THE EFFECT OF REST INTERVAL DURATION ON THE VOLUME COMPLETED DURING A HIGH INTENSITY BENCH PRESS EXERCISE

By

Dennis J. Hernandez

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Committee Membership

Dr. Young Sub Kwon, Committee Chair

Dr. Sean Healy, Committee Member

Dr. Mona Hass, Committee Member

Dr. Justus Ortega, Program Graduate Coordinator

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ABSTRACT

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Between set rest intervals (RI) are one of the most important variables in resistance training; however, no known research has investigated the effects of RIs greater than 5-min during strength training (>85% of 1RM). The purpose of this research was to examine the effects of three different RIs (2, 5, and 8-minute) on training volume (kg, sets x reps x resistance) and repetition sustainability during a high-intensity bench press exercise (> 85% of 1RM). Fifteen resistance trained males (mean±sd, age = 26+5 yr, height = 161+6 cm, body mass = 79+6 kg, bench press 1RM ratio = 1.39+0.1) completed 3 experimental sessions, during which 4 sets of the bench press were performed with 85% of a 1RM load. During experimental sessions, the bench press was performed with a 2, 5, or 8-minute RI in a random counterbalanced design. Data was analyzed using both a one and two-way ANOVA with repeated measures. As sets progressed, repetitions were significantly different ($p < 0.05$) between all RIs and only the 8-min RI ($p < 0.05$) allowed for the complete sustainability of repetitions over four consecutive sets. Greater training volume ($p < 0.05$) was attained when subjects used an 8-min RI between sets compared to a 2 or 5-min RI. Resistance trained males, with the goal of greater volume during strength training, would benefit from longer RIs; specifically, using an 8-min RI between 4 consecutive sets of a bench press exercise.

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INTRODUCTION

Resistance training is commonly associated with sports and the enhancement of sport performance (Kraemer, 2002). Furthermore, resistance training can be used for injury prevention, rehabilitation, and in preparation for high-risk jobs such as law enforcement, firefighting, or military service (Jan et al., 2008; Weiss, 1991; Willardson, 2006). With a large demographic heavily reliant on training benefits, the understanding of resistance training is imperative to prevent any incidental adverse effects such as a training plateau (Kraemer & Fleck, 2007). The training plateau is caused by muscular adaptations (obtained from an invariable resistance training program) and impedes further improvements in muscular size, power, and strength. The progressive overload principle can be applied to inhibit or rectify a training plateau by introducing variation that enables further muscular growth and absolute strength (Kraemer & Fleck, 2007).

The progressive overload principle states that in order for a muscle to grow and strength to be increased, the training stimulus must be progressively increased to force the body to adapt to a tension it has never experienced (Kenny et al., 2012). This principle is essential to acquire further gains in muscular strength and power because it manipulates specific training variables to provide variation in an otherwise invariable training program (Kraemer & Fleck, 2007). According to the American College of Sports Medicine (2009), training variables include exercise intensity, order of exercise, movement velocity, training frequency, training volume (sets x repetitions x load), and the duration of rest between sets. Prior research demonstrates the rest duration between

sets as one of the most important variables affecting the repetitions, training volume, and muscular strength (Larson & Potteiger, 1997; Miranda et al., 2009; Mirzaei, Arazi, & Saberi, 2008; Willardson, 2006).

The duration of rest between sets, or rest interval (RI), is based on the resistance training goal. Resistance training goals include muscular endurance, hypertrophy, power, and strength. The NSCA recommends RIs of at least 30 seconds for muscular endurance and a range between 30 to 90 seconds for muscular hypertrophy. In addition, the NSCA recommends a RI between two and five minutes for muscular strength and power (Baechle & Earle, 2016). Corroborating research also suggests, for optimal performance during resistance training, the use of short RIs (30s – 2-min) during muscular endurance and hypertrophy training (the ability to perform more training volume over a shorter amount of time) and long RIs (2-min – 5-min) during muscular power and strength training (strenuous activity requires greater recovery time to replenish energy systems) (Donnelly et al., 2009; Kraemer & Fleck, 2007).

Resistance training, with the goal of muscular strength, requires longer resting periods to resynthesize the depleted energy substrates, adenosine triphosphate (ATP) and phosphocreatine (PCr) (Willardson & Burke, 2008). The energy required for muscular strength training is provided from the hydrolysis (breakdown) of ATP; ATP reserves are limited and must be resynthesized for high-tension muscle contractions to continue (Baechle & Earle, 2016; Weiss, 1991). ATP resynthesis is achieved through the hydrolysis of PCr and is known as the phosphagen energy system (Kenney et al., 2012; Robergs, Ghiasvand, & Parker, 2004; Weiss, 1991). Muscular strength training primarily

relies on the phosphagen energy system and depletes concentrations of PCr drastically to equate ATP concentrations (Baechle & Earle, 2016; Robergs, Ghiasvand, & Parker, 2004). After high-intensity exercise, ATP concentrations deplete between 50% to 60% and PCr concentrations are nearly eliminated. A comprehensive review of rest duration effects on muscular strength (Weiss, 1991) suggests, the depletion of ATP and PCr concentrations contribute to the fatigue experienced during physical activity. ATP concentrations completely resynthesize between three to five minutes, and PCr concentrations completely resynthesize within eight minutes following high-intensity exercise (Baechle & Earle, 2016; Harris et al., 1976).

The length of the RI also affects the removal of proton accumulation caused by high levels of ATP hydrolysis and glycolysis during high-intensity exercise (Mirzaei, Arazi, & Saberi, 2008; Robergs, Ghiasvand, & Parker, 2004; Weiss, 1991). A high-intensity exercise, such as a bench press, requires the body to rely mainly on fast-twitch muscle fibers for energy production. Fast-twitch muscle fibers rely heavily on anaerobic glycolysis and accumulate high levels of hydrogen ions during low-to-moderate intensity resistance performed to failure (Larson & Potteiger, 1997). The inability to buffer or remove the accumulation of hydrogen ions has been shown to lower intracellular pH, which results in metabolic acidosis and muscle fatigue (Robergs, Ghiasvand, & Parker, 2004). At low pH values (muscle acidosis), muscle contraction shortening-velocity and the peak isometric force decreases significantly (Larson & Potteiger, 1997). Other research also suggests that increased hydrogen ion concentration may be the main contributor to reduced force production, which is necessary for eccentric and concentric

muscle contraction to continue during high-intensity exercise (Kramer & Fleck, 2007; Larson & Potteiger, 1997; Robergs, Ghiasvand, & Parker, 2004).

REVIEW OF LITERATURE

Literature Search

This section is the review of literature to evaluate the effect of RI duration on the sustainability of repetitions and training volume during heavy resistance training. Relevant research was selected using kinesiology research electronic database (SPORTDiscus and Pubmed), Medicine & Science in Sports & Exercise (MSSE) and Journal of Strength and Conditioning Research (JSCR), searching journal articles and reference lists, and World Wide Web searches using Google Research engine identifying pertinent databases and online journals. Thirty-five original studies, two abstracts, and three textbooks were focused on the effect of between-set RIs during resistance training, specifically using the following terms: fitness testing, rest interval, rest period, recovery, recover-time, training volume, and strength training. Table 1 to Table 4 summarize studies describing RIs effect on the maximum number and sustainability of repetitions, training volume and overall strength gains.

Maximal Number and Sustainability of Repetitions

The ability to sustain repetitions throughout sets increases the maximum number of repetitions performed during a bout of exercise (Willardson and Burkett, 2005). Greater sums of repetitions acutely increase training volume (repetitions x sets x load) and chronically increase muscular strength (Kraemer, 1997). Heavy training loads place a greater metabolic demand on the body and negatively affect repetition performance

(Mirzaei, Arazi, & Saberi, 2008; Willardson and Burkett, 2008). Increasing the training load decreases energy substrates (ATP and PCR) and increases metabolic waste (H+); thus, impeding necessary chemical reaction pathways that assist in the transformation of chemical energy into mechanical energy (Kraemer & Fleck, 2007). Previous RI research was primarily concerned with the effect of heavier training loads on repetition performance; specifically, how age, training status, RI method, or exercise type are affected by between-set RI manipulation.

A study by Faigenbaum et al. (2008) was the first to research the effects of age and RI duration on lifting performance in a group of resistance trained males that consisted of: 12 boys (11.3 $\pm$ 0.8 yrs), 13 teens (13.6 $\pm$ 0.6 yrs), and 17 men (21.4 $\pm$ 2.1 yrs). The study used a randomized crossover design to test the effects of one, two, and three-minute RIs on the number and sustainability of repetitions completed during three sets of bench pressing using a ten-repetition maximum (RM) load. The findings indicated that for all ages and all intervals, repetitions completed during each set significantly decreased as sets progressed; however, boys and teens had a less pronounced decrease in lifting performance (due to their ability to resist fatigue) compared to men (Table 1). Men's lifting performance declined significantly from an average of ten repetitions during the first set, to an average six repetitions during the third set. This study concluded that men would benefit the most from longer RIs and a minimum of three minutes of rest between sets may be needed to sustain repetitions.

Research conducted by Evangelista, Pereira, Hackney, & Machado (2011) used 28 healthy untrained-men (18.0 $\pm$ 1.0 yrs) to test the effects of one and three-minute RI

on the number of repetitions performed during three sets of a bicep curl. The bicep curl load was determined using 40% of the subject's maximal voluntary isometric contraction strength (MVC) measured by electromyography (EMG). The results indicated that neither RI was successful at sustaining repetitions throughout sets (Table 1). A similar study, that used twenty untrained-male subjects (18.6 $\pm$ 0.4 yrs), also used one and three-minute RIs between sets, but tested five upper-body exercises using 80% of subject's 1RM load. The results showed a significant reduction in repetitions for both RI groups, particularly when comparing the first and third set of all exercises (Table 1). In addition, a greater number of repetitions were performed in each set for all exercises using a three-minute RI (Table 2) (Rodrigues et al., 2012). A possible limitation in the previous studies was the use of untrained subjects; current research suggests that resistance-trained men may benefit the most from longer RIs because they require a longer recovery period to prevent a decrease in the number of repetitions performed (Richmond & Godard, 2004).

Miranda et al. (2009) included 12 healthy men (23.6 + 2.5 yrs) with at least two years of recreational resistance training experience. The subjects performed five different upper-body resistance training exercises using an 8RM load (80% of 1RM) with either a one or three-minute RI between sets. The results showed significant differences in the repetitions completed during each exercise set for both RIs; however, the three-minute RI allowed for the greatest consistency in repetitions throughout all three sets (Table 1). Furthermore, significant differences were found in the number of repetitions completed during most exercise sets between both rest conditions (Table 2). The researchers

concluded that instituting a longer RI (e.g. three-minutes) allowed for a greater amount and sustainability of repetitions compared to a shorter RI (e.g. one-minute).

Another possible limitation of all the aforementioned studies was the use of only fixed RIs between sets. Monteiro et al. (2013) wanted to compare the effects of between set RIs using different methods of recovery. These methods included exercise-recovery ratios (1:3, 1:5, and 1:7), progressive intervals in each subsequent set (1:3-1:5-1:7-1:9), and a 2-minute fixed interval. The subjects included 16 men (25.0 $\pm$ 2.0 yrs) with a least one year of resistance training experience. All subjects performed five sets of the bench press and triceps extension using 80% of their 1RM load. The results showed that the shortest rest ratio (1:3) had the greatest decrease in the number of repetitions completed; although, all other strategies were also unable to sustain repetitions within multiple sets (Table 1). A similar study by Larson & Potteiger (1997) also investigated the effects of different methods of recovery on the number of squat repetitions performed over four sets using 85% of subject's 10RM. RIs included a post-exercise heart rate of 60% age-predicted maximum heart rate, three-minute fixed interval, and a 1:3 rest ratio. No significant differences were found in the repetitions performed to exhaustion between all rest conditions (Table 2); however, no RI allowed for complete sustainability of repetitions throughout the consecutive sets (Table 1). Both studies concluded that the duration of the RI may be more influential than the strategy used to determine it.

Dias et al. (2014) used a different approach to test the effects of RI duration during upper-body resistance training. The purpose of the study was to compare the differences in the number of repetitions completed during an uni-joint (peck deck fly) or

multi-joint (bench press) exercise. This randomized study included 18 healthy resistance-trained men (23.4 ± 3.5 yrs) who performed three sets of a 10RM load using either a one-minute or two-minute RI between sets for both exercises. The results showed a greater number of repetitions performed during the third set of the peck deck fly exercise when using a two-minute RI compared to a one-minute RI (Table 2). Similarly, a two-minute RI allowed for a significantly greater amount of repetitions performed during the second and third set of the bench press exercise (Table 2). The study concluded multi-joint exercises, such as the bench press, may benefit the most from longer RIs in regards to the maximum number of repetitions performed during each set.

Corroborating research conducted by Richmond & Godard (2004), investigated the effects of three different between-set RIs (1-min vs 3-min vs 5-min) on multi-joint resistance training performance. Subjects were comprised of 28 healthy resistance-trained males (21.5 ± 3.2 yrs) who performed two sets of the bench press exercise using 75% of their 1RM load. The results indicated that repetitions significantly decreased between the first and second set for all resting periods (Table 1). In addition, the repetitions performed during the second set for all rest conditions were significantly different between groups (Table 2). The study concluded that the prescribed recovery between sets did not prevent a decrease in the number of repetitions; however, the three and five-minute RIs allowed for a greater sustainability of repetitions as sets progressed. The longer RIs were determined to be the most beneficial because they allowed targeted muscle groups a longer recovery period to resynthesize energy substrates (Harris et al., 1979; Richmond & Godard, 2004).

Finally, research performed by Mirzaei, Arazi, & Saberi (2008) investigated the effects of different RIs on the sustainability of repetitions when using either a heavy or light resistance load. The study included 17 resistance-trained men (21.7 $\pm$ 1.9) who performed four consecutive sets of a bench press using two different loads (60% vs 90% of 1RM) and three different RIs (1.5-min vs 2.5-min vs 4-min). The results of the study demonstrated that the longest RI (4-min) resulted in a greater sustainability of repetitions when compared to the shorter RIs (1.5-min vs 2.5-min) for both training loads (Table 1). Furthermore, sustainability of repetitions over four consecutive sets were significantly greater for the heavier training load (90%). This study concluded that longer RIs highly influence the amount of repetitions performed, particularly during upper-body resistance training with heavy loads.

Training Volume

As previously mentioned, a longer RI has the greatest effect on the number and sustainability of repetitions over consecutive sets during a resistance training session. The sustainability of repetitions can allow for greater training volume (repetitions x sets x load), which prompts gains in muscular strength (Willardson & Burkett, 2008). Prior investigations have suggested the use of a longer duration of rest between sets, particularly when the training goal requires a heavy training load and a large amount of training volume (Ratamess et al., 2007). A previously mentioned study by Dias et al. (2014) compared differences between the training volume completed during uni-joint (peck deck fly) and multi-joint (bench press) exercises using either a one or two-minute

RI between sets at a 10RM load. The study reported longer RIs (2-min) allowed for a greater training volume completed for both the uni-joint and multi-joint exercises (Table 3).

To contribute to the findings of Dias et al. (2014), a study performed by Willardson and Burkett (2005) investigated the effects of one, two, and five-minute RIs on squat and bench press training volume. A group of 15 resistance-trained men (20.7 ± 2.6 yrs) performed four sets of a squat and bench press exercise using an 8RM load (85% of 1RM) and three different between-set RIs. The results showed that total training volume completed was significantly different between all RIs for both exercises, but the five-minute RI allowed for the greatest amount of volume to be completed (Table 3). Similar results were reported during a four-week study consisting of a 10RM bench press exercise using one, three, and five-minute RIs (Table 3) (Richmond and Godard, 2004).

To determine an optimal resting duration, Ratamess et al. (2007) tested multiple RI lengths to examine and quantify the total training volume completed during the bench press exercise. This eight-week study included eight healthy resistance trained men (21.4 ± 2.4 yrs). Subjects performed either a 10RM or 5RM load during the bench press exercise using five different RIs between sets (i.e., 30s, 1,2,3,5-min). Training volume significantly decreased over four consecutive sets between all rest conditions except with the use of a five-minute RI (Table 3). A similar study investigated the total training volume completed during multiple upper-body resistance exercises using either a one or three-minute RI. The results also highlighted the linear relationship between RI duration

and total training volume completed during an upper-body resistance training session (Table 3) (Miranda et al., 2009).

The results of aforementioned studies determined longer RIs were the most beneficial to significantly increase training volume; however, a study conducted by Monteiro et al. (2013) found no significant differences in training volume after subjects rested between two and five-minutes between sets while performing both the triceps extension and bench press using 80% of subject's 1RM load (Table 3). A possible causation for conflicting results may be the duration of the experimental procedure. Reports of acute responses due to RI manipulations have been inconsistent due to varied methodologies; therefore, chronic response research might infer more conclusive results regarding the effects of RI duration on training volume.

De Souza Jr. et al. (2010) was the first study to compare the chronic effects of decreasing (2-min to 30s) and constant (2-min) RIs during an eight-week resistance training program. Twenty resistance trained males were equally divided into either a decreasing (22.0 + 4.8 yrs) or constant (20.5 + 1.0 yrs) RI group and performed two different training programs. During the first two weeks, three sets of 10-12RM load were performed for various upper-body and midsection exercises using two-minute RIs between sets. After the first two weeks, the constant RI group continued the same protocol while the descending RI group implemented decreasing RIs between sets (2min-30secs). The results highlighted that the total training volume completed for both the squat and leg press were significantly greater in the constant RI group when compared to the descending RI group after the eight-week experimental treatment (Table 3).

Lastly, another study by Willardson and Burkett (2008) reported consistent results with De Souza Jr. et al. (2010). The researchers used four mesocycles (three week periods) to compare training volume for 15 resistance trained men using both a heavy (70 – 90% 1RM) and light (60% 1RM) resistance load for the squat exercise. Subjects were prescribed two and four-minute RIs and asked to perform between five and eight sets for all exercises until exhaustion. The data indicated that a significantly greater training volume was completed during the heavy workouts (70-90% of 1RM) when a four-minute RI was used (Table 3). An investigation by De Salles et al. (2010) also suggested training volume was significantly greater when a longer RI was prescribed for both upper and lower-body exercises (Table 3). The major finding of all studies was training volume increased proportionally as the RI duration increased during resistance exercises using heavy loads.

Strength Gains

Prior research suggests a greater amount of repetitions and training volume leads to increases in muscular strength; however, contradictory research indicates that the duration of the RI may not affect overall strength (Willardson and Burkett, 2008). Such results were found in the study conducted by Gentil et al (2010). The researchers performed a longitudinal study to investigate the chronic effects of two different between-set rest ratios (1:3 vs 1:6) on muscle strength (Final 1RM load) in 32 non-resistance trained young men (22.4 ± 2.6 yrs). The subjects were prescribed a 12-week whole-body resistance training program comprised of two upper body exercises, two

lower body exercises, and one midsection exercise. All exercises included either rest ratio (1:3 vs 1:6) between sets with an 8-12RM load. The results showed that the 1RM load significantly increased from pre-treatment to post-treatment following the 12-week resistance training intervention regardless of the rest ratio employed (Table 4).

A similar study by Buresh, Berg, and French (2009) compared the effects of two different RIs (1 vs 2.5-min) on strength gains obtained from a whole-body resistance training program. Twelve untrained men were randomly divided into two separate groups (short rest: 25.3 $\pm$ 2.0 vs long rest: 21.5 $\pm$ 3.6). Subjects participated in four training sessions per week, for ten weeks, of an alternating upper and lower-body training program. Subjects baseline and post-training 1RM values were used to determine strength increases. No significant differences were found between groups in relative strength in either the squat or bench press exercise (Table 4). A possible limitation from the previously mentioned studies was the use of non-resistance trained individuals. Untrained subjects acquire strength increases no matter what type of RI was used due to no previous neuromuscular adaptations (Baechle & Earle, 2016).

De Salles et al. (2010) performed a longitudinal study to determine the influence of different RIs on upper-body strength increases in 36 resistance trained men during a 16-week exercise regimen. The subjects prescribed either a 1-min, 3-min, or 5-min RI treatment during a bench press exercise. The results indicated that the group that used a 5-min RI were significantly stronger when compared to the 1-min group (Table 4). The researchers concluded that longer RIs between sets may contribute to greater strength increases. Conversely, a similar longitudinal study using resistance trained men found no

significant differences in squat strength gains between groups that used either two or four-minute RI between sets (Table 4) (Willardson and Burkett, 2008). A consensus of previous research suggests muscular strength gains may not be affected by the duration of rest between sets.

Summary

The recommended rest duration between sets consists of using either a short (~30s - 2-min) or long (~2 - 5-min) RI based on an individual's resistance training goal (Baechle & Earle, 2016). Prior investigations in RI effects have suggested the use of longer RIs during training with a heavy load because it allowed for a greater amount of time to resynthesize energy substrates and remove metabolic waste (Kraemer & Fleck, 2007; Harris et al, 1976). Furthermore, longer RIs were the most successful at sustaining and increasing the repetitions performed (Richmond & Godard, 2004). The population most affected by longer RIs was resistance-trained men, specifically during multi-joint exercises with a heavy training load (Dias et al., 2014; Faigenbaum et al., 2008; Mirzaei, Arazi, & Saberi, 2008)

Increasing the maximum number of repetitions performed leads to a greater training volume completed during an exercise session. In prior research, subjects overall training volume was the most affected by longer RIs (Miranda et al., 2009). The most reliable results of the linear relationship between RI duration and training volume was found in studies that observed chronic effects with longer experimental treatments (De Souza Jr. et al., 2010; Willardson and Burkett, 2008). The only inconclusive results of RI

manipulation were studies that investigated muscular strength adaptations (Buresh, Berg, and French, 2009). The results showed a possible link between longer rest between and strength gains, but a consensus from the literature suggests further longitudinal research may be needed (De Salles et al., 2010; Gentil et al, 2010; Willardson and Burkett, 2008).

Despite certain findings, none of the RIs prescribed to subjects allowed for the complete maintenance of repetitions throughout sets, which ultimately affects the training volume completed (reps x sets x load). This lead the researchers in the aforementioned studies to conclude that further research is needed on longer RIs to see if there are any further contributions to resistance training performance, specifically in repetition performance and the volume of training completed.

Statement of the Problem

A maximum of five-minute rest intervals for recovery were used in the presented studies due to practicality and existing recommendations from the National Strength and Conditioning Association (Baechle & Earle, 2016). However, research suggests complete phosphocreatine resynthesis occurs within eight-minutes (Harris et al., 1979; Baechle & Earle, 2016). Due to a proposed eight-minute resynthesis period, more research is needed on longer rest intervals to allow for the complete resynthesis of phosphocreatine in the phosphagen energy system. Having more energy substrates (ATP and PCR) aid in muscle recovery and would allow individuals to increase performance during resistance training.

Purpose

The unique purpose of this study was to investigate the effects of between set rest intervals on training volume (reps x sets x load). Specifically, the effect of three different rest intervals (2-, 5- or 8-min) on bench press volume completed over four sets using 85% of subject's 1RM load.

Limitations

A small sample size was used due to a minimal number of valid subjects. Due to inconsistent subject availability, experimental sessions were flexible to maintain subject participation.

Assumptions

Subject's natural repetition tempo (bar speed) will not affect bench press performance. Subject's arm length will not affect bench press performance. Participants will give their best effort and performed at the best of their capability for the bench press exercise.

Hypotheses

1) There is no statistical difference between all rest intervals when comparing the sustainability of repetitions between four consecutive sets.

2) There is no statistical difference between all rest intervals when comparing the training volume completed during a bench press workout.

METHODS

Experimental Approach to the Problem

To examine the effect of three different RIs on the training volume completed, the study included a total of four experimental days where subjects performed a high-intensity bench press exercise. The bench press exercise was chosen because of its reliability in previous studies and the popularity of the exercise with advanced resistance training enthusiasts (Kwon et al., 2010; Mirzaei, Arazi, & Saberi, 2008). Initially, subject's 1RM load was assessed for the bench press exercise. Following the 1RM assessments, subjects completed three experimental resistance training sessions using two, five, and eight minutes of rest between sets in a counterbalanced design (Figure 1). A counterbalanced design was used to minimize any learner or order effects (Kwon et al., 2010). The number of repetitions and workout volume completed (repetitions x sets x load) was recorded for each subject during each session and used later to compared the RI conditions. In accordance to the super-compensation theory (Zatsiorsky & Kraemer, 2006), there was a 48-hour period between each session.

Participants

The study included 15 volunteer males (mean ± sd, age = 26±5 yr, height = 161±6 cm, body mass = 79±6 kg, bench press 1RM ratio = 1.39±0.1). The subjects had a year or more experience in resistance training with a frequency of three or more days per week and a ratio of training load to body weight greater than 80% of age-based upper body

strength (ACSM guidelines, 2013) (Table 5). Subjects were screened for cardiovascular and musculoskeletal disease using a medical history questionnaire, an activity questionnaire, and the Physical Activity Readiness Questionnaire (PAR-Q) (Heyward, 2002). Subjects were excluded from the study if they had more than two positive cardiovascular risk factors as outlined by the American College of Sports Medicine (2009), or using ergogenic supplementation that could affect their exercise performance. The subjects were also instructed to refrain from upper-body resistance training throughout the course of the study.

Power Analysis

The number of subjects was based on a power analysis using data from Kwon et al. (2010). Mean exercise volume (kg) of thermal natural condition was 1972 ± 632 (average±SD). Using the standard deviations from Kwon's data, approximately 15 subjects would be sufficient to detect a significant difference in average total volume between two, five, and eight-minute rest periods (α=0.05 and a power of 0.9). Therefore, fifteen healthy, resistance-trained male subjects were recruited for this study

Repetition Maximum Testing

The 1RM assessments for the bench press exercise were conducted during the first session. To increase the reliability of the 1RM assessments, the following strategies were employed; 1) all subjects received standard instructions on exercise technique prior to testing; 2) exercise technique was monitored and corrected as needed; 3) all subjects

received verbal encouragement during testing sessions (Miranda et al., 2009). Prior to 1RM assessments, subjects performed a warm-up consisting of: 10 repetitions at 50% of (predicted) 1RM, 5 repetitions at 70% of 1RM, 3 repetitions at 80% of 1RM, and 1 repetition at 90% of 1RM (Kraemer et al., 1991; Kwon et al., 2010). During the 1RM assessments, each subject had a maximum of five 1RM attempts for the bench press, with a five-minutes rest between attempts (Miranda et al., 2009). There was no pausing between eccentric and concentric phases and complete range of motion was required for the repetition to be counted. The highest load obtained was the subject's 1RM load and used to calculate their 85% of 1RM load.

Experimental Resistance Training Sessions

During the three experimental sessions, four sets were performed using 85% of subject's 1RM load with at least 48 hours between each session. A warm-up was used prior to each session consisting of 10 repetitions at 50% of (predicted) 1RM, 5 repetitions at 70% of 1RM, and 3 repetitions at 80% of 1RM (Kwon et al., 2010). Subjects were randomly assigned one of the three RIs for the first session, then rotated through each RI throughout the duration of the testing sessions; therefore, all subjects alternated between each RI after each session. There was no attempt to control subject's repetition velocity, but subjects were instructed to maintain a fluid motion throughout the concentric and eccentric phases of the exercise. Only completed repetitions were counted and later used to compare the training volume completed between the RIs.

Statistical Analysis

After experimental testing sessions, the data was first analyzed using both a boxplot graph to determine if there were any outliers and a Shapiro-Wilk's test to determine normality within groups. To determine a difference between the average repetitions performed between each set and between each treatment group, a two-way repeated measures ANOVA was used. Additionally, to determine a difference between training volumes completed using the three different RIs, a one-way repeated measures ANOVA was used. Since this study is one of the first to test an eight-minute RI, a moderate alpha level of $P = .05$ was used to determine a statistically significant treatment effect.

RESULTS

Repetition Sustainability

A two-way repeated measures ANOVA was run to determine the effect of three different RIs on the average repetitions performed between each set and between each treatment group. Results were reported as the mean ± standard deviation for the average repetitions performed each set (Table 6). Box plot graphs determined that there were no outliers. Average repetitions were not normally distributed ($p < .05$) as assessed by Shapiro-Wilk's test of normality on the studentized residual; however, results were still interpreted due to the ANOVA statistic being robust to deviations in normality. Mauchly's test of sphericity indicated that the assumption of sphericity was met for the two-way interaction, $\chi2(2) = 17.117$, $p = .660$. There was a statistically significant two-way interaction between treatment and time, $F(6, 84) = 31.325$, $p < .001$. Therefore, simple main effects were run.

Between Consecutive Sets

2-min. Average repetitions performed using the two minute RI were statistically different between all sets $F(1.75, 24.46) = 120.73$, $p < .001$. Set 2 ($M = 4.20$, $SD = 0.34$) had a mean difference of 2.20 reps, 95% CI [1.20, 3.20], $p < .001$, compared to Set 1($M =$ 6.40, $SD = 0.16$). Set 3 ($M = 3.20$, $SD = 0.18$) had a mean difference of 3.20 reps, 95% CI [2.66, 3.74], $p < .001$ compared to Set 1 ($M = 6.40$, $SD = 0.16$). Finally, Set 4 ($M =$

1.93, SD = 0.18) had a mean difference of 4.47 reps, 95% CI [3.96, 4.97], p < .001 compared to Set 1 (M = 6.40, SD = 0.16), as seen in Figure 2.

5-min. Average repetitions performed using the five minute RI were statistically different between all sets F(3, 42) = 68.96, p < .001. Set 2 (M = 5.40, SD = 0.24) had a mean difference of 1.00 reps, 95% CI [0.48, 1.52], p < .001, compared to Set 1(M = 6.40, SD = 0.16). Set 3 (M = 4.13, SD = 0.26) had a mean difference of 2.27 reps, 95% CI [1.51, 3.03], p < .001 compared to Set 1 (M = 6.40, SD = 0.16). Finally, Set 4 (M = 3.40, SD = 0.25) had a mean difference of 3.00 reps, 95% CI [2.40, 3.60], p < .001 compared to Set 1 (M = 6.40, SD = 0.16), as seen in Figure 2.

8-min. Average repetitions performed using the two minute RI were not statistically different between all sets F(1.55, 21.65) = 6.872, p > .05. Set 2 (M = 6.13, SD = 0.22) had a mean difference of mean difference of 0.27 reps, 95% CI [-0.20, 0.74], p = .623, compared to Set 1(M = 6.40, SD = 0.16). Set 3 (M = 5.93, SD = 0.27) had a mean difference of 0.47 reps, 95% CI [-0.19, 1.13], p = .287 compared to Set 1 (M = 6.40, SD = 0.16). Finally, Set 4 (M = 5.40, SD = 0.40) had a mean difference of 1.00 reps, 95% CI [-0.04, 2.04], p = .062 compared to Set 1 (M = 6.40, SD = 0.16), as seen in Figure 2.

Between Treatment Groups

Set 2. Average repetitions during the second set were statistically significantly different between all RIs F(2,28) = 24.867, p < .001. The 2-min RI (M = 4.20, SD = 0.34) had a

mean difference of 1.20 reps, 95% CI [0.40, 2.00], $p = .004$, compared to the 5-min RI ($M = 5.40$, $SD = 0.24$), and a mean difference of 1.93 reps, 95% CI [1.08, 2.79], $p < .001$, compared to the 8-min RI ($M= 6.13$, $SD = 0.22$). In addition, average repetitions for the 5-min RI ($M = 5.40$, $SD = 0.24$) were statistically significantly different compared to the 8-min RI ($M= 6.13$, $SD = 0.22$), with a mean difference of 0.73 reps, 95% CI [0.17, 1.29], $p = .009$, as shown in Figure 3.

Set 3. Average repetitions during the third set were statistically significantly different between all RIs $F(2,28) = 80.361$, $p < .001$. The 2-min RI ($M = 3.20$, $SD = 0.18$) had a mean difference of 0.93 reps, 95% CI [0.31, 1.55], $p = .003$, compared to the 5-min RI ($M = 4.13$, $SD = 0.26$), and a mean difference of 2.73 reps, 95% CI [2.06, 3.41], $p < .001$ compared to the 8-min RI ($M= 5.933$, $SD = 0.27$). In addition, average repetitions for the 5-min RI ($M = 4.13$, $SD = 0.26$) were statistically significantly different compared to the 8-min RI ($M= 5.933$, $SD = 0.27$), with a mean difference of 1.80 reps, 95% CI [1.33, 2.27], $p < .001$, as shown in Figure 3.

Set 4. Average repetitions during the fourth set were statistically significantly different between all RIs $F(2,28) = 77.132$, $p < .001$. The 2-min RI ($M = 1.93$, $SD = 0.18$) had a mean difference of 1.47 reps, 95% CI [0.77, 2.16], $p < .001$, compared to the 5-min RI ($M = 3.40$, $SD = 0.25$), and a mean difference of 3.47 reps, 95% CI [2.59, 4.34], $p < .001$, compared to the 8-min RI ($M= 5.40$, $SD = 0.40$). In addition, average repetitions for the 5-min RI ($M = 3.40$, $SD = 0.25$) were statistically significantly different compared to the

8-min RI (M= 5.40, SD = 0.40), with a mean difference of 2.00 reps, 95% CI [1.30, 2.70], $p < .001$, as shown in Figure 3.

Training Volume

A one-way repeated measures ANOVA was conducted to determine whether there were statistically significant differences in training volume using three different between set RIs. Results were reported as the mean ± standard deviation for the total training volume performed using each RI (Table 7). There were no outliers and the data was normally distributed, as assessed by a boxplot and Shapiro-Wilk test ($p > .05$), respectively. The assumption of sphericity was violated, as assessed by Mauchly's test of sphericity, $\chi2(2) = 8.312$, $p = .016$. Therefore, a Greenhouse-Geisser correction was applied ($\varepsilon = 0.679$). Training volume was statistically significantly different for the three different RIs during the exercise intervention, $F(1.358, 19.017) = 78.922$, $p < .001$, with training volume increasing between the 2-min (M = 1447.80, SD = 215.36 kg), 5-min (M = 1793.11, SD = 315.58 kg), and 8-min RIs (2207.42, SD = 372.27 kg). Post hoc analysis with Bonferroni adjustment revealed that training volume was statistically significantly different between the 8-min RI and the 5-min RI (M = 414.32 kg, 95% CI [310.64, 517.99], $p <.001$), the 8-min RI and the 2-min RI (M = 759.62 kg, 95% CI [552.32, 966.92], $p <.001$), and the 5-min RI and the 2-min RI (M = 345.30 kg, 95% CI [179.452, 511.15], $p <.001$), as seen in Figure 4.

DISCUSSION

The present study investigated the effects of three different between set RIs (2-, 5-, and 8-min) on the sustainability of repetitions within multiple sets and the training volume completed during a high-intensity (85% of 1RM) bench press exercise. The average number of repetitions performed throughout four successive sets were significantly different from each other using either the two or five minute RIs ($p \leq 0.05$); however, there were no significant differences between the average number of repetitions performed each set using the eight minute RI ($p > 0.05$). Additionally, greater sustainability using the eight minute RI ultimately led to the greatest number of repetitions performed each set ($p \leq 0.05$).

Furthermore, the eight minute RI elicited the greatest training volume compared to both the five and two minute RI ($p \leq 0.05$). Similarly, a significantly greater training volume was achieved using the five-minute RI compared to the two minute RI ($p \leq 0.05$). These results were consistent with related studies that compared repetition performance and the volume completed using RIs of five minutes or less (De Salles et al., 2010; Miranda et al. ,2009; Mirzaei, Arazi, and Saberi, 2008; Monteiro et al., 2013; Rahimi, 2005; Ratamess et al., 2007; Richmond and Godard, 2004; Rodrigues et al., 2012; Willardson & Burkett, 2005; Willardson & Burkett, 2008)

Sustainability of Repetitions

During heavy resistance training, the ability to sustain repetitions over successive sets increases the amount of repetitions performed (Willardson & Burkett, 2005). A greater volume of repetitions will stimulate the growth of muscle and increase absolute strength (Ahtiainen et al., 2005; Willardson and Burkett, 2008; Willardson, 2006). Mirzaei, Arazi, and Saberi (2008) used a sample of resistance trained men to compare the effect of three different RIs on the sustainability of bench press repetitions over four sets. During each experimental session, the bench press was performed using either a light or heavy load (60% and 90% of 1RM) and using three different RIs between sets (1.5-, 2.5-, or 4-min). A significant difference was seen in average repetitions between all sets and rest conditions; however, the four minute RI resulted in the greatest sustainability throughout the four sets. In the current study, repetitions were also not sustained over the four sets using RIs five minutes or less and the longest RI (8-min) had the greatest influence on repetition sustainability.

A study by Miranda et al. (2009) compared the effects of two different RIs on repetition sustainability throughout three successive sets. Twelve resistance trained men performed two experimental treatments consisting of five upper body exercises performed with an 80% of 1RM load and a one or three minute RI between sets. The results suggested that subjects who rested three minutes had the greatest consistency of repetitions, but the RI did not allow for the complete sustainability over all three sets. In addition, a significantly greater amount of repetitions were completed each set while

resting three minutes compared to resting one minute. These results were consistent with the current study emphasizing that shorter RIs do not allow for sufficient recovery time during heavy resistance training exercises.

Similar results were seen in the study conducted by Monteiro et al. (2013). In their study, 16 trained men participated in a four-week study where five experimental treatments of the bench press were performed using an 80% of 1RM load over five sets. Subjects were also prescribed various RI methods and durations ranging from a 1:3 rest ratio and a two-minute fixed interval. The greatest decrease in the number of repetitions along successive sets were always observed with the shortest RI. Furthermore, no significant differences in repetition sustainability were seen between all other resting conditions; indicating, RIs of two min or less always result in greater fatigue (Faigenbaum et al., 2008; Miranda et al., 2009; Rodrigues et al. 2012).

Richmond and Godard (2004) used 12 resistance trained men who performed, in a counterbalanced design, two sets of the bench press with a 75% of 1RM load and either a one, three, or five-minute RI between sets. The results showed significant differences in the repetitions performed between the first and the second set at all periods. The average repetitions performed in the second set were also significantly different between all three RIs. The results of the aforementioned study were similar to the current study, suggesting RIs less than or equal to five minutes are not long enough to prevent a decrease in the number of repetitions between successive sets. A limitation of the study was that subjects only performed 2 sets. Had more than two sets been attempted; further inferences could be made on the five-minute RI’s repetition sustainability during multiple sets.

Rodrigues et al. (2012) wanted to investigate the effects of two RIs (1-min vs 3-min) on the repetition sustainability and the average repetitions performed each set during multiple upper body resistance exercises. In a counterbalanced design, 20 untrained men performed five upper body exercises using an 80% of 1RM load to failure. The results highlighted that there was a decrease in the average repetitions performed each set being the most evident in the one minute RI. These results were consistent with the current study, where a decrease in repetition sustainability was most seen, from set to set, with the two and five minute RIs. Furthermore, the Rodrigues et al. (2012) study found a greater number of repetitions performed for all exercises using the three minute RI. Again, these results are consistent with the current study showing that longer RIs produced a greater average of repetitions each set when compared to the shorter RIs. However, there was a difference between study methodologies due to the use of untrained subjects. The untrained subjects in the study by Rodrigues et al. (2012) would have different responses to training stimulus compared to advanced resistance trained individuals.

Conflicting with the current study's results, Kraemer (1997) demonstrated that subjects who rested 3-min between sets, could complete 10 repetitions over 3 sets of a bench press with 85% of a 10RM load. In the current study, repetitions were only sustained throughout all four sets using the eight-minute RI. Possible explanations for these inconsistencies may have been the use only three sets, a lower training intensity and the experience of the subjects. Kraemer (1997) used Division I football players who possibly developed abilities to train with heavy resistance loads over multiple sets and

with shorter rest periods. By contrast, the subjects in the current study performed four sets with a heavier training load (85% of 1RM) and had minimal experience training with maximal exertion over multiple sets.

Training Volume

Enhancing repetition performance automatically influences the training volume completed during a resistance exercise. The ability to perform a greater training volume during high-intensity resistance exercises elicits greater strength adaptations (Willardson & Burkett, 2008). When training for absolute strength, longer RIs have been recommended to maintain overall volume (Ratamess et al., 2007). Willardson and Burkett (2005), investigated the effects of one, two, and five-minute RIs on training volume completed for two upper and lower body exercises. The study included 15 resistance-trained men (20.7 ± 2.6 yrs) who performed four sets of a squat and bench press exercise using an 8RM load (85% of 1RM). The results showed that total training volume completed was significantly different between all RIs for both exercises. The five-minute RI allowed for the greatest amount of volume to be completed for both exercises. In the current study, training volume was also significantly greater using a five-minute RI between sets when compared to the two-minute RI.

Ratamess et al. (2007) performed an eight-week study which included eight healthy resistance trained men (21.4 ± 2.4 yrs). Subjects performed either a 10RM or 5RM load during the bench press exercise using five different RIs between four sets (e.g., 30s, 1,2,3,5-min). Training volume significantly decreased throughout sets between all

rest conditions except with the use of a five-minute RI. Similar results were seen by Rahimi (2005), who investigated the effects of three different RIs on squat volume. During three experimental sessions, 20 college-age men performed four sets using an 85% of a 1RM load. The results of this study also indicated that the five-minute RI allowed for the greatest training volume performed. Additionally, De Salles et al. (2010) also suggested training volume was significantly greater when a longer RI was prescribed for both upper and lower-body exercises. The major finding of all previously mentioned studies was the training volume increased proportionally as the RI duration increased during resistance exercises using heavy loads.

Another study by Willardson and Burkett (2008) used four mesocycles (period of three weeks) to compare training volume for 15 resistance trained men using both a heavy (70 – 90% 1RM) and light (60% 1RM) resistance load. Subjects were prescribed two and four-minute RIs and asked to perform between five and eight sets for exercises until exhaustion. The data indicated that a significantly greater training volume was completed during the heavy workouts (70-90% of 1RM) when a four-minute RI was used. Contradictive to Willardson and Burkett (2008) and the current study, Monteiro et al. (2013) found no significant differences in training volume after subjects rested around two minutes between sets while performing both the triceps extension and bench press using 80% of subject’s 1RM load. A limitation of the previous study was the use of RIs two minute or less. Previous research has already demonstrated that two minute RIs cannot prevent muscular fatigue during the use heavy training loads (Faigenbaum et al., 2008; Miranda et al., 2009; Rodrigues et al. 2012).

A limitation of these studies (De Salles et al., 2010; Miranda et al. ,2009; Mirzaei, Arazi, and Saberi, 2008; Monteiro et al., 2013; Rahimi, 2005; Ratamess et al., 2007; Richmond and Godard, 2004; Rodrigues et al., 2012; Willardson & Burkett, 2005; Willardson & Burkett, 2008) and related studies (Faigenbaum et al., 2008; Evangelista, Pereira, Hackney & Machado, 2011; Dias et al., 2014; De Souza et al., 2010; Larson and Potteiger, 1997) was the use of only RIs of five minutes or less between sets. A heavy training load has been shown to require a longer RI to enhance repetition sustainability and provide an increase in the average repetitions performed each set (De Salles, 2009; Weiss, 1991). A possible explanation for the current study's results may be the utilization of a longer than recommended recovery period used to resynthesize more energy substrates and buffer/remove proton accumulation.

Conclusion

The energy required for muscular strength training is provided by the breakdown of ATP (ATP hydrolysis). Once all energy substrates are used, resynthesis must occur for high-tension muscle contractions to continue (Baechle & Earle, 2016; Weiss, 1991). ATP resynthesis is achieved through the hydrolysis of PCr and is known as the phosphagen energy system (Kenney et al., 2012; Robergs, Ghiasvand, & Parker, 2004; Weiss, 1991). Muscular strength training primarily relies on the phosphagen energy system to resynthesize energy and drastically depletes PCr concentrations to equate ATP concentrations (Baechle & Earle, 2016; Robergs, Ghiasvand, & Parker, 2004). ATP and

PCr concentrations deplete, contributing to the fatigue experienced during resistance training (Weiss, 1991).

ATP resynthesis occurs within three to five minutes and PCr resynthesis can take up to eight minutes following high-intensity exercise (Baechle & Earle, 2016; Harris et al., 1976). This eight minute PCr resynthesis period may explain why muscular strength training requires longer resting periods. Previous RI research has not attempted to test RIs longer that five minutes due to existing recommendations provided by the NSCA, thus limiting the amount of time for full PCr resynthesis (Harries et al., 1976). Weiss (1991) suggests, ATP and PCr concentrations cannot be fully resynthesized, following strenuous exercise, if exercise is resumed without full recovery. Although longer resting periods between sets have been shown to resynthesize more energy substrates (Willardson & Burke, 2008), other biochemical forces must contribute to the benefit of longer RIs (Robergs, Ghiasvand, & Parker, 2004).

Lifting a submaximal load, during a resistance training exercise, recruits both slow and fast-twitch muscle fibers (Type I and Type II). During the initial phases, the recruitment of slow-twitch fibers exerts a force to produce movement leading to progressive fiber fatigue. The neuromuscular system must then recruit fast-twitch muscle fibers to maintain the force applied to the training load. Once all available muscle fibers are fatigued, the set is ended due to a lack of sufficient muscle force (Sale et al., 1987; Zatsiorsky, 1995). RI consideration between sets should be based on the type of muscle fibers being recruited. Slow-twitch muscle fibers require shorter recovery due to oxidative characteristics and fast-twitch muscle fibers require longer recovery due to

glycolytic characteristics (Wiess, 1991). A high-intensity resistance training exercise, such as the bench press, requires additional recruitment of fast-twitch muscle fibers to maintain force production throughout the exercise (Larson & Potteiger, 1997).

Prevailing belief suggests fast-twitch muscle fibers rely heavily on anaerobic glycolysis leading to an accumulation of lactic acid during high intensity exercise. The accumulation of lactic acid lowers intracellular pH through the dissociation of a proton [H+] (Jones et al., 1986; Taylor et al., 1900). A low intracellular pH causes metabolic acidosis resulting in muscular fatigue (Larson and Potteiger, 1997). However, a profusion of research suggests that metabolic acidosis is not caused by lactate production (Corey, 2003; Kowalchuk, 1998; Robergs et al, 2004; Tafaletti, 1991). The production of lactate intensifies during metabolic acidosis to prevent an accumulation of pyruvate and to supply the NAD+ needed for step 6 of glycolysis. Lactate aids in muscle recovery, acting as a buffering system, by consuming and transporting protons to offset acidosis. Therefore, other biochemical reactions within the body must be responsible for the occurrence of metabolic acidosis within the cell (Robergs et al, 2004).

During muscular contraction, energy is required to move the skeletal muscle. This energy is obtained from the hydrolysis of ATP, resulting in the products: ADP, Pi, [H+], heat, and energy (Robergs et al, 2004). When the energy demand is proportional to the rate of mitochondrial respiration, proton accumulation retards within the cell. Mitochondria use hydrogen ions for oxidative phosphorylation and to maintain the proton gradient within the inter-membranous space. Once an exercise intensity increases beyond a steady state, there is a greater reliance on glycolysis and the phosphagen system to

regenerate ATP (Baechle & Earle, 2016; Kenny et al., 2012). The ATP supplied by glycolysis and the phosphagen system leads to the increase of proton concentration and metabolic acidosis during high intensity exercise. Proton release from ATP hydrolysis occurs during the release of free energy and from glycolysis via the Glyceraldehyde 3-phosphate dehydrogenase reaction (NAD+H+ accumulation).

Onset metabolic acidosis is not fully dependent on proton release; rather, due to an imbalance between the ratio of protons released and the rate of buffering or removal. In addition, intracellular pH regulation is delayed due to capacity and various buffering/removal components. The intracellular buffering system includes: mitochondria, amino acids, proteins, Pi, HCO3-, Creatine-phosphate hydrolysis, and lactate production. These buffering agents bind to or consume protons; protecting the cell from a lower intracellular pH. Protons can also be removed from the cytosol through membrane exchange systems (mitochondrial or sarcolemmal transports) (Kowalchuk, 1988; Corey, 2003). When there is insufficient time to decrease intracellular pH or proton accumulation exceeds the rate of buffering and removal, metabolic acidosis ensues leading to muscular fatigue (Rahimi, 2005; Robergs, Ghiasvand, & Parker, 2004). In the current study, the eight minute RI was the only duration of rest to allow for the complete sustainability of repetitions over four consecutive sets. The longer RI likely had enough time to completely resynthesize energy substrates, uptake protons, and delay fatigue, allowing subjects to complete a higher volume of training, compared to the two and five minute RIs.

Practical Application

Resistance training is commonly associated with athletes and sport performance. However, resistance training can also benefit the rehabilitation process and increase productivity in the work place. In a physical therapy setting, resistance training decreases pain and increases strength in bones, muscles, tendons, and ligaments (Jan et al., 2007). In the work place, resistance training can increase safety for firefighters and the productivity of labor workers by providing the body a stimulus that allows for increased joint stability and muscular strength.

Multiple variables can be manipulated, in accordance to the progressive overload principle, to provide further benefits from resistance training (Kraemer & Fleck, 2007). The progressive overload principle states that there is a need for greater demands to be placed on the body to see continued increases in performance. A longer RI between sets allows for greater demands to be placed on the body (a higher training volume) because more energy substrates can be resynthesized and more metabolic waste can be removed. Therefore, a longer RI can be used to manipulate a resistance training program to increase performance and strengthen musculoskeletal components in hopes to provide added benefits to resistance training participants in the clinical and professional settings. Future research should focus on RIs between five and eight minutes to find an optimal resting time between sets to aid in gym efficiency.

Table 1. *Repetition Sustainability Throughout Sets Using Various Rest Intervals*

Study	**Load**	**Exercises and Rest Intervals**	**Set 1**	**Set 2**	**Set 3**	**Set 4**	**Set 5**
Faigenbaum et al. (2008)	75% of 1RM	**Bench press**					
Men's Values		1 min	10.0 ± 0.0[2,3]	5.7 ± 2.4[3]	2.7 ± 1.5		
		2 min	10.0 ± 0.0[2,3]	7.2 ± 2.2	4.2 ± 2.2		
		3 min	10.0 ± 0.0[3]	7.9 ± 2.7	6.0 ± 2.8		
Teens' Values		1 min	10.0 ± 0.0[3]	9.5 ± 1.4[3]	7.4 ± 2.6		
		2 min	10.0 ± 0.0[3]	9.3 ± 1.4	8.5 ± 2.2		
		3 min	10.0 ± 0.0	9.8 ± 0.8	9.1 ± 1.8		
Boys' Values		1 min	10.0 ± 0.0[3]	9.2 ± 1.4	8.7 ± 2.1		
		2 min	10.0 ± 0.0	10.0 ± 0.0	9.6 ± 1.0		
		3 min	10.0 ± 0.0	10.0 ± 0.0	10.0 ± 0.0		
Evangelista et al. (2011)	40% of MVC	**Bicep curl**					
		1 min	20.0 ± 1.5[2,3]	9.0 ± 0.7[3]	7.0 ± 1.3		
		3 min	24.0 ± 1.7[2,3]	14.0 ± 1.1[3]	10.0 ± 0.7		
Miranda et al. (2009)	8RM	**Barbell bench press**					
		1 min	8.4 ± 0.2[2,3]	6.4 ± 0.5[3]	4.2 ± 0.6		
		3 min	8.3 ± 0.2[3]	7.3 ± 0.5	5.9 ± 1.0		
		Inclined bench press					
		1 min	5.0 ± 0.7[3]	3.9 ± 0.7	3.3 ± 0.5		
		3 min	7.3 ± 0.5[3]	6.6 ± 0.5	6.1 ± 0.7		

Study	Load	Exercises and Rest Intervals	Set 1	Set 2	Set 3	Set 4	Set 5
		Peck deck fly					
		1 min	4.6 ± 0.8	3.8 ± 0.7	3.3 ± 0.8		
		3 min	6.8 ± 0.4	5.9 ± 0.7	5.3 ± 0.8		
		Barbell lying triceps extension					
		1 min	6.5 ± 0.9[2,3]	4.9 ± 0.9	3.4 ± 1.0		
		3 min	7.3 ± 0.7[3]	6.6± 0.7	6.0 ± 0.7		
		Triceps pushdown					
		1 min	4.6 ± 0.6[2,3]	3.1 ± 0.8[3]	2.0 ± 0.7		
		3 min	6.1 ± 0.7[3]	5.3 ± 0.7	4.9 ± 0.6		
Rodrigues et al. (2012)	80% of 1RM	**Barbell bench press**					
		1 min	5.8 ± 2.3[2,3]	3.6 ± 1.5	2.8 ± 1.2		
		3 min	6.9 ± 2.5[2,3]	4.7 ± 1.7	4.1 ± 1.8		
		Machine lat pull down					
		1 min	6.9 ± 2.0[2,3]	3.6 ± 1.1	2.9 ± 1.0		
		3 min	7.4 ± 1.9[2,3]	6.2 ± 1.3[3]	4.4 ± 1.5		
		Seated machine shoulder press					
		1 min	3.7 ± 1.9[2,3]	2.1 ± 1.6	1.3 ± 1.1		
		3 min	4.5 ± 2.7[2,3]	2.7 ± 1.8	2.3 ± 1.7		

Study	Load	Exercises and Rest Intervals	Set 1	Set 2	Set 3	Set 4	Set 5
		Machine triceps extension					
		1 min	8.3 ± 2.9^{2,3}	5.3 ± 1.5^{3}	3.8 ± 1.0		
		3 min	9.9 ± 2.7^{2,3}	7.6 ± 2.5	6.4 ± 2.6		
		Free weight standing bicep curl					
		1 min	5.2 ± 1.7^{2,3}	2.5 ± 1.0	1.9 ± 0.9		
		3 min	5.6 ± 1.6^{2,3}	4.4 ± 1.2^{3}	3.1 ± 1.1		
Monteiro et al. (2013)	80% of 1RM	**Bench press**					
		Ratio 1:3	12.9 ± 3.6^{2,3,4,5}	10.2 ± 3.8^{3,4,5}	6.3 ± 3.1^{4,5}	4.6 ± 2.6	3.8 ± 2.2
		Ratio 1:5	12.3 ± 4.0^{2,3,4,5}	9.9 ± 3.6^{3,4,5}	7.6 ± 3.6^{4,5}	5.9 ± 3.1	4.6 ± 2.6
		Ratio 1:7	12.4 ± 3.7^{2,3,4,5}	10.9 ± 3.7^{3,4,5}	8.6 ± 3.4^{4,5}	6.7 ± 3.0	5.6 ± 2.6
		Progressive: 1:3-1:5-1:7-1:9	12.5 ± 4.0^{2,3,4,5}	10.2 ± 4.0^{3,4,5}	7.9 ± 3.5^{5}	6.9 ± 3.1	6.2 ± 2.6
		Fixed: 2 min	13.5 ± 4.1^{2,3,4,5}	11.1 ± 4.5^{3,4,5}	8.7 ± 4.2^{5}	7.3 ± 3.4	6.0 ± 2.7
		Triceps extension					
		Ratio 1:3	12.6 ± 2.9^{2,3,4,5}	9.9 ± 1.8^{3,4,5}	7.3 ± 2.1^{4,5}	5.7 ± 1.8	4.4 ± 1.6
		Ratio 1:5	12.1 ± 3.9^{2,3,4,5}	10.6 ± 3.3^{3,4,5}	8.5 ± 2.4^{5}	7.2 ± 2.3^{5}	5.6 ± 2.0
		Ratio 1:7	12.9 ± 3.9^{3,4,5}	11.8 ± 3.2^{3,4,5}	9.6 ± 3.2^{4,5}	8.1 ± 2.8^{5}	6.2 ± 2.3
		Progressive: 1:3-1:5-1:7-1:9	13.2 ± 3.1^{2,3,4,5}	11.1 ± 3.8^{3,4,5}	9.1 ± 3.3^{5}	8.9 ± 2.9^{5}	8.1 ± 2.7

Study	Load	Exercises and Rest Intervals	Set 1	Set 2	Set 3	Set 4	Set 5
		Fixed: 2 min	12.4 ± 3.7^{2,3,4,5}	10.8 ± 3.5^{3,4,5}	9.1 ± 3.4^{4,5}	7.7 ± 2.8	6.7 ± 2.1
Larson & Potteiger (1997)	85% of 10RM	**Squat**					
		Post HR	15.7 ± 0.7^{2,3,4}	10.6 ± 0.5^{3,4}	8.8 ± 0.4^{4}	7.9 ± 0.6	
		3 min	15.5 ± 0.6^{2,3,4}	10.7 ± 0.7^{3,4}	8.1 ± 0.4^{4}	6.5 ± 0.5	
		Ratio 1:3	15.6 ± 0.7^{2,3,4}	10.9 ± 0.8^{3,4}	8.3 ± 0.6^{4}	6.8 ± 0.6	
Richmond & Godard (2004)	75% of 1RM	**Bench press**					
		1 min	11.9 ± 2.5^{2}	5.5 ± 2.2			
		3 min	11.5 ± 2.2^{2}	8.3 ± 2.6			
		5 min	11.5 ± 2.3^{2}	9.7 ± 2.4			
Mirzaeli, Arazi, & Saberi (2008)	90% of 1RM	**Bench press**					
		1.5 min	4.4 ± 0.7^{2,3,4}	3.2 ± 0.6^{3,4}	2.2 ± 0.6^{4}	1.4 ± 0.6	
		2.5 min	4.5 ± 0.7^{2,3,4}	3.8 ± 0.9^{3,4}	3.1 ± 0.7^{4}	2.5 ± 0.8	
		4 min	4.5 ± 0.7^{2,3,4}	4.4± 0.6^{3,4}	3.8 ± 0.9^{4}	3.4 ± 0.6	

Note. The superscript numbers designate significant difference in relation to the indicated set ($P<0.05$). **HR** = Heart rate. **MVC =** maximum velocity contraction. **RM** = Repetition maximum.

Table 2. *Maximum Repetitions Performed Each Set Using Various Rest Intervals*

Study	Load	Exercises and Rest Intervals	Set 1	Set 2	Set 3	Set 4
Rodrigues et al. (2012)	80% of 1RM	**Barbell bench press**				
		1 min	5.8 ± 2.3	3.6 ± 1.5	2.8 ± 1.2	
		3 min	6.9 ± 2.5	4.7 ± 1.7*	4.1 ± 1.8*	
		Machine lat pull down				
		1 min	6.9 ± 2.0	3.6 ± 1.1	2.9 ± 1.0	
		3 min	7.4 ± 1.9	6.2 ± 1.3*	4.4 ± 1.5*	
		Seated machine shoulder press				
		1 min	3.7 ± 1.9	2.1 ± 1.6	1.3 ± 1.1	
		3 min	4.5 ± 2.7*	2.7 ± 1.8	2.3 ± 1.7*	
		Machine triceps extension				
		1 min	8.3 ± 2.9	5.3 ± 1.5	3.8 ± 1.0	
		3 min	9.9 ± 2.7*	7.6 ± 2.5*	6.4 ± 2.6*	
		Free weight standing bicep curl with straight bar				
		1 min	5.2 ± 1.7	2.5 ± 1.0	1.9 ± 0.9	
		3 min	5.6 ± 1.6	4.4 ± 1.2*	3.1 ± 1.1*	
Miranda et al. (2009)	8RM	**Barbell bench press**				
		1 min	8.4 ± 0.2	6.4 ± 0.5	4.2 ± 0.5	
		3 min	8.3 ± 0.2	7.3 ± 0.5	5.9 ± 1.0*	

Study	Load	Exercises and Rest Intervals	Set 1	Set 2	Set 3	Set 4
		Inclined bench press				
		1 min	5.0 ± 0.7	3.9± 0.7	3.3 ± 0.5	
		3 min	7.3 ± 0.5*	6.6 ± 0.5*	6.1 ± 0.7*	
		Peck deck fly				
		1 min	4.6 ± 0.8	3.8 ± 0.7	3.3 ± 0.8	
		3 min	6.8 ± 0.4*	5.9 ± 0.7*	5.3 ± 0.8*	
		Barbell lying triceps extension				
		1 min	6.5 ± 0.91	4.9 ± 0.9	3.4 ± 1.0	
		3 min	7.3 ± 0.65	6.6± 0.7	6.0 ± 0.7*	
		Triceps pushdown				
		1 min	4.8 ± 0.6	3.1 ± 0.8	2.0 ± 0.7	
		3 min	6.1 ± 0.7	5.3 ± 0.7*	4.9 ± 0.6*	
Larson & Potteiger (1997)	85% of 10RM	**Squat**				
		Post HR	15.7 ± 0.7	10.6 ± 0.5	8.8 ± 0.4	7.9 ± 0.6
		3 min	15.5 ± 0.6	10.7 ± 0.7	8.1 ± 0.4	6.5 ± 0.5
		Ratio 1:3	15.6 ± 0.7	10.9 ± 0.8	8.3 ± 0.6	6.8 ± 0.6
Dias et al. (2014)	10RM	**Peck deck fly**				
		1 min	10.0 ± 0.0	7.9 ± 2.1	4.9 ± 1.9	
		2 min	10.0 ± 0.0	8.4 ± 2.1	6.4 ± 1.8 *	

Study	Load	Exercises and Rest Intervals	Set 1	Set 2	Set 3	Set 4
		Bench press				
		1 min	10.5 + 1.1	5.7 + 2.8	3.3 + 2.2	
		2 min	11.2 + 1.5	7.9 + 2.4*	5.2 + 2.9*	
Richmond & Godard (2004)	75% of 1RM	**Bench press**				
		1 min	11.9 + 2.5	5.5 + 2.2		
		3 min	11.5 + 2.2	8.3 + 2.6*		
		5 min	11.5 + 2.3	9.7 + 2.4*		

Note. * = set significantly different between all rest intervals.

Table 3. *Total Training Volume Completed Using Various Rest Intervals*

Study	Subjects	Duration	Intervention	Intervals	Results
Dias et al. (2014)	18 trained men (23.4 ± 3.5 yrs.)	2 weeks	2 experimental sessions: • Bench press • Peck deck fly • 3 sets 10RM	1 min 2 min	Total training volume significantly greater for both exercises using 2 min rest interval
Willardson & Burkett (2005)	15 trained men (20.7 ± 2.6 yrs.)	~ 4 weeks	3 experimental sessions • Bench press • Squat • 4 sets 8RM	1 min 2 min 5 min	Total training volume significantly different between all rest intervals for both exercises
Richmond & Godard (2004)	28 trained men (21.5 ± 3.2 yrs.)	~ 4 weeks	3 experimental sessions: • Bench press • 75% of 1RM	1 min 3 min 5 min	Training volume performed in 2nd set significantly different between all rest intervals
Ratamess et al. (2007)	8 trained men (21.4 ± 2.4 yrs.)	~ 8 weeks	5 experimental sessions per week • Bench press Alternating: • 75% of 1RM • 85% of 1RM	30 sec 1 min 2 min 3 min 5 min	Training volume significantly decreased as sets progressed for all rest intervals except 5 min interval
Miranda et al. (2009)	12 trained men (23.6 ± 2.5 yrs.)	~ 4 weeks	2 experimental sessions: • Barbell bench press • 3 sets 8RM	1 min 3 min	Significantly greater training volume completed for exercises using 3 min rest interval
Monteiro et al. (2013)	16 trained men (25.0 ± 2.5 yrs.)	~ 4 weeks	5 experimental sessions: • Bench press • Triceps extension • 5 sets 80% 1RM	Ratio 1:3 Ratio 1:5 Ratio 1:7 IP 2 min	No significant differences in training volume between rest intervals
De Souza et al. (2010)	20 trained men CI: 2 min (20.5 ± 1.0 yrs.) DI: 2 min – 30 s (22.0 ± 4.8 yrs.)	8 weeks	6 experimental sessions per week alternating between: • Program A • Program B • 10–12RM • 8-10RM	CI: 2 min DI: 2 min – 30 sec	Total training volume significantly greater for CI group compared to DI group for both bench press and squat exercises

Study	Subjects	Duration	Intervention	Intervals	Results
Willardson & Burkett (2008)	15 trained men 2 min (20.7 ± 1.4 yrs.) 4 min (22.6 ± 4.6 yrs.)	~ 16 weeks	3 mesocycles (4 weeks): • Squat Alternating: • Heavy workouts (70% - 90% of 1RM) • Light workouts (60% of 1RM)	2 min 4 min	Total training volume completed significantly different between 2 and 4 min rest interval
De Salles et al. (2010)	36 trained men 1-min: (22.4 ± 1.3 yrs.) 3-min: (22.3 ± 1.0 yrs.) 5-min: (22.3 ± 1.0 yrs.)	16 weeks	4 experimental sessions per week: Alternating: • Program A (upper body) • Program B (lower body) • 4-6RM • 8-10RM	1 min 3 min 5 min	Total training volume significantly greater for groups using 3 min and 5 min rest intervals compared to 1 min rest interval (bench press plus leg press)

Note. RM **= Repetition Maximum.** IP **= Progressive Interval.** CI **= Constant Rest Interval.** DI **= Decreasing Rest Interval.**

Table 4. *Strength Increases Using Various Rest Intervals*

Study	**Subjects**	**Duration**	**Intervention**	**Intervals**	**Results**
Gentil et al. (2010)	32 untrained men Long rest (1:6) (22.4±2.6 yrs.) Short rest (1:3) (21.4±3.2 yrs.)	~ 16 weeks	3 programs (12weeks) • 2 upper body exercises • 2 lower body exercises • 1 midsection exercise • 2 sets 8-12RM	1:3 1:6	Similar and significant increases in upper and lower body strength no matter what rest ratio was used
Buresh, Berg, & French (2009)	12 untrained men (24.8 + 5.9 yrs.)	10 weeks	4 experimental sessions per week: • Bench Press • Squat Alternating: • Session 1 (lower body) • Session 2 (upper body)	1 min 2.5 min	There was no difference between groups in relative strength increase in either the squat or bench press.
De Salles et al. (2010)	36 trained men 1-min: (22.4±1.3 yrs.) 3-min: (22.3±1.0 yrs.) 5-min: (22.3±1.0 yrs.)	16 weeks	4 experimental sessions Alternating: • Program A (upper body) • Program B (lower body) Alternating: • 4-6RM • 8-10RM	1 min 3 min 5 min	Bench press group that used 5 min rest intervals were significantly stronger when compared to the 1 min group.
Willardson & Burkett (2008)	15 trained men 2 min (20.7 + 1.4 yrs.) 4 min (22.6 + 4.6 yrs.)	~ 16 weeks	3 mesocycles (4 weeks): • Squat Alternating: • Heavy workouts (70% - 90% of 1RM) • Light workouts (60% of 1RM)	2 min 4 min	No significant difference in squat strength gains between groups that used 2 and 4 min rest intervals

Note. RM = Repetition Maximum.

Table 5. *Subject Demographics*

Age (yrs)	Ht. (cm)	Wt. (lbs)	Wt. (kg)	1RM (lbs)	1RM (kg)	1RM Ratio
25.5 ± 4.6	161.5 ± 6.5	173.3 ± 15.4	78.8 ± 6.3	240.3 ± 29.4	108.1 ± 13.1	1.4 ± 0.1

Note. Results reported in mean ± standard deviation.

Table 6. *Average Number of Repetitions Completed in all Sets*

	Set 1	Set 2	Set 3	Set 4
2-min	6.40 ± 0.63	4.20 ± 1.32*#♦	3.20 ± 0.68*#♦	1.93 ± 0.70*#♦
5-min	6.40 ± 0.63	5.40 ± 0.91*♦	4.13 ± 0.99*♦	3.40 ± 0.99*♦
8-min	6.40 ± 0.63	6.13 ± 0.83	5.93 ± 1.03	5.40 ± 1.55

Note. Results reported in mean ± standard deviation. *$p < 0.05$, value significantly different from 8-min RI. #$p < 0.05$, value significantly different from 5-min RI. ♦$p < 0.05$, value significantly different from Set 1.

Table 7. *Bench Press Training Volume Completed Over 4 Sets*

	2-min	5-min	8-min
Volume (Kg)	1447.80 ± 215*#	1793.11 ± 315*	2207.42 ± 372

Note. Results reported in mean ± standard deviation. * $p < 0.05$, value significantly different from 8-min RI. # $p < 0.05$, value significantly different from 5-min RI

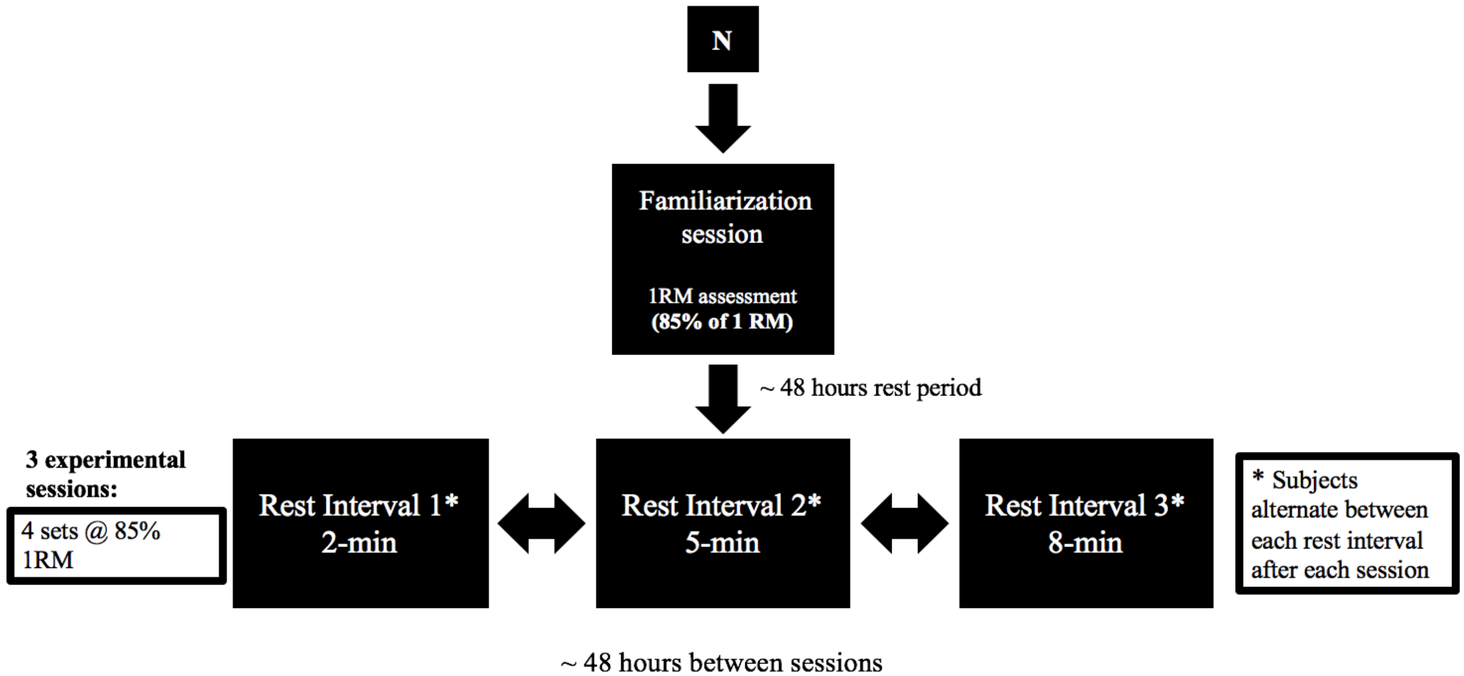

Figure 1. Experimental protocol.

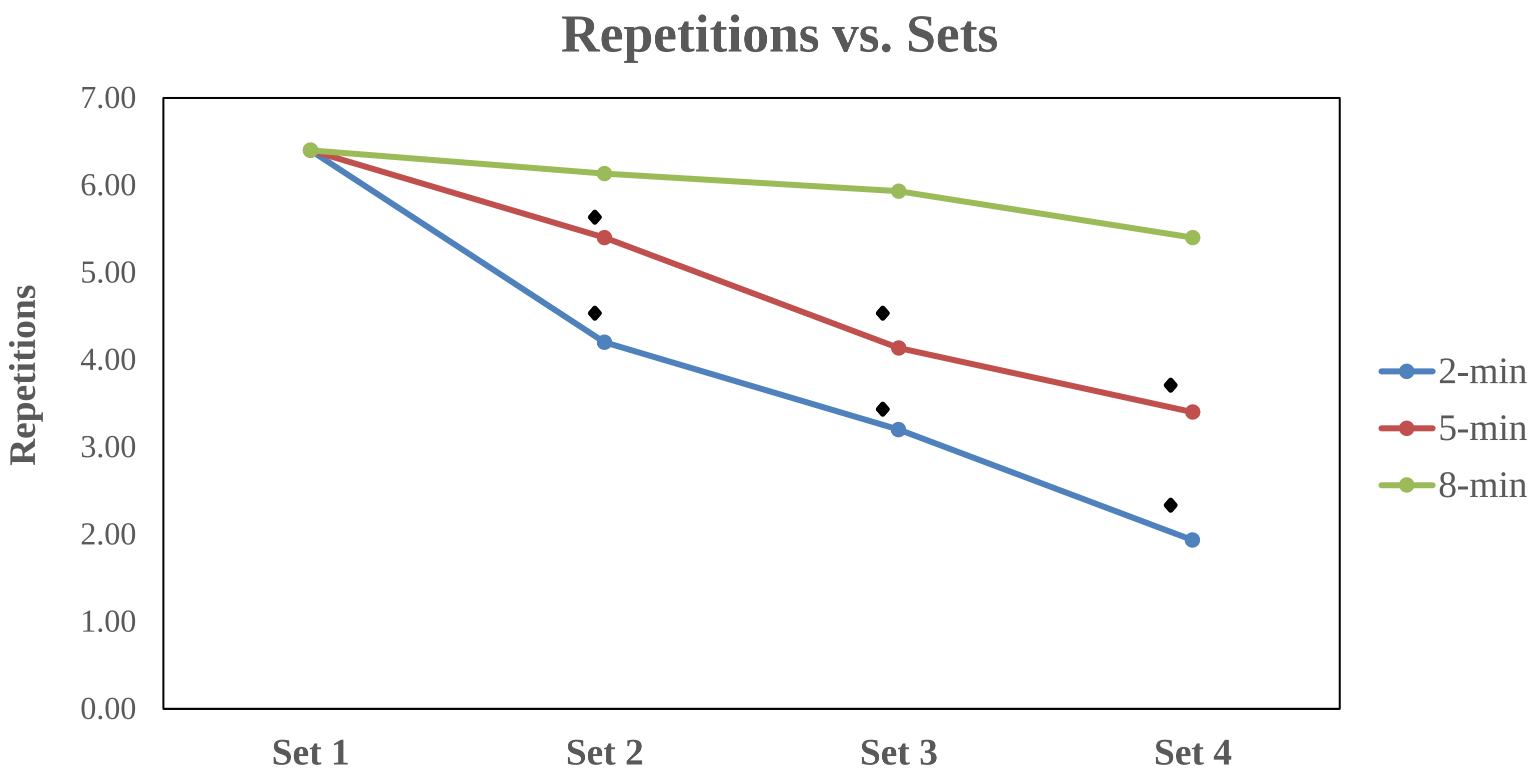

Figure 2. Repetition sustainability.
Note. ⧫ $p < .05$, value significantly different from Set 1.

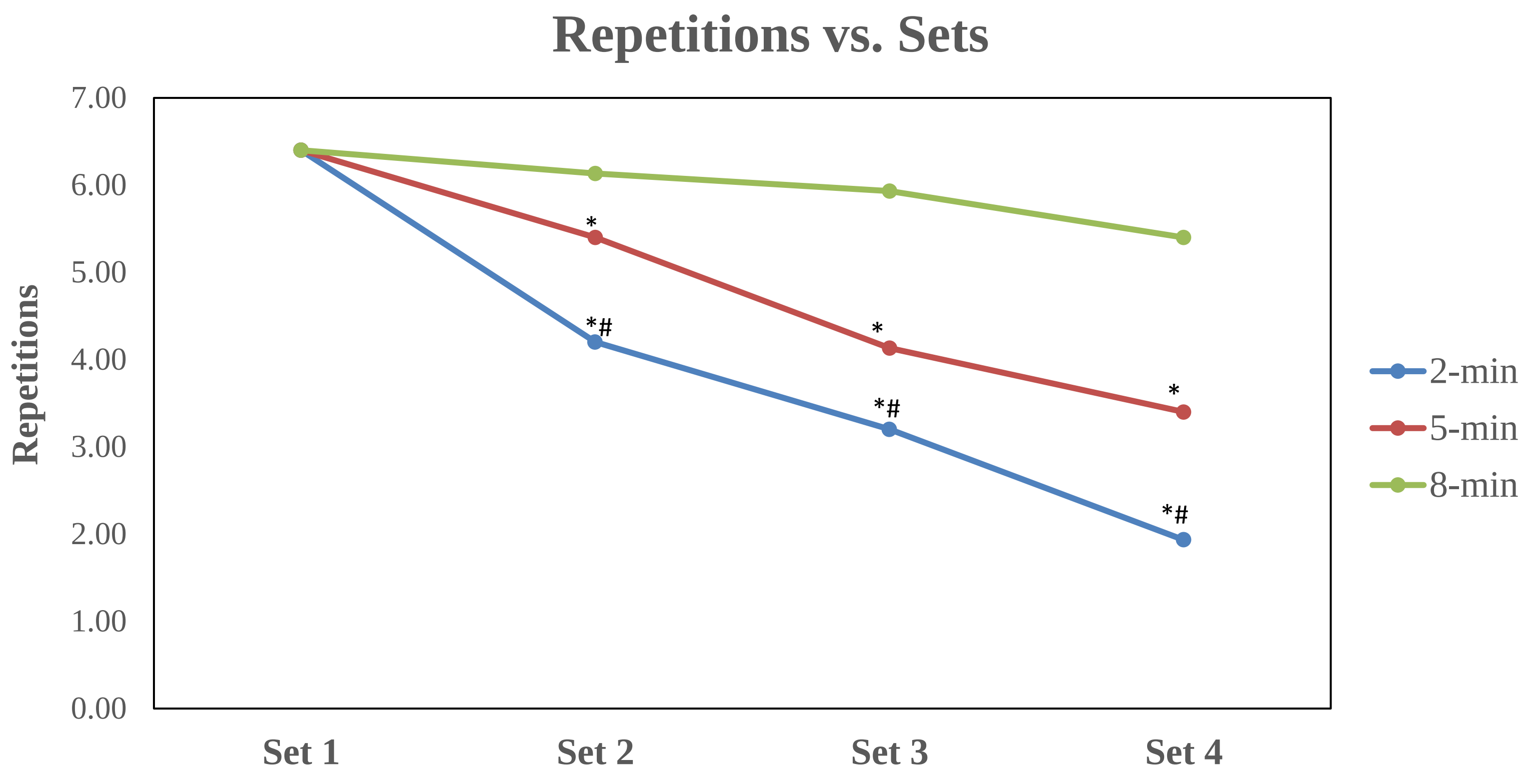

Figure 3. Maximum repetitions performed each set.
Note. *p < .05, value significantly different from 8-min RI. #p < 0.05, value significantly different from 5-min RI.

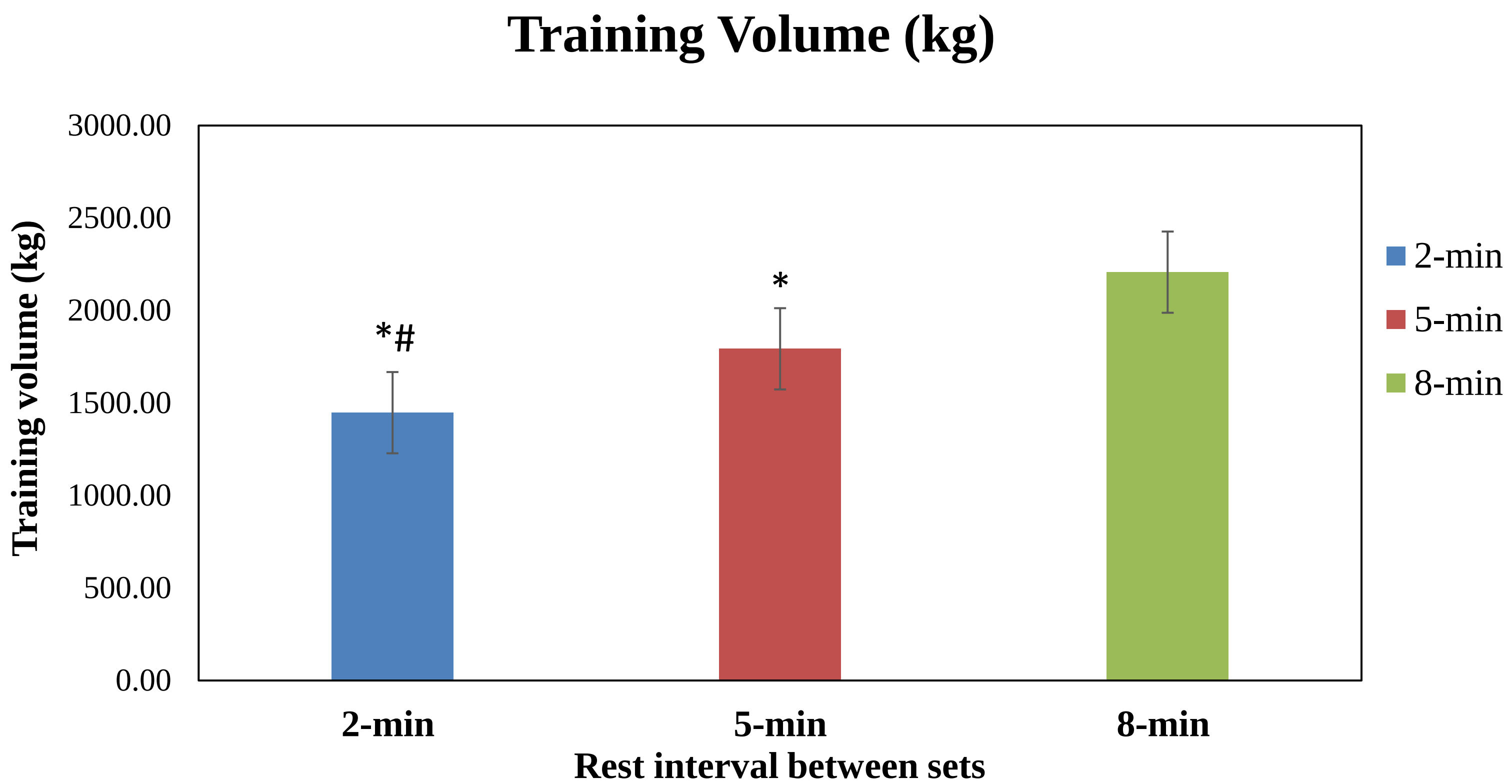

Figure 4. Total training volume completed for each RI.
Note. * $p < 0.05$, value significantly different from 8-min RI. # $p < 0.05$, value significantly different from 5-min RI.

REFERENCES

Ahtiainen, J. P., Pakarinen, A., Alen, M., Kraemer, W. J., & Häkkinen, K. (2005). Short vs. long rest period between the sets in hypertrophic resistance training: influence on muscle strength, size, and hormonal adaptations in trained men. *The Journal of Strength & Conditioning Research*, *19*(3), 572-582.

American College of Sports Medicine. (2013). *ACSM's guidelines for exercise testing and prescription*. Lippincott Williams & Wilkins.

American College of Sports Medicine (2009). Position stand: progression models in resistance training for healthy adults. *Med Sci Sports Exercise 36*(1), 687-708

Baechle, T. R., & Earle, R. W. (2016). *Essentials of strength training and conditioning*. Human kinetics.

Buresh, R., Berg, K., & French, J. (2009). The effect of resistive exercise rest interval on hormonal response, strength, and hypertrophy with training. *The Journal of Strength & Conditioning Research*, *23*(1), 62-71.

Corey, H,E. (2003) Stewart and beyond: new models of acid-base balance. *Kidney International 64*, 777–787.

De Souza Jr, T. P., Fleck, S. J., Simão, R., Dubas, J. P., Pereira, B., de Brito Pacheco, E. M., ... & de Oliveira, P. R. (2010). Comparison between constant and decreasing rest intervals: influence on maximal strength and hypertrophy. *The Journal of Strength & Conditioning Research*, *24*(7), 1843-1850.

De Salles, B. F., Simao, R., Miranda, F., da Silva Novaes, J., Lemos, A., & Willardson, J. M. (2009). Rest interval between sets in strength training. *Sports Medicine*, *39*(9), 765-777.

Dias, M. R. C., de Matos, D. G., Filho, M. L. M., Moreira, O. C., Hickner, R. C., Cardozo, D., ... & Aidar, F. J. (2014). Comparison of Repetition Number between Uni-Joint and Multi-Joint Exercises with 1-Min and 2-Min Rest Intervals. *Journal of Exercise Physiology*, *17*(4), 93-101.

Donnelly, J. E., Blair, S. N., Jakicic, J. M., Manore, M. M., Rankin, J. W., & Smith, B. K. (2009). Appropriate Physical Activity Intervention Strategies for Weight Loss and Prevention of Weight Regain for Adults. *Medicine and Science in Sport and Exercise 41*(7), 1532-1532.

Evangelista, R., Pereira, R., Hackney, A. C., & Machado, M. (2011). Rest interval between resistance exercise sets: length affects volume but not creatine kinase activity or muscle soreness. *Int J Sports Physiol Perform*,*6*(1), 118-127.

Faigenbaum, A. D., Ratamess, N. A., McFarland, J., Kaczmarek, J., Coraggio, M., Kang, J., & Hoffman, J. (2008). Effect of rest interval length on bench press performance in boys, teens, and men. *Pediatr Exerc Sci*, *20*(4), 457-469.

Gentil, P., Bottaro, M., Oliveira, E., Veloso, J., Amorim, N., Saiuri, A., & Wagner, D. R. (2010). Chronic effects of different between-set rest durations on muscle strength in nonresistance trained young men. *The Journal of Strength & Conditioning Research*, *24*(1), 37-42.

Harris, R. C., Edwards, R. H. T., Hultman, E., Nordesjö, L. O., Nylind, B., & Sahlin, K. (1976). The time course of phosphorylcreatine resynthesis during recovery of the quadriceps muscle in man. *Pflügers Archiv*, *367*(2), 137-142.

Heyward, H. (2002). *Advanced Fitness Assessment and Exercise Prescription*. Human kinetics.

Jan, M. H., Lin, J. J., Liau, J. J., Lin, Y. F., & Lin, D. H. (2008). Investigation of clinical effects of high-and low-resistance training for patients with knee osteoarthritis: a randomized controlled trial. *Physical therapy*, *88*(4), 427-436.

Jones, N.L., McCartney, M.R. and McComas, A.J. (1986) *Human muscle power*. Champaign, IL: HumanKinetics. 215-238.

Kenney, W. L., Wilmore, J., & Costill, D. (2015). *Physiology of Sport and Exercise 6th Edition*. Human kinetics.

Kowalchuk, J.M., Heigenhauser, G.J.F., Lindinger, M.I., Sutton, J.R. and Jones, N.L. (1988) Factors nfluencing hydrogen ion concentration in muscle after intense exercise. *Journal of Applied Physiology*, *65,* 2080-2089.

Kraemer, W. J. (1997). A Series of Studies-The Physiological Basis for Strength Training in American Football: Fact Over Philosophy. *The Journal of Strength & Conditioning Research*, *11*(3), 131-142.

Kraemer, W. J., Adams, K., Cafarelli, E., Dudley, G. A., Dooly, C., Feigenbaum, M. S., ... & Newton, R. U. (2002). American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Medicine and science in sports and exercise*, *34*(2), 364-380.

Kraemer, W., & Fleck, S. (2007). *Optimizing strength training: Designing nonlinear periodization workouts*. Champaign, IL: Human Kinetics.

Kraemer, W.J., Gordon, S.E., Fleck, S.J., Marchitelli, L.J., Mello R., Dziados, J.E., Friedl, K., Harman, E., Maresh, C., Fry, A.C. (1991). Endogenous anabolic hormonal and growth factor responses to heavy resistance exercise in males and females. *Int. J. SportsMe*, 12, 228-235.

Kwon, Y. S., Robergs, R. A., Kravitz, L. R., Gurney, B. A., Mermier, C. M., & Schneider, S. M. (2010). Palm cooling delays fatigue during high-intensity bench press exercise. *Med Sci Sports Exerc*, *42*, 1557-1565.

Larson Jr, G. D., & Potteiger, J. A. (1997). A Comparison of Three Different Rest Intervals Between Multiple Squat Bouts. *The Journal of Strength & Conditioning Research*, *11*(2), 115-118.

Miranda, H., Simão, R., Moreira, L. M., de Souza, R. A., de Souza, J. A., de Salles, B. F., & Willardson, J. M. (2009). Effect of rest interval length on the volume completed during upper body resistance exercise. *Journal of Sports Science & Medicine*, *8*(3), 388-392.

Mirzaei, B., Arazi, H., & Saberi, Y. (2008). The effect of different rest intervals on sustainability of bench press repetitions with heavy vs light loads. *International journal of fitness*, *4*(2).

Monteiro, W. D., Venturim, F. O., Perez, A. J., & Farinatti, P. T. (2013). Work volume in strength training is not affected by rest interval strategy. *The Journal of sports medicine and physical fitness*, *53*(3), 312-318.

Rahimi, R. (2005). Effect of different rest intervals on the exercise volume completed during squat bouts. *Journal of sports science & medicine*, *4*(4), 361.

Ratamess, N. A., Falvo, M. J., Mangine, G. T., Hoffman, J. R., Faigenbaum, A. D., & Kang, J. (2007). The effect of rest interval length on metabolic responses to the bench press exercise. *European journal of applied physiology*, *100*(1), 1-17.

Richmond, S. R., & Godard, M. P. (2004). The effects of varied rest periods between sets to failure using the bench press in recreationally trained men. *The Journal of Strength & Conditioning Research, 18*(4), 846-849.

Robergs, R. A., Ghiasvand, F., & Parker, D. (2004). Biochemistry of exercise-induced metabolic acidosis. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *287*(3), R502-R516.

Rodrigues, B. M., Rodrigues, A. M., Sandy, D. D., Filho, M. M., & Dantas, E. M. (2012). The Effect of Two Different Rest Intervals on the Number of Repetitions in a Training Session. *Serbian Journal of Sports Sciences, (1*), 37-41.

Sale, D.G. (1987) Influence of exercise and training on motor unit activation. *Exercise and Sport Science Reviews 15*, 95-151.

Tafaletti, J.G. (1991) Blood lactate: biochemistry, laboratory methods and clinical interpretation. *Critical Reviews in Clinical Laboratory Sciences 28*, 253–268.

Taylor, A.W., Gollnick, P.D., Green, H.J., Ianuzzo, C., Noble, E.G., Metivier, G. and Sutton, J.R., (1990) *Biochemistry of exercise VII*. Champaign, IL: Human Kinetics. 333-339.

Weiss, L. W. (1991). The Obtuse Nature of Muscular Strength: The Contribution of Rest to its Development and Expression. *The Journal of Strength & Conditioning Research*, *5*(4), 219-227.

Willardson, J. M. (2006). A brief review: factors affecting the length of the rest interval between resistance exercise sets. *The Journal of Strength & Conditioning Research*, *20*(4), 978-984.

Willardson, J. M., & Burkett, L. N. (2005). A Comparison of 3 Different Rest intervals on the Exercise Volume Completed during a Workout. *The Journal of Strength & Conditioning Research*, *19*(1), 23-26.

Willardson, J. M., & Burkett, L. N. (2008). The effect of different rest intervals between sets on volume components and strength gains. *The Journal of Strength & Conditioning Research*, *22*(1), 146-152.

Zatsiorsky, V.M. (1995) *Science and practice of strength training*. Champaign, IL: Human Kinetics. 85-107.

Zatsiorsky, V. M., & Kraemer, W. J. (2006). *Science and practice of strength training*. Human Kinetics.

APPENDIX: INFORMED CONSENT

Humboldt State University Department of Kinesiology
Consent to Participate in Research

The Effect of Rest Interval Duration on the Volume Completed During a High Intensity Bench Press Exercise

Purpose and General Information
You are being asked to participate in a research study conducted by Dennis J. Hernandez, B.Sc. (Principal Investigator) and Dr. Young Sub Kwon, Ph.D. There is plenty of research on rest interval duration and its effect on resistance training performance, but very little research has been done in this area with rest intervals longer than five minutes. This research is being conducted to determine if there is any further benefit in resistance training performance past a five-minute recovery period between sets in the bench press exercise. You are being asked to participate because you are healthy, between the ages of 18-44 years and do not have high blood pressure or a previous history of muscle or bone injuries in your upper body. Additionally, you are being asked to participate because you engage in regular weight training for at least one year. Your data will not be shared with your employers.

This form will explain the study, including possible risks and benefits of participating, so you can make an informed choice about whether or not to participate. Please read this consent form carefully. Feel free to ask the investigators or study staff to explain any information that you do not clearly understand.

What will happen if I participate?
This proposed project will be developed based on science and theory in the fields of Exercise Science. All testing will take place in the Human Performance Lab (HPL) at Humboldt State University (HSU). When scheduling takes place, you will be asked to to refrain from using alcohol for 24 hours prior to each session, caffeine 3 hours prior to each session, and eating 2 hours prior to each session. If you agree to be included in this study, you will be asked to read and sign this consent form. Upon signing, the following will occur:

- The study will be described in detail and your questions will be answered, then you will fill out all pre-screening forms in a private room in the Human Performance Lab. You will be introduced to the study, the purposes and procedures, and the risks and benefits. Following this introductory information, a Health History and Activity Questionnaire and the Physical Activity Readiness Questionnaire (PAR-Q) will be filled out. The investigators

will provide a detailed description of the protocol both verbally and in writing. You will be encouraged to ask questions.

- Your physical fitness will be assessed and training interventions will be prescribed with three different rest intervals prescribed in a counterbalanced design. Repetitions will be counted and recorded each set to be used later to calculate training volume. Immediately after the set you will report you feeling of exertion using the modified RPE scale. The length of time for subject participation is around 1-2 hours.
- The risk of breaching confidentiality will be minimized by using only professional personnel to perform all study activities, identification numbers instead of names, and rooms at times when others will not need access. A private room is available for discussion and testing, and all study data will be kept in a file cabinet in the supervising faculty's office. All data will continue to be coded so that your identity is not revealed throughout the duration of the research.
- The period of this study is from May 23, 2016 thru May 23, 2017.

What are the possible risks or discomforts of being in this study?
Every effort will be made to protect the information you give us. Every effort will also be made to minimize any risk by allowing proper warm-up and having a certified strength and conditioning specialist conducting all the testing. As with any research, there may be unforeseeable risks. These risks include muscle soreness, muscle fatigue, and common injuries and issues associated with exercise, for more information about risks, contact the Principal Investigator, Dennis J. Hernandez B.Sc. or the supervising faculty, Dr. Young Sub Kwon (505-350-4345)

How will my information be kept confidential?
Your name and other identifying information will be maintained in files, available only to authorized members of the research team for the duration of the study. For any information entered into a computer, the only identifier will be a unique study identification (ID) number. Any personal identifying information and record linking that information to study ID numbers will be destroyed when the study is completed. Information resulting from this study will be used for research purposes and may be published; however, you will not be identified by name in any publications.

What other choices do I have if I don’t participate?
Taking part in this study is voluntary so you can choose not to participate. The investigators have the right to end your participation in this study if they determine that you no longer qualify for various reasons such as health or injury issues, not following study procedures, or absenteeism.

Will I be paid for taking part in this study?

There will be no compensation.

Can I stop being in the study once I began?
Yes, you can withdraw from this study at any time without consequence.

Protected health information (PHI)
By signing this consent document, you are allowing the investigators and other authorized personnel to use your protected health information for the purposes of this study. This information may include: resting blood pressure, height, weight, age, %body fat, and health and fitness related items on the questionnaires. In addition to researchers and staff at the Human Performance Lab (HPL) at Humboldt State University (HSU) and other groups listed in this form, there is a chance that your health information may be shared (re-disclosed) outside of the research study and no longer be protected by federal privacy laws. Examples of this include disclosures for law enforcement, judicial proceeding, health oversight activities and public health measures.

Right to Withdraw
Your authorization for the use of your health information shall not expire or change unless you withdraw or change that information. Your health information will be used as long as it is needed for this study. However, you may withdraw your authorization at any time provided you notify the Humboldt State University investigators in writing. To do this, please contact to:

Dennis J. Hernandez, B.Sc.
djh583@humboldt.edu
Department of Kinesiology
Humboldt State University

Please be aware that the research team will not be required to destroy or retrieve any of your health information that has already been used or shared before your withdrawal is received.

Refusal to Sign
If you choose not to sign this consent form, you will not be allowed to take part in the project.

What if I have questions or complaints about this study?
The investigator will answer any question you have about this study. Your participation is voluntary and you may stop at any time. If you have any questions, concerns, or complaints about this study, please contact Dennis J. Hernandez, B.Sc. If you would like to speak with someone other than the research team, you may call the chair of the Institutional Review Board (IRB) for the Protection of Human Subjects, Dr. Ethan Gahtan, at eg51@humboldt.edu or (707)826-4545. The IRB is a group of people from

Humboldt State University and the community who provide independent oversight of safety and ethical issues related to research involving human subjects.

Liability
No compensation for physical injury resulting from participating in this research is available.

What are my rights as a research projects
If you have questions about your rights as a participant, report them to the Humboldt State University Dean of Research, Dr. Rhea Williamson, at Rhea.Williamson@humobldt.edu or (707) 826-5169

Consent and Authorization

You are making a decision whether to participate in this study. Your signature below indicates that you read the information provided (or the information was read to you). By signing this Consent Form, you are not waiving any of your legal rights as a research subject.

Sincerely,

Dennis J. Hernandez, B.Sc.
djh583@humboldt.edu

I have read the consent form and had an opportunity to ask questions and all questions have been answered to my satisfaction. By signing this consent form, I agree to participate to this study and give permission for my health information to be used or disclosed as described in this consent form.

A copy of this consent form will be provided to me.

____ ______________
Signature of participant Date