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A Comparison of Linear and Daily Undulating Periodizied Strength Training Programs.

Andrew Morrow Caldwell
East Tennessee State University

A Comparison of Linear and Daily Undulating Periodized Strength Training Programs.

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Andrew Caldwell

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Dr. Diego De Hoyos, Chair

Dr. Tom Coates

Dr. Diana Mozen

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ABSTRACT

A Comparison of Linear and Daily Undulating Periodizied Strength Training Programs.

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The purpose of this study is to compare linear periodized (LP) and daily undulating (DUP) periodized strength training programs, and determine if either method of periodization elicits superior gains in 1 Repetitions maximums (1RM) for back squat (BS) and bench press (BP) (core exercises). Nineteen subjects (n=19) underwent a 6-week resistance-training (RT) program. Participants performed both BS and BP two day a week. The LP group linearly increased intensity while decreasing volume. While the DUP group daily changed intensity and volume. Total volume for both BS and BP were equal for both LP and DUP. Both BP and BS increased significantly from pre to post for both groups. However, there was no significant difference in pre-post strength measure in the LP compared to DUP.

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CHAPTER 1

INTRODUCTION

Periodization is a method of planning periods or cycles in which training specificity, intensity, and volume changes within an overall training program (Baechle & Earle, 2000). Periodized training programs are shown to be more effective in eliciting strength and body mass improvements than nonperiodized resistance training (RT) programs (Kraemer, 1997; Kraemer et al., 2002; Kramer et al., 1997; Schiotz, Potteiger, Huntsinger, & Denmark, 1998; Stone, O'Bryant, & Garhammer, 1981; Stone et al., 2000; Stowers et al., 1983) Linear Periodization (LP) is the classic form of periodization that which gradually increases the training intensity while decreasing the training volume within and between cycles. A less used form of periodization is called daily undulating periodization (DUP). It is characterized by more frequent changes in intensity and volume. Rather than making changes over a period of months, the undulating model makes these changes on a weekly or even daily basis (Baechle & Earle).

Statement of the Problem

The purpose of this study is to compare linear and daily undulating periodized strength training programs and determine if either method of periodization is superior to the other.

Significance of Study

Strength and conditioning professionals are concerned with determining the most effective means for developing muscular strength. Most strength professionals agree that strength-training programs should be periodized (Plisk & Stone, 2003). However, they have not yet decided what type of periodized program is the most effective (Rhea, Ball, Phillips, & Burkett, 2002). There are various types of the periodized programs due to the numerous configurations of the program variables such as; number of sets or reps, exercises performed, the length of rest periods between sets, the amount or type of resistance used, type of contractions performed, or the training frequency(Fleck, 1999; Rhea et al., 2002). Currently, LP and DUP are two commonly used types of periodization. However, it is unclear whether LP compared to DUP programs elicit greater strength gains, which is commonly quantified by 1 repetition maximums (1RM).

Research Hypothesis

There will be no significant differences in muscular strength (1RM) accrual between groups that trained with a LP compared to DUP strength training program.

Delimitations

This study is focused on determining the effects of LP and DUP training programs on muscular strength. This study required subjects to perform exercises at high intensities. Consequently, this study was limited to individuals that denied the following health prescreening criteria determined by the ETSU institutional review board: Cardiovascular disease, bone/ joint problems, low back pain, recent injury/ surgery, diabetes, pregnancy, hypertension, and those who had been told by a physician that they should not perform either high-intensity exercise or labor. This study was also limited to volunteers between the ages of 18-55 years. The study was limited to a 6-week period and maximum of 60 participants.

Assumptions

The assumptions of this study were:

1. That all participants completed the prescribed exercises as required.
2. That all participants avoided resistance training outside that which was prescribed.
3. That all participants preformed to the best of their ability when tested.
4. Exercise training was carried out according to the prescribed training regimen.

Limitations

The following are limitations to this research study:

1. Participants discontinuing before post-testing.
2. Total number of participants.

Definitions

One Repetition Maximum (1RM): maximum amount of weight that can be lifted with proper technique for one repetition.

Frequency: the number of training sessions completed in a given period of time.

Intensity: the difficulty of the training relative to the maximum that the athlete is capable of and represented by power output (work performed per unit of time).

Linear (traditional) Periodization: the classical form of periodization, which gradually increases intensity while decreasing volume within and between cycles.

Load: the amount of weight assigned to an exercise set

Periodization: planned variation in training methods and means on a cyclic or periodic basis.

Power: work preformed per unit of time.

Repetitions: the number of times an exercise can be performed.

Repetition maximum (RM) the greatest amount of weight that can be lifted with proper technique for a specified number or repetitions.

Set: a group of repetitions sequentially performed before the athlete stops to rest.

Specificity: the distinct adaptations to the physiological systems that arise with specific training

Strength: the maximal force that a muscle or muscle group can generate at a specified velocity.

Undulating Periodization: a form of periodization that frequently alternates the intensity and volume on a weekly or even daily basis.

Volume: the function of the amount lifted multiplied by the number of repetitions multiplied by the number of sets in a given time period.

CHAPTER 2

REVIEW OF LITERATURE

The purpose of this study is to compare linear and daily undulating periodized strength training programs and determine if either method of periodization is superior to the other. This chapter has been divided into seven pertinent areas; history of periodization, physiological basis for periodized training, comparison of non-periodized to periodized training, proposed models of periodized training, research in support of LP, research in support of DUP, sex of participants in other studies, and a summary.

History of Periodization

The concept of proper organized training according to periods can be traced back to ancient Roman, Greek, and Chinese cultures (Pedemonte, 1986). These cultures largely depended on their military capabilities to survive and therefore, needed be prepared to function at optimal levels (Graham, 2002). During the height of the ancient Olympic games, it is reported that competitors were subjected to a period of training of at least 10 months prior to competing (Pedemonte).

The foundations of modern periodization were developed in Eastern Europe. In the 1960s, the Russian physiologist Leo Matveyev formally proposed the modern concept of periodization (Graham, 2002). American exercise scientists further modified Matveyev's concept with the application to training athletes for strength and power (Baechle & Earle, 2000; Graham; Stone et al., 1981). Modern periodization is defined as a method of planned periods or cycles in which training specificity, intensity, and volume changes within an overall program (Baechle & Earle).

Physiological Basis for Periodization

The General Adaptation Syndrome (GAS) (see Figure 1) (Baechle & Earle, 2000), is the physiological concept on which periodization was based. GAS was developed by Hans Selye, a Canadian endocrinologist who studied various types of stressors to organisms. He defined a three-stage response to stress (alarm, resistance, and exhaustion) (Baechle & Earle). During the alarm stage, the body experiences a new or more intense stress (e.g., lifting a heavier load) and homeostasis is altered as result. The alarm phase can last several days or several weeks. At this stage the athlete may experience excessive soreness, stiffness, and temporary drop in performance. Following the alarm phase, the body adapts to the stimulus and returns to a more normal functioning. This is known as the resistance phase. It is during this stage that the body exhibits its ability to endure stress, an attribute that may continue for an extended period of time depending on the health and training status of the athlete. Neurological adaptations are needed at this point for the athlete to continue training while the muscle tissue adapts by making various biochemical, structural, and mechanical adjustments that lead to increased performance. These physiological adaptations are generally known as supercompensation. However, if a specific stress persists for an extended period of time, the symptoms experienced during the alarm phase reappear and the athlete loses the ability to adapt to the stressors. These responses are known as the exhaustion phase. As a result, over-training and maladaptations may occur unless the athlete alters training intensity or variety (Baechle & Earle).

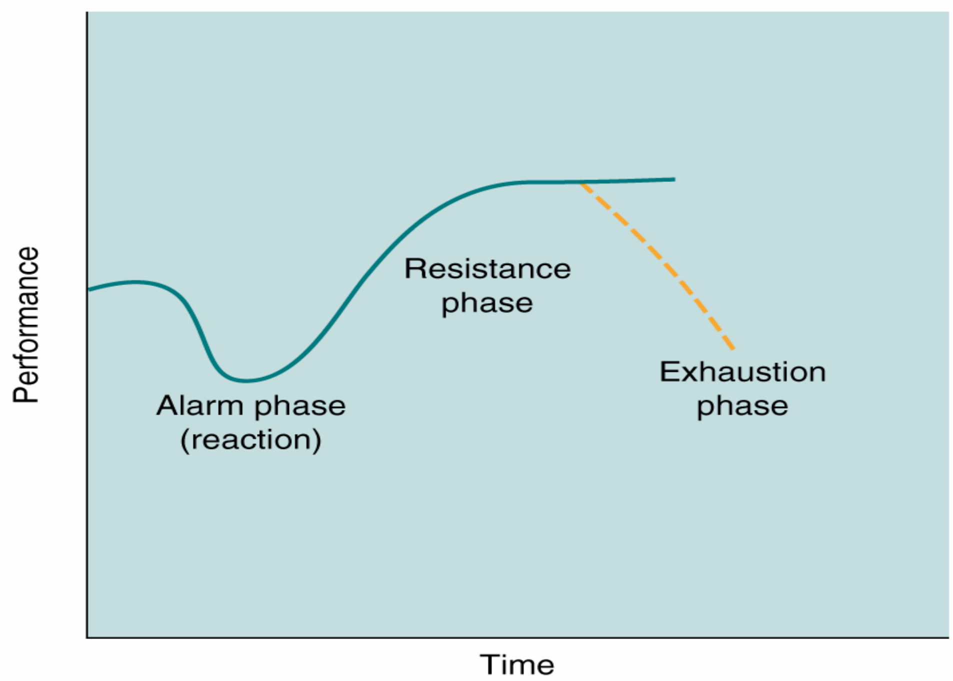

Figure 1. General Adaptation Syndrome (GAS)

The principle of progressive overload is another physiological concept important to comprehension of the basis of periodized. The progressive overload principle states that a physiological system will adapt to stresses and loads. The goal of the strength professional is to optimize the principle of overload. In order to elicit a maximal neuromuscular response and to avoid fatigue and overstraining, stressors and loads must be altered to maximize stimulation by periodically altering training variables such as volume, specificity, intensity, and duration. The balance between stimulus and rest will ideally optimize performance and recovery (Baechle & Earle, 2000).

The Comparison of Non-Periodization vs. Periodization

The majority of earlier research has compared non-periodized programs to periodized training and has shown periodized training elicited superior results in one or more performance measures relating to strength, power, and high-intensity exercise endurance (Kraemer, 1997; Kraemer et al., 2002; Kramer et al., 1997; Schiotz et al., 1998; Stone et al., 1981; Stone et al., 2000; Stowers et al.,1983).

Willoughby (1993) compared a periodized trained group and a non-periodized trained group and found that the periodized program elicited a greater upper and lower body strength gain for previously weight-trained males. The non-periodized group trained with an intensity that was kept constant throughout the 16-week training program. The periodized group's training program consisted of four weeks of 5-sets of 10-repetitions (5x10) at 79 % of 1RM, four weeks of 6x 8 at 83 % of 1RM, four weeks of 3x6 at 88% of 1RM, and four weeks of 3x4 at 92 % of 1RM. At training weeks 8, 12, and 16; the periodized training group demonstrated significantly greater improvements in strength levels in the bench press compared to the non-periodized group. For the squat, the periodized group demonstrated a significantly greater strength increases/levels compared to the non-periodized groups at week 16.

In the Kraemer's study (Kraemer et al., 2000), 24 women collegiate tennis players were matched by playing ability and randomly placed into three groups: 1) no resistance control group, 2) single-set circuit resistance training group, and 3) periodizied multi-set circuit resistance training group. After four, six, and nine months of training the periodized training group significantly increased one-repetition maximum strength for bench press, free-weight shoulder-press, and leg press. The single-set circuit group only increased strength after the initial 4 months of training. Only the periodized group significantly increased power output ability following nine months of training. Significant increases in serve velocity were observed after four and nine months of training in the periodized group and not in the single-set group. This study shows that sport specific resistance training using a periodized training protocol is superior to low-volume single-set resistance training in the development of physical abilities.

It is believed that more frequent changes in stimuli, such as those presented by the periodized training program, facilitated the greater strength development. However, a clear criticism of the Kramer study was that training volume differed greatly between the two training groups. Thus, it cannot be determined if the training volume, periodization, or a combination of these two variables produced the significantly greater training adaptations in the multi-set, LP group.

The underlying physiological mechanisms that explain the differences between periodized and non-periodized programs remain to be fully investigated and explained (Fleck & Kraemer, 1997). Some researchers believe that neural adaptations and the avoidance of overtraining are possible factors for periodized trainings superiority (Stone et al., 1999).

Standard Cycles of a Traditional Periodized Training Program

The traditional periodization divides the total training program into specific time periods, which are termed cycles. The largest cycle is known as a macrocycle (long-length cycle), which typically is 1 year in duration. However, a cycle can vary in duration between 9 months to 4 years (Baechle & Earle, 2000). Within the macrocycle are two or more mesocylces (middle-length cycle). A mesocycle typically lasts for several weeks or several months. Each mesocycle is divided into microcycles (short length), lasting typically 1 week (Baechle & Earle; Hoffman, Wendell, Cooper & Kang, 2003). According to Stone's revised version of Matveyev's model of periodization (Figure 2) (Baechle & Earle; Stone et al., 2000), the mesocycle contains 4 distinct periods: (a) Preparatory, (b) First Transition, (c) Competition, and (d) Second Transition or

Active Rest. The marocycle and the mesocycle generally begin with high-volume and low-intensity training and end with high-intensity and low-volumes of training(Stone et al.).

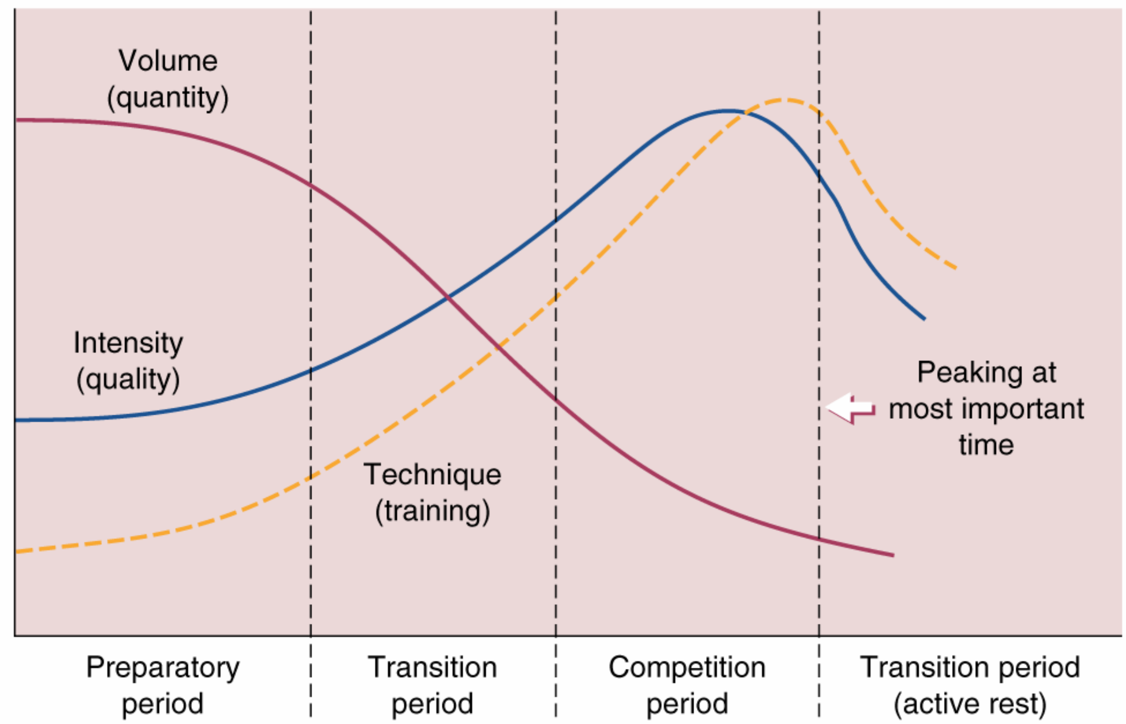

Figure 2. Matveyev's Model of Periodization

<u>Standard Periods of a Traditional Periodized Training Program</u>

The Preparatory period is typically the longest and occurs during the off-season when no competitions are scheduled and only a limited number of sports–specific skill practices are planned. The focus is primarily on the attainment of base level of conditioning to increase the athlete's tolerance to more intense training. Conditioning activities begin at relatively low intensity and high volumes (hypertrophy phase) and progress to moderate/high intensity with moderate/high volumes (strength phase) to high intensity and low volumes (power phase) (see Table 1)(Baechle & Earle, 2000). Workouts consisting of alternate modes of exercise such as swimming, circuit weight training, and cycling are suitable and allow for creating a foundation for the next levels of training (Graham, 2002). Because high volume training typically causes fatigue which will compromise optimal conditions for improving sport-specific trainng, technique training is not of high priority (Baechle & Earle).

Table 1.

A Periodization Model for Resistance Training

Period	**Preparation**	**First transition**		**Competition**	
Phase Variable	**Hypertrophy**	**Basic Strength**	**Strength/ Power**	**Peaking**	**OR Maintenance**
	Low to moderate	High	High	Very high	Moderate
Intensity	50-75% 1 RM	80-90 % 1RM	87-95 % 1RM	$\geq$ 93 % 1 RM	80-85 % 1 RM
Volume	High to moderate	Moderate	Low	Very low	Moderate
	3-6 sets	3-5 sets	3-5 sets	1-3 sets	2-3 sets
	10-20 repetitions	4-8 repetitions	2-5 repetitions	1-3 repetitions	6-8 repetitions

Adapted from (Baechle & Earle, 2000).

The First Transition Period occurs typically during the preseason. The primary objective of this period is to promote a break between high volume training and high intensity training between the preparatory and competitive period (Graham, 2002). Following the prolonged competitive phase it is important to the athlete's long-term progress to allow time to rehabilitate any injuries and to rest, physically and mentally (Baechle & Earle, 2000; Graham).

The primary objective of the competition period is to allow the athlete to reach peak strength and power through further increases in training intensity accompanied by decreases in training volume (Graham, 2002). Practice in skill technique and game strategy will increase as volume in physical conditioning will decrease. This period will contain all the competitions of that year. This period may vary from one week to several months depending on the nature of the sport schedule. In general this period is characterized by very high intensities and very low volume training.

The second transition occurs between the end of the competitive season and the next macrocycle's preparatory period and typically lasts 1 to 4 weeks. It is this period right after the final competition and before the start of the next year's off-season when active rest occurs and rehabilitation is the primary objective. During this period the focus is on unstructured, non-sport-specific recreational activities performed at low intensities with low volume. For example, a wrestler may engage in swimming, racquetball, or flag football. Resistance training may be permitted, however at only light loads. The reduction of volume and loads is thought to make the athlete less susceptible to overtraining.

Phases within the Preparatory, Competition, and Peaking Periods

The following section will discuss the phases within preparatory, competition, and peaking periods. The first phase is the hypertrophy phase where the primary goal is to increase muscular development or a strength-endurance base. During this phase, training volume is very high (3-6 sets of 10-20 repetitions) and intensity is very low (50-75% of the 1RM) which is conducive for increasing lean body mass and muscular endurance (see Table 1). This muscular and strength-endurance development will provide a base for more intense training in later phases (Baechle & Earle, 2000; Graham, 2002)

The second phase is basic strength, which aims to increase the strength of the muscles vital to the primary sport movements. Resistance training becomes more specific to the respective sport. For example, an Olympic weightlifter would begin to do snatches and clean and jerks. During the basic strength phase the intensity is high (80-90% of the 1 RM) and volume is moderate (3-5 sets of 4-8 repetitions) (see Table 1)(Baechle & Earle, 2000; Graham, 2002).

Lastly is the strength/power phase. During this phase the primary goal is to increase the speed of the force development of the muscles or increase muscle power(Graham, 2002). Here the intensity would increase to near competition levels. That is, 75-95% of the 1RM. The volume during this phase is low (3-5 sets of 2-5 repetitions) (see Table 1) (Baechle & Earle, 2000; Graham, 2002).

Periodization Models within a Mesocyle

This study will focus on periodization within a mesocycle. A mesocycle, which includes a six-week strength training phase, is frequently prescribed to increase the muscular strength of athletes (Baechle & Earle, 2000). Therefore, incite about the most effective method for increasing strength within a mesocycle will be beneficial.

Most strength professionals agree that strength-training programs should be periodized (Plisk & Stone, 2003). However, it is unclear as to what type of periodized program is the most effective (Rhea et al., 2002). There are various types of the periodized programs due to the numerous configurations of the program variables such as number of sets or reps, type of exercises preformed, the length of rest periods between sets, the amount or type of resistance used, type of contractions performed, and the training frequency (Fleck, 1999; Fleck & Kraemer, 1997; Rhea et al).

The predominant types of periodized strength training and conditioning models are briefly described below:

Linear (Traditional) Periodization (LP): Volume and intensity are systematically manipulated. Training cycle begins with a high-volume, low-intensity profile then progresses to low volume, high intensity over time.

Undulating Periodization (UP) : Training volume and intensity increase and decrease on a regular basis but they do not follow the traditional pattern of increasing intensity and decreasing volume as the mesocycle progresses (Fleck & Kraemer, 1997).

Daily Undulating Periodization (DUP): Training volume and intensity increase and decrease on a daily basis (Rhea et al., 2002).

Stepwise: Like the traditional model, intensity increases and volume decreases during the training period. Volume is decreased during the training period. Volume is decreased in a stepwise fashion: Repetitions are reduced from eight to five, five to three, and so forth, at specific time intervals.

Overreaching: Volume or intensity is increased for a short period of time (one to two weeks) followed by a return to normal training. This method is use primarily with advanced strength trained athletes.

This study will focus on linear and undulating periodized programs.

Linear Periodization Model

Linear Periodiaztion (LP) is characterized by a high initial training volume and low intensity (see Figure 3).As training progresses, volume decreases and intensity increases to maximize strength, power, or both (Fleck, 1999; Kraemer et al., 2002). Often the intensity and volume of training remain constant within the specific mesocycle of linear periodized training (Hoffman et al., 2003). Each training phase or mesocycle (hypertrophy, strength, strength/power, and peaking or maintenance) of the LP program is designed to emphasize a specific physiological training adaptation (Hoffman et al.; Kraemer et al., 2002). For example, hypertrophy is the goal during the initial high-volume phase, while the subsequent high intensity phase targets strength and power development (Kraemer et al., 2002). LP programs are designed to peak an individual's strength and power at a given period, making it effective for sports that required peak performance for particular event, such as Olympic Weightlifting. Some strength professionals believe that the ever-increasing training intensities associated with the LP result in neural fatigue, which would adversely affect strength gains (Baechle & Earle, 2000). Poliquin (1988) stated that LP presents two main problems. One problem is that the intensity continuously increases, which creates ever increasing levels of stress. This allows very little time for regeneration. The hypertrophy gained in the first month of training is not maintained in periods where volume was decreased is the second main problem.

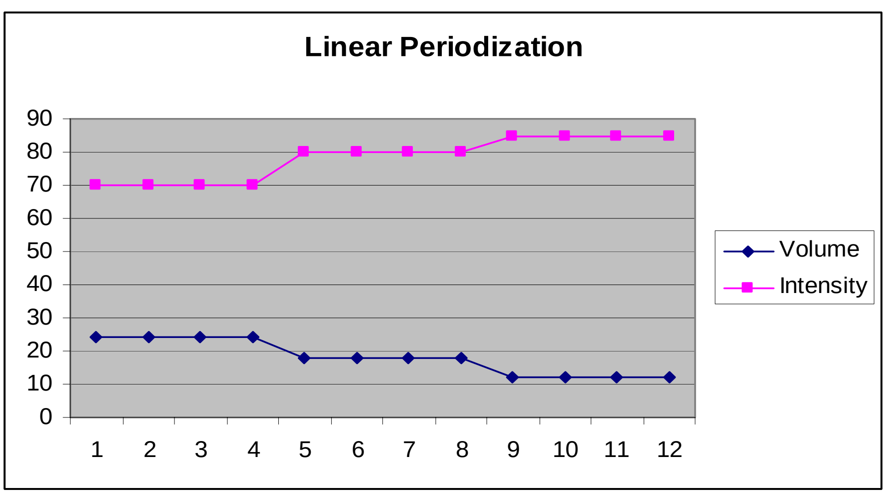

Figure 3. A Linear Periodized Resistance Training Model

Hoffman et al.(2003) compared linear and undulating in-season training models for freshman football players during the course of two seasons. A significant improvement in 1 RM squat was reported in the linear group but not in the undulating. No significant difference was reported for the bench press. The training volume and intensity for the linear and the undulating group was not equal between both the liner and undulating groups. Therefore, the strength response for the LP group could have come from the difference in amount of volume and intensity rather than the configuration of the volume and intensity within the cycle . Currently, there are no other studies in which volume and intensity are equated between groups that verify that the LP is superior UP. Also, there is no currently study that reports LP superior DUP when volume and intensity are equated between groups.

Undulating Periodization Model

Undulating Periodization is a less used form of periodization, characterized by more frequent changes in intensity and volume. In undulating programs, the volume and intensity are acutely varied by workouts (daily) or by microocycle (weekly) (Hoffman et al., 2003). A undulating program may require an individual to perform 3 sets with an 8RM load on the first training day of the week (e.g., Monday), three sets with a 6 RM load on the next training day (Friday), and 3 sets with a 4RM load on the following Monday (Baechle & Earle, 2000). The DUP program above provides daily changes and this provides a frequent change in neural stimulation. This frequent change in stimulation is thought to be highly beneficial for strength gains. Proponents of the undulating model suggest the training days requiring 30-65% of 1RM allow for sufficient recovery between similar sessions while preventing detraining. It is also speculated that during the frequent light workouts common to the undulating model, the slow twitch fibers will be exercised while the fast twitch (FT) are afforded rest, thus preventing overtraining (Brown, 2001).

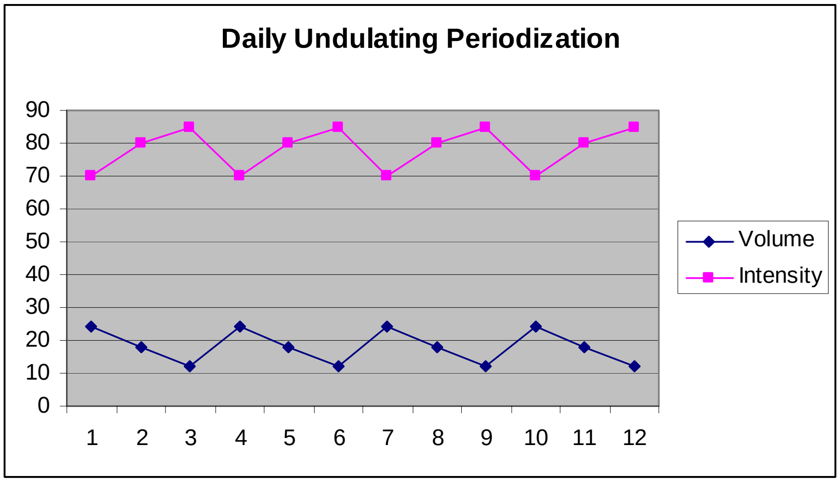

Figure 4. A Daily Undulating Periodized Resistance Training Model.

Only three studies (Baker, Wilson & Carlyon, 1994; Hoffman et al., 2003; Rhea et al., 2002) have directly compared the strength gains of undulating periodization to LP training and only one on muscular endurance (Rhea et al., 2002)(see Table 3). Baker et al. reported no significant difference in strength gains between LP and UP groups when volume and intensity was altered every 2 weeks for the UP group and every 3-4 weeks for the LP group. However, in the Baker et al. study, the difference between the two training regimens may have not been large enough to elicit significant differences in strength gains (see Table 2).

Table 2.

Current Linear Verses Undulating Studies

Study	Subjects	Undulating Periodization		Linear Periodization	
		Strength	Muscle Mass	Strength	Muscle Mass
Baker (1994)	Trained Males	↑	↑	↑	↑
Hoffman (2003)	Trained Males	↑	_	↑↑	_
Rhea (2002)	Trained Males	↑↑	⇔	↑	⇔

↑ significantly from pre to post
↑↑ significantly increased compared to other group
⇔ no significant difference from pre to post
- no pre to post data reported

Rhea et al., (2002) compared LP and Daily Undulating Periodized (DUP) training for strength improvements. In the Rhea et al study, the DUP group altered training volume and intensity on a daily basis. The LP group followed a traditional periodization program, whereas the volume decreased and the intensity increased every 4-week period. Both groups increased strength from baseline values; however, the percent change was greater for the DUP group. The mean percent increases in strength for LP group was 14% and 26% for bench press and leg press, respectively. The DUP group increased bench press and leg press strength by 29% and 59%, respectively (see Table 3). These data suggest that DUP provides added variation necessary to elicit maximal strength gains by alternating the volume and intensity of training on a daily basis rather than monthly or weekly.

Sex of Participants in Other Periodized Training Studies

Participants in previous studies were trained men. In the Rhea et al. (2002) study, participants reported to have strength trained 2 days per week for a minimum of 2 years. The average age of the men were 21 years. In the Hoffman et al (2003) study participants were freshman football players of an NCAA Division III football team. In the Baker et al (1994) study the participants were reported to be experienced athletes. Thus, at present it is unknown whether strength affects of linear and undulating periodized programs differently impact females compared to males.

Summary

In review, the DUP training increases and decreases volume and intensity on a daily basis which is speculated to be highly conducive to strength gains (Poliquin, 1988; Rhea et al., 2002). The continuous change in program variables places stress on the neuromuscular system by manipulating the General Adaptation Response. That is, once a new training stimulus is presented to an organism, it begins to supercompensate (adapt). Thus a training adaptation will occur. If new or different training stimuli are not presented, then further adaptation will not take place. Therefore, it can be hypothesized that daily change in stimuli (sets and repetitions of a resistance training program) will result in more opportunity for supercompensation, which means more muscular development. The LP is characterized by a high initial training volume and low intensity. As training progresses, volume decreases and intensity increases between each mesocycle. This gradual escalation of intensity provides a safe method of increasing training loads, which would be ideal for novice athletes (Baker, 1998; Rhea et al).

The current literature comparing LP and DUP programs are limited. There are only three to date (Baker et al., 1994; Hoffman et al., 2003; Rhea et al., 2002). In addition, of the three current DUP and LP studies, one reports DUP Superior (Hoffman et al.), another says the DUP is superior (Rhea et al., 2002), and another says that neither model is superior to the other (Baker et al.). Because there is an obvious inconsistency between these studies another study is needed for the distingish the superiority between each method.

CHAPTER 3

METHODS

The purpose of this study is to compare LP and DUP strength training programs and determine if either method of periodization elicits superior gains in 1 Repetitions maximums for back squat and flat bench press. This chapter describes where the study took place, the purpose of the study, how participants where recruited, how the data were stored, the specific role of participants, the risk to participants, and how the data were analyzed.

Place

This study was conducted at the East Tennessee State University Center for Physical Activity and at the Department of Physical Education, Exercise, and Sport Sciences' Strength Training and Conditioning Laboratory located in the Brooks Gymnasium.

Objective

The objective of this study is to evaluate physical adaptations to two different resistance training programs: LP versus DUP periodized training.

Methods of Recruitment

Twenty-two participants were recruited by flyers (Refer to Appendix A). Flyers were posted in both the East Tennessee State University Center for Physical Activity and the Physical Education, Exercise, and Sport Sciences Department. Flyers included a request for participation, the principal investigator's name and contact information, and a statement that participants over the age of 40 years would require a physician's approval to participate.

Inclusion criteria for this study:

- Males or females ages 18-55 years.
- Participants over the age of 40 years who have written documentation from a physician that approves their participation in this study.

Exclusion criteria for this study:

- Pregnancy
- Cardiovascular disease
- Diabetes
- Hypertension
- Musculoskeletal or orthopedic conditions that prevent regular, high-intensity exercise training
- Individuals who have been told by a physician that they should not perform either high-intensity exercise or labor

Prior to obtaining informed consent to participate in this study, potential participants were asked to complete a pre-participation health screen. Those who possessed any of the exclusion criteria for this study, listed both above and in the health screen, were excluded from participation in this study.

Orientation

After completion of the pre-screening and informed consent process, participants were asked to complete two instructional training sessions to ensure that the proper technique is used throughout the study.

Testing

Strength Testing

Participants performed pre-training (week 0) and post-training (week 6) 1RM test to determine both upper body and lower body strength. A ramped protocol described by Beachle & Earle (2000) was used to determine 1RM for the bench press and back squat. Results of the 1RM tests were used to develop a safe and effective resistance training prescription for each of the study participants.

Anthropometric Testing

Body composition was determined by a Three cite Jackson-Pollock formula (Baechle & Earle, 2000). Subjects' body mass was determined to the nearest 0.1 kilogram.

Research Data

Data were recorded by the principal investigator (PI) or by a co-investigator and stored in a Microsoft Excel format. All participant data were kept confidential and under lock and key. Participants were assigned a subject number and only the PI and co-investigators had access to participant files.

Specific Roles of Participants

All strength training and testing sessions were supervised by properly trained and qualified exercise physiologists. The staff was comprised of East Tennessee State University, Department of Physical Education, Exercise, and Sport Science faculty, graduate, and undergraduate students.

Each exercise training and testing session began and ended with approximately 10 minutes of the appropriate warm-up and cool-down exercises. Resistance levels were determined for each individual, for each exercise to be completed, and for each training session. This was communicated through a training log-sheet prepared for each participant.

Training

Following pre-training testing subjects were assigned to one of two groups: LP or DUP. Following randomization, subjects underwent a 6-week resistance-training program (Tables 3 and 4). Subjects trained 3 days per week, with each session lasting approximately 45 minutes. All participants performed both BP and BS (core exercises) during training days 1, 3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18 (see Table 3). For the core exercises the LP group performed 3 sets of 8RM each session for the first 2 weeks, 6 RM for weeks 3-4, 4 RM during weeks 5-6 (Table 3). For the entire 6 weeks, the DUP group performed 8 RM, 6 RM, and 4 RM respectively for the Core exercises for sessions 1, 3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18 (Table 3). Both the (LP) and the (DUP) group performed additional exercises as listed: Lat. Pull-downs (3x 8), dumbbell bicep curl/shoulder press combination (3x 8), and abdominal crunches (3x 30) each session. The participants performed a light dynamic warm up and stretching exercises before performing the prescribed program. Additionally, a light warm up set of 10 repetitions was performed before beginning both the back squat and bench press. The participants were prohibited from performing other strength-developing exercises during the span of the 6-week study. Overall, the training groups will be matched for the volume of training performed at each intensity level.

Table 3.

A Six Week Resistance Training Program for Participants.

Training Session Number (out of 18 sessions)	Exercise	Training Sets	Loads Repetitions
1, 4, 7, 10, 13, 16	Warm up	-	-
	Bench Press	See Table 3	
	Back Squat	See Table 3	
	Lat Pull Down	4	8
	Arms & Shoulders Combo	4	8
	Crunch	3	30
2, 5, 8, 11, 14, 17	Warm up	-	-
	Push Press	4	5
	DB Jumps	4	5
	DB RDL	4	8
	Crunch	3	30
3, 6, 9, 12, 15, 18	Warm up	-	-
	Bench Press	See Table 3	
	Back Squat	See Table 3	
	Lat Pull Down	4	8
	Arms & Shoulders Combo	4	8
	Crunch	3	30

Table 4.

Training Intensity and Number of Repetitions for the Core Training Exercises: Bench Press and Back Squat (Both groups performed 3 sets per training session for each of the two core exercises).

Week	**Training Session #**	**DUP Periodization Training Group**		**LP Training Group**	
		Repetitions	% 1RM	Reps	% 1RM
1	1	8	70	8	70
	3	6	80	8	70
2	4	4	85	8	70
	6	8	70	8	70
3	7	6	80	6	80
	9	4	85	6	80
4	10	8	70	6	80
	12	6	80	6	80
5	13	4	85	4	85
	15	8	70	4	85
6	16	6	80	4	85
	18	4	85	4	85

Informed Consent

The Informed Consent Document (ICD)(See Appendix :B) document was reviewed by either the PI or co-investigator for all subjects. Any questions were answered by the principal investigator or other a knowledgeable, qualified designees (ICD)

Data Analysis

The primary outcome measure assessed in this study is muscular strength (1RM). Additionally, the impact of the training interventions on total body mass, fat free mass, and fat mass was were evaluated.

Data will be analyzed using the Statistical Package for Psychological Sciences, version 11 (Chicago, Illinois). A two-way repeated measures analysis of variance (ANOVA) will be used to test for the main effect of training program type (LP vs. DUP) through the comparison of pre- to post-training 1RM values. and body composition. An additional two-way repeated measures analysis of variance (ANOVA) will be used to test for the main effect of training program type (LP vs. DUP) on pre- to post-training body composition values. Additionally, the statistical models were evaluated for interaction effects of sex and athletic status on pre- and post-training 1RM and body composition values. An α level of $p \leq 0.05$ will be used as the criterion to determine either significant main or interaction effects. In the case of either significant main or interaction effects, pairwise comparisons (T-tests) will be used to determine exactly which values are impacted by which factors. The Tukey HSD procedure will be used to control for Type I error across the pairwise comparisons.

CHAPTER 4

RESULTS

The purpose of this study is to compare linear periodized (LP) and daily undulating periodized (DUP) strength training programs and determine if either method of periodization elicits superior gains in 1RM strength for back squat and bench press. This chapter is divided into 4 pertinent areas; subjects, LP compared to DUP, males compared to females, and football players compared to non-players.

Subjects

Thirteen males and six females successfully completed the six-week resistance training protocol. Six of the male participants were semi-professional football players, and the remaining 13 participants were either sedentary or recreationally active.

DUP Compared to LP

Anthropometric

The pre- and post-training mean age, height, body mass, fat free mass, fat mass, and percent body fat of the study participants are reported in Table 5. From pre- to post- training, both the DUP and LP groups significantly decreased percent body fat by 11.5 % and 8.3 % ($p=0.46$ and $p=0.48$, respectively). From pre- to post-, only the LP group significantly decreased fat mass (kg) by 8.8 % ($p=.026$). There were no significant ($p < 0.05$) differences between any of the other physical characteristic either across time or between treatment groups.

Table 5.

Pre- and Post-Training Anthropometric Values for DUP and LP.

	Linear (N=10)		**Undulating (N=9)**	
	Pre	Post	Pre	Post
Age (yrs)	24.18 ± 6.8	24.18 ± 6.8	24.18 ± 6.0	24.18 ± 6.0
Height (cm)	171.77 ± 7.9	171.77 ± 7.9	170.60 ± 7.8	170.60 ± 7.8
Body mass (kg)	81.30 ± 15.2	80.7 ± 15.3	76.19 ± 19.3	76.62 ± 21.1
FFM (kg)	66.81 ± 13.5	67.71 ± 13.7	63.67 ± 14.5	65.49 ± 167.0
Fat mass (kg)	16.09 ± 8.2	14.68 ± 8.52	17.02 ± 9.28	15.77 ± 9.7*
Fat (%)	19.20 ± 8.5	17.61 ± 9.0*	21.93 ± 8.9	19.40 ± 9.1*

Values are means ± 1 S.D.
* $p \leq 0.05$ within group from pre- to post-training

Strength

The pre- and post-training strength measurements for the LP compared to DUP groups are reported in Table 6. Both the absolute and relative (kg/kg body mass) bench press(BP) 1RM increased significantly from pre- to post-training for both groups ($p \leq 0.05$). However, in the DUP group, BP relative to muscle mass did not significantly change ($p > 0.05$) from pre- to post-training. There was no significant main effect ($p > 0.05$) for the DUP versus the LP training program on BP 1RM. In other words, the DUP versus LP training groups responded similarly to the two training protocols.

From pre to post, absolute and relative (to both body mass and muscle mass) back squat(BS) 1RM values also increased significantly ($p \leq 0.05$) for both training groups (Refer to Table 7). There was no significant main effect ($p > 0.05$) for the DUP versus the LP training program on BS 1RM. In other words, lower body 1RM strength adaptations were similar between the DUP and LP training groups. Absolute and relative (to both body mass and muscle mass) total body strength (TBS, combined BP and BS 1RM values) also increased significantly

($p \leq 0.05$) for both training groups. Refer to Table 6. There was no significant main effect ($p > 0.05$) for the DUP versus the LP training program on TBS 1RM.

Table 6.

Pre-and Post-Training Strength Values for LP and DUP

	LP (N=8)		DUP (N=9)	
	Pre	Post	Pre	Post
BP				
(kg)	88.38 ± 46.0	95.71 ± 7.00*	68.07 ± 31.0	74.72 ± 32.9*
(kg/kg body mass)	0.51 ± 0.2	0.55 ± 0 .2*	0.4 ± 0.2	.45 ± 0.1*
(kg/kg ffm)	0.66 ± 0.3	0.7 ± 0.2*	0.66 ± 0.3	0.7 ± 0.2
BS				
(kg)	118.86 ± 57.6	133.86 ± 59.1*	89.65 ± 46.6	109.34 ± 56.8*
(kg/kg body mass)	0.65 ± 0.3	0 .74 ± 0.3*	0.51 ± .2	0.62 ± 0.2*
(kg/kg ffm)	0.89 ± 0.3	0.97 ± 0.2*	0.72 ± .2	0.84 ± 0.3*
TBS				
(kg)	112.13 ± 56.3	222.98 ± 104.4*	78.26 ± 32.5	168.47 ± 67.0*
(kg/kg body mass)	0.65 ± 0.3	1.29 ± 0.5*	0.48 ± 0.1	1.04 ± 0.2*
(kg/kg ffm)	0.88 ± 0.3	1.67 ± 0.5*	0.64 ± 0.1	1.31 ± 0.2*

Values are mean ± 1 S.D.
*$p \leq 0.05$ within group from pre- to post-training
BP = bench press
BS= back squat
TBS= total body strength
FFM= fat free mass

Table 7.

Pre to Post-Training Strength Changes (Δ, %) of Significance Values (p) for the LP and DUP

	Linear (N=8)		DUP (N=9)	
	Δ (%)	p	Δ (%)	p
BP	8.3	0.005	9.8	0 .007
BS	12.6	0 .001	22.0	0 .003
TBS	98.9	0 .000	115.3	0 .000

Values are means ± S.D.
Significant difference between groups ($p < 0.05$)

Males Compared to Females

Anthropometric

Pre- and post-training anthropometric values for both males and females are listed in Table 8. At both pre- and post-training measurement points, the females compared to males had significantly ($p \leq 0.05$) lower body mass and fat free mass (FFM). Pre- or post-training absolute fat mass was not significantly different ($p > 0.05$) between males and females. Females compared to males had a significantly greater ($p \leq 0.05$) body fat percentage at both time points.

Table 8.

Pre-and Post-Training Anthropometric Values for Males and Females

	Females (N=6)		Males (N=13)	
	Pre	Post	Pre	Post
Age (yrs)	24 ± 7.6	24 ± 7.6	24.25 ± 6.0	24.25 ± 6.9
Height (cm)	166.79 ± 8.8	166.79 ± 8.8	173.26 ± 6.4	173.26 ± 6.4
Body mass (kg)	65.55 ± 16.7[a]	64.21 ± 10.4[b,c]	85.03 ± 15.8	85.49 ± 16.7
FFM (kg)	49.68 ± 4.7 [a]	49.03 ± 5 [b]	70.37 ± 11.2	72.21 ± 11.4 [c]
Fat mass (kg)	21.46 ± 4.4	20.45 ± 2.8	14.94 ± 8.6	13.5 ± 9.2 [c]
Fat (%)	29.94 ± 2.9	29.37 ± 1.3 [b]	17.76 ± 7.4 [a]	15.38 ± 7.3 [c]

Values are means ± S.D.
[a] $p \leq 0.05$ males vs. females at pre-training
[b] $p \leq 0.05$ males vs. females at post-training
[c] $p \leq 0.05$ within group from pre- to post-training

From pre- to post-training only the males significantly ($p \leq 0.05$) increased fat free mass and significantly ($p \leq 0.05$) decreased fat mass. Consequently, the percentage of body fat significantly ($p \leq 0.05$) decreased only for the males.

Strength

Pre- to post-training 1RM values for both the females and males are listed in Table 9. The females' pre- and post-training BP, BS, and TBS 1RM values (both absolute and relative to body mass) were significantly ($p \leq 0.05$) lower than those of the males' 1RM values.

Both males and females also significantly ($p \leq 0.05$) increased pre- to post-training BP and TBS 1RM values relative to FFM. Only the males significantly ($p \leq 0.05$) increased BS 1RM values relative to FFM.

Table 9.

Pre-and Post-Training Strength Values for Males and Females

	Females (N=6)		Males (N=11)	
	Pre	Post	Pre	Post
BP				
(kg)	36.74 ± 4.4 [a]	40.91 ± 4.1 [b,c]	101.78 ± 29.7	110.33 ± 28.8 [b,c]
(kg/kg body mass)	.56 ± .0 [a]	.64 ± .0 [b,c]	1.29 ± .4	1. 40 ± .3 [b,c]
(kg/kg ffm)	.76 ± .0 [a]	.87 ± .0 [b,c]	1.57 ± .4	1.66 ± .1 [b,c]
BS				
(kg)	56.82 ± 18.9 [a]	67.8 ± 15.1 [b,c]	127.27 ± 49.3	147 ± 52.4 [b,c]
(kg/kg body mass)	.85 ± .2 [a]	1.05 ± .1 [b,c]	1.49 ± .5	1.71 ± .5 [b,c]
(kg/kg ffm)	1.34 ± .3 [a]	1.57 ± .2 [c]	1.95 ± .5	2.16 ± .5 [b,c]
BP and BS combined				
(kg)	57.08 ± 18.8 [a]	108.71 ± 19 [b,c]	117.52 ± 46.5	245.66 ± 75.2 [b,c]
(kg/kg body mass)	.86 ± .2 [a]	1.70 ± .1 [b,c]	1.46 ± .54	3.06 ± .8 [b,c]
(kg/kg ffm)	1.35 ± .4 [a]	2.43 ± .24 [b,c]	1.89 ± .5	3.73 ± .81 [b,c]

Values are means ± S.D.

[a] $p \leq 0.05$ males vs. females at pre-training

[b] $p \leq 0.05$ males vs. females at post-training

[c] $p \leq 0.05$ within group from pre- to post-training

Football Players Compared to Non-Players

Anthropometric

Pre- and post-training anthropometric values for both football players and non-players are listed in table 10. At pre- and post-training time points, the football players had significantly greater body mass and fat free mass. No other physical characteristics were significantly different between the groups. From pre-to post-training, only the non-players significantly ($p < 0.05$) decreased fat mass and percent body fat. The players did not significantly ($p < 0.05$) differ in any anthropometric measures from pre to post-training.

Table 10.

Pre-and Post-Training Anthropometric Values for Football Players and Non-Players

	Football players (N=6)		**Non-players (N=13)**	
	Pre	Post	Pre	Post
Age (yrs)	24.67 ± 3	24.67 ± 3	23.85 ± 7.9	23.85 ± 7.9
Height (cm)	173.14 ± 7.8	173.14 ± 7.8	170.60 ± 7.7	170.60 ± 7.7
Body mass (kg)	96.15 ± 13.3	96.57 ± 14.9	71.25 ± 12.1[a b c]	70.55 ± 12.4[a b c]
FFM (kg)	76.37 ± 7.5	78.4 ± 8	56.25 ± 11.8[a b c]	59.64 ± 12.6[a b c]
Fat mass (kg)	19.78 ± 8.8	18.62 ± 9.8	15 ± 7.2	12.9 ± 7.6
Fat (%)	19.95 ± 7.4	19.14 ± 6.6	21.03 ± 9.1	17.61 ± 9.0

Values are means ± S.D.
[a] $p \leq 0.05$ football players vs. non-players at pre-training
[b] $p \leq 0.05$ football players vs. non-player at post-training
[c] $p \leq 0.05$ within group from pre- to post-training

Strength

Pre- to post-training 1RM values for both football players and non-players are listed in Table 11. At both pre- and post-training, absolute and relative (kg/body mass) 1RM values for BP, BS, and TBS were significantly ($p < 0.05$) greater for the football players compared to the non-players. Relative to body mass, TBS increased significantly ($p \leq 0.05$) in football players compared to non-players.

Table 11.

Pre-and Post-Training Strength Values for Both Football Players and Non-Players

	Football players (N=6)		Non-players (N=13)	
	Pre	Post	Pre	Post
BP				
(kg)	119.9 ± 37.7 [a]	129.55 ± 33.8 [b]	101.78 ± 29.7	110.33 ± 28.8 [c]
(kg/kg body mass)	1.46 ±.57	1.59 ± .43 [b]	1.29 ± .4	1. 40 ± .3 [c]
(kg/kg ffm)	1.71 ± .55 [a]	1.83 ±.39	1.57 ± .4	1.66 ± .1 [c]
BS				
(kg)	153.41 ± 51.5 [a]	181.44 ± 52.8 [b,c]	82.69 ± 38.2	94.93 ± 35.9 [c]
(kg/kg body mass)	1.62 ± .58 [b]	1.87 ± .54 [b,c]	1.14 ± .4	1.33 ± .4 [c]
(kg/kg ffm)	2.12 ± .59 [a]	2.41 ± .55 [b,c]	1.61 ± .42	1.78 ± .3 [c]
BP and BS combined				
(kg)	138.69 ± 59.3 [a]	294.89 ± 91.3 [b,c]	83.11 ± 38.3	167.31 ± 68.5 [c]
(kg/kg body mass)	1.51 ± 0.52	3.38 ± 1.1 [b]	1.14 ± 0.43 [c,d]	2.34 ± 0.77
(kg/kg ffm)	2.07 ± .8 [a]	4.18 ± 1.1 [c]	1.62 ± .4	3.08 ± .69 [c]

[a] $p \leq 0.05$ football players vs. non-players at pre-training
[b] $p \leq 0.05$ football players vs. non-players at post-training
[c] $p \leq 0.05$ within group from pre- to post-training
[d] $p \leq 0.05$ Magnitude of change from pre- to post-training significantly greater in Football players vs. Non-players

CHAPTER 5

DISCUSSION

The following chapter will discuss the results of current study. This chapter will be divided into the following pertinent areas; Significance of the Study, DUP Compared to LP, Males Compared to Females, Players Compared to Non-Players, Limitations, and Conclusion.

Significance of the Study

The purpose of this study was to compare linear periodized (LP) and daily undulating periodized (DUP) strength training programs and determine if either method of periodization elicits superior gains in 1RM for BS and BP. The results of this study provide additional insight on the impact of two differently periodized, short-term resistance training programs, DUP and LP, on 1RM strength adaptations. The data from the current study suggest DUP and LP are effective methods of eliciting upper and lower body strength gains during a six-week strength phase for male, females, athletes, and non-athletes. However, one method is not superior to the other in eliciting strength gains during a six-week training phase.

DUP Compared to LP

The following section will discuss the DUP compared to LP results of the current study. The anthropometric response to the training will be discussed first. The strength responses to the training will be discussed second. This will be followed by a discussion of the methods and results compared to other relevant studies.

Anthropometric Response of DUP and LP

Both groups significantly decreased percent body fat. However, only the LP group both significantly decreased fat mass and percent body fat. No other anthropometric changes were observed from pre- to post-training. The pre- to post-training FFM response in the current study are similar to the results reported by Rhea et al (2002). Rhea et al. reported no significant difference in FFM for pre to post following the 12-week RT program in both DUP and LP. To date, no study has reported a significant difference in FFM for those that train with DUP or LP. Only Baker et al. (1994) has reported FFM increases from pre- to post-training for both DUP and LP. However, the volume used in the Baker et al. study was greater than the volume used in the current study, Rhea et al., and Hoffman et al. Training volume has been shown to affect both hypertrophic and metabolic responses (Kraemer et al., 2002) Therefore, the greater total training volume (726 total repetitions for each core lift) used in Baker's (1994) study may explain the greater FFM increases reported in the subjects compared to Rhea et al., Hoffman et al., and the current study, which used an average of 468 total repetitions for each core lift (Hoffman et al. and Rhea et al). The total training volume for each core lift of the current study was only 216 total repetitions. It is generally accepted that high volume (6-12 repetitions per set) RT will increase fat free muscle mass (Dons, Bollerup, Bonde-Petersen, & Hancke, 1979; Tesch, Komi, & Hakkinen, 1987; Baechle & Earle, 2000; Kraemer et al., 2002). So, the repetition range (4-8) performed in the current study was not sufficient to increase significant FFM in either group. The current study illustrates that both DUP and LP training programs are effective methods of decreasing percent body fat. However, neither method is superior to the other.

Strength Response of DUP and LP

The following section will discuss the strength changes evaluated between LP and DUP. Bench Press (BP) absolute and relative (to both body mass and muscle mass) increased significantly from pre to post for both LP and DUP except for BP relative to muscle mass in DUP. Because FFM increased proportionately to BP 1RM in the DUP, it is plausible that no significant neural adaptation (e.g., greater recruitment or rate of discharge of motor units) occurred in the DUP group. Therefore, upper body strength increases in the undulating group were simply a result of increased muscle mass not neuromuscular efficiency. In contrast, the LP FFM did not increase proportionally to BP 1RM. Therefore, upper body strength gains were a result of neuromuscular adaptations since strength gains in the absence of hypertrophy are explained by a efficiency of motor unit recruitment (Wilmore & Costill, 1999).

It has been suggested muscular hypertrophy is elicited at high training volumes (3 sets of 8-12 repetitions) and low training intensities(60-70% 1RM) (Kraemer et al., 2002). During the 6-week training phase, the DUP frequently altered the intensity and volume. Whereas, the LP group progressively increased intensity and decreased volume thought the 6-week phase. Therefore, of the four high volume (8 repetitions) and low intensity (70% 1RM) sessions completed by both LP and DUP groups, the DUP performed two of the four during first three weeks and two during the latter three weeks. While, the LP group performed all four high volume and low intensity sessions following pre-training but none during the last three weeks of training. It is possible that if a significant hypertropic effect did occur, it was not maintained during the last three weeks due to a lack of high volume and low intensity during the latter phases of LP sessions. Likewise, this explains the neuromuscular effect that occurred in the LP group. The LP group trained with high intensity and low volume three weeks before post-testing which would be conducive for a increasing neuromuscular activation (Hakkinen & Kallinen, 1994; Tan, 1999). Neural adaptations facilitate increases in strength through greater recruitment of motor units, quicker firing frequency of motor units, and improved synchronization of motor unit firing (Chestnut & Docherty, 1999; Burger & Burger, 2002).

Neural activity has been shown to increase during high-intensity training (80% of 1RM) and decrease during low-intensity training (Hakkinen, Alen, & Komi, 1985). It has also been shown that neural activation contributes to strength gains (Hakkinen & Keskinen, 1989; Tan, 1999). The four high-intensity (3 sets of 4 repetitions at 85 % 1RM) sessions performed three weeks before post-testing caused significant neuromuscular effect in only the LP group. In contrast, the DUP group only performed two high-intensity training sessions three weeks before post-testing and did not show a significant neuromuscular response at post-testing time points. This illustrates that the constant high-intensity over four weeks can elicit and maintain a neurological effect. Also, daily changing the intensity either does not elicit a neurological adaptation or is not conducive for maintaining the adaptation.

Unlike BP, Back squat (BS) increased absolute and relative (to both body mass and muscle mass) 1RM values significantly for both DUP and LP in all categories. Therefore, BS 1RM increased disproportionately to FFM and FM. This suggests both DUP and LP groups underwent significant neural adaptations and no significant hypertrophy of the lower body. Otherwise, 1RM relative to FFM would have not changed. This supports the idea that significant increases in strength without muscle hypertrophy in the early stages of a RT program are possible (Behm, 1995; Burger & Burger, 2002; Chestnut & Docherty, 1999; Hakkinen, Pakarinen, & Kallinen, 1992). The 1RM relative to FFM response was different for BP and BS in the DUP group. This could have been a result of the training status for the BS in both groups.

It is possible that both were groups were untrained in the BS but only the DUP trained in the BP. It has been shown that greater neurological adaptation are possible for the untrained compared to strength trained individuals. Therefore, it possible that the greater neuromuscular adaptation experienced by the DUP group was due to the untrained status of the participants (Ahtiainen, Pakarinen, Alen, Kraemer, & Hakkinen, 2003).

Method and Results Compared to Other Relevant Studies

In order to attribute strength changes to the frequency of change rather than the total training volume, the total training volume must be equated in each group. This is the first study to investigate the difference in strength gains between DUP and LP training with equated volumes in females and athletes (see Table 12). Training volume (total repetitions) and intensity (%RM) was equal in both the DUP and LP groups. Therefore, any difference could be attributed to manipulation of volume and intensity rather than greater volume (Baker et al., 1994). Only one other study (Rhea et al., 2002) has investigated the differences between DUP and LP training with equated volume. However, Rhea et al. included only males in the study population. Hoffman, 2003, studied responses to DUP and LP training in freshman football players but the intensity and volume were not equated in both groups (Hoffman et al., 2003). Therefore, this study illustrates that both males and females can increase strength in six weeks with either DUP or LP RT.

Table 12.

Updated Linear verses Undulating Studies

Study	Subjects	Undulating Periodization		Linear Periodization	
		Strength	Muscle Mass	Strength	Muscle Mass
Present Study	Male Athletes Males Females	↑	-	↑	-
Baker (1994)	Trained Males	↑	↑	↑	↑
Hoffman (2003)	Trained Males	↑	_	↑↑	_
Rhea (2002)	Trained Males	↑↑	⇔	↑	⇔

↑ significantly increased from pre to post
↑↑ significantly increased compared to other group
⇔ no significant difference from pre to post
- no pre to post data reported

The data from the current study suggest DUP and LP are effective methods of eliciting upper and lower body strength gains during a 6-week strength phase for both males and females, and athletes and non-athletes. However, one method is not superior to the other in eliciting strength gains during a 6-week training phase. These results support the Baker et al. (1994) study which reported no significant difference in strength gains between LP and undulating periodized (UP) groups when volume and intensity was altered every two weeks for the UP group and every three to four weeks for the LP group. However, in the Baker et al. study, the UP group did not undulate the training volume and intensity on a daily bases. Therefore, it was suggested that the difference between the training regimens may have not been large enough to elicit significant differences in strength gains (Rhea et al., 2002). Therefore, the current study daily undulated the intensity and volume for the undulating group and still found no significant difference.

Rhea reported the DUP to be significantly ($p < 0.05$) superior to the LP in increasing strength in trained males. This conflicts with the reports of the current study and Hoffman et al. which found neither method superior to the other. However, it is important to note that the participants in DUP group had lower pre-training 1RM values for both bench press and leg press. For leg press the DUP groups pre-training 1RM value was significantly ($p < 0.05$) 36.82 kg. (44%) lower than the LP groups. Therefore, it could be speculated that the DUP group was less trained. Thus, the DUP group would have a larger window of opportunity for strength gains compared to the LP group.

Males Compared to Females

The following section will discuss the males compared to the females results of the current study. The anthropometric response to the training will be discussed first. The strength responses to the training will be discussed second.

Anthropometric Responses of Males and Females

From pre-to post-training, males significantly increased FFM while significantly decreasing fat mass. This resulted in no change in total body mass. Consequently, percent body fat improved for the males. However, the females did not significantly improve body composition or FFM. It appears that the 6-week RT training volume was enough to produce hypertrophy in males but not in females. The fact that there was no change in fat mass for females suggests that perhaps the low training volume prescribed for both groups was insufficient in eliciting metabolic effect. Because the lifts of the current study were less than 30 seconds (per set) in duration and were high intensity (70-85 % 1RM), the primary fuel source for ATP production was not subcutaneous fat (Baechle & Earle, 2000). Thus, less subcutaneous fat was metabolized. The significant body mass decline in the females reflects small but not significant decreases in FFM and fat mass.

Females compared to males have less testosterone response to RT (Burger & Burger, 2002; Fleck & Kraemer, 1997; Kraemer et al., 1991; Kraemer et al., 1993). It has been shown that both pre- and post-training males have higher testosterone compared to females (Hickson, Hidaka, Foster, Falduto, & Chatterton, 1994; Kraemer et al., 1991; Kraemer et al., 1998). It is well known that anabolic hormones such as testosterone contribute to hypertrophy. Therefore, this could explain why the females did not increase FFM and the males did.

These results could be beneficial for male athletes concerned with increasing strength while having to maintaining body mass; such as a wrestler or gymnast. Athletes participating in a 6-week periodized training program with a relatively low repetition range (4-8) and high intensity (70- 85%), similar to the current study, can increase strength and maintain body mass. In addition, females concerned with increasing strength and maintaining their feminine figure could benefit from either the DUP or the LP protocol used in current study.

<u>Strength Response of Males and Females</u>

The strength results of the current study support the fact that males are significantly stronger than females in upper and lower body strength. Males had greater 1RM values pre- and post-training. The same was true when compared to body mass and muscle mass. From pre- to post-training, both males and females significantly increased absolute and relative(relative to body mass and FFM) strength except for strength relative to body mass in the females. Thus, both male and female increase in strength was a result of increased neural activation as described earlier. Therefore, upper body strength gains were a result of neuromuscular adaptations since strength gains in the absence of hypertrophy are explained by an efficiency of motor unit recruitment (Wilmore & Costill, 1999).

Players Compared Non-Players

Anthropometric Response of Players and Non-Players

Only non-players significantly reduced body fat and improved body composition from pre- to post-training. Because the lifts of the current study were less than 30 seconds (per set) in duration and were high intensity (70-85 % 1RM), the primary fuel source for ATP production was not subcutaneous fat (Baechle & Earle, 2000). Thus, less subcutaneous fat was metabolized. The relatively low training volume performed by both groups combined with dietary habits possibly could explain the players physiological response to the training program. Possible the football players increased baseline kilocalories proportionately to calories expended and the Non-players consumed kilocalories disproportionately to calories expend. A dietary log was beyond the scope of the current study. Therefore, more research is need to understand anthropometric impact of LP and DUP training for males and females.

Strength Response of Players and Non-Players

At pre- and post-training time points, players had greater upper and lower body strength compared to the non-players (see Table 16). Relative to body mass, TBS increased significantly ($p < 0.05$) in football players compared to non-players. It was expected that players would increase less because they are assumed to be at a higher level of conditioning at pre training. It could be possible that some of the players were not at a highly trained state at pretest time points.

BP absolute and relative 1RM did not increase in players pre to post but did increase in non-players. This suggests that this 6-week training stimulus was not sufficient to increase upper body strength in trained athletes compared to untrained.

Limitations

Although the current study provides some insight on the effects of LP and DUP RT in both males and females, athletes and non-athletes, the sample size was relatively small for each group. Thus, another study is needed to understand the effects specifically in women and elite athletes. More long-term studies with larger sample sizes of women and elite athletes will be beneficial in understanding the effects of periodized training in other populations. More time point 1RM values are needed in future studies to identify the optimal length of a microcycle or mesocycle. Understanding the optimal supercompenstion period will additional provide insight to preventing overtraining.

Conclusion

Research has proven that periodization is an effective method of RT (Kraemer, 1997; Kraemer et al., 2002; Kramer et al., 1997; Rhea et al., 2002; Rhea et al., 2003; Schiotz et al., 1998; Stone et al., 1981; Stone et al., 2000; Stowers et al., 1983). However, the physiological mechanics behind the effectiveness of DUP and LP and the optimal frequency in which these variables should change is not yet known. Hypertrophy, muscle fiber transformation, neural adaptations, and hormonal adaptations have been shown to have occurred as result of resistance training (Fleck, 1999; Rhea et al., 2002). The measurement of these physiological changes was beyond the extent of this study. Future evaluation of these changes will help researchers understand the mechanics of DUP effectiveness.

The avoidance of overtraining and the maximization of strength gains should be the goal of any strength professional and athlete. RT programs should periodized according to current research (Kraemer, 1997; Kraemer et al., 2002; Kramer et al., 1997; Rhea et al., 2002; Rhea et al., 2003; Schiotz et al., 1998; Stone et al., 1981; Stone et al., 2000; Stowers et al., 1983). However, the optimal length of the periods is not yet known. Both DUP and LP are both effective means of eliciting strength gains. Therefore, strength professionals can apply either method to the event schedule of any sport. Multi-event sports that require many peaking time points would appropriately correspond with the DUP program since changes in intensity and volume can be daily manipulated. Moreover, the gradual increase in intensity and decrease in volume common to the LP program would be suitable with sports such as Olympic Weightlifting where an athlete would be preparing for less frequent events. In conclusion, both LP and DUP are effective methods of eliciting strength gains.

REFERENCES

Ahtiainen, J. P., Pakarinen, A., Alen, M., Kraemer, W. J., & Hakkinen, K. (2003). Muscle hypertrophy, hormonal adaptations and strength development during strength training in strength-trained and untrained men. *Eur J Appl Physiol., 89*, 555-63.

Baechle, T. B., & Earle, R. E. (2000). *Essentials of strength training and conditioning.* Champaign, IL.

Baker, D., Wilson, G., & Carlyon, R. (1994). Periodization: The effects on strength of manipulating volume and intensity. *Journal of Strength and Conditioning Research, 8*, 235-242.

Baker, D. (1998). Applying the In-Season Periodization of Strength and Power Training to Football. *Strength and Conditioning Journal 20*,18-24.

Behm, G. D. (1995). Neuromuscular implications and applications of resistance training. *Journal of Strength and Conditioning Research, 9*, 264.

Brown, A. L. (2001). Nonlinear verses linear periodized models. *Strength and Conditioning Journal*, *23,* 42-43.

Burger, E. M., & Burger, M. S. (2002). Neuromuscular and hormonal adaptations to resistance training: Implication for strength development in females athletes. *National Strength & Conditioning Association, 24*, 51-59.

Chestnut, J. L., & Docherty, D. (1999). The effects of 4 and 10 repetition maximum weight-training protocols on neuromuscular adaptations in untrained men. *National Strength and Conditioning Research, 13*, 353-359.

Dons, B., Bollerup, K., Bonde-Petersen, F., & Hancke, S. (1979). The effect of weight-lifting exercise related to muscle fiber composition and muscle cross-sectional area in humans. *Eur J Appl Physiol Occup Physiol*, *10*, 95-106.

Fleck, S. J. (1999). Periodized strength training: A critical review. *Journal of Strength and Conditioning Research, 13*, 82-89.

Fleck, S. J., & Kraemer, W. J. (1997). *Designing resistance training programs*. Champaign, IL: Human Kinetics.

Graham, J. (2002). Periodization research and example application. *Nation Strength and Conditioning Journal*, *24*, 62-70.

Hakkinen, K., Pakarinen, A., & Kallinen, M. (1992). Neuromuscular adaptations and serum hormones in women during short-term intensive strength training**.**. *Eur J Appl Physiol Occup Physiol.*, *64*, 106-11.

Hakkinen, K., Alen, M., & Komi, P. V. (1985). Changes in isometric force- and relaxation-time, electromyographic and muscle fiber characteristics of human skeletal muscle during strength training and detraining. *Acta Physiol Scand., 125*, 573-85.

Hakkinen, K., & Kallinen, M. (1994). Distribution of strength training volume into one or two daily sessions and neuromuscular adaptations in female athletes. *Electromyogr Clin Neurophysiol., 34*, 117-24.

Hakkinen, K., & Keskinen, K. L. (1989). Muscle cross-sectional area and voluntary force production characteristics in elite strength- and endurance-trained athletes and sprinters. *Eur J Appl Physiol Occup Physiol, 59*, 215-20.

Hickson, R. C., Hidaka, K., Foster, C., Falduto, M. T., & Chatterton, R. T. J. (1994). Successive time courses of strength development and steroid hormone responses to heavy-resistance training. *J Appl Physiol, 76*, 663-670.

Hoffman, J. R., Wendell, M., Cooper, J., & Kang, J. (2003). Comparison between linear and Non-Linear in-season training programs in freshman football players. *Journal of Strength and Conditioning Research, 17*, 561-565.

Kraemer, W. J., Gordon, S. E., Fleck, S. J., Marchitelli, L. J., Mello, R., & Dziados, J. E. et al. (1991). Endogenous anabolic hormonal and growth factor responses to heavy resistance exercise in males and females. *Int J Sports Med. 12*, 228-235.

Kraemer, W. J., Fleck, S. J., Dziados, J. E., Harman, E. A., Marchitelli, L. J., & Gordon, S. E. et al. (1993). Changes in hormonal concentrations after different heavy-resistance exercise protocols in women. *J Appl Physiol., 75*, 594-604.

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

Kraemer, W. J., Staron, R. S., Hagerman, F. C., Hikida, R. S., Fry, A. C., & Gordon, S. E., et al. (1998). The effects of short-term resistance training on endocrine function in men and women. *Eur J Appl Physiol Occup Physiol, 69*, 69-76.

Kraemer, W. J., Adams, K., Cafarelli, E., Dudley, G. A., Dooly, C., & Feigenbaum, M. S. et al., (2002). Progression Models in Resistance Training for Healthy Adults. *Medicine & Science in Sports & Exercise, 34*,364-380

Kraemer, W. J., Ratamess, N., Fry, A. C., Triplett-McBride, T., Koziris, L. P., & Bauer, J. A., et al. (2000). Influence of resistance training volume and periodization on physiological and performance adaptations in collegiate woman tennis players. *The American Journal of Sports Medicine, 28*, 626.

Kramer, J. B., Stone, M. H., O'Bryant, H. S., Conley, M. S., Johnson, R. L., & Nieman, D. C., et al. (1997). Effects of single vs. multiple sets of weight training: Impact of volume, intensity, and variation. *Journal of Strength and Conditioning Research, 11*, 143-147.

Pedemonte, J. (1986). Foundations of training periodization part I: Historical outline. *Strength and Conditioning Journal, 8*, 62-65.

Plisk, S. S., & Stone, M. H. (2003). Periodization strategies. *Strength and Conditioning Journal, 25*, 19-37.

Poliquin, C. (1988). Five steps to increasing the effectiveness of your strength training program. *Strength and Conditioning Journal, 10*, 34-39.

Rhea, M. R., Ball, S. D., Phillips, W. T., & Burkett, L. N. (2002). A comparison of linear and daily undulating periodized programs with equated volume and intensity for strength. *Journal of Strength and Conditioning Research, 16*, 250-255.

Rhea, M. R., Phillips, W. T., Burkett, L. N., Stone, W. J., Ball, S. D., & Alvar, B. A. et al. (2003). A comparison of linear and daily undulating periodized programs with equated volume and intensity for intensity for local muscular endurance. *Journal of Strength and Conditioning Research, 17*, 82-87.

Schiotz, M. K., Potteiger, J. A., Huntsinger, P. G., & Denmark, L. C. D. C. (1998). The short-term effects of peridization and Constant Intensity training on the body composition, strength, and performance. *Journal of Strength and Conditioning Research, 12*, 173-178.

Stone, M. H., O'Bryant, H., & Garhammer, J. (1981). A hypothetical model for strength training. *Journal of Sports Medicine Physical Fitness, 21*, 342-351.

Stone, M. H., O'Byrant, H. S., Schilling, B. K., Johnson, R. L., Pierce, K. C., & Haff, G. G. et al. (1999). Periodization: Effects of manipulating volume and intensity. part 2. *Jounral of Strength and Conditioning Research, 21*, 54-60.

Stone, M. H., Potteiger, J. A., Pierce, K. C., Proulx, C. M., O'Bryant, H. S., & Johnson, R. L. et al. (2000). Comparison of the effects of three different weight- training programs on the one repetition maximum squat. *Journal of Strength and Conditioning Research, 14*, 332-337.

Stowers, T., McMillan, J., Scala, D., Davis, V., Wilson, D., & Stone, M. (1983). The short-term effects of three different strength-power training methods. *Nation Strength and Conditioning Journal, 5*, 24-27.

Tan, B. (1999). Manipulating resistance training program variables to optimize maximum strength in men: A review. *Journal of Strength and Conditioning Research*, *13*, 289-304.

Tesch, P. A., Komi, P. V., & Hakkinen, K. (1987). Enzymatic adaptations consequent to long-term strength training. *Int J Sports Med.*, *8*, 66-69.

Willoughby, D. S. (1993). The effects of mesocycle- length weight training programs involving periodization and partially equated volumes on upper and lower body strength. *Journal of Strength and Conditioning Research*, *7*, 2-8.

Wilmore, J. H., & Costill, D. L. (1999). *Physiology of sport and exercise*. Champaign, IL: Human Kinetics.

APPENDIXES

Appendix A: Flyer for Participants

Participants Needed

12 Week Resistance
Training Study

Particpants over forty years of age will be required to obtain a physician’s approval to participate.

Contact
Andrew Caldwell at (423) 439-7986

Appendix B: Informed Consent Document

East Tennessee State University
Informed Consent

PRINCIPAL INVESTIGATORS: Andrew Caldwell, Deigo Dehoyos, Ph.D.

TITLE OF PROJECT: A Comparision of Linear and Daily Undulating Periodized Strength Training Programs

This Informed Consent will explain about being a research subject in an experiment. It is important that you read this material carefully and then decide if you wish to be a volunteer.

PURPOSE:

The purpose of this study is to compare linear and undulating periodized strength training programs, and determine if either method of periodization is superior to the other. If so, it will be beneficial for the strength and conditioning community to choose the superior method when developing strength programs.

DURATION

The total duration of the study will be thirteen weeks. You will be required to attend one week of instructional training. Following the instructional training, you will undergo twelve weeks of physical training for your respective periodized program.

PROCEDURES

You will participate in two instructional training sessions to ensure proper technique is used throughout the study. Pre-training 1 repetition maximum (1RM), which is the greatest amount of weight an individual can lift, with proper technique, for a specified number of repetitions will be determined for upper and lower body strength. You will be tested and trained on a standard flat bench for upper body strength. A ProStar leg press will be used for testing and training lower body. You will be required to warm up and stretch before attempting a 1 RM for each exercise with a relatively lightweight for 12 repetitions. Then the resistance will progressively increase until a 1RM is obtained. You will be given 4-6 attempts to determine their 1 RM. 1RM testing will be repeated after 4, 8 and 12 weeks of training. After pre-training 1RM are determined, you will be randomly assigned to one of two groups: Linear Periodizied (LP) or Daily Undualting

Periodizied (DUP). Following randomization, subjects will undergo 12 weeks of training. You will train 3 days per week, with each session lasting approximately 45 minutes. All participants will perform both leg press and bench press (Core) exercises during each training sessions.

Linear Periodized Training Program for Core Exercises:
The LP group will perform 3 sets of 12 RM each session for the first 2 weeks, 10 RM for weeks 3-4, 8 RM during weeks 5-6, 6 RM for weeks 7-8, 4 RM for weeks 9-10, and 2 RMfor weeks 11-12 for the Core exercise.

Daily Periodized Training Program for Core Exercise:
The DUP group will perform 12 RM on Mondays, 10RM on Wednesdays, and 8 RM on Fridays for weeks 1-3. For weeks 4-6, the DUP group will perform 10 RM on Mondays, 8RM on Wednesdays, and 6RM on Fridays. For weeks 7-9, 8 RM Mondays, 6 RM on Wednesdays, and 4 RM on Fridays. For weeks 10-12, 6 RM Mondays, 4 RM on Wednesdays, and 2 RM on Fridays for Core exercises.

Auxiliary Exercise Program for both groups:
Both the (LP) and the (DUP) group will perform additional exercises as listed: Lat. pull-downs (3x 10), bicep curls (3x 10), and abdominal crunches (3x 25) each session. Each participant will perform a 10 minute aerobic warm up and stretching exercises before performing the prescribed program. A light warm up set of 10 repetitions at 40% of 1RM will be preformed before beginning both the leg press and bench press. You will be prohibited from performing any other strength-building exercises during span of the study (12-weeks) (Rhea, Ball, Phillips, and Burkett, 2002).

POSSIBLE RISKS/DISCOMFORTS

You may experience mild muscular soreness and fatigue due to the maximal effort that will be required during attempting 1 RM for bench press and leg press. They may also experience soreness and fatigue during and following resistance training sessions.

POSSIBLE BENEFITS

You have the potential to develop muscular strength, increase lean body mass and increase or maintain bone density. You will be given a summary of their test results.

ALTERNATIVE PROCEDURES/TREATMENTS

No alternative procedures will be offered.

CONFIDENTIALITY

Every attempt will be made to see that your study results are kept confidential. A copy of the records from this study will be stored in the Center for Physical Activity for at least 10 years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as a subject. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, the ETSU/VA IRB, and the Department of Physical Education have access to the study records. Your records will be kept completely confidential according to current legal requirements. They will not be revealed unless required by law, or as noted above.

COMPENSATION FOR MEDICAL TREATMENT:

East Tennessee State University (ETSU) will pay the cost of emergency first aid for any injury that may happen as a result of your being in this study. They will not pay for any other medical treatment. Claims against ETSU or any of its agents or employees may be submitted to the Tennessee Claims Commission. These claims will be settled to the extent allowable as provided under TCA Section 9-8-307. For more information about claims call the Chairman of the Institutional Review Board of ETSU at 423/439-6134.

CONTACT FOR QUESTIONS

If you have any questions, problems or research-related medical problems at any time, you may call Andrew Caldwell at (423) 439-7986 and at (423) 341-9368, or Dr. Diego DeHoyos at (423) 439-5796. You may call the Chairman of the Institutional Review Board at 423/439-6134 for any questions you may have about your rights as a research subject.

VOLUNTARY PARTICIPATION

Participation in this research experiment is voluntary. You may refuse to participate. You can quit at any time. If you quit or refuse to participate, the benefits or treatment to which you are otherwise entitled will not be affected. You may quit by calling Andrew Caldwell, whose phone number is 423-439-7986. You will be told immediately if any of the results of the study should reasonably be expected to make you change your mind about staying in the study.

By signing below, I certify that I have read or had this document read to me. I will be given a signed copy. I have been given the chance to ask questions and to discuss my participation with the investigator. I freely and voluntarily choose to be in this research project.

____

SIGNATURE OF VOLUNTEER DATE

____

SIGNATURE OF PATIENT/LEGAL GUARDIAN (if applicable) DATE

PRINCIPAL INVESTIGATOR: ____

SIGNATURE OF INVESTIGATOR DATE

SIGNATURE OF WITNESS (if applicable) DATE

VITA

Andrew M. Caldwell, C.S.C.S

Personal Data:	Date of Birth: July 27, 1979 Place of Birth: Spartanburg, S.C.

Education:	Public School, Landrum, South Carolina
	Gardner-Webb University; Boiling Springs, N.C.
	  Health Education, B.S., 2002
	East Tennessee State University, Johnson City, Tennessee;
	  Physical Education, M.A., 2004

Professional Experience:	Sports Performance Coach; Velocity Sports Performance
	  Montgomery, Alabama, 2004- Present
	Graduate Assistant, East Tennessee State University, Campus Recreation
	  Department, 2002-2004

Certifications:	Certified Strength and Conditioning Coach
	  National Strength and Conditioning Association
	Certified Level 1 Track and Field Coach
	  U.S.A. Track and Field Association