THE EFFECTS OF HIGH AND LOW REPETITION DAILY UNDULATING PERIODIZATION MODELS WITH EQUATED VOLUME ON STRENGTH AND HYPERTROPHY IN TRAINED MALES

by

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ABSTRACT

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Periodized training programs seem to augment muscle performance (i.e., hypertrophy, strength and muscle endurance), however, optimal repetition ranges to achieve these adaptations are unclear. Thus, the purpose was to compare high and low repetition daily undulating periodization (DUP) models, with equal volume on performance. Eleven trained, college-aged males were counterbalanced into high (DUP-HR) or low (DUP-LR) repetition groups. Subjects performed the squat and bench press 3X/wk. for 8wks. Outcome measures included one-repetition maximum (1RM) bench press, squat, and total strength (TS=squat+bench press), and muscle thickness (MT). 1RM strength increased with no difference between groups. Both groups increased total chest and total body MT ($p<0.05$); but only DUP-HR increased thigh MT ($p<0.05$). Effect sizes showed meaningful differences in strength favoring DUP-LR for bench press-1.48 and TS-0.89. Our findings indicate with equal volume, there may be

meaningful differences in strength that are repetition-dependent, and varying responses to MT across different muscle groups.

THE EFFECTS OF HIGH AND LOW REPETITION DAILY UNDULATING PERIODIZATION MODELS WITH EQUATED VOLUME ON STRENGTH AND HYPERTROPHY IN TRAINED MALES

List of Tables xiii

List of Figures xiv

I. INTRODUCTION 1

Specific Aims 4

Research hypotheses 5

Assumptions 7

Delimitations 7

Limitations 7

Operational Definitions: 8

II. REVIEW OF LITERATURE 9

1. SKELETAL MUSCLE ADAPTATIONS TO RESISTANCE TRAINING 9

2. STRUCTURED PROGRAMMING IN RESISTANCE TRAINING 11

2.1 Periodization: 11

2.2 Linear periodization: 12

2.3 Non-linear periodization: 13

3. TRAINING VARIABLES 15

3.1 Training Volume: 15

3.2 Training Intensity: 17

4. ANALYSIS OF HIGH AND LOW REPETITION RESISTANCE TRAINING 19
5. CONCLUSION 26
III. METHODS 28
Subjects 28
Experimental Design 28
Experimental Protocol 29
Experimental Conditions: DUP Models (DUP-HR vs. DUP-LR) 30
Dietary Log 31
Physical Activity Questionnaire 32
Medical History Questionnaire 32
One Repetition Maximum (1RM) Testing 32
Muscle Thickness (MT) 33
Muscle Endurance: Maximum Repetitions at 60% 34
Average Velocity at 1RM 35
Statistical Analysis 35
Complete Study Protocol 39
IV. RESULTS 41
Subjects 41
1RM Squat Strength 42
1RM Bench Press Strength 43
Total Strength (TS) 44
Wilk's Coefficient 45

Muscle Thickness 46

Chest MT 47

Vastus Lateralis 50% 48

Vastus Lateralis 70% 48

Vastus Medialis 50% 48

Vastus Medialis 70% 48

Total Chest MT 49

Total Thigh MT 49

Total Body MT 49

Average Velocity at 1RM 49

Muscular Endurance (ME): Maximum Repetitions at 60% 50

MT/Strength Relationship 52

MT/ME Relationship 52

Body Composition 53

Body Weight and Body Fat % 53

Body Weight/Strength Relationship 53

Effect Size 54

V. DISCUSSION 56

One-Repetition Maximum (1RM) 56

Hypertrophy 59

Muscular Endurance (ME) 61

1RM Velocity 62

Conclusions 63

APPENDICES 65

Appendix A: Dietary Log 66

Appendix B: Physical Activity Questionnaire 68

Appendix C: Medical History Questionnaire 70

Appendix D. Consent Form 73

Appendix E: IRB Approval form 78

REFERENCES 79

TABLES

Table 1: Comparison of a non-periodized to periodized design....................................11

Table 2: A comparison of linear and non-linear periodization designs..........................15

Table 3: Outcomes of studies comparing high and low repetition training. 20

Table 4: Introduction cycle for DUP-HR. 37

Table 5: Introduction cycle for DUP-LR..37

Table 6: Sample Illustration of a Training Week for DUP-HR.....................................37

Table 7: Sample Illustration of a Training Week for DUP-LR. 38

Table 8: Taper week for DUP-HR..38

Table 9: Taper week for DUP-LR. 38

Table 10: Hypothetical Model of Subjects' Daily Activities in the Purposed Study 39

Table 11: Changes in strength variables pre-to post-training in DUP-LR and DUP-HR...42

Table 12: Changes in muscle thickness pre- to post-training in DUP-LR and DUP-HR...46

Table 13: Changes body weight and body fat% pre- to post-training in DUP-LR and DUP-HR...53

Table 14: Effect size (ES) for values for outcome measures. 54

FIGURES

Figure 1: Comparison of mean 1RM squat strength between groups pre- to post-study. 43

Figure 2: Comparison of mean 1RM bench press strength between groups pre- to post-study. 44

Figure 3: Comparison of total strength (TS) total between groups pre- to post-study. 45

Figure 4: Comparison of mean Wilk's Coefficient values between groups pre- to post-study. 46

Figure 5: Comparison of average velocity of the squat at 1RM between groups, pre- to post-study. 50

Figure 6: Comparison of squat muscular endurance between groups pre- to post-study. 51

Figure 7: Comparison of bench press muscular endurance between groups pre- to post-study. 52

I. INTRODUCTION

Resistance-training is an effective and common mode of exercise used to increase muscle mass and strength (7, 17, 28, 31). Often resistance-training programs are designed in a precise way to elicit specific adaptations, such as, strength, hypertrophy, and/or power. When considering the design of a resistance-training program to maximize these adaptations, research has established that a periodized model (i.e., programmed manipulation of variables such as volume and intensity) is superior to a non-periodized model (no manipulation of variables) (25, 28, 50). Within a periodized model, two main sub-types of designs exist, linear periodization (LP) and non-linear periodization (NLP). LP incorporates planned alterations to training volume and intensity every 3-6 weeks (31). NLP involves alterations to training variables more frequently than LP (5, 25, 40). In the current literature, two options of NLP have been identified; weekly undulating periodization (WUP) and daily undulation periodized (DUP). WUP, which makes changes to training variables in a weekly manner, has been rarely been explored in the previous literature (5). The more commonly utilized option is DUP, which implements alterations to training variables each training session (25, 30, 31). Additionally, research has consistently demonstrated DUP to increase muscular strength in previously trained individuals more than LP (25, 30, 31). Therefore, these findings suggest that daily variations in training volume and intensity seem to be important for maximizing muscular strength.

Training volume can be calculated by multiplying sets, repetitions, and load (weight lifted) together (i.e., Sets X Repetitions X Weight Lifted). A growing body of evidence suggests training volume may be the central variable, which influences strength and hypertrophy (14, 17, 21, 31, 33, 35, 41). Training intensity, which is defined by a relative training load of one-repetition maximum (1RM), is often expressed as a percentage of 1RM or as an RM (i.e., 5RM, 10RM, 15RM). Even though volume is the most important variable to determine muscle performance outcomes, when volume has been equated, intensity may then be the overriding factor to elicit hypertrophy, strength, and power (7, 19).

Although total volume seems to be the main factor affecting measures of muscle performance, long-established repetition ranges are commonly implemented for specific adaptations. Traditionally, hypertrophy training is defined by moderate repetitions (i.e., 8-12) performed at a moderate intensity (i.e., 65-75% 1RM) (3, 8, 17). Conversely, typical strength training consists of low repetitions (i.e., 3-6) performed at a high intensity (i.e., 85-95% 1RM) (3, 8, 17). These repetition ranges also follow the strength training continuum proposed by Anderson and Kearney (1982), which stipulates that low repetitions increase strength to a greater extent than high repetitions (2). More recently, several studies (7, 19, 29, 49) have since confirmed this continuum by demonstrating that low repetition training increases strength to a significantly greater extent than high repetition training. To date, however, very little empirical data exists that supports the notion of the typical hypertrophy type training repetition range to be superior to lower repetition ranges for maximizing skeletal muscle cross-sectional area.

Consequently, many studies have investigated the effects high and low repetition resistance training for strength and/or hypertrophy (2, 4, 7, 8, 18, 19, 24, 27, 29, 38, 44, 49, 51). The literature, however, shows inconclusive findings with some studies showing no differences (4, 8, 18, 27, 44, 51), while others have demonstrated that lower repetitions may be more beneficial for strength and/or hypertrophy (2, 7, 19, 24, 29, 49). Although, many of the studies that examined differences between high and low repetition training have several limitations including: A non-periodized program design (7, 8, 44, 51), unequal training volume (7, 8, 44, 51) or both (2, 4, 19, 24, 27, 29, 45, 49). Since training volume may be the central factor which influences strength and hypertrophy adaptations, (14, 17, 21, 31, 33, 35, 41) precautions should be made to ensure training volume is equal between groups to determine if any differences truly exist between high- and low-repetition training.

Another possible cause for the inconclusive of findings comparing high versus low repetitions is that all the aforementioned studies utilized a population of untrained individuals. This may be a limitation, because researchers have previously hypothesized that untrained individuals experience neurological adaptations first, opposed to increases in hypertrophy, which, is seen in trained individuals and contributes greatly to strength improvements (15). Thus, when taking these considerations into account it is not completely unexpected that the literature has been inconclusive in regards to comparing adaptations of high and low repetition training. Therefore, the purpose of this study was to investigate two different DUP protocols that utilize repetitions solely in the hypertrophy range through a given week (i.e., Mon: 12, Wed: 10, and Fri: 8) or solely in the strength range (i.e., Mon: 6, Wed: 4, and Fri: 2) among trained individuals with equated volume. The findings from this study will provide further insight into the relationship between resistance training variables and their impact on strength and hypertrophy.

Specific Aims

Specific Aim 1: Examine the extent that low repetition DUP (DUP-LR) alters maximum strength in comparison to high repetition DUP (DUP-HR) with equated volume over the course of 6 weeks.

This will be accomplished by measuring changes in subjects' one repetition maximum (1RM) in the back squat and bench press exercises using the United States of America Powerlifting (USAPL) protocol for the back squat, bench press, and deadlift 1RM (46).

Specific Aim 2: Investigate the degree by which DUP-LR influences muscle hypertrophy in comparison to DUP-HR after 6 weeks of training. Further, to examine if any relationship exists between increases in muscle thickness (MT) and improvements in 1RM strength.

This will be determined by assessing differences in MT as measured by ultrasound scanning.

Specific Aim 3: Observe the extent that DUP-HR influences the amount of repetitions that can be performed at 60% compared to DUP-LR following 6 weeks of training. Determine any correlation between increases in MT and repetitions performed at 60% of 1RM.

Following the performance of a 1RM test subjects will complete as many repetitions as possible with 60% 1RM in the squat and bench press.

Specific Aim 4: Examine the effect of DUP-LR on average velocity at 1RM in the squat and bench press compared to DUP-HR after 6 weeks of training.

Subjects will have their average velocity (m/s) measured via a Tendo unit (Trencin, Slovakia) which measures average velocity (m/s) of the barbell, for each 1RM attempt at pre- and post-training.

Specific Aim 5: Examine the effect of DUP-LR on changes in body weight and body fat % compared to DUP-HR over the course of 6 weeks.

Also, to investigate if any correlation exists between changes in body weight and changes in 1RM strength.

Research hypotheses

Aim 1 hypothesis: 1) DUP-LR will produce significantly greater increases in 1RM strength than DUP-HR following 6 weeks of training.

Rationale for Aim 1 hypothesis: The anticipated outcome of Aim 1 is based on the size principle, which stipulates a greater number of high threshold motor units are recruited at higher intensity exercise (i.e., 80-90%) compared to lower intensity exercise (i.e., 60-70%). It is speculated the constant recruitment of these motor units will result in enhanced neuromuscular efficiency at a higher percentage of 1RM strength and thus increase maximum strength.

Aim 2 hypothesis: There will be no significant difference in hypertrophy between DUP-LR and DUP-HR.

Rationale for Aim 2 hypothesis: This rationale is based off the results of several studies that have shown when training volume is equal, hypertrophy is not significantly different despite a difference in the intensity and number of repetitions completed during various resistance training protocols (24, 29).

Aim 3 hypothesis: DUP-HR will perform significantly more repetitions at 60% of 1RM compared to DUP-LR.

Rationale for Aim 3 hypothesis: The purposed outcome of Aim 3 is a result of the findings of several studies which have shown that engaging in high repetition (i.e., 11-28) resistance training paired with a low intensity improves the ability to perform a greater number of repetitions at submaximal intensities (2, 7). Therefore, it is speculated that the DUP-HR group will make specific adaptations that increase the ability to perform significantly more repetitions at 60%.

Aim 4 hypothesis: DUP-LR will perform a 1RM significantly slower in the squat compared to DUP-HR.

Rationale for Aim 4 hypothesis: The predicted outcome for Aim 4 is based on the principle of specificity, which stipulates that training adaptations will be specific to the training stimulus. Further, previously research has suggested slower 1RM average velocities to signify greater efficiency (53). As such, DUP-LR will be training closer to 1RM intensity than DUP-HR and, therefore, should become more efficient at maximum intensity, quantified as a slower 1RM velocity.

Aim 5 hypothesis: Body weight and body fat will not be significantly different between groups.

Rationales for Aim 5 hypothesis: We hypothesize that any increase in body weight will be due to increased hypertrophy. As we postulate that hypertrophy will be equal between groups, we believe body weight and body fat % will not be significantly different between groups following 6 weeks of training.

Assumptions

The following assumptions for this study include:

1. All laboratory equipment will function properly and provide truthful results during times of data collection.
2. All subjects will abide by the conditions specified in the Informed Consent form.
3. All subjects will give maximum effort and complete testing sessions to the best of their ability.
4. All subjects will honestly complete their medical history and activity questionnaire.

Delimitations

The delimitations of this study will include:

1. Inclusion criteria for this study requires that subjects be able to perform the back squat and bench press exercises with at least 1.5 and 1.25 their bodyweight, respectfully. Additionally, subjects must perform these exercises to the rules and conditions of the United States of America Powerlifting (USAPL).
2. Subjects must currently be engaged in a resistance-training program in which they have performed the back squat and bench press for at least 2 years.
3. Subjects will be instructed to not partake in any additional exercise during their participation in this study.

Limitations

The limitations for this study include:

1. This study will only examine two models of daily undulating periodization.
2. Subjects will be primarily college-aged (18-35 years).
3. Only male subjects will be utilized.
4. Only trained subjects will be utilized.

Operational Definitions:

Periodization- The planned manipulation of training variables (volume and intensity) in an attempt to maximize training adaptations and prevent overtraining (5, 31).

Linear periodization (LP)- A training program in which volume is progressively decreased while intensity is increased over several mesocycles (31).

Non-linear Periodization (NLP)-A training program that incorporates more frequent alterations than LP in training variables such as on a weekly or daily basis (5, 31).

Daily Undulating Periodization (DUP)- A sub-type of NLP that features alterations to training variables each training sessions (31).

Relative Training Volume- The product of repetitions multiplied by sets multiplied by intensity.

One Repetition Maximum (1RM)- The maximum amount of weight one can lift through a full range of motion with proper form.

Hypertrophy- An increase in MT of the skeletal muscle (3).

II. REVIEW OF LITERATURE

1. SKELETAL MUSCLE ADAPTATIONS TO RESISTANCE TRAINING

Resistance training is primarily performed with an external load applied to the skeletal muscle with repeated concentric and eccentric contractions. Furthermore, resistance training is known for its ability to increase muscular strength and hypertrophy, however, the underlying mechanisms responsible are not well elucidated. Recent literature has suggested that mechanical stimuli plays a critical role in the regulation of muscle mass (20, 52). Mechanical stimuli is effectively placing tension on the skeletal muscle in the form of external resistance or a stretch. This tension then triggers a complex cascade of cell signaling and activates specific anabolic pathways within the muscle resulting in an increase in muscle protein synthesis (mPS) (6, 16). The mechanical stimuli induced increase in mPS ultimately leads to an accretion of new protein in the muscle and thus an increase in muscle mass.

The major pathway that is studied when examining resistance training's effects on mPS is the Akt-mTOR-p70S6K pathway. Within this complex pathway, investigators have determined the activation of Mammalian target of rapamycin (mTOR) and ribosomal protein kinase S6 (p70S6K) appears to be a crucial step. P70S6K lies downstream of mTOR and is correlated with an increase in translation of specific mRNAs, which cumulates in an increase in protein synthesis and, thus, muscle growth

(6, 12, 52). Indeed, Burd and colleagues (2010) have shown that mPS may be volume dependent with a higher training volume resulting in increased phosphorylation of p70S6K, which was positively related to the mPS response(6). Furthermore, Mitchell et al. (2012) suggested that phosphorylation of p70S6K might have an intensity threshold (24). Their study consisted of three groups with one training at 30% and the others training at 80%. While no difference existed in mTOR phosphorylation, only the 80% groups significantly increased phosphorylation of p70S6K. Although greater strength increases were detected in the 80% compared to the 30% group, muscle mass was not significantly different between groups, which indicates p70S6K as a key factor in determining strength gains at the cellular level in response to resistance exercise.

Another aspect to consider in the muscular adaptation to resistance training is satellite cell activation. Satellite cells are myogenic stem cells located between the basal lamina and sarcolemma of myofibers (48). Their role in muscle growth is a part of the myonuclear domain theory, which states the nucleus of a muscle cell can only control a finite area of muscle before more nuclei must be added for growth to continue (42). Initially the cause of muscle growth is due to an increase in mPS, however, once a muscle cell reaches its myonuclear domain limit, a satellite cell is responsible for the donation of an additional nuclei that allows for continued growth of the muscle. Normally dormant, the activation of satellite cells is caused by damage to muscle fibers, which causes a release of growth factors (48). Satellite cells then proliferate and either fuse to one another to from myotubes or fuse to the damaged fiber and donate their nuclei (26).

2. STRUCTURED PROGRAMMING IN RESISTANCE TRAINING

2.1 Periodization:

Resistance-training programs are often designed in a structured manner to elicit maximum adaptations. Two options are considered when designing a program, which include a non-periodized or periodized model. A non-periodized model does not incorporate any variation in acute training variables (e.g., volume and intensity) for the length of the program. Conversely, in a periodized program, alterations are made to training variables at certain time points within the program. For example, in a nine-week program, the first three weeks may require three sets of twelve repetitions. Then the following three weeks would consist of three sets of eight repetitions and final three weeks three sets of six repetitions. An example comparing non-periodized to periodized design is provided in the table below.

Table 1: Comparison of a non-periodized to periodized design.

	Non-periodized	Periodized (Linear)
Week	Sets x repetitions	Sets x repetitions
1-3	3x12	3x12
4-6	3x12	3x8
7-9	3x12	3x6

Several studies have compared non-periodized to periodized training for strength gains (25, 28, 44, 50). The results have shown that in untrained individuals no significant difference exists in strength gains between training models (44). However, in trained individuals, a periodized design augments superior strength gains than non-periodized (25, 50). The effectiveness of periodization can be attributed to the variation incorporated into its design, which may reduce “staleness” (28) or overtraining (50) and lead to greater increases in strength.

2.2 Linear periodization:

Within the periodized model, two main sub-types of designs are linear periodization (LP) and non-linear periodization (NLP). Traditionally, LP begins with high training volume with low intensity and progresses to low training volume with high intensity over a time period of several weeks or mesocycles (5, 25, 28, 50). Additionally, LP is commonly designed using four phases; preparatory, first transition, competition, and second transition (43). During the preparatory phase, volume is high and intensity is low with the aim to increase lean body mass (LBM). The first transition phases functions to slightly lower the volume with an increase in training volume to increase “basic strength”. Following this phase into competition a further decrease in volume is accompanied by a rise in intensity to maximize strength and power adaptations, which is also referred to as “peaking”. The final phase is the second transition in which volume and intensity are drastically reduced to facilitate rest and recovery from the training block. The LP design has been shown to be effective at increasing strength (5, 25, 30, 31, 50) in trained individuals.

Despite these results, several limitations are still within this design. As mentioned previously, the transition from high-training volume with low intensity to low-training volume with high intensity may require several weeks spent in one phase. The extended time spent in any one phase may cause a loss of training adaptations received in the previous stage resulting in the inability to maximize neurological and skill adaptations. Furthermore, due to the length of the LP design, there are a limited amount of times an individual can “peak” within a year.

2.3 Non-linear periodization:

A second sub-type of periodization design is NLP. NLP encompasses more frequent alterations to training variables in a shorter time period (i.e., weekly or daily) (5, 25, 40). In the literature two types of NLP periodization have been identified; weekly undulating periodization (WUP) and daily undulating periodization (DUP). WUP is a less utilized model and involves changes to training variables on a weekly basis. A more commonly employed model is DUP, in which alterations to training variables are made on daily basis or during each training session (40). Burford et al. (2007) compared differences between WUP, DUP, and LP for strength gains in recreationally trained individuals (5). They found no significant differences between groups. The subjects used for this study only completed four weeks of resistance training prior to participating and, therefore, were still relatively inexperienced to resistance exercise. In any case, these findings indicated that in the early stages of resistance training the type of periodization model may not be essential to maximize training adaptations.

Rhea et al. (2002), in a classic study, was the first to compare LP to DUP with equated volume for strength gains in trained males (32). Subjects were randomly assigned to either a LP or DUP group for 12 weeks of resistance training three times a week utilizing leg press and bench press exercises. The results found the LP group increased 14% and 26% for the leg press and bench press, respectively. However, the DUP group increased 29% and 56% in the leg press and bench press, respectively, which was significantly greater than the LP group. These findings indicate DUP is superior to LP in terms of prompting strength gains. Additional studies have compared the effectiveness of DUP to LP for strength and hypertrophy in trained individuals with the results indicating that DUP is superior at augmenting strength gains (25, 30, 40) with no differences observed in hypertrophy (31, 40).

Although not fully understood, researchers speculate that the effectiveness of DUP for strength may be due to enhanced neurological adaptations (25, 31). Both studies that measured hypertrophy found no significant differences in spite of a significant difference in favor of DUP for strength, which strongly suggests an increased efficiency of the neuromuscular system is responsible for the adaptations. The key to these adaptations may be similar to the same reason why LP is more effective than non-periodized training at increasing strength; variation of the training variables. While LP offers more variation than non-periodized programs, DUP offers even more variation of training variables. Moreover, the design of DUP allows for more frequent recruitment of high threshold motor units by reducing the duration between high intensity training days, which should increase neuromuscular efficiency at heavier loads, and, subsequently, improve strength. However, very little research has been conducted with the DUP subtype of periodization, and, therefore, more studies are required to better elucidate the underlying mechanisms of DUP.

Table 2: A comparison of linear and non-linear periodization designs.

	Linear Periodization		Non-linear (DUP)
Week	Sets x repetitions	Day	Sets x repetitions
1-3	3x12	1	3x12
4-6	3x8	2	3x8
7-9	3x6	3	3x6

3. TRAINING VARIABLES

3.1 Training Volume:

Training volume can be defined as the number of sets multiplied by the number of repetitions multiplied by the load or intensity. Recent literature indicates training volume might be the central factor that influences strength and hypertrophy, with greater volume achieving better increases (17, 22, 31, 33, 35, 41). Finding mechanisms as to why more volume elicits greater skeletal muscle adaptations is still in the beginning stages, however, recent literature implies that neurological alterations might be the cause (22). McBride et al. (2003) investigated the effects of different resistance training volume on strength in the biceps curl and leg press exercises (22). The study design used two experiment groups in which one group performed one set and the other six sets of the both exercises two times a week for 12 weeks. The results found the six-set group increased strength significantly more than the one-set group for the biceps curl exercise, while there was a trend towards significance for the six-set group in strength of the leg press exercise. Additionally, significantly larger electromyography (EMG) values were recorded for the six-set group in the biceps curl compared to the one-set group with no difference in muscle mass indicating that the difference in strength was due to neuromuscular changes. Interestingly, the trend toward significance for the six set group in strength of the leg press exercise was not accompanied by changes in EMG values or muscle mass. If resistance exercises are thought of as a skill, it is reasonable to conceive the group with higher training volume increased strength simply by becoming better at the skill. In a very simplistic view the six-set group practiced the exercise more than the one-set group and, therefore, improved that specific movement.

A different body of evidence suggests that greater volume increases muscle mass, which subsequently leads to increases in strength (17, 35). Ronnestad et al. (2007) supported this theory (35). They investigated differences in training volume on strength and muscle mass in the upper and lower body. Subjects were divided into two groups and completed either one or three sets of various upper and lower body exercises three times a week for 11 weeks. The results revealed the three set group (higher volume) increased lower body strength and hypertrophy significantly more than the one set group (lower volume). No differences were observed between groups in upper body strength or hypertrophy. Since only the high volume group increased hypertrophy and strength these results imply strength and hypertrophy might be dependent upon one another. Unfortunately, no EMG values were measured, and neuromuscular changes could not be assessed.

Goto et al. (2004) also examined the relationship between training volume and its effect on strength and muscle mass (17). In this study, all subjects completed an initial six weeks of the same hypertrophy type of training. Following this subjects were divide into either a “combi type” group that performed both hypertrophy training and strength type training, or a strength group that only performed strength type training. The results concluded the "combi type" training increased strength and hypertrophy significantly more than the strength group. Additionally, upon further analysis they determined the "combi type" group performed significantly greater volume than the strength group. Therefore, the findings of this study further support the notion that strength and hypertrophy may be dependent on one another and, possibly a product of training volume. On a molecular level, higher training volume (3 sets) has been shown to acutely increase p70S6K phosphorylation and subsequent mPS levels to a greater extent than lower training volume (1 set) (6). Although this study only examined the response following one bout of exercise, if these effects are seen chronically, then this would provide an explanation for the increase in hypertrophy seen in high-volume resistance training programs.

3.2 Training Intensity:

Training intensity is defined as a relative training load of one-repetition maximum (1RM), and is often expressed as a percentage of 1RM or as an actual RM (e.g., 5RM, 10RM, 15RM). To highlight the importance of intensity some studies have shown when training volume is equated for intensity may be the determining factor that impacts resistance-training adaptations (7, 19). Campos et al. (2002) observed the effects of different repetition maximum ranges with equal volume on strength and hypertrophy (7). Participants performed eight weeks of low (3-5RM), intermediate (9-11RM), or high repetitions (20-28RM) two to three times a week. The results found strength was increased significantly more in the low-repetition group, while hypertrophy was improved significantly more in the low and intermediate groups. The low-repetition group performed the same volume as the other groups with the only difference being the intensity at which the resistance training was done, thus, signifying the importance of intensity. Holm et al. (2008) later confirmed the importance on training intensity by showing a lower intensity (15.5%) was inferior to a higher intensity (70%) at augmenting strength and hypertrophy gains when training volume was equal (19). Furthermore, greater training intensity (e.g., greater than 80%) has been shown to increase the activation of anabolic pathway ways associated with muscle growth (24). Findings from Mitchell et al. (2012) revealed that resistance exercise at an intensity of 80% compared to 30% increased p70S6K phosphorylation significantly more, which suggest that stimulation of these pathways could be intensity-sensitive (24). However, training volume was not calculated or equated for between groups. Despite this, the outcome of this study provides a further example of the importance of training intensity at the cellular level.

The importance of training intensity can be partially attributed to what is known as Hennemen's size principle. This principle stipulates motor unit recruitment follows an orderly progression according to size, with smaller low threshold motor units are recruited prior to larger high threshold motor units (10). A motor unit consists of a motor neuron and all the muscle fibers it innervates and, when stimulated, causes muscle fibers to contract generating a force. It is thought that during low-intensity contractions (e.g., less than 30%) only low threshold motor units are recruited, thus requiring high-intensity (e.g., 85%) contractions to recruit high threshold motor units (13). Once the maximum number of motor units is recruited, the amount of force generated is regulated by the rate at which these motor units fire (23). Therefore, to maximize force production, all available motor units must be recruited and fire at an optimal level.

Several studies have confirmed the size principle by examining contractions and motor unit activity at various intensities. Conwit et al. (1999) investigated the effects of isometric contractions at different intensities (5-75%) on motor unit firing rate (10). The findings indicated with higher intensities larger motor units where recruited along with an increase in firing rate. To expand on the previous results Del Valle et al. (2005) studied the effects of dynamic contractions at various intensities (0-100%) on the firing rate of motor units (11). They reported similar results with high intensities cumulating in a greater firing rate. Additionally, resistance exercise has been shown to increase the maximum firing rate (47) following training, which most likely contributes to an increase in strength. Overall, training intensity appears to contribute to strength and hypertrophy through activation of anabolic pathways along with enhancing the neuromuscular system by recruitment of and an increasing maximum firing rate of high threshold motor units. Based on these findings, to maximize strength adaptations, high intensity days must be incorporated into resistance-training programs.

4. ANALYSIS OF HIGH AND LOW REPETITION RESISTANCE TRAINING

The use of a particular repetition range (e.g., 4-6RM) in resistance training is often utilized to elicit a specific training adaptation, such as strength or hypertrophy. Traditionally, lower repetition ranges have been accepted to augment strength, while higher repetition ranges have been purported to promote hypertrophy. Anderson and Kearney (1982) designed a pioneer study to examine repetition ranges, which lead to the development of the strength-training continuum (2). This continuum has lead to strength-training being defined as low repetitions (i.e., 3-6) and a high intensity (i.e., 85-95%) with hypertrophy training defined as high repetitions (i.e., 8-12) with a moderate intensity (i.e., 65-75%) (3, 8, 17).

Many studies have compared the effects of high and low repetition resistance training for differences in strength and hypertrophy (2, 4, 7, 8, 18, 19, 24, 27, 29, 44, 49, 51). However, the results of these studies have proven to be inconsistent. A number of studies found both high (i.e., 9-40) and low repetition (i.e., 2-8) training were effective at enhancing strength and hypertrophy, with no significant differences between them (4, 8, 18, 27, 44, 51). Conversely, some studies found low-repetition training was superior to high-repetition training at eliciting strength and hypertrophy (2, 7, 19, 24, 29, 49). An overview of these studies is provided in the table below.

Table 3: Outcomes of studies comparing high and low repetition training.

Researcher	Duration & frequency	Protocol	Outcome
Anderson and Kearney 1982	Each group trained for 9 weeks, 3 times a week.	High resistance low repetition group (HRLR) performed 3 sets of 6-8RM Medium resistance medium repetition group (MRMR) performed 2 sets of 30-40RM Low resistance high repetition group (LRHR) performed 1 set of 100-150RM All groups only used the bench press exercise. Training volume was not calculated.	HRLR group increased maximum strength 20% compared to 8% and 5% for the MRMR and LRHR groups respectfully.

Table 3 Continued

Researcher	Duration & frequency	Protocol	Outcome
Berger, 1963	All groups trained 3 times a week for 9 weeks.	Group I trained with 6 sets of 2RM. Group II trained with 3 sets of 6RM. Group III trained with 3 sets of 10RM. All groups only used the bench press exercise. Training volume was not calculated.	There were no differences between training groups in terms of strength.
Campos et al., 2002	The total length of training was 8 weeks. The first 4 weeks subject trained 2 days a week. The final 4 weeks subjects trained 3 days a week.	Low repetition group (low rep) completed 4 sets of 3-5RM. The intermediate group (int group) completed 3 sets of 9-11RM The high repetition group (high rep) completed 2 sets of 20-28RM. Exercises were performed in the order of leg press, squat and leg extension. Groups were approximately equal in total volume.	The low rep group increased 1RM strength significantly more than the int and high rep groups. Hypertrophy increased significantly more in the low and int rep groups than the high rep group.

Table 3 Continued

Researcher	Duration & frequency	Protocol	Outcome
Chestnut and Docherty 1999	Training was performed 3 times a week for 10 weeks.	The 4RM group performed 6 sets of 4RM (~85%) of "core" exercises including triceps bench press, triceps pulley press-downs, standing biceps barbell curls, and standing simultaneous dumbbell curls. Along with two sets to failure of supplementary exercises such as bench press, bench pulls, and shoulder press. The 10RM group performed 3 sets of 10RM (~70%) of the same core exercises along with one set to failure with the supplementary exercises. Training volume was equal between groups.	There were no differences between groups in terms of strength or hypertrophy.
Hisaeda et al., 1996	The training protocol lasted for 8 weeks and subjects exercises 3 times a week.	Group H performed 4-5 sets of 15-20RM. Group S performed 8-9 sets of 4-6RM. Both groups only used the isotonic knee extension exercise. Training volume was not calculated.	No significant differences were found between groups for strength or hypertrophy.

Table 3 Continued

Researcher	Duration & frequency	Protocol	Outcome
Holm et al., 2008	Training was done for 12 weeks, 3 times a week.	The light load (LL) group completed 10 sets of 36 repetitions at 15.5% of their 1RM. The high load (HL) group completed 10 sets of 8 repetitions at 70% of their 1RM. All subject used a unilateral knee extension as the resistance exercise. Training volume was equal between groups.	The HL increased strength and hypertrophy significantly more than the LL group.
Mitchell et al., 2012	All groups trained for 10 weeks, 3 times a week.	Group I was assigned 3 sets at 30% intensity to voluntary failure. Group II was assigned 1 set at 80% intensity to voluntary failure. Group II was assigned 3 sets at 80% intensity to voluntary failure. Resistance exercise was in the form of unilateral knee extension. Training volume was not calculated.	Hypertrophy increased to the same extent for all 3 groups. Strength increased significantly more in the 80% groups compared to the 30% group.

Table 3 Continued

Researcher	Duration & frequency	Protocol	Outcome
Ogasawara et al., 2013	Participates trained for 3 times a week for 6 weeks.	Participates first completed 6 weeks of 3 sets of 10 repetitions at 75% (HL-RT). Then following a 12-month detraining period performed 6 additional weeks of 4 sets at 30% to voluntary failure (LL-RT). The bench press was the only exercise used. Total volume was not calculated.	Strength and hypertrophy were improved significantly more in the HL-RT compared to the LL-RT group.
Stone and Coulter 1994	Training was assigned for 3 times a week for 9 weeks.	The high resistance low repetition (HRLR) group performed 3 sets of 6-8RM. The medium resistance medium repetition (MRMR) group performed 2 sets of 15-20RM The low resistance high repetition (LRHR) group performed 30-40RM. Training volume was not calculated.	Strength was not found to be significantly different among the 3 groups.
Weiss et al., 1999	Subjects trained 3 times a week for 7 weeks.	Group I completed 4 sets of 3-5RM. Group II completed 4 sets of 13-15RM. Group III completed 4 sets of 23-25RM. The squat exercise was the only exercise used. Training volume was not calculated.	Group I was superior to the Group III in terms of strength gains.

Table 3 Continued

Researcher	Duration & frequency	Protocol	Outcome
Withers 1970	The training protocol lasted for 9 weeks and subjects exercises 2 times a week.	Group I performed 3 sets of 7RM. Group II performed 4 sets of 5RM. Group III performed 5 sets of 3RM. The exercises used were the bench press, squat, and curl. Training volume was not calculated.	The results did not find any significant differences between groups for strength.

A major aspect that may have contributed to the inconsistence findings is the lack of calculating and equating training volume between groups in most studies (2, 4, 18, 24, 29, 44, 49, 51). As discussed previously, training volume has been shown to be instrumental in determining strength and hypertrophy adaptations. Ultimately if training volume is not measured and equated for between groups, the results cannot be confidently attributed to the experimental protocol. Future research should make careful calculations to attempt to control for this important variable.

A second aspect to consider for future research is the use of resistance-trained individuals. All of the studies reviewed utilized an untrained population of subjects. Thus, it is not known if high- and low-repetition training impacts trained individuals differently than untrained. Additionally, a periodized design can be incorporated with this population as well. Although a periodized model in untrained persons does not have an effect, in a trained population it has been shown to be the most efficacious type of resistance-training program to promote strength and hypertrophy.

5. CONCLUSION

This review discussed the adaptations to resistance training, structured programing in resistance training, training variables, and an analysis of studies involving high and low repetition training. Although resistance training has been well defined as the optimal way to increase muscular strength and hypertrophy, there is still much to be elucidated in the area of resistance training adaptations. Currently, no consensus exists among researchers as to the most effective type of resistance training (i.e., high- or low-repetitions) for promoting these adaptations. However, a growing body of research suggests low repetitions may be superior to high repetitions at enhancing underlying mechanisms involved in strength and hypertrophy.

To date, numerous studies have failed to control for training volume, which may be related to the inconclusive findings of research examining high- and low-repetition training. Additionally, the majority of literature has focused exclusively on the untrained population. In this population, a periodization model is often not utilized, as research has shown it is not more effective than any other model at increasing strength or hypertrophy. With this previous research, an interesting area to examine would be the effects of high and low repetition training using a DUP model and equating for volume on strength and hypertrophy in trained individuals. It is conceivable that if training volume is equal hypertrophic adaptations will be similar, however, it may be necessary to utilize a greater intensity to achieve optimal strength gains via neuromuscular efficiency. In any case, this study would offer insight into an understudied population while improving upon previous research designs. With these findings will come a better understanding of the interrelationship of training volume and intensity, and their respective impact on strength and hypertrophy.

III. METHODS

Subjects

Eleven college-aged, resistance-trained males were recruited for this study. The average 1RM strength of all subjects for the squat was 1.73± 0.24 times bodyweight and 1.43± 0.22 times bodyweight for the bench press. Additionally, subjects must have had at least 2 years of resistance training experience, and must have been performing the squat and bench press exercises with a minimum frequency of 1 times per week for the past 6 months. These parameters were determined by the usage of a physical activity questionnaire (Appendix B) that subjects completed before participating in the study. Subjects also completed a medical history questionnaire before partaking in the study (Appendix C). If subjects did not meet the minimum strength or resistance-training experience requirements or had any contraindications exercise (i.e., heart disease), they were excluded. Prior to participating in the study, subjects reviewed and signed an informed consent form that was approved by the Florida Atlantic University Institutional Review Board (Appendix D).

Experimental Design

Subjects were assigned to one of two groups, in which they performed a different 6-week resistance-training protocol that utilized a daily undulating periodization (DUP) model consisting of either high repetitions (DUP-HR group) or low repetitions (DUP-LR group). Subjects were counterbalanced by relative strength to ensure no differences between groups existed (46). The design of the DUP-HR protocol consisted of repetitions solely in the traditional hypertrophy range during a given week (i.e., Mon: 12, Wed: 10, and Fri: 8). The DUP-LR protocol included repetitions solely in the traditional strength range (i.e., Mon: 6, Wed: 4, and Fri: 2). Relative strength was calculated by Wilk's coefficient, which considers individuals' bodyweight combined with the total amount of weight lifted (1RM values for the squat plus bench press).

Experimental Protocol

Subjects reported to the laboratory for a total of 25 days over 8 consecutive weeks (See Table X). Pre- and post-testing for 1RM strength, maximum repetitions at 60%, and muscle thickness (MT) took place during weeks 1 and 8. Weeks 2-7 consisted of a 6-week DUP training protocol (DUP-HR or DUP-LR). Subjects performed resistance training 3 days a week on non-consecutive days (i.e., Monday, Wednesday, Friday).

At pre- and post-testing 1RM strength, maximum repetitions at 60%, MT, body composition, and anthropometrics were assessed. During weeks 1 and 8 prior to 1RM testing, subjects had MT of their chest, vastus lateralis, and vastus medialis muscles measured via ultrasound (BodyMetrix, IntelaMetrix, Livermore, CA.). Body composition was assessed by skinfolds, using the sum of 3 sites (chest, abdomen, and thigh). Prior to 1RM testing, all subjects performed a standardized 10-minute dynamic warm-up routine designed to increase the body's core temperature and prepare the muscles for the exercises that were performed. Additionally, subjects were fed branched chain amino acids (BCAAs) containing 3.5g of leucine 30 minutes prior to each training session and 30g of whey protein immediately after each training session.

Experimental Conditions: DUP Models (DUP-HR vs. DUP-LR)

As briefly described, this study consisted of two different DUP training protocols (See tables 7 & 8 for more details). However, prior to the start of their training protocol and 48 hours following the 1RM testing subjects engaged in 3 alternating days of low volume resistance training otherwise known as an 'introductory microcycle' (See tables 4 & 5 for specific design) aimed to protect against muscle damage and prepare subjects for the upcoming protocol. This low intensity training was specifically designed for subjects' upcoming DUP training protocols.

Following the introductory microcycle subjects trained three non-consecutive days (e.g., Monday, Wednesday, Friday) a week for six weeks performing either a DUP-HR or DUP-LR protocol. Although each protocol contained a different number of sets, repetitions, and intensities, careful calculations were done to ensure that training volume between groups was relatively equated for.

The DUP-HR protocol consisted of: four sets of 12 repetitions at 60% of 1RM for day 1, four sets of 10 repetitions at 65% of 1RM for day two, and five sets of eight repetitions at 70% of 1RM for day three. The DUP-LR protocol consisted of eight sets of six repetitions at 75% of 1RM for day one, nine sets of four repetitions at 80% of 1RM for day two, and 10 sets of two repetitions at 85% of 1RM for day three. Both groups performed the squat and bench press during each training session. To standardize rest periods, investigators administered 5 to 7 minute rest intervals following each set for all subjects. Training load progression was made on a weekly basis and contingent upon subjects' completion of the prescribed sets and repetitions. For the squat 5 kg was added from week 1-2, 2.5 kg each week from weeks 2-4, 1.25 kg for week 4-5, and 1 kg for week 5-6 for a total of 12.25kg over eight weeks. For the bench press 2.5 kg was added each week from weeks 1-4, 1.5 kg for week 4-5 and 1kg for week 5-6 for a total of 10kg over 8 weeks. However, if subjects did not complete the prescribed sets and repetitions there was either no addition of weight or a reduction in weight based upon the percentage of repetitions missed. If subjects completed 99-80% of the prescribed repetitions, they increased the subsequent weeks load at 50% of the normal progression for that week, while if 89-80% was completed, no progression was made the following week. If only 79-70% was completed, a reduction of 50% of the normal progression was applied to the subsequent weeks load. For 69-60% completion rate, 100% of the normal progression was reduced from subsequent weeks load. For every 10% subsequent drop in competition rate, subjects would decrease the 100% of the normal progression plus an additional 2.5kg. This strategy was implemented to ensure subjects would be able to complete the prescribed repetitions and sets the following week.

Subjects then began 'taper' (reduced volume training) training 48 hours following the completion of week 7 DUP training. The taper consisted of 2 non-consecutive days of low volume training (See table 8 & 9 for specific design). This training was designed to allow for rest and recovery to occur in preparation for post-testing. Finally, 48 hours following subjects' 2nd taper training day post-testing for 1RM strength, maximum repetitions at 60%, MT, body composition, and anthropometrics were conducted.

Dietary Log

To control for diet, subjects kept a record of their nutritional intake (all food and beverages) for each day prior to a resistance-training session. The diet logs were given to each subject with the instructions to replicate their food consumption 24 hours prior to each resistance-training session. Further, subjects were instructed to cease any supplementation use prior to the study, and only consume the supplements provided to them for the duration of the study. See appendix A for dietary log

Physical Activity Questionnaire

Prior to engaging in the proposed study each potential subject completed a physical activity questionnaire. The purpose of this questionnaire was to obtain detailed information about exercise history and qualifications of entry into the study. The questions inquired about how many years subjects have been resistance training, how frequently they perform the squat and bench press exercises a week, and their current estimated 1RM in the squat and bench press exercise. See appendix B for physical activity questionnaire

Medical History Questionnaire

Upon subjects first visit to the laboratory they completed a medical history questionnaire. The questionnaire provided information about the health history and any current contraindications to exercise (i.e., high blood pressure, valvular disease, cardiovascular disease). Subjects, who reported contraindications, were not allowed to participate. See appendix C for medical history questionnaire.

One Repetition Maximum (1RM) Testing

Subjects were tested for maximum strength in the squat and bench press exercises using a 1RM protocol. This testing occurred pre-study during week 1 and post-study during week 8. All exercises were performed under the rules set by USAPL (46). For the squat 1RM test, subjects removed the weight with the bar placed across the upper back/shoulders from the rack and stand with their knees locked. Subjects then descend bending at the knees and hips until the top of the leg at the hip crease is below the top of the knee. Finally, subjects returned to an erect standing position. During the bench press, subjects were supine on a weight bench, while maintaining contact of the buttocks and shoulders on the bench with the feet flat on the ground at all times throughout the lift. Subjects removed the bar from the rack and held it in their hands with arms extended before beginning the lift. The bar was lowered in a controlled manner until it touched the chest where it was then be pressed until the arms were fully locked.

Squat and bench press 1RM testing was administered according the guidelines of the National Strength and Conditioning Association (NSCA). To begin this protocol, subjects performed 5 repetitions with 20% of their estimated 1RM, followed by 3 repetitions at 50% of estimated 1RM, and 2 repetitions at 75% 1RM. Next, they performed 1 repetition at 85% of estimated 1RM and then proceeded to find their 1RM in no more than 5 attempts with weight selected by the investigator. Each subject was given 5 to 7 minutes of rest between 1RM attempts.

Muscle Thickness (MT)

Muscle thickness, as measured by ultrasound, was used as an index of muscular hypertrophy of the chest, vastus lateralis, and vastus medialis. All sites were measured on left and right sides of the body to account for any muscular imbalances. These measures occurred pre-study during week one and post-study during week eight before exercise. Each site was scanned using a transducer, which interfaced with a computer to produce an image of MT (in mm). Prior to scanning each site, a conduction gel was applied to the distal end of the transducer. This conduction gel served to reduce the friction between the transducer and skin of the measurement site, which ultimately enhanced the image quality. For each site, the muscle was scanned distal to proximal with the transducer positioned perpendicular to the skin. Furthermore to ensure an accurate measure was obtained, each site was scanned twice and the average of both values was taken. However, if the difference between the two values was greater than 2 mm, a third scan was performed and all three values were averaged together.

All subjects had MT measured with the chest first, followed by the thigh. The chest site was located with subjects standing relaxed at half the distance between the anterior axillary line and the nipple. Following the chest measures, subjects laid supine on an examination table to begin measures of the vastus lateralis and vastus medialis. The vastus lateralis was measured at 50 and 70% of the distance from the greater trochanter to the lateral epicondyle of the femur. The vastus medialis was also measured at 50 and 70% of the distance from the greater trochanter to the medial epicondyle of the femur. To maintain consistency pre- to post-study, the same investigator palpated and scanned each site for all subjects.

Muscle Endurance: Maximum Repetitions at 60%

Subjects were instructed to perform the maximum number of repetitions they could complete at 60% of their pre-study 1RM in the squat and bench press exercises. This took place following 1RM testing during weeks 1 and 8. After completing a 1RM test in either the squat or bench press subjects were given a 10-minute rest period then performed as many repetitions as possible at 60% of the same exercise. All repetitions were performed to the USAPL standards.

Average Velocity at 1RM

During 1RM attempts of the squat and bench press, average velocity (m/s) was displayed via a Tendo unit (Trencin, Slovakia) for each subject. The Tendo unit consists of two components: a velocity sensor and display unit. The velocity sensor was placed on the floor directly under the barbell with a leash fastened at the end of the barbell creating a perpendicular angle between the velocity sensor and barbell. When the barbell was moved concentrically during the squat and bench press, the display unit provided measures of average velocity. Following each 1RM attempt, average velocity was manually recorded. However, due a shorter range of motion in the bench press, the velocity sensor did not measure all 1RM attempts and, therefore, statistical analysis could not be performed on average 1RM bench press velocity.

Statistical Analysis

A comparison of variables between groups was performed by repeated measures ANOVA with the significance set at $p \leq 0.05$. Data were screened for normality and outliers. If there was a lack of normality or outliers occurred, then we attempted to correct the data through transformation (REF). If the data were not transformed then the statistical analysis was performed with and without the irregular points. If the irregular points did not affect the data, they were maintained, otherwise they were removed. A Tukey post-hoc test was performed, when appropriate, to probe for statistical significance. The software Statistica® 12 (StatSoft, Tulsa, OK.) was used to perform all statistical analyses.

Effect size (ES) data was also calculated using the Cohen's *d* formula (1988) (9), which finds the difference between two means divided by the standard deviation of either group. In studies with smaller sample sizes, as in the current study, utilizing ES to analyze data may be more beneficial than statistical significance. Smaller sample sizes reduce statistical power, which creates difficulty in recognizing differences between experimental groups. Additionally, ES was reported in a previous periodization study (30), which also examined strength outcomes, indicating it to be a reliable form of analysis.

A Pearson's correlation was utilized to examine relationships between several outcome measures including: MT and 1RM strength, MT and ME, body weight and 1RM strength.

Table 4: Introduction cycle for DUP-HR.

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday & Sunday
Volume	2x13@50% 1x12@55%	Rest	2x11@55% 1x10@60%	Rest	2x9@60% 1x8@65%	Rest
Exercise	Back Squat + Bench Press	Rest	Back Squat + Bench Press	Rest	Back Squat + Bench Press	Rest

Table 5: Introduction cycle for DUP-LR.

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday & Sunday
Volume	3x7@65% 2x6@70%	Rest	3x5@70% 2x4@75%	Rest	5x3@75% 2x2@80%	Rest
Exercise	Back Squat + Bench Press	Rest	Back Squat + Bench Press	Rest	Back Squat + Bench Press	Rest

Table 6: Sample Illustration of a Training Week for DUP-HR.

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday & Sunday
Volume	4x12@60%		4x10@65%		5x8@70%	
Exercise	Back Squat + Bench Press	Rest	Back Squat + Bench Press	Rest	Back Squat + Bench Press	Rest

Table 7: Sample Illustration of a Training Week for DUP-LR.

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday & Sunday
Volume	8x6@75%		9x4@80%		10x2@85%	
Exercise	Back Squat + Bench Press	Rest	Back Squat + Bench Press	Rest	Back Squat + Bench Press	Rest

Table 8: Taper week for DUP-HR.

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday & Sunday
Volume	3x6@55%	Rest	2x3@65%, 1x2@70%	Rest	1RM test	Rest
Exercise	Back Squat + Bench Press	Rest	Back Squat + Bench Press	Rest	Back Squat + Bench Press	Rest

Table 9: Taper week for DUP-LR.

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday & Sunday
Volume	5x3@70%	Rest	2x2@80%, 2x1@85%	Rest	1RM test	Rest
Exercise	Back Squat + Bench Press	Rest	Back Squat + Bench Press	Rest	Back Squat + Bench Press	Rest

Complete Study Protocol

Table 10: Hypothetical Model of Subjects' Daily Activities in the Purposed Study

	Week 1	**Week 2**	**Week 3**	**Week 4**
Monday	Baseline 1RM strength, maximum repetitions at 60%, MT, body composition, and anthropometrics measured.	Rest	Rest	Rest
Tuesday	Rest	DUP-LR or DUP-HR Training	DUP-LR or DUP-HR Training	DUP-LR or DUP-HR Training
Wednesday	Introduction cycle	Rest	Rest	Rest
Thursday	Rest	DUP-LR or DUP-HR Training	DUP-LR or DUP-HR Training	DUP-LR or DUP-HR Training
Friday	Introduction cycle	Rest	Rest	Rest
Saturday	Rest	DUP-LR or DUP-HR Training	DUP-LR or DUP-HR Training	DUP-LR or DUP-HR Training
Sunday	Introduction cycle	Rest	Rest	Rest

Table 10 Continued

	Week 5	**Week 6**	**Week 7**	**Week 8**
Monday	Rest	Rest	Rest	Taper
Tuesday	DUP-LR or DUP-HR Training	DUP-LR or DUP-HR Training	DUP-LR or DUP-HR Training	Rest
Wednesday	Rest	Rest	Rest	Taper
Thursday	DUP-LR or DUP-HR Training	DUP-LR or DUP-HR Training	DUP-LR or DUP-HR Training	Rest
Friday	Rest	Rest	Rest	Post-study 1RM strength, maximum repetitions at 60%, MT, body composition, and anthropometrics measured.
Saturday	DUP-LR or DUP-HR Training	DUP-LR or DUP-HR Training	DUP-LR or DUP-HR Training	
Sunday	Rest	Rest	Rest	

IV. RESULTS

Subjects

There was no difference between training groups in baseline relative strength as determined from Wilk's coefficient. Additionally, four subjects were unable to complete the protocol: two due to injuries during the study and two for failure to adhere to the training protocol. Overall, the average compliance rate was 97.8% for all subjects that finished.

1RM Strength

Mean values for pre-and post-training strength variables, for both groups, can be seen in Table 11.

Table 11: Changes in strength variables pre-to post-training in DUP-LR and DUP-HR (N=11).

Outcome Measure	DUP-LR n=5		DUP-HR n=6	
	Pre-training	**Post-training**	**Pre-training**	**Post-training**
1RM Squat (kg)	152.4 ± 25.75	171.00 ± 31.75* (+12.20%)	147.83 ± 19.94	162.25 ± 19.05* (+9.75%)
1RM Bench Press (kg)	138.1 ± 30.04	150.7 ± 26.37* (+9.12%)	111.75 ± 8.88	121.92 ± 8.06* (+9.10%)
Total Strength (kg)	290.5 ± 53.79	357.29 ± 54.58* (+10.74%)	259.58 ± 27.57	284.16 ± 24.27* (+9.47%)
Wilk's Total	189.45 ± 25.5	207.32 ± 22.85* (+9.43%)	171.57 ± 17.99	186.35 ± 17.99* (+8.61%)

Values are in means ± standard deviation.
*p≤0.05, significantly different from pre-training
DUP-LR=Daily Undulating Periodization Low Repetition
DUP-HR= Daily Undulating Periodization High Repetition
1RM= One-Repetition Maximum

1RM Squat Strength

There was no group x time interaction for pre to post 1RM squat strength (p>0.05). However, as expected, there was a significant time effect for DUP-LR (p=0.02) and DUP-HR (p=0.05). Mean values can be seen in Table 11. Effect size (ES) was also calculated, however, only a small effect (0.33) was seen in favor of DUP-LR. Effect Size values can be seen in Table 14

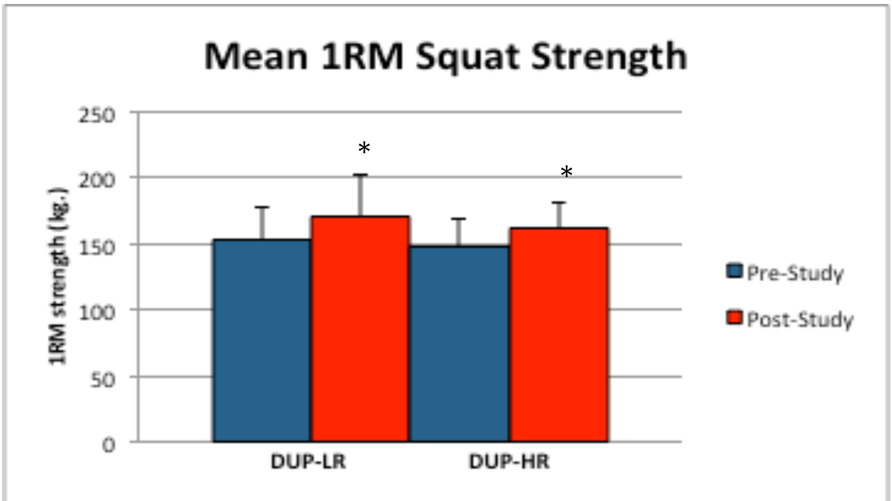

Figure 1: Comparison of mean 1RM squat strength between groups pre- to post-study.

DUP-LR= Daily Undulating Periodization Low Repetition. DUP-HR=Daily Undulating Periodization High Repetition. 1RM= One-repetition Maximum. Mean 1RM squat strength increased significantly in both groups from pre- to post-training ($p \leq 0.05$). *$p \leq 0.05$, significantly different from pre- to post-training. The DUP-LR and DUP-HR groups increased their 1RM squat 12.20 and 9.75%, respectively. Values are reported in means ± standard deviation.

1RM Bench Press Strength

There was no group x time interaction for pre to post 1RM bench press strength ($p>0.05$), however, as expected, there was a significant time effect for DUP-LR ($p=0.02$) and DUP-HR ($p=0.04$). Mean values can be seen in Table 11. Additionally, ES was calculated, which revealed a relatively large effect (1.48) in favor for DUP-LR. Effect Size values can be seen in Table 14.

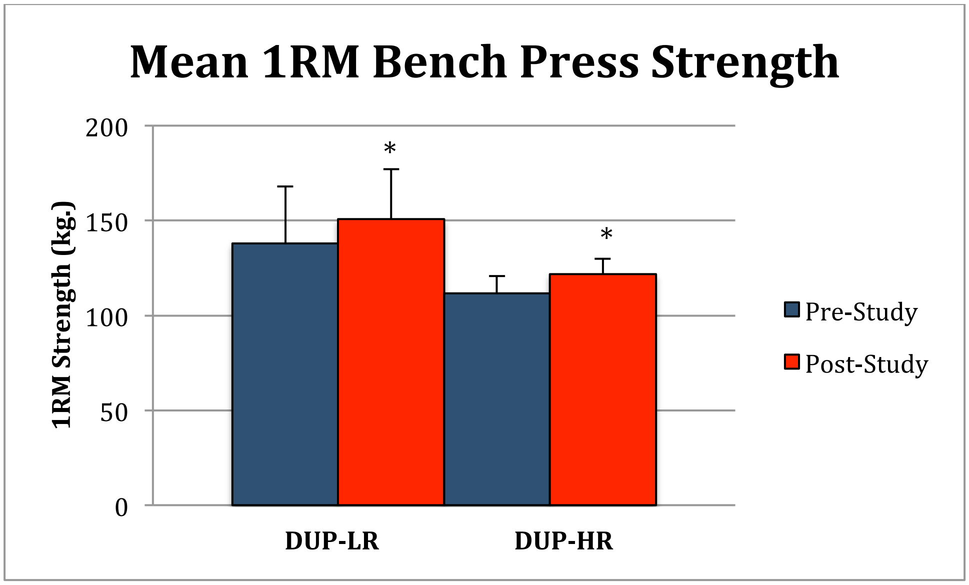

Figure 2: Comparison of mean 1RM bench press strength between groups pre- to post-study.

DUP-LR= Daily Undulating Periodization Low Repetition. DUP-HR=Daily Undulating Periodization High Repetition. 1RM= One-repetition Maximum. Mean 1RM bench press strength increased significantly in both groups from pre- to post-training ($p \leq 0.05$). *$p \leq 0.05$, significantly different from pre- to post-training. The DUP-LR and DUP-HR groups increased their 1RM bench press 9.12 and 9.10%, respectively. Values are reported in means ± standard deviation.

Total Strength (TS)

There was no group x time interaction for pre to post TS ($p>0.05$), however, as expected, there was a significant time effect for DUP-LR ($p=0.005$) and DUP-HR ($p=0.01$). Mean values can be seen in Table 11. Additionally, ES was calculated, which revealed a relatively large effect (0.89) in favor for DUP-LR. Effect Size values can be seen in Table 14.

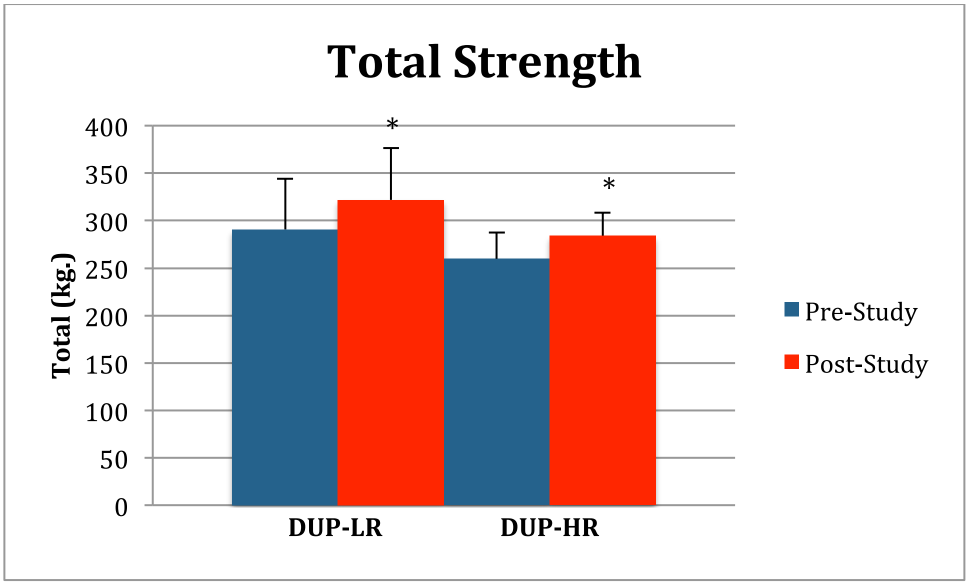

Figure 3: Comparison of total strength (TS) total between groups pre- to post-study.

DUP-LR= Daily Undulating Periodization Low Repetition. DUP-HR=Daily Undulating Periodization High Repetition. TS increased significantly in both groups from pre- to post-training ($p<0.05$). *$p\leq0.05$, significantly different from pre- to post-training. The DUP-LR and DUP-HR groups increased their TS 10.74 and 9.47%, respectively. Values are reported in means ± standard deviation.

Wilk's Coefficient

There was no group x time interaction for pre to post Wilk's coefficient ($p>0.05$), however, as expected, there was a significant time effect for DUP-LR ($p=0.005$) and DUP-HR ($p=0.009$). Mean values can be seen in Table 11. Additionally, ES was calculated, which revealed a relatively large effect (1.02) in favor for DUP-LR. Effect Size values can be seen in Table 14.

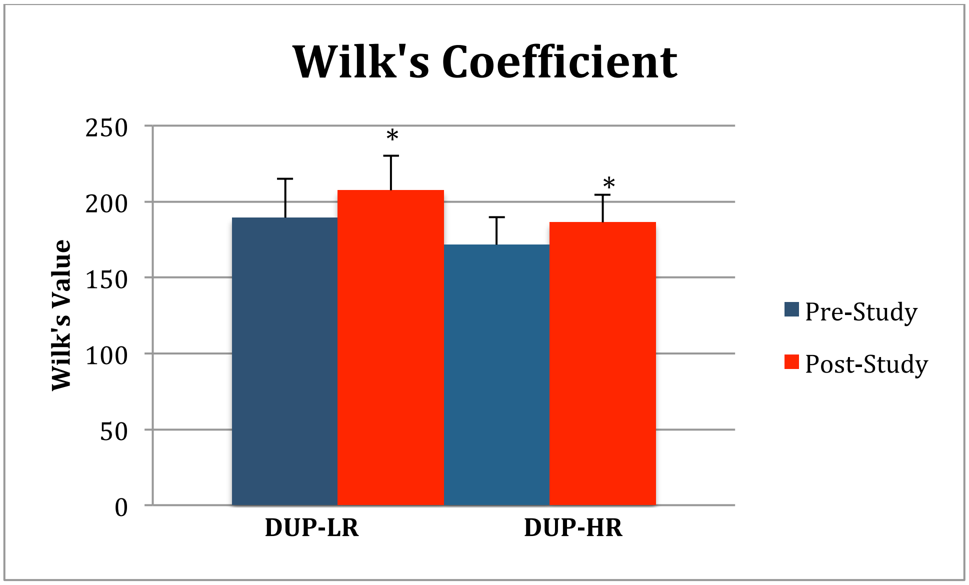

Figure 4: Comparison of mean Wilk's Coefficient values between groups pre- to post-study.

DUP-LR= Daily Undulating Periodization Low Repetition. DUP-HR=Daily Undulating Periodization High Repetition. Wilk's coefficient increased significantly in both groups from pre- to post-training ($p \leq 0.05$). *$p \leq 0.05$, significantly different from pre- to post-training. The DUP-LR and DUP-HR groups increased their squat and bench total 9.43 and 8.61%, respectively Values are reported in means ± standard deviation

Muscle Thickness

Mean values for pre- to post-training MT measures can be seen in Table 12.

Table 12: Changes in muscle thickness pre- to post-training in DUP-LR and DUP-HR (N=11).

Muscle Thickness	**DUP-LR n=5**		**DUP-HR n=6**	
	Pre-Training	Post-Training	Pre-Training	Post-Training
Chest Right (mm)	40.06 ± 7.80	46.61 ± 8.18* (+16.33%)	34.89 ± 5.89	40.38 ± 4.01* (+15.74%)
Chest Left (mm)	40.25 ± 7.70	45.04 ± 7.36* (+11.90%)	37.49 ± 4.14	39.50 ± 3.66 (+11.58%)

Table 12 continued

Muscle Thickness	DUP-LR n=5		DUP-HR n=6	
	Pre-training	Post-training	Pre-training	Post-training
Vastus Lateralis Right 50% (mm)	45.4 ± 5.76	47.40 ± 4.80 (+4.41%)	50.48 ± 4.46	53.50 ± 5.67 (+5.98%)
Vastus Lateralis Left 50% (mm)	47.27 ± 6.43	45.45 ± 6.03 (-3.85%)	49.11 ± 6.35	56.08 ± 6.58 (+14.17 %)
Vastus Lateralis Right 70% (mm)	38.55 ± 10.12	43.42 ± 4.23 (+12.63%)	42.50 ± 5.26	48.98 ± 5.30 (+15.25%)
Vastus Lateralis Left 70% (mm)	40.75 ± 6.45	44.21 ± 5.94 (+8.49%)	45.52 ± 6.21	52.36 ± 5.00* (+15.03%)
Vastus Medialis Right 50% (mm)	46.98 ± 7.24	54.86 ± 4.77 (+16.78%)	45.40 ± 7.20	49.26 ± 2.46 (+8.52%)
Vastus Medialis Left 50% (mm)	48.93 ± 7.18	51.32 ± 2.07 (+4.89%)	45.78 ± 5.13	50.61 ± 5.60 (+10.55%)
Vastus Medialis Right 70% (mm)	40.71 ± 9.93	44.66 ± 7.99 (+9.70%)	38.67 ± 12.87	43.17 ± 10.35 (+11.64%)
Vastus Medialis Left 70% (mm)	35.33 ± 3.87	40.33 ± 1.13 (+14.15%)	38.61 ± 14.75	44.84 ± 13.05* (+16.14%)
Total Chest (mm)	80.32 ± 14.5	91.65 ± 14.96* (+14.11%)	72.38 ± 9.46	79.88 ± 7.46* (+10.36%)
Total Thigh (mm)	339.79 ± 48.13	370.93 ± 29.66 (+9.16%)	356.05 ± 50.32	398.80 ± 39.66* (+12.01%)
Total Body (mm)	422.85 ± 63.00	465.48 ± 42.79* (+10.08%)	428.43 ± 53.07	478.68 ± 41.91* (+11.73%)

Values are in means ± standard deviation.
*p≤0.05, significantly different from pre-training
DUP-LR= Daily Undulating Periodization Low Repetition.
DUP-HR=Daily Undulating Periodization High Repetition.

Chest MT

There was no significant group x time interaction for pre- to post-training MT in both the left and right chest (p>0.05). However, there was a significant time effect, in chest MT, for DUP-LR in both the left (p=0.002) and right chest (p=0.04), while DUP-HR approached significance in the right (p=0.06) but not in the left chest (p=0.21). Mean values can be seen in Table 12.

Vastus Lateralis 50%

For MT, in both the left and right vastus lateralis at 50%, there was no significant group or time interaction for pre- to post-training (p>0.05). Mean values can be seen in Table 12.

Vastus Lateralis 70%

For MT, in both the left and right vastus lateralis at 70%, there was no significant group x time interaction for pre- to post-training (p>0.05). Intriguingly, there was a significant time effect in the left vastus lateralis at 70%, for DUP-HR (p=0.02) and not for DUP-LR (p=0.34). Mean values can be seen in Table 12.

Vastus Medialis 50%

For MT, in both the left and right vastus medialis at 50%, there was no significant group or time interaction (p>0.05). Mean values can be seen in Table 12.

Vastus Medialis 70%

For MT, in both the left and right vastus medialis at 70%, there was no significant group x time interaction for pre- to post-training (p>0.05). However, there was a significant time effect in the left vastus medialis at 70%, for DUP-HR (p=0.01) and not DUP-LR (p=0.08). There was no significant time effect right vastus medialis at 70% for either group. Mean values can be seen in Table 12.

Total Chest MT

Total MT for the chest was calculated as the sum of all the chest sites. There was no significant group x time interaction for pre- to post-training ($p>0.05$). However, there was a significant time effect for DUP-LR ($p=0.01$) and DUP-HR ($p=0.05$). Refer to Table 12 for mean values. Additionally, ES was calculated, which revealed a large effect (1.00) in favor for DUP-LR. Effect Size values can be seen in Table 14.

Total Thigh MT

Total thigh MT was calculated as the sum of all thigh MT sites. No significant group x time interaction was found pre- to post-training ($p>0.05$). Interestingly, there was a significant time effect for DUP-HR ($p=0.01$) and not for DUP-LR ($p=0.12$). Refer to Table 12 for mean values. ES was also calculated, which revealed a relatively large effect (0.80) in favor for DUP-HR. Effect Size values can be seen in Table 14.

Total Body MT

Total body MT was calculated by the sum of all chest and thigh sites. No significant group x time interaction was found pre- to post-training ($p>0.05$). However as expected, DUP-LR ($p=0.03$) and DUP-HR ($p=0.004$) experienced a significant time effect for total body MT. Refer to Table 12 for mean values. ES was also calculated, however, only a small effect (0.31) was seen in support for DUP-HR. Effect Size values can be seen in Table 14.

Average Velocity at 1RM

There was no time or group effect for average 1RM squat velocity ($p>0.05$). Refer to Figure 5 for mean values. ES was calculated and revealed a moderate effect (0.54) for

DUP-HR. Additionally, due to a shorter range of motion in the bench press, the velocity sensor did not measure all 1RM attempts and, therefore, statistical analysis could not be performed on average 1RM bench press velocity. Effect Size values can be seen in Table 14.

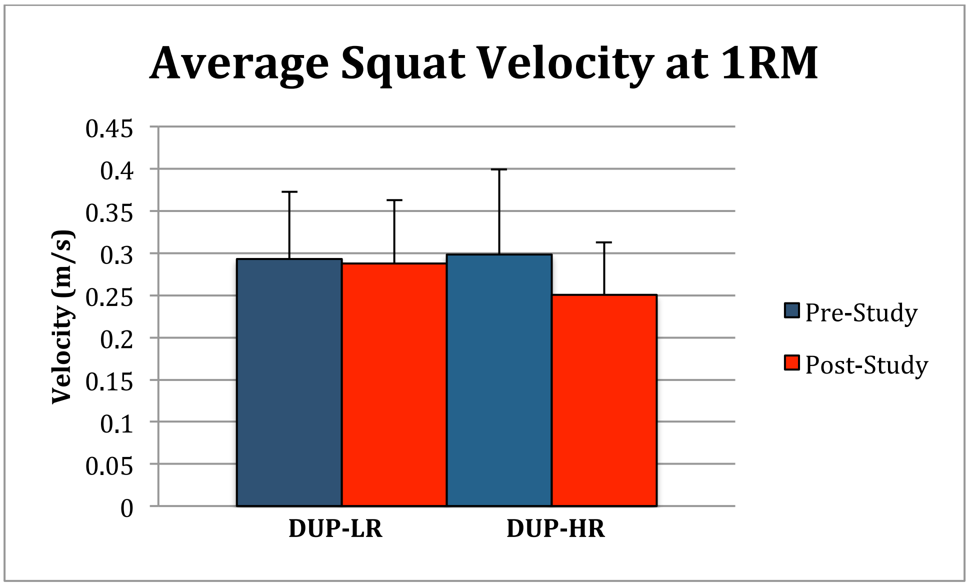

Figure 5: Comparison of average velocity of the squat at 1RM between groups, pre- to post-study.

DUP-LR= Daily Undulating Periodization Low Repetition. DUP-HR=Daily Undulating Periodization High Repetition. There were no significant differences pre- to post-training or between groups for average velocity at 1RM ($p>0.05$). Values are reported in means ± standard deviation.

Muscular Endurance (ME): Maximum Repetitions at 60%

There was no time or group effect for ME in the squat or bench press ($p>0.05$). Refer to Figures 6 and 7 for mean values. ES was calculated for squat ME, which found a moderate effect (0.58) in favor of DUP-LR, while ES for bench press ME, displayed a small effect (0.21) for DUP-HR. Effect Size values can be seen in Table 14.

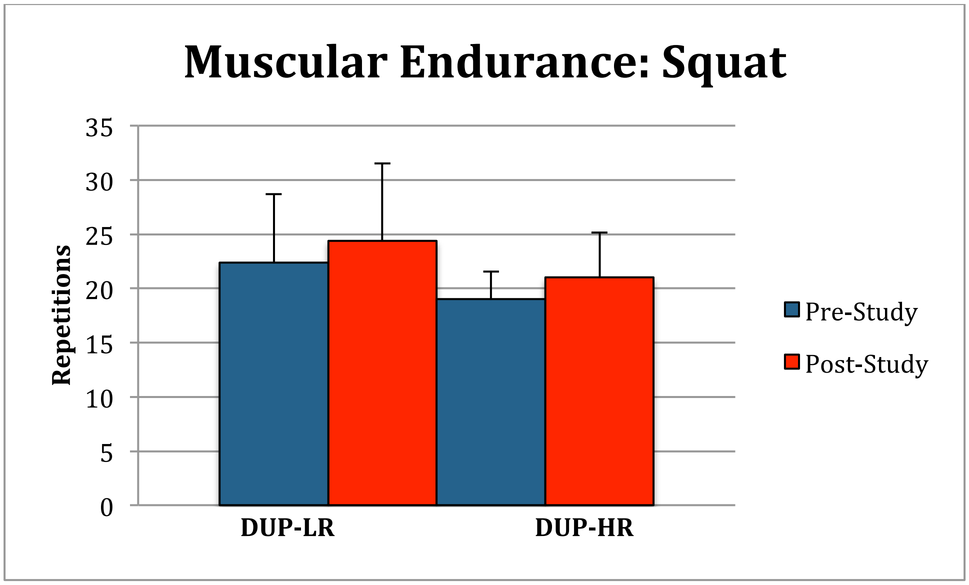

Figure 6: Comparison of squat muscular endurance between groups pre- to post-study.

DUP-LR= Daily Undulating Periodization Low Repetition. DUP-HR=Daily Undulating Periodization High Repetition. Muscular endurance of the squat did not increase significantly in both groups from pre- to post-training ($p>0.05$). Values are reported in means ± standard deviation.

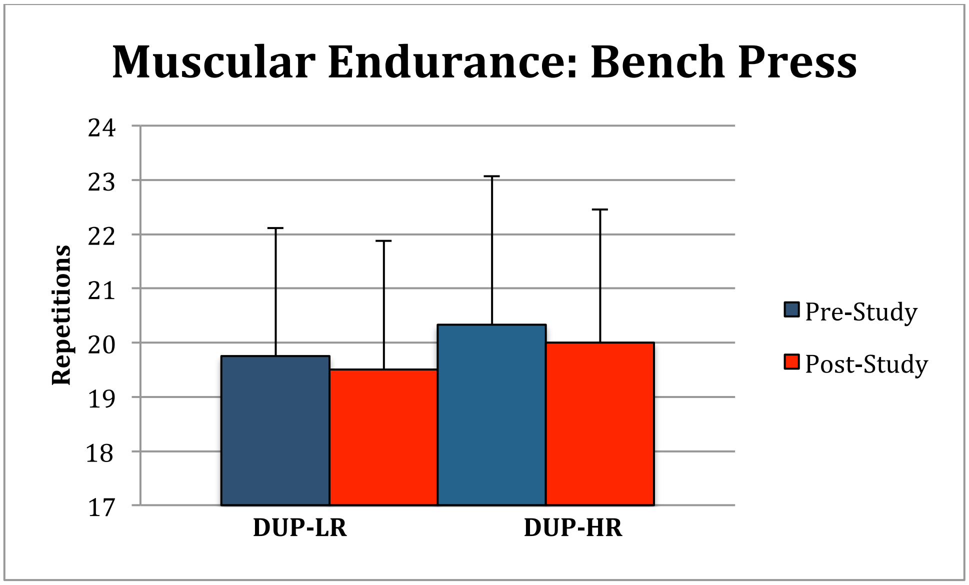

Figure 7: Comparison of bench press muscular endurance between groups pre- to post-study.

DUP-LR= Daily Undulating Periodization Low Repetition. DUP-HR=Daily Undulating Periodization High Repetition. Muscular endurance of the bench press did not increase significantly in both groups from pre- to post-training ($p>0.05$). Values are reported in means ± standard deviation.

MT/Strength Relationship

Overall, no correlation was observed between changes in MT of the chest and changes in 1RM strength of the bench press (r=0.027), along with changes in MT of the thigh and changes in 1RM strength of the squat (r=0.001). Furthermore, no correlation was found between changes in total MT (chest plus thigh muscles) and mean squat and bench press total (r=-0.012) or Wilk's total (r=-0.080).

MT/ME Relationship

Overall, no correlation existed between changes in MT of the chest and ME of the bench press (r=-0.316), along with changes in thigh MT and ME of the squat (r=0.126).

Body Composition

Mean values for pre- to post-training body composition measures can be seen in Table 13.

Table 13: Changes body weight and body fat% pre- to post-training in DUP-LR and DUP-HR (N=11).

Body Composition Measure	**DUP-LR n=5**		**DUP-HR n=6**	
	Pre-training	Post-training	Pre-training	Post-training
Body Weight (kg)	88.90 ± 17.01	91.03 ± 17.86	84.84 ± 4.64	85.86 ± 4.50
Body Fat %	13.43 ± 5.79	15.20 ± 6.55	11.67 ± 2.58	13.65 ± 2.47

Values are in means ± standard deviation.
DUP-LR= Daily Undulating Periodization Low Repetition.
DUP-HR=Daily Undulating Periodization High Repetition.

Body Weight and Body Fat %

There was no significant group x effect for body weight or body fat % pre- to post-training ($p>0.05$). There was not a significant time effect for either group in body weight ($p>0.05$). Additionally, there was no significant time effect for body fat % in either group, however both groups saw an increase (DUP-LR: $p=0.09$, DUP-HR: $p=0.06$), which approached significance. Refer to table 13 for mean values.

Body Weight/Strength Relationship

Interestingly, a fairly strong correlation was observed between increases in body weight and increases in TS ($r=0.746$), and bench press 1RM strength ($r=0.773$). A moderate correlation was seen for increases in body weight and 1RM squat strength increases ($r=0.507$).

Effect Size

Effect Size values can be seen in Table 14.

Table 14: Effect size (ES) for values for outcome measures (N=11).

Outcome measure	Group ES favored	ES	ES classification
1RM Squat Strength	DUP-LR	0.33	Small
1RM Bench Press Strength	DUP-LR	1.48	Large
Total Strength	DUP-LR	0.89	Large
Total Chest MT	DUP-LR	1.00	Large
Total Thigh MT	DUP-HR	0.80	Large
Total Body MT	DUP-HR	0.31	Small
ME Squat	DUP-LR	0.58	Moderate
ME Bench	DUP-HR	0.21	Small

DUP-LR= Daily Undulating Periodization Low Repetition.
DUP-HR=Daily Undulating Periodization High Repetition.
1RM= One-repetition Maximum.
MT= Muscle Thickness
ME= Muscular Endurance
ES calculation and classification is from Cohen (1988)

To briefly summarize the primary findings of this study, both groups significantly increased their 1RM in squat, bench press, and TS from pre- to post-training with no significant differences between groups. Interestingly, total chest muscle thickness (MT) increased significantly in DUP-LR and DUP-HR from pre- to post-training with no significant differences between groups. However, total thigh MT, increased significant in only DUP-HR from pre- to post-training with no significant differences between groups. Results for total body MT revealed significant increases for both groups pre- to post-training, although no differences were found between groups. Lastly, no correlations were observed between MT, 1RM strength, and muscular endurance (ME). However, for all subjects there was a fairly strong correlation between increases in body weight and total strength (TS) (r=0.746), and body weight and 1RM bench press (r=0.773). While, a moderate correlation was observed between body weight and 1RM squat increases (r=0.507).

V. DISCUSSION

One-Repetition Maximum (1RM)

The current study is the first to compare the outcomes of high and low repetition DUP training with equal volume on 1RM strength of trained males. Both groups experienced significant increases from pre- to post-training in 1RM strength of the squat and bench press. However, no significant differences were found between groups. Similarly, both groups significant increased TS pre- to post-training with no differences between groups. When examining our 1RM findings in terms of ES, these values favored DUP-LR in 1RM bench press (1.48 – large effect), 1RM squat (0.33 – small effect) and TS (0.89 – large effect).

Our results support previous findings, which demonstrate DUP to be efficacious at enhancing maximum strength in trained individuals (25, 30, 31). In support, Rhea et al. (2002) found DUP to increase upper body strength (bench press 1RM) 28.78% and lower body (leg press 1RM) 55.78% over the course of 12 weeks (32). Although, this percent change is much greater than our results, the training status of subjects should be taken into consideration; The average 1RM bench press strength in relation to bodyweight for subjects in Rhea et al. was 0.77 compared to 1.43 for our study (32). Additionally, Peterson et al. (2008) employed a DUP protocol with a length comparable to our current study (9 weeks with 27 total sessions versus 8 weeks and 25 total sessions) and reported 20.52% and 16.77% increase in 1RM squat and bench strength, respectively (30). Peterson and colleagues (2008) used subjects with an average 1RM bench press in relation to body weight as 1.17, while the squat was 1.41. In comparison, our current study contained subjects of a higher training status, as the average 1RM strength in relation to body weight was 1.43 and 1.73 for the bench press and squat, respectively (30). Moreover, when considering training status of subjects, individuals of a lower training status may experience accelerated rates of training adaptations compared to individuals of a higher training status when exposed to the same stimulus, which is possibly driven by neuromuscular adaptations (36). Therefore, the differences in results of the aforementioned studies may be attributed to the higher training status of our subjects, which may have resulted in smaller increases in strength.

Conversely, our results contrasted with several findings (7, 39), which purport lower-repetition training to be superior at eliciting maximum strength adaptations when compared to higher repetition training. Campos et al. (2002) demonstrated low repetitions (3-5RM) to elicit significantly greater increases in maximum strength, compared to intermediate (9-11RM) and high (20-28RM) repetitions in untrained individuals (7). The conflicting findings may be due to several factors including: the use of varied rest intervals, selection of lower body exercises, and untrained subjects, as all of these factors cannot be overlooked. Campos et al. prescribed several rest intervals between groups consisting of 3 minutes for the low repetitions group, 2 minutes for the intermediate, and 1 minute for the high repetition group (7). Several researchers have found that variation of rest intervals influences strength adaptations to resistance training programs, with longer rest intervals resulting in greater increases in strength (1, 34). As such, the low repetition group received the longest rest interval, which may have affected strength adaptations to the protocol. To control for this aspect, both groups in our study adhered to constant rest intervals of 5 to 7 minutes between sets. Additionally, the inclusion of additional exercises that stress synergistic muscles may provide a carryover effect to the main exercises selected (i.e., squat), possibly augmenting 1RM performance. Finally, the inclusion of untrained subjects makes it challenging to compare outcomes, as they acquire dissimilar adaptations to resistance training compared to trained subjects (37).

In a recent study that is comparable to the present one, Schoenfeld et al. (2014) examined 8 weeks of bodybuilding-type (BBT - 10RM) versus powerlifting-type (PLT - 3RM) resistance-training programs with equal volume in trained males (39). The results of this study reported a significant increase in percent change of 1RM bench press strength in favor of PLT, while no significant differences group differences were observed in the squat. Although similar protocol designs were employed, several confounding factors existed with the authors design. Training session frequency for each muscle group was not equal between experimental groups; BBT trained each muscle group once per week and PLT used a per muscle group frequency of 3X/wk. This greater frequency of PLT group may have attributed to an increase in strength via skill acquisition through enhanced motor learning, increasing the efficiency of the movement patterns, of the bench press. Further, a periodized design was not implemented with the use of trained individuals, despite research indicating a periodized design to be optimal in terms of strength increases (25, 50). The present study addresses these cofounding factors, as frequency between groups was equated and a periodized design was implemented to comply with previous literature. Therefore, our findings provide further support that DUP is an effective resistance-training model for eliciting increases in 1RM strength of trained individuals. Moreover, a large ES was exhibited for TS and 1RM bench press strength in favor of DUP-LR indicating the low-repetition training may augment superior strength adaptations compared to high repetition training. However, large sample sizes are needed to better elucidate differences in strength.

Hypertrophy

In addition to strength, MT changes were also assessed to determine the influence of the high and low repetitions on hypertrophy. Overall, total thigh MT increased significantly only in DUP-HR pre- to post-training, but there were no group differences. Intriguingly, total chest MT responded differently than total thigh MT with both DUP-LR and DUP-HR displaying significant increases pre- to post-training, with no group differences. As for total body MT, both groups increased significantly from pre- to post-training, although there were no significant differences between groups. When examining these results in terms of ES, DUP-HR had a large effect (0.80) on total thigh MT, while DUP-LR had a large effect (1.00) on total chest MT. It is difficult to infer why there are conflicting results between muscle groups, however, when considering total body MT, the effect was much smaller with only a 0.31 in favor of DUP-HR signaling minimal difference between groups for total body hypertrophy. We speculate the different hypertrophy response across muscle groups may be due to the divergent nature of the squat and bench press movements. When performing the squat movement the barbell is placed on the upper back across the shoulders, which distributes the weight across a large number of muscles, ultimately decreasing the stress placed on each muscle. As compared to the bench press where the barbell is held and moved directly over the chest, involving a smaller number of muscles, and possibly stressing the chest muscles to a greater degree.

Therefore during higher intensities, there might be more direct stress placed on the chest muscles during the bench press compared to the thigh muscles during the squat and, thus, augmenting more hypertrophy.

Campos et al. (2002) also assessed muscle hypertrophy differences between high and low repetition resistance training of thigh muscles (7). Their results indicated that low (3-5RM) and intermediate (9-11RM) repetitions ranges increased thigh hypertrophy significantly from pre- to post-training, however, no differences were found between groups. Interestingly, our study utilized comparable repetition ranges (DUP-LR 6-2 repetitions, DUP-HR 12-8 repetitions), and found only DUP-HR to significantly increase thigh hypertrophy from pre- to post-training. As mentioned previously, several methodological factors may account for the differences seen with the current study (the use of varied rest intervals, length of the protocol, untrained subjects, and selection of lower body exercises). Additionally, Campos et al. evaluated muscle hypertrophy as cross-sectional area (CSA) with muscle biopsies, compared to our study, which examined muscle hypertrophy as MT via ultrasound (7). Although both measures have been utilized within the literature to assess changes of muscle size (7, 39), no comparisons have been made between the two methods and, therefore, make it problematic to compare results.

Schoenfeld et al. (2014) also examined hypertrophic adaptations between BBT and PLT (39). The authors reported a significant increase in percent change of biceps brachii MT from pre- to post-training, although, no differences were found between groups. Although these results agree with our findings in respect to upper body (chest) MT, as DUP-LR and DUP-HR increased significantly, it may be more appropriate to compare these results utilizing ES, as both studies employed relatively small sample sizes. When comparing these results in terms of ES, there was a large effect in favor of DUP-LR for upper body MT, while little or no effect (0.19) was found for groups in Schoenfeld et al (39). Certainly, previously discussed aspects (unequal frequency, non-periodized) concerning the resistance-training design contributed to these conflicting results. In addition, the MT site (biceps brachii) for Schoenfeld et al. was not trained directly (i.e., bicep curls), only indirectly through other exercises (i.e., lat pulldowns, seated rows), which may have affected the ability to distinguish any differences (39). However in the current study, MT was only assessed for muscles that were directly trained (i.e., chest and thigh), which possibly allowed for actual differences between protocols to manifest. In any case, our hypertrophy findings suggest that muscles of the chest and thigh may not respond uniformly to specific repetition ranges in resistance-training.

Muscular Endurance (ME)

In regards to resistance-training, ME can be defined as the ability to complete many repetitions at sub-maximal intensities. Past research has suggested when resistance-training programs are designed with low intensity and higher repetitions; ME is improved (2, 7). Anderson and Kearney (1982), in a classic study, demonstrated enhanced ME following a low-intensity high-repetition protocol (100-150RM), which eventually led to the development of the strength-training continuum (2). A later study by Campos et al. (2002) supported this continuum, founding a higher repetition (20-28RM) protocol to augment ME (7). However, the high repetition group in the present study failed to support this, showing no significant difference in the ability to perform more repetitions at a lower intensity pre- to post-training. These contradictory findings may stem from key differences within the methods employed. Both of the aforementioned studies contained untrained subjects, which is dissimilar from our study, as we utilized only trained individuals. Additionally, the number of repetitions in the high repetition schemes (20-28RM and 100-150RM) was exceptionally higher than DUP-HR (12-8). Interestingly, the intermediate group (9-11RM) from Campos et al. did not experience an increase in ME (7). This coincides with our findings of DUP-HR, which contains a comparable repetition range, and did not yield improvements in ME. Therefore the number of repetitions might have been too low to elicit a significant adaptation.

1RM Velocity

One of the many adaptations to chronic resistance training is becoming more efficient under near maximum and maximum loads. This adaptation might be partially attributed to neuromuscular improvements that allow for an increase in motor unit recruitment and firing rate (47) and is commonly measured via electromyography (EMG). However, a separate method of quantifying muscular efficiency is by measuring the average velocity of the barbell during lifting attempts, with a low velocity (m/s) indicating greater efficiency than a faster velocity (53). In accordance with the principle of specificity, which stipulates that training adaptations will be specific to the training stimulus, those that train closer to maximum intensity should become more efficient and complete repetitions at a slower velocity during high intensity loads, such as 1RM loads. Contrary to this notion, our results did not show any significant differences pre- to post-training or between groups for average velocity during 1RM. Intriguingly, when interpreting these results in terms of ES, DUP-HR had a moderate effect (0.54) on average squat velocity post-training indicating that higher repetitions may increase efficiency, despite utilizing a lower intensity.

Conclusions

Improving 1RM strength and muscular hypertrophy are common goals of individuals engaged in resistance-training programs. Currently, there are long established "strength" and "hypertrophy" repetition ranges that are commonly employed to optimize these adaptations, despite a lack of empirical data. Traditionally, hypertrophy training is defined by moderate repetitions (i.e., 8-12) performed at a moderate intensity (i.e., 65-75%) (3, 8, 17). Conversely, typical strength training consists of low repetitions (i.e., 3-6) performed at a high intensity (i.e., 85-95%) (3, 8, 17). Although many studies have investigated high and low repetition ranges on strength and hypertrophy (2, 4, 7, 8, 18, 19, 24, 27, 29, 38, 44, 49, 51), no consensus exists in the literature to signify which scheme is ideal to achieve these outcomes. Therefore, the overarching aim of the present study was to investigate the effects of high and low repetition daily undulating periodization (DUP) models with relatively equated volume on muscle performance (i.e., 1RM strength, hypertrophy, and ME) in trained males. While the two DUP models (DUP-LR and DUP-HR) had no significant difference in training volume, each model utilized varying repetition ranges. The design of the DUP-LR protocol employed repetitions in the traditional "strength" range (6-2), and the DUP-HR protocol consisted of a traditional "hypertrophy" repetition range (12-8) (3, 8, 17). Moreover, it was also investigated if any correlations existed between increases in 1RM strength, muscular endurance, and muscle thickness, more so in one repetition range than the other. We also examined the relationship between increases in body weight and increases in 1RM strength of the squat, bench press and total strength.

To the best of our knowledge, we are the first to compare high and low repetition DUP models with equal volume in trained males. Our findings indicate there may be meaningful differences in strength between low and high repetition ranges after controlling for training volume as noted by large effects sizes for bench press and TS in favor of DUP-LR. The hypertrophic response in our study was not uniform across muscle groups, as both groups significantly increased total chest MT, while only DUP-HR experienced significant increases in thigh MT. However, total body increases in muscle thickness were the same as expected with equated volume. Additionally, ME did not significantly increase in either group, as drastically higher repetition ranges may be necessary to sufficiently evoke actual ME adaptations. Lastly after 8 weeks of training, no correlations were observed for changes in 1RM strength, MT and ME between groups, which may require a longer training duration in a trained subjects to emerge.

One limitation is that our study only compared 2 different DUP models, therefore it is crucial that future research focus on a examining a wider ranger of repetition schemes to better elucidate where specific strength, hypertrophy, and ME adaptations are optimized. Further, when investigating hypertrophy responses, researchers should focus on elucidating the relationship of anatomical muscle location and training variables (i.e., volume and intensity). Ultimately, future periodized resistance-training studies should implement longer training durations and larger training populations, to aid in expanding the current literature.

APPENDICES

Appendix A. Dietary Log

Appendix B. Physical Activity Questionnaire

Appendix C. Medical History Questionnaire

Appendix D. Consent Form

Appendix E. IRB Approval Form

Appendix A: Dietary Log

DIETARY RECORD INSTRUCTIONS

1. Use the Dietary Record Forms provided to record everything you eat or drink for each day of this study.
2. Indicate the name of the FOOD ITEM, the AMOUNT eaten, how it was PREPARED (fried, boiled, etc.), and the TIME the food was eaten. If the item was a brand name product, please include the name. Try to be accurate about the amounts eaten. Measuring with measuring cups and spoons is best, but if you must make estimates, use the following guidelines:
   Fist is about 1 cup
   Tip of Thumb is about 1 teaspoon
   Palm of the hand is about 3 ounces of meat (about the size of a deck of cards)
   Tip of Thumb is about 1 ounce of cheese
3. Try to eat what you normally eat and record everything. The project will only be useful if you are HONEST about what you eat. The information you provide is confidential.
4. MILK: Indicate whether milk is whole, low fat (1 or 2%), or skim. Include flavoring if one is used.
5. VEGETABLES and FRUITS: One average serving of cooked or canned fruits and vegetables is about a half cup. Fresh whole fruits and vegetables should be listed as small, medium, or large. Be sure to indicate if sugar or syrup is added to fruit and list if any margarine, butter, cheese sauce, or cream sauce is added to vegetables. When recording salad, list items comprising the salad separately and be sure to include salad dressing used.
6. EGGS: Indicate method of preparation (scrambled, fried, poaches, etc.) and number eaten.
7. MEAT / POULTRY / FISH: Indicate approximate size or weight in ounces of the serving. Be sure to include any gravy, sauce, or breading added.
8. CHEESE: Indicate kind, number of ounces or slices, and whether it is made from whole milk, part skim, or is low calorie.
9. CEREAL: Specify kind, whether cooked or dry, and measure in terms or cups or ounces. Remember that consuming 8 oz. of cereal is not the same as consuming one cup of cereal. 1 cup of cereal generally weighs about 1 ounce.
10. BREAD and ROLLS: Specify kind (whole wheat, enriched wheat, rye, etc.) and number of slices.
11. BEVERAGES: Include every item you drink excluding water. Be sure to record cream and sugar used in tea and coffee, whether juices are sweetened or unsweetened and whether soft drinks are diet or regular.
12. FATS: Remember to record all butter, margarine, oil, and other fats used in cooking or on food.
13. MIXED DISHES / CASSEROLES: List the main ingredients and approximate amount of each ingredient to the best of your ability.

14. ALCOHOL: Be honest. Record amounts in ounces. Specify with "light" or "regular" beer.

DIETARY RECORD FORM

Day of the Week: _________________
Date: ____________________

FOOD ITEM	AMOUNT	TIME

- Express approximate measures in cups (C), tablespoons (T), teaspoons (t), grams (g), ounces (oz.), pieces, etc.

Appendix B: Physical Activity Questionnaire

Physical Activity Questionnaire

Think about all the exercise training in which you engage. Use that information to appropriately answer the following questions.

1. Have you competed before in strength competitions? If so, how often?

Yes or No　　　　If so, ___________________ times/year

2. If yes to #1: How long have you been training for strength competitions?

______________ years

3. How many hours of resistance training do you perform on average each week?

___________________ hours/week

4. How many times do you resistance train per week? Please indicate if you do more than once a day.

___________________ days/week　Average___________________ times/day

5. Please describe your resistance training intensity based on your self-estimated maximum load.

___________________ % your maximum

6. Do you incorporate any aerobic training? If so, how many times per week?

Yes or No　　　　If so, ___________________ times/week

7. Please describe your average aerobic training intensity on a scale below (as close as possible):

1	2	3	4	5	6	7	8	9	10
Very Light		Light		Moderate			Intense		Very Intense

8. Do you currently compete in strength competitions? If so, for whom (FAU, National competitions, etc.)?

Yes or No　　　　If so, name:___________________ and when:_____________________

If not please provide the name and the time of the last event that you most recently attended - name:___________________ and when:_____________________

9. When you compete, which sport do you compete in (Powerlifting, Strongman, or Bodybuilding)?

Event:___________________________________

10. Are you currently been in engaged in a structured resistance-training program? If so, how long?

    Yes or No   If so, ___________________ months or years

11. Do you currently perform the squat exercise? If so, how many years experience do you have with the squat? What is your estimated 1RM? How many times per week do you perform this exercise?

    Yes or No   If so, ___________________ months or years
    1RM ______________ lbs.
    Times Per Week ___________________.

12. Do you currently perform the bench press exercise? If so, how many years experience do you have with the squat? What is your estimated 1RM? How many times per week do you perform this exercise?

    Yes or No   If so, ___________________ months or years
    1RM ______________ lbs.
    Times Per Week ___________________.

13. Please best describe your occupation or daily activities other than your exercise training.

14. Do you have any coaching by a certified professional in the squat exercise? Any coaching by a certified professional in general resistance training?

Appendix C: Medical History Questionnaire

Florida Atlantic University

Medical History Form

Demographics:

Name: ________________________________ Sport: ___________ Pos.: _______

Date: ___________ Age: _______________ Birth Date: ____/____/____

Family History:

Has anyone in your immediate family had any of the following: Please circle yes or no.

Heart Disease	Yes	No	Diabetes	Yes	No
High Blood Pressure	Yes	No	Cancer	Yes	No
Stroke	Yes	No	Tuberculosis	Yes	No
Sudden Death (before 50)	Yes	No	Asthma	Yes	No
Epilepsy	Yes	No	Gout	Yes	No
Migraine Headaches	Yes	No	Marfan's Syndrome	Yes	No
Eating Disorder	Yes	No	Sickle Cell	Yes	No

Personal History:

1. Have you ever been hospitalized? Yes No
   Have you ever had surgery? Yes No
   Are you presently under a doctor's care? Yes No
   Please explain and give dates for all "Yes" answers: ___________________________

____

____

2. Please list any medications you are currently taking and for what conditions.

____

3. Please list any known allergies.

____

____

4. Have you ever had a head injury / concussion? Yes No
   Have you ever been knocked out or unconscious? Yes No
   Have you ever had a seizure, "fit", or epilepsy? Yes No
   Have you ever had a stinger, burner, or pinched nerve? Yes No
   Do you have recurring headaches or migraines? Yes No
   Pleas explain and give dates of "Yes" answers:

____

____

____

____

5. Have you ever had the chicken pox? Yes No
   If yes, at what age? _________

6. Have you ever had the mumps or measles? Yes No

7. Do you have a history of asthma? Yes No

8. Are you missing an eye, kidney, lung, or testicle? Yes No

9. Do you have any problems with your eyes or vision? Yes No

10. Have you ever had any other medical problems (mononucleosis, diabetes, anemia)? Yes No

11. Have you ever taken any supplements for improved performance? Yes No

12. Are you presently taking any supplements for diet or performance? (creatine, protein, BCAA, etc.)? Yes No
    If Yes then what substance and for how long? ___________________

13. What is the lowest weight you have been at in the last year _____, highest _____? What is your ideal weight _______?

14. Do you have any trouble breathing or do you cough during or after practice? Yes No

15. Have you ever had heat cramps, heat illness, or muscle cramps? Yes No

16. Do you have any skin problems (itching, rashes, acne)? Yes No

Explain all "Yes" answers for questions 5 – 16: ____
____
____
____
____
____

17. Have you ever passed out during or after exercise? Yes No
Have you ever been dizzy during or after exercise? Yes No
Have you ever had chest pain during or after exercise? Yes No
Have you ever had high blood pressure? Yes No
Have you ever been told you have a heart murmur? Yes No
Have you ever had racing of you heart or a skipped heart beat? Yes No
Has anyone in your family died of heart problems or a sudden death before the age of 50? Yes No
Have you ever had an EKG or echocardiogram? Yes No

Explain all "Yes" answers for question 17:

____
____
____
____
____

18. Have you ever sprained / strained, dislocated, fractured, or had repeated swelling or other injury of any bones or joints? Explain any "Yes" answers.

Head/Neck Yes No
____

Shoulder Yes No
____

Elbow & arm Yes No
____

Wrist, hand & fingers Yes No
____

Back Yes No
____

Hip / Thigh Yes No
____

Knee Yes No
____

Shin/Calf Yes No
____

Ankle, foot, toes Yes No
____

Please sign:

I hereby state that, to the best of my knowledge, my answers to the above questions are correct.

____
Subject's Signature Date Signed

Appendix D. Consent Form

RESEARCH SUBJECT INFORMATION AND CONSENT FORM

TITLE: Examination of High and Low Repetition Daily Undulating Periodization Training with Equated Volume on Muscle Performance in Trained Males

PROTOCOL NO.: 560550

SPONSOR: None

INVESTIGATOR: Michael C. Zourdos, Ph.D., CSCS Alex Klemp, B.S., CSCS

SITE(S): Skeletal muscle physiology lab (GY 170) and Biochemisty lab (GY 152) at Florida Atlantic University, Boca Campus.

STUDY-RELATED
PHONE NUMBER(S): Michael C. Zourdos: 561-297-1317, Alex Klemp 386-747-5194

This consent form may contain words that you do not understand. Please ask the study investigator or the study staff to explain any words or information that you do not clearly understand. You may take home an unsigned copy of this consent form to think about or discuss with family or friends before making your decision.

SUMMARY

This informed consent provides important information that you need to know for your participation in this research study. This study will investigate the effects of two different resistance training protocols on muscle performance along with various hormonal and biomarker responses. The hormones that will be examined are testosterone, insulin-like growth factor one (IGF-1), and cortisol, which all provide information about the anabolic or catabolic state of the body. The biomarkers to be examined are creatine kinase and fibroblast growth factor 21 (FGF-21), which have been correlated with muscle damage following resistance training. In this consent from you will find the purpose, procedures, risks, and your rights and responsibilities. Do not sign this consent form unless you have had the opportunity to ask questions and have received satisfactory answers. If you have questions about your rights as a research subject or if you have questions, concerns or complaints about the research, you may contact: Institutional Review Board (561-297-0777).

PURPOSE OF THE STUDY

The purpose of this study is to examine the different effects of low and high repetition resistance training on
Maximum strength
Changes in hypertrophy
Muscular endurance
Acute and chronic hormones and biomarker response

PROCEDURES

If you choose to participate in this study there will be a total of 25 laboratory visits. These visits will occur 3 times a week for 8 weeks, with each visit lasting approximately 100-150 minutes. During your first and final visit there will be several measurements assessed including:
1 repetition maximum (1RM) strength in the squat and bench press
Muscular endurance in the squat and bench press
Muscle thickness (MT) in the chest and thigh muscles via ultrasound
Body composition by skinfold calipers (Chest, abdomen, thigh)
Anthropometrics (height & weight)

Measurements of MT, body composition, and anthropometrics will be completed before 1RM and muscular endurance testing. Additionally, you will be asked to consume branched chain amino acids (BCAAs) containing 3.5g of leucine, 1.75g of Isoleucine, 1.75g of Valine (Ratio of 2:1:1), and 2.5g of glutamine 30 minutes prior to each training session and 30g of whey protein immediately after each training session. These supplements will be supplied by Scivation™ and provided to you from the Department of Exercise Science and Health Promotion (ESHP). You will also be required to fill out a dietary log 24 hours before testing and training days.

To begin the 1RM testing (and all training days), you will perform a standardized 10-minute dynamic warm-up routine designed to increase the body's core temperature and prepare the muscles for the exercises that will be performed. Then you will begin the 1RM testing protocol with the squat exercise, which will be administered according the guidelines of the National Strength and Conditioning Association (NSCA). During all your 1RM attempts average and peak velocity (m/s), and average and peak power (Watts) will be measured and recorded via a Tendo unit.

After finding your 1RM in the squat a 10-minute rest period will be administered. Following this you will perform the maximum number of repetitions you can complete at 60% of your 1RM in the squat, which will serve as the measure of muscular endurance. All repetitions must be performed to the USAPL standards (see next paragraph) to be counted. Then another 10-minute rest period will be given before you perform the same protocol with the bench press exercise.

The squat and bench press exercises will be performed by the rules set by the United States of America Powerlifting (USAPL). For the squat subjects will stand with their knees locked, and the barbell placed across the upper back/shoulders. Subjects will then descend with a bending of the knees, until the top of the leg at the hip joint is below the top of the knee. Ultimately, subjects will return, on their own volition, to an erect standing position. During the bench press subjects will lie supine on a weight bench while maintaining contact of the butt and shoulders on the bench with the feet flat on the ground at all times throughout the lift. Subjects will remove the bar from the rack and hold it in their hands with arms extended before beginning the lift. The bar will be lowered in a controlled manner until it touches the chest where it will then be pressed upward until the arms are fully locked.

At this point in the study you will be assigned to your specific training protocol. For the remainder of week 1 and 48 hours following the 1RM test you will complete 3 alternating days of low volume resistance training otherwise known as an ‘introductory microcycle’. This low intensity training is specifically designed for the training group to which you are assigned. Following the introductory microcycle you will train on 3 non-consecutive days (e.g. Monday, Wednesday, Friday) a week for 6 weeks performing the specific protocol that you are assigned to.

Lastly, you will begin ‘taper’ training 48 hours following the completion of week 7 of your assigned training protocol. The taper will consist of 2 non-consecutive days of low intensity. This training will allow for rest and recovery and prepare you for post-testing.

Finally, 48 hours following your 2nd taper training day you will again be tested for:

1 repetition maximum (1RM) strength in the squat and bench press

Muscular endurance in the squat and bench press

Muscle thickness (MT) in the chest and thigh muscles via ultrasound

Body composition by skinfold calipers (Chest, abdomen, thigh)

Anthropometrics (height & weight)

A second component of this study consists of blood draws, which will be taken at various time points through out the study to analysis biomarker and hormone responses.

Week 1: Prior to 1RM testing

Weeks 2-7:

Day 1-Pre and post exercise

Day 2 & 3-Pre exercise only

Week 8: Prior to 1RM testing

On days which blood draws are scheduled you are required to fast for 2 hours prior. An experienced and trained technician will draw 10ml (approximately 2 teaspoons) of blood from your antecubital vein for each blood draw. It is anticipated that this procedure will take a total of 5 minutes. The weekly total of blood that will be drawn for weeks 1 and 8 is 10ml (approximately 2 teaspoons). For weeks 2-7 a weekly total of 40ml of blood will be taken.

RISKS AND DISCOMFORTS

Inserting the needle and drawing blood from your arm may cause pain, bruising, lightheadedness, and on rare occasions, infection or hematoma. There may be some slight discoloration and a bruise at the site of the needle insertion. To minimize these risks, a trained technician will perform all blood sampling. You will receive instructions for care following the needle insertion. The cumulative blood draws will not add to the minor risk involved with any one blood draw. Additionally, with any bout of resistance training, there is a chance that minor soreness may occur, as well as, the small possibility of muscle injury. The fasting of 2 hours prior to exercise will also not enhance any risk involved in this study. Finally, since you will be given a whey protein supplement please inform the investigators if you are allergic.

NEW INFORMATION
You will be told about anything new that might change your decision to be in this study. You may be asked to sign a new consent form if this occurs.

BENEFITS
Data collection during this study will contribute to scientific knowledge of the relationship between training variables and their effect on muscle performance. You will receive free measurements of weight, body composition, MT, and 1RM testing. Additionally, the ESHP department will provide you with BCAAs and whey protein supplements for the duration of the study. During each training session you will be training with calibrated equipment that is state of the art, and United States of American Powerlifting Lifting (USAPL) approved, which is not available in most gyms. Finally, you will be able to apply the findings from this study to any clients that you may coach or train.

COSTS
No costs will be incurred to you for any lab visits other than the cost of your time. ESHP will supply the supplements in this study.

CONFIDENTIALITY
Potentially identifiable information about you will consist of a medical history questionnaire and research data sheets. The blood samples will be stored in the freezer in the Exercise Science Laboratory and be discarded into biohazard waste containers within 10 years after completion of the study. Data are being collected only for research purposes. All personal identifying information will be kept in password-protected files and a code number will be used for identification purposes. Data records will be kept in a locked file cabinet in an office within the department of Exercise Science and Health Promotion. Although results of this research may be presented at meetings or in publications, identifiable personal information pertaining to participants will not be disclosed.

COMPENSATION FOR INJURY
Florida Atlantic University has no plan for providing long-term care or compensation in the event that you suffer injury because of your participation in this research study. If you are injured or if you become ill because of your participation in this study, contact the Principal Investigator immediately. Your health insurance company may or may not pay for treatment of injuries as a result of your participation in this study.

VOLUNTARY PARTICIPATION AND WITHDRAWAL
Your participation in this study is voluntary. You may decide not to participate or you may leave the study at any time. Your decision will not result in any penalty or loss of benefits to which you are entitled.

Your participation in this study may be stopped at any time by the investigators without your consent for any of the following reasons:

If it is in your best interest
If it is for your health and safety
You do not follow instructions
You do not consent to continue in the study after being told of changes in the research that may affect you
Administrative reasons require your withdrawal

SOURCE OF FUNDING FOR THE STUDY
Funding for this study will be from the FAU Department of Exercise Science and Health Promotion.

QUESTIONS
Contact Michael C. Zourdos: 561-297-1317 or Alex Klemp: 386-747-5194 for any of the following reasons:
If you have any questions about this study or your part in it,
If you have questions, concerns or complaints about the research

If you have questions about your rights as a research subject or if you have questions, concerns or complaints about the research, you may contact: Institutional Review Board (561-297-0777).

Do not sign this consent form unless you have had a chance to ask questions and have gotten
satisfactory answers.

CONSENT
I have read this consent form (or it has been read to me). All my questions about the study and my part in it have been answered. I freely consent to be in this research study. I have been provided a copy of this consent form for my records.

By signing this consent form, I have not given up any of my legal rights.

____ ____________________
Subject name, printed

____ ____________________
Subject signature Date

____ ____________________
Signature of Person Conducting Informed Date

Appendix E: IRB Approval form

Institutional Review Board
Mailing Address:
Division of Research
777 Glades Rd., Bldg. 80, Rm. 106
Boca Raton, FL 33431

Tel: 561.297.0777 Fax: 561.297.2573

http://www.fau.edu/research/researchint
Christine Williams, R.N., D.N.Sc., Chair

DATE:	March 3, 2014
TO:	Michael Zourdos, Ph.D.
FROM:	Florida Atlantic University Health Sciences IRB
IRBNET ID #:	560550-2
PROTOCOL TITLE:	[560550-2] Examination of High and Low Repetition DUP Training with Equated Volume on Muscle Performance in Trained Males
PROJECT TYPE:	*New Project*
ACTION:	APPROVED
APPROVAL DATE:	February 28, 2014
EXPIRATION DATE:	February 27, 2015
REVIEW TYPE:	Full Committee
REVIEW CATEGORY:	*C*

Thank you for your submission of Response/Follow-Up materials for this research study. The Florida Atlantic University Health Sciences IRB has APPROVED your *New Project*. This approval is based on an appropriate risk/benefit ratio and a study design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

- This study is approved for a maximum of **50** subjects.
- It is important that you use the approved, stamped consent documents or procedures included with this letter.
- **<u>**Please note that any revision to previously approved materials or procedures, including modifications to numbers of subjects, must be approved by the IRB before it is initiated.</u>** Please use the amendment form to request IRB approval of a proposed revision.
- All SERIOUS and UNEXPECTED adverse events must be reported to this office. Please use the appropriate adverse event forms for this procedure. All regulatory and sponsor reporting requirements should also be followed, if applicable.
- Please report all NON-COMPLIANCE issues or COMPLAINTS regarding this study to this office.
- Please note that all research records must be retained for a minimum of three years.
- **This approval is valid for one year.** A Continuing Review form will be required prior to the expiration date if this project will continue beyond one year.

If you have any questions or comments about this correspondence, please contact Angela Clear at:

Institutional Review Board

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