculated for each intensity during each rest interval length" (3). When individuals rested less than 1-minute between sets, a higher fatigue rate was noted versus when participants rested at least 2-minutes between sets (41% compared to 17%). Fatigue is often due to an increase in hydrogen ions in the blood and muscles. The participants in Larson & Potteiger's (1997) study demonstrated elevated lactate concentrations in the blood. These participants were recreational lifters. Previous studies have demonstrated high blood lactate concentrations in Bodybuilders, Power-Lifters, and/or Olympic weightlifters, indicative of involvement of Anaerobic Glycolysis during heavy resistance training programs (Kraemer, Noble et al.; Stone et al.; Tesch et al. as cited in Larson & Potteiger, 1997).

Kraemer & Noble et al. (1987) demonstrated no differences in physiological responses between Bodybuilders and Power-Lifters with the use of 10-60 second rest intervals; however, it is important to note that Bodybuilders were able to train at a higher percentage of their 1-RM than Power-Lifters which is possibly due to greater capillary density (Schantz as cited in Kraemer & Nobel et al., 1987). Although results indicated no significant differences in lactate levels and heart rate, bodybuilding style training stimulates higher levels of lactate which in turn causes the body to become more efficient in buffering acidity within the muscles. This is the main reason why 100% of the Power-Lifters in Kraemer & Noble et al. (1987) study experienced dizziness and nausea during the exercise sessions compared to 11.1% of the Bodybuilders. Therefore, it is important to note a participant's training history when prescribing a resistance training program or assessing the results of a research study.

Effects of Different Resistance Training Programs

Specific improvements caused by strength training are due to many factors such as the selection of exercises, volume (i.e. number of sets and repetitions), intensity, and the participant's training history. By altering certain variables such as the repetition range, different muscular adaptations occur. Delorme was the first to develop the strength and endurance continuum theory. He believed that the development of maximal strength is best achieved through the performance of high intensity and low repetitions, whereas the development of localized muscular endurance is best achieved through the performance of low intensity and high repetitions. Throughout the years, studies have been conducted to test Delorme's (1945) theory.

Previous research by Anderson and Kearney (1982) has demonstrated the validity of Delorme's (1945) theory. Anderson and Kearney studied the effects of three different resistance training programs on muscular strength and absolute and relative muscular endurance. Forty-three untrained male college students volunteered to participate in a nine week study. If the participants 1-RM bench press was less than 120% of their bodyweight, they were considered untrained. Maximal strength was determined using the 1-RM in the bench press. Relative endurance was obtained using 40% of the participant's 1-RM and the rate was set at 40 repetitions per minute (rpm). Absolute endurance was assessed using 27.23 kilograms during both pre- and post-testing sessions.

After completion of the pre-test, participants were randomly assigned to one of three groups. The first group was the high resistance-low repetition group whose training consisted of three sets of 6-8 repetitions (Anderson and Kearney, 1982). Once the participant was able to complete more than eight repetitions on a set, resistance was increased by 2.27 kg increments. A low resistance-high repetition group completed one set of 100-150 repetitions at a rate of 40 rpm. Each group trained three days per week for nine weeks.

Results demonstrated that both groups improved muscular strength and absolute muscular endurance (Anderson and Kearney, 1982). The high resistance-low repetition group demonstrated the greatest gain in muscular strength (20.22%), whereas the low resistance-high repetition group only gained 4.92%. Conversely, the low resistance-high repetition group demonstrated a 41.30% gain in absolute muscular endurance, whereas the high resistance-low repetition group only gained 23.58%. The gains in relative muscular endurance followed the same trends as the absolute muscular endurance gains for each group respectively.

For example, during pre-testing, the low resistance-high repetition group had a mean of 37.50 repetitions on the relative muscular endurance test (Anderson and Kearney, 1982). After training, the mean increased to 48.17 repetitions. Conversely, the high resistance-low repetition group completed 2.81 fewer repetitions (-6.99%) on the post-test compared to their pre-test results. This study demonstrated that the outcomes were different based on the repetition ranges practice during training. Therefore, resistance and repetitions need to be altered in order to optimize specific outcomes.

Weiss et al. (1999) conducted a study that assessed different adaptations to short term resistance training using low, moderate, and high repetitions. Thirty-eight men volunteered and all reported they were not engaged in any physical training involving the legs for at least three months before the study. Before and after the seven week training period, dynamic constant external resistance (DCER) squat strength, isokinetic knee extension and flexion peak torque at both 60 and $300°\cdot s^{-1}$, and vertical jump height were tested. Training took place three times per week for seven weeks.

The thirty-eight untrained men were divided into four groups (Weiss et al., 1999). Groups 1, 2, and 3 completed four sets of the barbell squat. Group 1 trained in the 3-

5RM range; group 2 trained in the 13-15RM range and group 3 trained in the 23-25RM range. Group 4 was the control group that did not train. The results from the study demonstrated there were greater improvements in all three groups compared to the control group for the DCER squat and the isokinetic knee extension at $60°\cdot s^{-1}$. Group 1 (3-5RM) demonstrated greater improvements in the squat than group 3 (23-25RM).

There were no differences between the three training groups for the isokinetic knee extension (Weiss et al., 1999). Vertical jump height did not improve in any of the groups. Although this study demonstrated that training with lower repetitions will improve 1-RM DCER squats to a greater extent versus training with higher repetitions, it also demonstrated that strength could be improved while utilizing higher repetition ranges (i.e. 23-25RM)

Recent research done by Campos et al. (2002) stated that the intensity and the number of repetitions performed in any exercise determines a participant's physical performance and physiological adaptations. Thirty-two untrained men participated in an eight week resistance training program which included the leg press, squat, and knee extension. The men were divided into four groups. The low repetition group performed four sets of 3-5 RM for each exercise. They were given 3-minutes of rest between sets. The intermediate repetition group performed 9-11 RM for three sets with 2-minutes of rest and the high repetition group did 20-28 RM for two sets with only 1-minute of rest. The last group was the control group that did not participate in any type of physical activity for the eight week study.

Each set was completed to failure and resistance progressively increased over the weeks in order to maintain the repetition range per set (Campos et al., 2002). During the first four weeks, all groups (excluding the control group) trained two days a week.

Training increased to three days a week for the last four weeks of the study. Maximal strength (1-RM), local muscular endurance (maximal number of repetitions performed with 60% of 1-RM), and muscle biopsy samples were assessed before and after the study.

Campos et al. (2002) demonstrated similar results as Weiss et al. (1999). Although all three groups increased their 1-RM in all three exercises, the low repetition group resulted in greater increases in maximal dynamic strength in the leg press and squat compared to the other groups (Campos et al., 2002). The low repetition group had a 61% increase in maximal dynamic strength in the leg press. Conversely, the high repetition group performed more repetitions in the leg press, squat, and knee extension at 60% 1-RM versus the other groups. In the leg press exercise, the high repetition group had a 94% increase in localized muscular endurance versus a 10% increase for the intermediate group, -20% for the low repetition group, and -19% for the control group.

Campos et al. (2002) concluded that intermediate and low repetition training resulted in a greater hypertrophic effect than the high repetition training. Type I, IIA, and IIB muscle fibers were larger after training for both the intermediate and low repetition groups. The findings demonstrated that training in a moderate repetition range (e.g. 8-10) with relatively short rest intervals between sets (e.g. 90-seconds to 2-minutes) will result in optimal gains in muscle size. Continual exposure to heavy resistance training stimulates protein synthesis. Hypertrophy occurs due to an increase in the cross sectional area of the muscle fibers which is the result of an increase in the actin and myosin contractile proteins (Hedrick, 1995). Hypertrophy has been shown to occur prominently in Type II fibers (i.e. fast twitch fibers) than in Type I fibers (i.e. slow twitch fibers) (Fleck et al.; MacDougall et al.; Tesch et al. as cited in Hedrick, 1995).

Other research does not support the strength/endurance continuum theory. Research conducted in 1968 by DeLateur, Lehmann, and Fordyce (as cited in Anderson and Kearney, 1982) have also rejected Delorme's theory. They found that participants that trained for muscular strength gained as much muscular endurance as those that trained for muscular endurance whereas those that trained for muscular endurance gained as much muscular strength as those that trained for strength; however, it was noted that the training stimulus applied to the strength group may have been similar to the endurance group therefore resulting in no differences between the groups. Results from this study may have been inaccurate due to other variables such as resistance used. It was stated that weight was not important as long as each set was completed to failure. Anderson and Kearney (1982) mentioned that the resistance used in the study was rather moderate. This may explain why both groups experienced similar results.

Stone and Coulter (1994) tested the strength/endurance continuum theory but with fifty untrained women. The participants were given three familiarization sessions in order to practice the five exercises that would be used during the study. The women were assigned to one of three resistance training protocols (e.g. high resistance/low repetitions (HRLR), medium resistance/medium repetitions (MRMR), and low resistance/high repetitions (LRHR). The women were tested in the bench press, squat, triceps push-down, arm curl, and the lat pull down. All three groups trained three days a week for nine weeks.

The HRLR training consisted of three sets of 6-8 RM with 2-3 minutes rest between sets. The MRMR group completed two sets of 15-20 RM with 2-3 minutes rest while the LRHR group trained for one set of 30-40 RM (Stone and Coulter, 1994). Additional weight (e.g. minimum 2.3 kg) was added when the participants were able to complete three sets of the maximal amount of repetitions prescribed for their respective conditions. Prior to training, the fifty participants were tested for muscular strength, muscular endurance (relative and absolute). A 1-RM bench press and squat were used to test maximal strength. Absolute endurance for the bench press was tested with 15.9 kg at 40 rpm and for the squat with 25kg at 30 rpm. Two loads were used to test relative endurance. The first load was based on each participants pretest 1-RM and load two was based the post-test 1-RM. The bench press was tested at 45% of 1-RM at 40 rpm, and the squat at 55% of 1-RM at 30 rpm.

Results indicated that all three groups demonstrated significant increases in maximum strength for both the upper and lower body (Stone and Coulter, 1994). The HRLR and LRHR groups had a significant increase in relative endurance using load 1 but not load 2. The HRLR training had an 18.9% increase for upper body and a 33% increase in lower body compared 11.6% and 25.1% for the LRHR training group. Lower body muscular endurance gains were three times greater than the upper body muscular endurance gains (65.3% vs. 22.8%). These results did not support the strength/endurance continuum theory in that the HRLR program did not produce greater strength than the MRMR or LRHR programs. Furthermore, the LRHR program did not produce statistically greater muscular endurance.

Differences in studies that support (e.g. Anderson and Kearney, 1982) versus reject (e.g. Stone and Coulter, 1994) the strength/endurance continuum theory might be accounted for due to factors such as training history of participants, intensity, volume, duration, and sample size. Individuals that are initially untrained or previously sedentary may achieve simultaneous gains in strength and endurance regardless of program design.

Conversely, individuals with consistent training experience may exhibit adaptations that are specific to the strength/endurance continuum.

Therefore, studies by Campos et al. (2002), Weiss et al. (1999), and Anderson and Kearney (1982) demonstrated that participants produced the greatest gains in maximal strength by using heavy resistance and lower repetitions and the greatest gains in localized muscular endurance by using light resistance and higher repetitions. A key point is that maintaining repetitions at a given target or within a training zone is crucial for achieving different training goals (i.e. strength, hypertrophy, localized muscular endurance).

Based on these studies, longer rest intervals (e.g. 2-5 minutes) are necessary to maintain volume and consistent repetitions over multiple sets. “Long recovery intervals are needed to establish normal blood flow, remove lactic acid, replenish energy sources, and reestablish force production capabilities” (Kraemer & Noble et al., as cited in Larson & Potteiger, 1997, p.115); however, if training with short rest intervals (e.g. 30-seconds to 1-minute) is necessary as in hypertrophy or muscular endurance oriented programs, the load may need to be reduced over consecutive sets to maintain consistency in repetition performance over multiple sets. Resistance (i.e. load) can be adjusted to ensure the maintenance of repetitions and volume when working with short rest intervals. Based on the conclusions of previous research, this study will address the effects of keeping the load constant or lowering the resistance by different percentages on the maintenance of repetitions during lower body resistance exercise sessions.

Summary

Resistance training has grown in popularity over the years. With busy schedules, people often place a low priority on exercising. As a result, there is a high demand to provide a time efficient but effective exercise program. The results of this study may lend incite into how resistance training sessions can be conducted efficiently with less time between sets while maintaining high repetitions per set. However, much depends on the individual's training goals and expectations. Those that want to focus on muscular endurance will train much differently than someone that is training for strength and power. Also, novice lifters will respond differently, physiologically, to a certain exercise program compared to advanced lifters; therefore, it is important to keep in mind each individual's training history when designing a resistance training program.

CHAPTER III

METHODS

Experimental Approach

A within participants design was used to assess repetition performance over consecutive sets of lower body resistance exercises. The back squat, leg curl, and leg extension were examined as part of this study due to the popularity of these exercises among recreational resistance trainers. These exercises are also commonly performed in the order listed above during lower body workouts.

The first three weeks were the preparatory period, during which 10 repetition maximum (i.e. 10-RM) loads were established for the back squat, leg curl, and leg extension exercises (in that order for each testing session). All leg curl and leg extension sets were performed using machines (S3LPC and S3LE, Nautilus, Vancouver, Washington, USA). The next four weeks were the data collection period, during which subjects completed one lower body testing session per week under one of the following load conditions: 1) constant load for all sets, 2) 5% load reduction following each set, 3) 10% load reduction following each set, and 4) 15% load reduction following each set.

Participants

Eleven recreationally trained men volunteered to participate in this seven week study (see Table 1 for demographical characteristics). To qualify for inclusion,

TABLE 1. Demographical characteristics.

Variable	Minimum	Maximum	Mean	Standard Deviation
Age (years)	19	23	21.18	1.25
Height (inches)	66	72	69.73	2.20
Body Weight (lbs)	147	208	179.73	19.89

participants were initially screened using the Physical Activity Readiness Questionnaire (PAR-Q) and were aware of the risks and procedures involved. None of the participants had low back, knee, or ankle injuries during the previous year and all participants had consistently performed the exercises examined in this study as part of their resistance training programs.

The current study was approved through the Institutional Review Board and participants were required to sign a consent form in accordance with human participant regulations. Participants were restricted from all other lower body resistance exercises during the course of the study and were not permitted to workout on the same day prior to a testing session. Participants were blinded as to the order of conditions to which they would be assigned during the data collection period.

Procedures

Each participant completed one exercise session per week for seven weeks. Each exercise session was conducted on a consistent day and time each week. A certified strength and conditioning specialist supervised each exercise session to ensure proper technique and provide spotting and verbal encouragement. During weeks 1, 2, and 3, the 10 repetition maximum (i.e. 10-RM) loads were established for the back squat, leg curl, and leg extension exercises (in that order for each testing session). The 10-RM for each exercise was assessed three times (i.e. once during each testing session).

Prior to the 10-RM tests, each participant completed five minutes of low intensity aerobic activity (i.e. jogging/walking). Two warm-up sets preceded testing of each exercise at 50% and 75% of the perceived 10-RM load for 10-repetitions each. After the warm-ups sets were completed, the load was increased to the perceived 10-RM, and one set was performed to voluntary exhaustion (i.e. muscle failure). The same spotters closely supervised each 10-RM attempt and participants were instructed to give a verbal signal when voluntary exhaustion was reached. If less than or more than 10-repetitions were accomplished during a 10-RM attempt, the load was adjusted during the next testing session.

The 10-RM loads established during the preparatory period were used to design the subsequent exercise sessions. During the data collection period, weeks 4, 5, 6, and 7, participants completed one lower body exercise session per week under one of the four load conditions. Similar to the preparatory period, each exercise session during the data collection period commenced with 5-minutes of low intensity aerobic activity (i.e. jogging/walking). However, warm-up sets were performed for the back squat only, at 50% and 75% of the pre-determined 10-RM for 10-repetitions each.

Following the back squat warm-up sets, three consecutive sets of each exercise (i.e. back squat, leg curl, and leg extension) were performed to the point of voluntary exhaustion (i.e. muscle failure) once a week under different conditions. The conditions were randomized and counterbalanced to control for order effects. Participants were allowed exactly 1-minute of rest between sets and 2-minutes of rest between exercises. The rest intervals were precisely controlled through the use of a handheld stopwatch.

Statistical Analyses

The independent variables for this experiment were four conditions (constant load, 5%, 10%, and 15% load reductions), three exercises (back squat, leg curl, and leg extension) and three sets (first, second, and third). The dependent variable was the number of repetitions performed. To assess the reliability of the 10-RM loads, intra-class correlations (ICC Rs) were calculated for each exercise (i.e. back squat, leg curl, leg extension) based on the repetition maximum reached during each of the testing sessions in the preparatory interval (i.e. weeks 1-3). A 4 (conditions) x 3 (exercises) x 3 (sets) repeated-measures ANOVA was used to compare repetition performance; the Greenhouse-Geisser correction was applied when the Mauchly's test of sphericity was violated. Significance of interactions and main effects was based on an alpha level of $p \leq 0.05$. All statistical comparisons were made using SPSS version 16.0 (SPSS Inc., Chicago, IL).

CHAPTER IV

RESULTS

The intra-class correlations for each exercise all exceeded 0.90, which indicated that the 10-RM loads were reliable. The 4 (conditions) x 3 (exercises) x 3 (sets) repeated measures ANOVA indicated that the three-way interaction for conditions*exercises*sets was not significant ($F = 1.53$; $p = .24$). However, the two-way interactions for conditions*exercises ($F = 3.22$; $p = 0.04$) and conditions*sets ($F = 39.35$; $p = 0.0001$) were significant. The two-way interaction for exercises*sets was not significant ($F = 2.05$; $p = .14$). Post hoc pairwise comparisons were then conducted on the significant two-way interactions. The significance of post hoc pairwise comparisons was determined using the Bonferroni correction.

*Conditions*Exercises*

Post hoc pairwise comparisons indicated that when averaged across sets, significantly greater repetitions were accomplished within the constant condition for the leg extension versus the back squat ($p = 0.002$) and the leg curl ($p = 0.022$). However, the repetitions accomplished within the constant condition were not significantly different for the back squat versus the leg curl ($p = 1.000$). Within the 5%, 10%, and 15% conditions, the repetitions accomplished were not significantly different between exercises ($p > 0.05$; see Table 2 & Figure 1).

TABLE 2. Condition by exercise interaction (repetitions averaged across sets; Mean ± SD).

	Squat	Leg Curl	Leg Extension	Post Hocs
Condition 1	1) 5.7576 ± 2.01710	2) 6.2727 ± 1.06268	3) 9.0303 ± 1.52355	1 vs 2; p = 1.000 1 vs 3; p = 0.022* 2 vs 3; p = 0.022*
Condition 2	4) 7.8788 ± 2.55722	5) 7.2727 ± 1.22763	6) 9.2727 ± 1.75004	4 vs 5; p = 1.000 4 vs 6; p = 1.000 5 vs 6; p = 0.554
Condition 3	7) 9.0000 ± 1.93218	8) 8.2727 ± 1.00905	9) 9.8485 ± 2.00202	7 vs 8; p = 1.000 7 vs 9; p = 1.000 8 vs 9; p = 1.000
Condition 4	10) 10.0303 ± 1.93480	11) 9.5455 ± 1.60743	12) 10.5152 ± 1.74078	10 vs 11; p = 1.000 10 vs 12; p = 1.000 11 vs 12; p = 1.000
Post Hocs	1 vs 4; p = 0.347 1 vs 7; p = 0.002* 1 vs 10; p = 0.0001* 4 vs 7; p = 1.000 4 vs 10; p = 0.308 7 vs 10; p = 1.000	2 vs 5; p = 1.000 2 vs 8; p = 0.554 2 vs 11; p = 0.002* 5 vs 8; p = 1.000 5 vs 11; p = 0.188 8 vs 11; p = 1.000	3 vs 6; p = 1.000 3 vs 9; p = 1.000 3 vs 12; p = 1.000 6 vs 9; p = 1.000 6 vs 12; p = 1.000 9 vs 12; p = 1.000	

* indicates significance

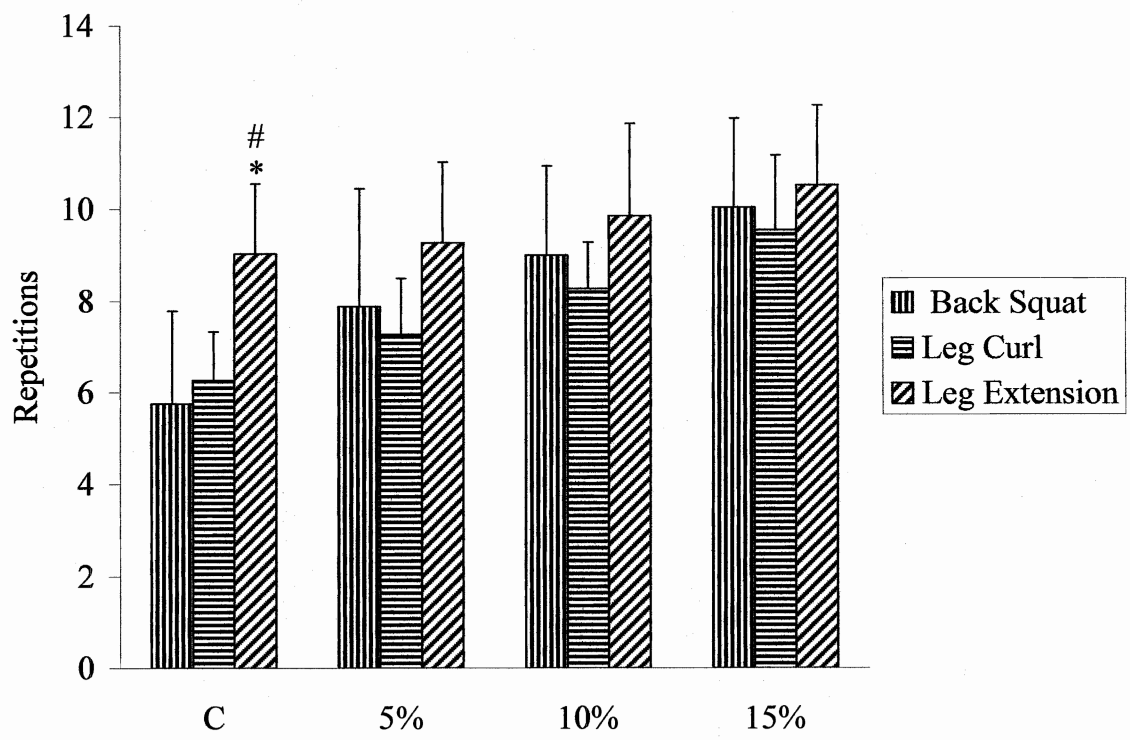

Figure 1—Condition*Exercise (repetitions averaged across Sets); * = constant load (C) significant difference repetitions back squat versus leg extension ($p < 0.01$); # = constant load (C) significant difference repetitions leg curl versus leg extension ($p < 0.05$).

Post hoc pairwise comparisons also indicated that when averaged across sets, significantly fewer repetitions were accomplished for the back squat within the constant condition versus the 10% condition ($p = 0.002$) and within the constant condition versus the 15% condition ($p = 0.0001$); there were no other significant differences between conditions ($p > 0.05$). For the leg curl, significantly fewer repetitions were accomplished within the constant condition versus the 15% condition ($p = 0.002$); there were no other significant differences between conditions ($p > 0.05$). For the leg extension, there were no significant differences in the repetitions accomplished between conditions ($p > 0.05$;

see Table 2 & Figure 2).

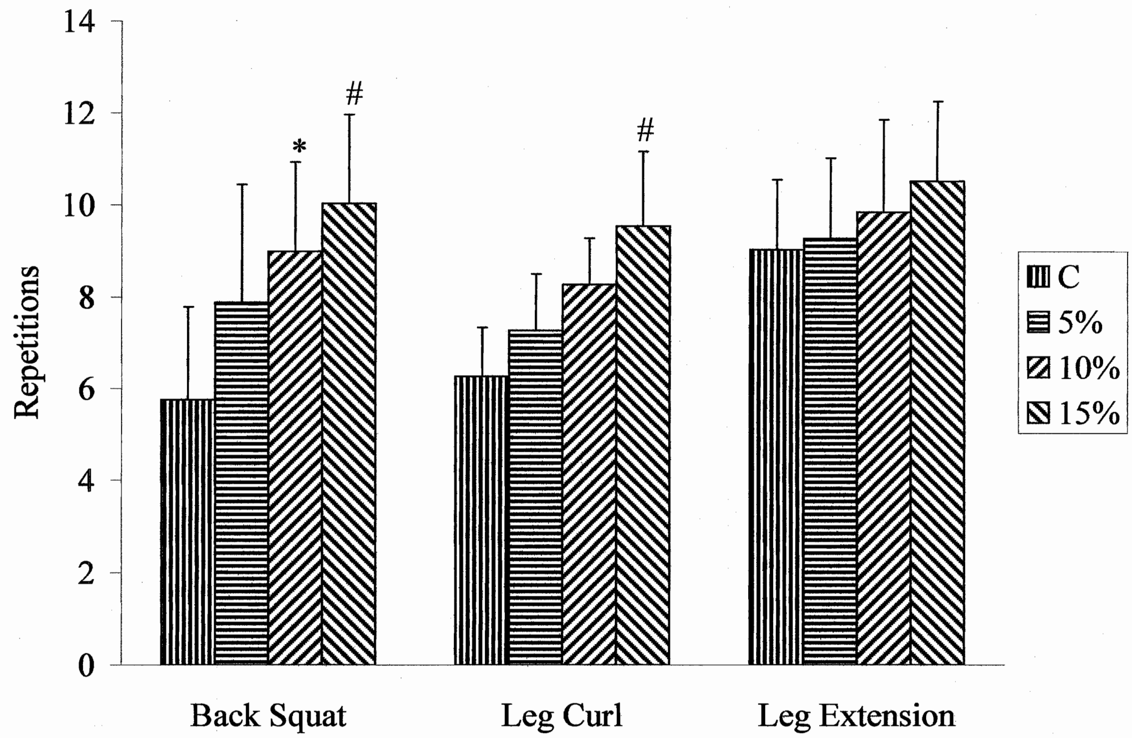

Figure 2—Condition*Exercise (repetitions averaged across Sets); * = back squat significant difference repetitions constant load (C) versus 10% load reduction ($p < 0.01$); # = back squat and leg curl significant difference repetitions constant load (C) versus 15% load reduction ($p < 0.01$).

*Conditions*Sets*

Post hoc pairwise comparisons indicated that when averaged across exercises, significantly greater repetitions were accomplished within the constant, 5%, and 10% conditions for set 1 versus set 2 ($p < 0.01$) and for set 1 versus set 3 ($p < 0.01$). Within the constant, 5%, and 10% conditions, the repetitions accomplished were not significantly different for set 2 versus set 3 ($p = 1.000$). Within the 15% condition, the repetitions accomplished were not significantly different between sets ($p > 0.05$; see Table 3 & Figure 3).

TABLE 3. Condition by set interaction (repetitions averaged across exercises; Mean ± SD).

	Set 1	Set 2	Set 3	Post Hocs
Condition 1	1) 11.3939 ± 1.48936	2) 5.5758 ± .96714	3) 4.0909 ± .92004	1 vs 2; p = 0.0001* 1 vs 3; p = 0.0001* 2 vs 3; p = 1.000
Condition 2	4) 11.1515 ± 1.55894	5) 6.8182 ± .91121	6) 6.4545 ± 1.32726	4 vs 5; p = 0.0001* 4 vs 6; p = 0.0001* 5 vs 6; p = 1.000
Condition 3	7) 11.0000 ± 1.96638	8) 8.2727 ± 1.00905	9) 7.8485 ± 1.53741	7 vs 8; p = 0.001* 7 vs 9; p = 0.0001* 8 vs 9; p = 1.000
Condition 4	10) 10.6667 ± 2.01660	11) 9.3030 ± 1.56670	12) 10.1212 ± 1.30190	10 vs 11; p = 1.000 10 vs 12; p = 1.000 11 vs 12; p = 1.000
Post Hocs	1 vs 4; p = 1.000 1 vs 7; p = 1.000 1 vs 10; p = 1.000 4 vs 7; p = 1.000 4 vs 10; p = 1.000 7 vs 10; p = 1.000	2 vs 5; p = 1.000 2 vs 8; p = 0.001* 2 vs 11; p = 0.0001* 5 vs 8; p = 1.000 5 vs 11; p = 0.005* 8 vs 11; p = 1.000	3 vs 6; p = 0.011* 3 vs 9; p = 0.0001* 3 vs 12; p = 0.0001* 6 vs 9; p = 1.000 6 vs 12; p = 0.0001* 9 vs 12; p = 0.019*	

* indicates significance

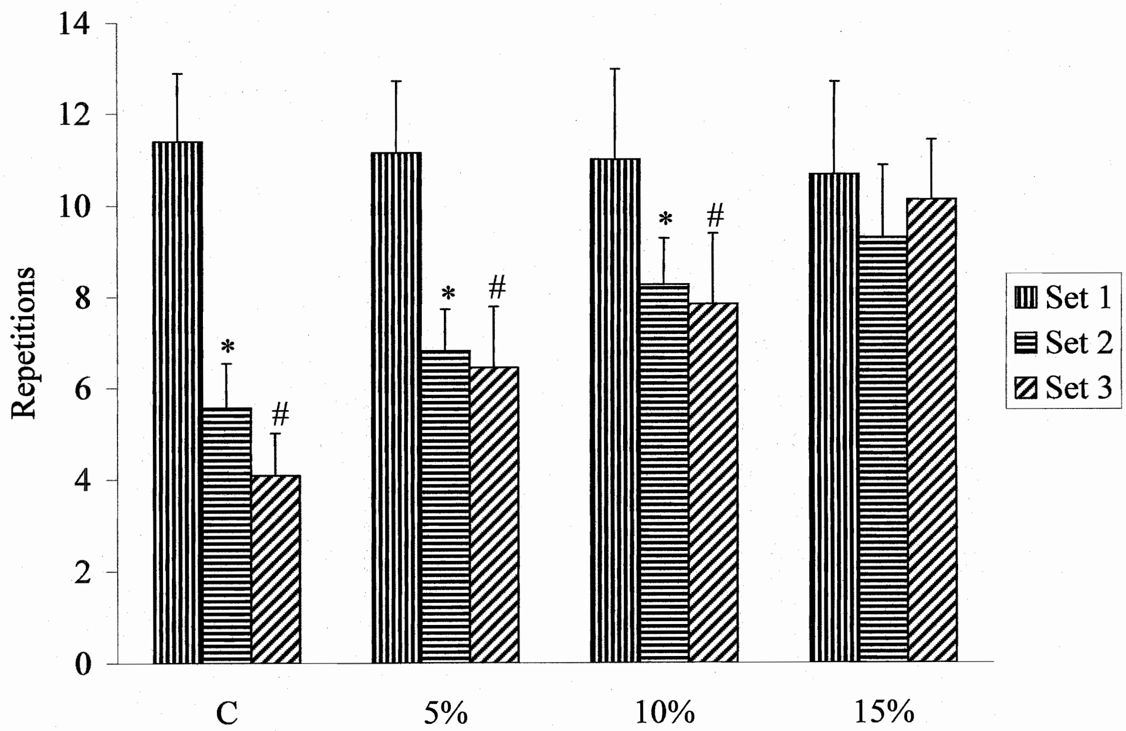

Figure 3—Conditions*Sets (repetitions averaged across Exercises); * = constant load (C), 5% load reduction, 10% load reduction significant difference repetitions set 1 versus set 2 ($p < 0.01$); # = constant load (C), 5% load reduction, 10% load reduction significant difference repetitions set 1 versus 3 ($p < 0.01$).

Post hoc pairwise comparisons also indicated that when averaged across exercises, the repetitions accomplished for set 1 were not significantly different between conditions ($p > 0.05$). For set 2, significantly fewer repetitions were accomplished within the constant condition versus the 10% condition ($p = 0.001$), within the constant condition versus the 15% condition ($p = 0.0001$), and within the 5% condition versus the 15% condition ($p = 0.005$); there were no other significant differences between conditions ($p > 0.05$). For set 3, significantly fewer repetitions were accomplished within the constant condition versus the 5% condition ($p = 0.011$), within the constant condition versus the 10% condition ($p =$

0.0001), within the constant condition versus the 15% condition (p = 0.0001), within the 5% condition versus the 15% condition (p = 0.0001), and within the 10% condition versus the 15% condition (p = 0.019); there were no other significant differences between conditions (p > 0.05; see Table 3 & Figure 4).

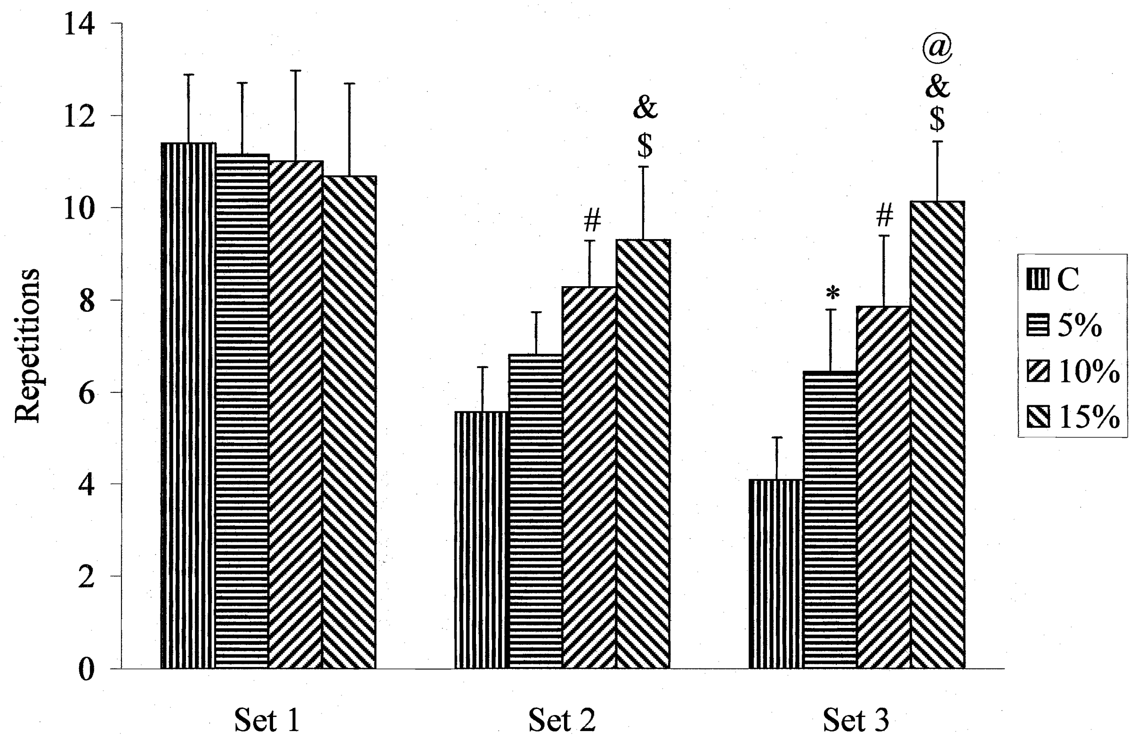

Figure 4—Conditions*Sets (repetitions averaged across Exercises); * = set 3 significant difference repetitions constant load (C) versus 5% load reduction ($p < 0.05$); # = sets 2 and 3 significant difference repetitions constant load (C) versus 10% load reduction ($p < 0.01$); $ = sets 2 and 3 significant difference repetitions constant load (C) versus 15% load reduction ($p < 0.01$); & = sets 2 and 3 significant difference repetitions 5% load reduction versus 15% load reduction ($p < 0.01$); @ = set 3 significant difference repetitions 10% load reduction versus 15% load reduction ($p < 0.05$).

CHAPTER V

DISCUSSION

Rest interval length is one variable that has a huge impact on specific muscular adaptations. Individuals that train with less rest are able to maintain repetitions throughout consecutive sets in different exercises. There is a less percent drop off compared to those that train with longer rest periods. According to Willardson and Burkett (2008), resting a minimum of 2-minutes between sets is ideal to prevent intensity levels from dropping. Training with less than 1-minute rest periods increases blood lactate concentrations which results in lack of oxygen to the muscles and in turn inhibits the muscles to contract. Training age can alter the need for rest interval length. Individuals that are unconditioned may have a harder time maintaining repetitions. Ratamess et al. (2007) noted in their study that the cardiovascular system was the limiting factor, not the muscular system. A few subjects in this present study reported "hard to catch breath" during condition 3 and 4 (i.e. 10%, 15% reduction). If it was not reported, the strength and conditioning specialists noticed an increase in respiration during those specific conditions. The majority had previous bodybuilding experience; so, they were able to withstand the 1-minute rest period between sets; however, during condition 1 (i.e. load held constant) the repetitions completed over consecutive sets significantly decreased compared to condition 2, 3, and 4 (i.e. 5%, 10%, 15% reduction).

The results of the current study demonstrated that the subjects were able to maintain repetitions in the leg extension throughout consecutive sets in all four conditions compared to the squat and leg curl. When repetitions were averaged across sets in condition 1 (i.e. load held constant), subjects were able to complete 9.0303 ± 1.52355

repetitions in the leg extension compared to 5.75 $\pm$ 2.02 and 6.27 $\pm$ 1.06 in the back squat and leg curl, respectively (see Figure 1). In condition 4 (i.e. 15% load reduction), subjects maintained 10.5152 ± 1.74078 repetitions (averaged across sets) in the leg extension whereas in the back squat and leg curl, the repetitions (averaged across sets) significantly increased to 10.0303 ± 1.93480 and 9.5455 ± 1.60743, respectively (see Figure 1 & Table 2). An average of 9.3030 ± 1.56670 and 10.1212 ± 1.30190 repetitions (averaged across exercises) in sets 2 and 3, respectively, in the back squat and leg curl were attainable when the load was reduced 15% after the first set (see Table 3). Conversely, individuals were able to maintain an average of 9.0303 ± 1.52355 repetitions in the leg extension when the load was held constant and 9.27 $\pm$ 1.75, 9.85 $\pm$ 2.00, and 10.51 $\pm$ 1.74 repetitions (averaged across sets) in conditions 2, 3 and 4, respectively (see Table 2).

Therefore, the results of the current study indicate that resistance needs to be reduced approximately 15% over consecutive sets for the back squat and leg curl in order to maintain repetitions over three sets, using a 10-RM load and 1-minute rest intervals between sets. In contrast, the load can be kept constant over consecutive sets for the leg extension (see Figure 2). These findings were surprising given that the leg extension was the last exercise to be completed and greater muscular fatigue is often expected.

The back squat involves multiple muscle groups, and the low back musculature may have fatigued prior to when the quadriceps were fully exhausted; thus limiting the repetitions accomplished for the back squat, but subsequently allowing greater repetitions for the leg extension. Furthermore, variations in back squat technique may have influenced the muscles most involved (Robergs et al., 2004; Stone and Coulter, 1994; Stone et al., 1987; Schwarzenegger and Dobbins, 1985; Tesch et al., 1978).

When examining the repetitions completed across exercises, reducing the load 15% (i.e. condition 4) following the first and second sets allowed for approximately 10-repetitions on each set (see Figures 3 and 4). In condition 4 (i.e. 15% reduction), when repetitions were averaged across exercises, individuals were able to maintain 10.6667 ± 2.01660 repetitions in the first set and 9.3030 ± 1.56670 and 10.1212 ± 1.30190 repetitions in the second and third set, respectively (see Figure 3 and 4). However, as seen in Figure 3, there was a significant decrease in repetitions in the second and third set when the load was held constant and when reducing the load 5% and 10%; however, a greater decrease in repetitions (averaged across exercises) was evident in the third set compared to the second set. Also, in set three, there were significantly fewer repetitions (averaged across exercises) in conditions 1, 2, and 3 versus condition 4 (see Figure 4). For the third set, 4.09 ± .92, 6.45 ± 1.33, 7.85 ± 1.54 repetitions (averaged across exercises) were accomplished in conditions 1, 2, and 3 versus 10.12 ± 1.30 repetitions in condition 4, respectively (see Figure 4).

According to these results, keeping the load constant, or lowering the load 5% or 10% after the first and second set was not sufficient in maintaining a 10-RM with one minute rest between sets of each exercise for recreationally trained men. However, factors such as the muscles involved, the movements examined, long-term training practices, and training age may have an influence on the proper amount of load reduction needed using at 10-RM.

Kraemer and Nobel et al. (1987) demonstrated that specific training practices may reduce the amount of rest needed between sets. Nine male bodybuilders and eight male power-lifters were used in this study and had been involved in competitive lifting for 4-6 years. For six months prior to the study, the workouts for each group were monitored.

The training practices for the bodybuilding group were characterized by intensities ranging from 6-12 RM and short rest periods between sets and exercises (e.g. 10-90 seconds). On the other hand, the Power-Lifter's training practices were characterized by intensities from 1-8 RM and with longer rest periods (e.g. 120-420 seconds). A major difference between the groups was that Power-Lifters typically had a lower training volume than Bodybuilders. Bodybuilders often train with higher volume and shorter rest periods. In the study, participants had to complete the same weight training protocol. The protocol mimicked the type of exercise session that is normally used by bodybuilders. Ten exercises for the entire body were chosen. The participants had to complete three sets of 10-RM with a 10-second rest between sets for each exercise. Thirty or sixty seconds rest was alternated between exercises. In order to maintain a full range of motion, each participant's body limb angles from start to finish were measured for each exercise. Heart rate, ratings of perceived exertion (RPE), and plasma lactate levels were gathered during the training protocol. Although the Power-Lifters were significantly stronger and had higher 1-RM strength values in each exercise, results indicated that the Bodybuilders were able to maintain a higher mean intensity during the performance of the bench press and leg press sets. Increases in plasma cortisol and lactate were observed pre- to 5-minute post-exercise; however, there was no significant difference between the groups. One hundred percent of the participants in the power-lifting group did report symptoms of dizziness and nausea whereas only 11.1% of the Bodybuilders reported the same feelings. According to Kraemer and Nobel et al. (1987), the Bodybuilders were able to resist the effects of fatigue due to the adaptations associated with the bodybuilding style of training. The body adapts to the high volume and shorter rest interval training by increasing capillary and mitochondrial density. Also, the body becomes more efficient in buffering and transporting hydrogen ions out of the muscles which in turn reduces the feelings of dizziness and nausea.

It is important to note that the results of the current study do not apply to upper body workouts. Research by Willardson and Burkett (2005) demonstrated a greater fatigue resistance in the lower body muscles versus the upper body muscles. Fifteen recreationally trained men volunteered to participate in the four week study. One testing session took place each week. The first week was used to determine the participant's 8-RM in the squat and bench press. During the last three weeks of the study, participants completed four sets of the squat and bench press with 1-, 2-, or 5-minute rest intervals between each set. Each set was completed to voluntary exhaustion with a set cadence of a 3-second eccentric phase and a 1-second concentric phase. Five minutes of rest was given between each exercise. Results indicated that the volume completed for the squat was significantly different between the 1- and 5-minute rest conditions and between the 2- and 5-minute rest conditions; although, there was no significant difference in volume between the 1- and 2-minute rest conditions. In the 1-minute rest condition, subjects performed 7.87 ± 0.52 repetitions on the first set, followed by 5.93 ± 1.90, 4.47 ± 1.85, and 4.20 ± 1.94 repetitions on the second, third, and fourth sets, respectively. By using longer rest periods (i.e. 5-minutes), subjects were able to maintain more repetitions versus the 1-minute condition. On the first set, subjects performed 8.00 ± .00 repetitions, followed by 7.80 ± 0.56, 7.00 ± 1.65, and 6.00 ± 1.77 repetitions on the second, third, and fourth sets, respectively. The mean volume totaled to 28.80 ± 3.08, 25.53 ± 4.29, and 22.47 ± 4.79 repetitions in the 5-, 2-, and 1-minute rest intervals, respectively. Since there was no significant difference in squat volume between the 1- and 2-minute conditions this may indicate greater muscular endurance in the lower body muscles verses the upper body muscles.

Similar results occurred in the bench press; however, the volume completed was significantly different in all rest conditions. Participants were able to complete the highest volume in the 5-minute rest condition (25.73 ± 4.23). When resting 1-minute between sets, subjects performed 7.47 ± 1.06 repetitions on the first set, followed by 4.40 ± 1.64, 2.87 ± 1.30, and 2.40 ± 1.18 repetitions on the second, third, and fourth set, respectively. Subjects were able to complete, 7.60 ± .91, 6.53 ± 1.55, 6.00 ± 1.41, and 5.60 ± 1.24 repetitions in the first, second, third, and fourth set, respectively, when resting for 5-minutes between sets. The mean volume totaled to 25.73 ± 4.23 repetitions using a 5-minute rest interval verses 17.13 ± 4.42 repetitions when resting for only 1-minute between sets.

In a follow up study, Willardson and Burkett (2006B) confirmed that the upper body muscles tend to fatigue at a faster rate than the lower body muscles. Fifteen recreationally trained men volunteered to participate in the four week study. Participants were to complete five sets in the squat and bench press using a 15-RM with a 30-second, 1-minute, or 2-minute rest interval between sets. Each set was completed to voluntary exhaustion. Velocity was set at a 3-second eccentric phase and a 1-second concentric phase. If the concentric phase exceeded 1-second due to fatigue, it was still counted. The squat and bench press were tested in the same day with a 5-minute rest period between each exercise. The sustainability of repetitions was evaluated separately for the squat and the bench press by dividing the repetitions completed in each consecutive set from the first set. The mean repetitions completed for the squat was 88.40 ± 11.13 kg versus 74.80 ± 9.31 kg for the bench press. Post hoc pairwise comparison indicated there was a significant difference in the ability to sustain repetitions between the 30-second and 2-minute rest conditions for both the squat and bench press. Even with a 2-minute rest period, repetitions were not sustainable over five consecutive sets with a 15-RM load. Similar results occurred with the current study. When the weight was held constant, the repetitions significantly decreased from the first set. According to the results for the squat with 1-minute rest periods, the mean values for the first set was 15.53 ± 0.99, 10.67 ± 2.87 for the second set, 8.40 ± 3.27, 6.27 ± 2.46, and 6.33 ± 2.69 for the third, fourth, and fifth set, respectively. On the other hand, the sustainability of repetitions in the bench press with 1-minute rest periods between sets greatly decreased from the first set. The mean values for the first set was 14.67 ± 1.50, 5.93 ± 1.98, 3.60 ± 1.18, 3.33 ± 1.11, and 2.80 ± 1.32 for the second, third, fourth, and fifth set, respectively.

These studies demonstrate that the ability to sustain repetitions depends on the specific muscles used. Participants were able to sustain a greater number of repetitions in the squat versus the bench press in both studies. This may be due to greater endurance characteristics in the muscles of the lower body versus the upper body (Willardson and Burkett, 2006B). The sustainability of repetitions over consecutive sets also depends on the amount of the load lifted. The intensity of a given workout effects different energy systems and the rate of fatigue. As the training load increases (i.e. greater intensity), the body relies greatly on intramuscular adenosine triphosphate and phosphocreatine (PCr) stores to supply the energy necessary for muscle contraction (Weiss, as cited in Willardson and Burkett, 2006B). Harris et al. conclude that the recovery of PCr is fairly quick, with half of the used PCr replenished within 30-seconds of recovery (as cited in Willardson and Burkett, 2006B). McMahon and Jenkins believe 50% of the ATP and CP are restored within 20-seconds and approximately 85% is restored within three minutes of recovery (as cited in Ratamess et al., 2007). During a recovery period, the replenishment of the ATP-PC system, buffering of hydrogen ions, and the removal of lactate occurs (Ratamess et al., 2007). According to Kraemer and Nobel et al., blood lactate concentrations increase during high-intensity resistance exercises when rest intervals are shorter than 1-minute (as cited in Willardson and Burkett, 2006). By shortening the rest interval, this limits the magnitude of recovery which in turn forces the participant to train in a pre-fatigued state and the sustainability of repetitions greatly decreases. In the current study, a 15% load reduction was sufficient in maintaining repetitions throughout three sets; however, according to these previous studies, a greater amount of load reduction may be necessary in maintaining repetitions in upper body workouts. Further research is necessary to determine the proper amount of load reduction for upper body workouts.

Limitations

A limitation of this study was the partial assessment of the subject's training history. On average, the eleven subjects worked out three days a week; however, the individual's training history was not assessed through the use of a questionnaire. Although every subject was familiar with each exercise and used bodybuilding as their main training method, some were more experienced than others especially for the squat exercise. Future research should address the differences between recreational lifters and advanced lifters that strictly follow the training methods of bodybuilding.

CHAPTER VI

CONCLUSION

Individuals that consistently train with short rest intervals (e.g. 30-seconds-1-minute) are likely to improve their ability in sustaining repetitions within a given exercise without having to significantly reduce the exercise intensity; however, most individuals do not train with this short amount of rest. In order to maintain repetitions at a specific target with little rest, variables such as intensity, rest, exercise mode, and etc. need to be altered. By changing these variables, individuals can achieve different goals such as power, absolute strength, hypertrophy, and localized muscular endurance. The repetition maximum with a given load is an important contributing factor in the ensuing neuromuscular adaptations. According to the results of the current study, load reductions were necessary to maintain consistency in repetition performance in a sample of recreational lifters. For the back squat and leg curl exercises, load reductions of 15% might be necessary following the first and second sets to allow for repetitions to be maintained in the 10-RM range when resting 1-minute between sets. Conversely, for the leg extension, the load might be kept constant over all three sets. It is important to note that previous studies have demonstrated that the amount of load reduction may lessen over time when individuals consistently training with greater effort and frequency.

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APPENDIX

CONSENT TO PARTICIPATE IN RESEARCH

Effect of Load Reductions over Consecutive Sets on Repetition Performance

You are invited to participate in a research study conducted by Dr. Jeffrey M. Willardson, Assistant Professor in the Kinesiology and Sport Studies Department at Eastern Illinois University. You have been invited to participate in this study because you are an experienced male lifter between the ages of 18 and 30 and answered "NO" to all questions on the Physical Activity Readiness Questionnaire (PAR-Q).

PURPOSE OF THE STUDY
The purpose of this research project will be to compare the maintenance of repetitions for the back squat, leg curl, and leg extension exercises, while keeping the resistance constant or lowering the resistance by different amounts.

PROCEDURES
This study will be carried out over a period of 7 weeks with 1 exercise session per week. During weeks 1, 2, and 3, testing sessions will take place under the direct supervision of an experienced strength and conditioning specialist. A 10 repetition maximum (i.e. 10-RM) for the back squat, leg curl, and leg extension exercises (in that order) will be assessed during each week. The testing sessions will begin with 5 minutes of low intensity aerobic activity (i.e. jogging/walking), followed by warm-up sets. The warm-up sets for each exercise will be performed for 10 repetitions each at 50% and 75% of the perceived 10-RM resistance, which represents the amount of resistance that can be lifted for a maximum of 10 repetitions to the point of voluntary exhaustion. Following the warm-up sets, the resistance will be raised to the perceived 10-RM and a set will be performed to the point of voluntary exhaustion. If you are able to perform more than 10 repetitions during this set, additional resistance will be added to the bar, and following a 5 minute rest, another 10-RM set will be attempted. A total of two 10-RM attempts will be allowed for each exercise during each of the familiarization sessions. The resistance for each 10-RM attempt will be recorded, with the highest being utilized to design the workouts during the subsequent four weeks of the study.

During weeks 4, 5, 6, and 7, one workout will be conducted each week under the direct supervision of an experienced strength and conditioning specialist. During each workout, three consecutive sets of each exercise will be performed to voluntary exhaustion with 1 minute rest between sets and 2 minutes rest between exercises. The back squat will be performed first followed by the leg curl and then the leg extension. The workout sessions will begin with 5 minutes of low intensity aerobic activity (i.e. jogging/walking), followed by warm-up sets for the back squat only, at 50% and 75% of the previously determined 10-RM. The workouts will be performed under four different conditions, including: 1) keeping the resistance constant for all sets of each exercise, 2) lowering the resistance 5% after the second set and after the third set of each exercise, 3) lowering the resistance 10% after the second set and after the third set of each exercise, and 4)

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lowering the resistance 15% after the second set and after the third set of each exercise. The conditions will be randomized and counterbalanced to control for order effects.

POTENTIAL RISKS AND DISCOMFORTS
The possible risks include injury to the low back and knee joints. You may experience mild muscle soreness following the workouts. However, there will be minimal risk of injury through close supervision of every repetition and a thorough warm-up prior to each testing or workout session. If you feel unable to complete a repetition, or experience discomfort at any time, you will be instructed to give a verbal cue at which time the weight will be removed. In case of injury the participant may seek immediate medical care at their own expense at the EIU Student Health Center (581-3014).

POTENTIAL BENEFITS TO SUBJECTS
The benefits of participation in this research are a greater understanding of how much the resistance should be lowered to maximize repetition performance during a typical lower body workout.

CONFIDENTIALITY
The results of this research study may be published, but your name or identity will not be used. In order to maintain confidentiality, your records will be assigned a code number. Further, all data will be kept on a disk in a locked desk, accessible only to Dr. Jeffrey M. Willardson.

PARTICIPATION AND WITHDRAWL
Your participation in this study is entirely voluntary. Please ask questions about anything you do not understand, before deciding whether or not to participate. If you choose not to participate or to withdraw from the study at any time, there will be no penalty.

IDENTIFICATION OF INVESTIGATORS
I understand that if I have any questions concerning the purposes or the procedures associated with this research project, I may call or write:

Dr. Jeffrey M. Willardson
Eastern Illinois University
Kinesiology and Sport Studies Department
2506 Lantz Bldg
600 Lincoln Avenue
Charleston, Illinois 61920
217.581.7592

_____ Initials

RIGHTS OF RESEARCH SUBJECTS

If you have any questions or concerns about the treatment of human subjects in this study, you may call or write:

Institutional Review Board
Eastern Illinois University
600 Lincoln Ave.
Charleston, IL 61920
Telephone: (217) 581-8576
E-mail: eiuirb@www.eiu.edu

You will be given the opportunity to discuss any questions about your rights as a research subject with a member of the IRB. The IRB is an independent committee composed of members of the University community, as well as lay members of the community not connected with EIU. The IRB has reviewed and approved this study.

I voluntarily agree to participate in this study. I understand that I am free to withdraw my consent and discontinue my participation at any time. I have been given a copy of this form.

____
Printed Name of Participant

____________________________________ _______________________
Signature of Participant Date

I, the undersigned, have defined and fully explained the investigation to the above subject.

____________________________________ _______________________
Signature of Investigator Date

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