A COMPARISON OF PERIODIZATION MODELS

WITH EQUATED VOLUME AND INTENSITY

FOR STRENGTH

By

THOMAS WAYNE BUFORD

Bachelor of Science in Education

Oklahoma Baptist University

Shawnee, Oklahoma

2004

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2006

A COMPARISON OF PERIODIZATION MODELS

WITH EQUATED VOLUME AND INTENSITY

FOR STRENGTH

Thesis Approved:

Dr. Frank Kulling

Dr. Steve Edwards

Dr. Doug Smith

Dr. A. Gordon Emslie

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my wife Stacy for supporting me throughout my coursework and thesis research at Oklahoma State. Thanks to Steve Rossi for all of his help in preparing the data collection. Steve, Dr. Aric Warren, and Dr. Doug Smith were integral parts in the testing of subjects. Dr. Smith also served as my advisor and helped me throughout my Master’s work. My committee, consisting of Dr. Smith, Dr. Frank Kulling, and Dr. Steve Edwards, was instrumental in this effort by supporting my research and pointing me in the right direction. I would like to thank Sarah Gladden and Terri Chen for all of their help with allowing me to work with the weight training classes to gather subjects. Terri was also very helpful during data collection and in helping to oversee the workout sessions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

1RM	1 Repetition Max
ATP-PC	Adenosine Triphosphate- Phosphocreatine
DUP	Daily Undulating Periodization
EMG	Electromyography
LP	Linear Periodization
OTS	Overtraining Syndrome
RPE	Ratings of Perceived Exertion
WUP	Weekly Undulating Periodization

CHAPTER I

INTRODUCTION

Background

The ability to produce large amounts of force through muscular strength has fascinated people throughout history. However, the methods used to increase strength have never been completely agreed upon. Many factors are involved in the improvement of muscular strength including genetics, hormonal factors, nutritional factors, and muscular overload. The most disputed of these factors is how to produce the greatest muscular overload via a resistance training program. Many variables can be manipulated within a resistance training program: types of muscle actions, rest between sets, velocity of repetitions, exercise volume, exercise selection, exercise order, workout frequency, rest between workouts, exercise intensity, and/or the use of periodization (2,6,15,16,19,38,41,49,67).

The possession of great strength has long fascinated people. The original Olympics were based on feats of strength, Irish weight throwing contests were known to exist over 3800 years ago, and ancient Chinese military traditions included strength training. Military units from the ancient Romans and Greeks to modern times have used various methods of improving strength to improve fighting and survival skills. In modern times, strength training has become a vital part of athletic performance. Several sports have directly evolved from strength training including power lifting, body building, and Olympic weightlifting. In addition, it has become necessary for athletic teams above the high school level to implement strength and conditioning programs involving resistance exercise to maximize performance potential of the athletes. The first professional strength coaches were hired by professional football teams in the 1960's (38). Private strength and conditioning programs have also become a big industry in America as athletes try to look for every possible advantage over their opponents. Anecdotally, this appears to be related to the growth of professional sports and the possibility of economic success for those select few who make it to that level.

At this point, strength training research is fairly young as a discipline. The first research in strength and conditioning began in the early 20th century, but extensive research on resistance training has only occurred in the past several decades. The primary emphasis of exercise science research in the past has been on the aerobic energy system (50). Among the earliest researchers to focus on muscular strength was Dudley Allen Sargent, a medical doctor at Harvard (38). He developed methods to assess strength, among them the Sargent vertical jump test which is still one of the simplest and effective ways to measure lower body muscular power. In the 1920's, German physiologist Werner W. Siebert first determined that muscular hypertrophy was the result of increased diameter of muscle fibers not hyperplasia, or an increase in the number of fibers. During World War II, A.S. Watkins first determined that 10 repetitions were optimal for eliciting muscular hypertrophy, and in fact 8-12 repetition sets are now recommended to train for hypertrophy (38). A pair of German physiologists in the 1950's, Erich A. Muller and Theodor Hettinger, first discovered that isometric exercise could contribute to muscular strength gains (38). Currently, the emphasis on resistance exercise is growing thanks to several professional organizations, primarily the National Strength and Conditioning Association (NSCA). The organization looks to unite field practitioners and research scientists and shows this effort through its two professional journals, *Strength and Conditioning Journal* and *The Journal of Strength and Conditioning Research*. All of these contributors have made an impact on the growth of resistance training practice and research.

Resistance Training as a Growing Exercise Discipline

Even though increased mechanization and technology have reduced the need for humans to produce muscular force to carry out the activities of daily living, strength training has become a more accepted as well as popular form of exercise over the past two decades (41,49). Research in this area is growing in importance alongside the growing popularity of weightlifting as a training method. Resistance training is no longer being viewed as just a necessary part of the athletic or military arenas. Resistance exercise has gained support as a form of exercise for both the elderly and adolescents/children if performed safely and properly according to the specific needs and abilities of the individual (1,2,6,15,49,61). It had once been thought to be too risky to allow these populations to perform strength training, but benefits have been shown with minimal risks for such populations.

Strength training is also no longer seen as form of exercise only for men. Resistance training is becoming as necessary a part of the female athlete's training program as it is in men's programs. In fact, women's competitive weightlifting became a medal sport in the 2000 Olympic Games. Many people think that training for women needs to be significantly different than for men, but generally the only difference lies in the amount of resistance to be used (6,15,30). Muscle fibers in both genders show the same characteristics and respond to training the same way. Per unit of muscle fiber cross-sectional area, male and female muscle fibers have the same force producing capabilities (6). The difference in force production stems from the generally larger cross-sectional area of male muscle fibers (37). Although research has shown resistance training for women to be safe and effective and more women are lifting today compared to the past, many women are still hesitant about beginning strength training programs because of the misconceptions about getting "bulky" or for fear of injury. More research including women as subjects needs to be done to help combat these misconceptions.

Benefits and Risks of Resistance Exercise

For most populations, the benefits of strength training greatly outweigh the risks that are associated with it. However, in order for strength training to continue to grow in recreational settings and for various populations to take advantage of the benefits, professionals must make both the benefits and risks more widely known. The most widely known benefit of resistance exercise is to improve strength. However, gaining strength does not always seem like a practical benefit to many people. They must become more aware of all of the benefits that can be reaped by including strength training in a workout regimen. While many of these benefits, such as improved muscle recruitment or muscle movement velocity, would not matter for many people, there are benefits that could help encourage a wider range of individuals to get involved in resistance training.

Some of these possible adaptations stemming from resistance include: muscular hypertrophy, increased lean mass, improved athletic performance and injury prevention (1), increased bone density, improved sleep, reduced risk of type II diabetes, osteoporosis, and heart disease, and reduced risk of falls among older adults (61).

With the benefits being aforementioned, it is also necessary for beginning strength trainers to understand risks that are associated with the discipline. First and foremost, at-risk populations need to have at least one proper health screening prior to beginning the program (6). The largest risk presents itself when novice lifters begin without supervision or a spotter. One must be aware of how much weight to use in the beginning, and proper form is a must. Strains and sprains are a common risk if pushing the body beyond its limits. Training children has been proven safe (1,6) as long as proper supervision and safety guidelines are followed. If they are not, possible concerns include repetitive soft-tissue injuries and/or injuries to the epiphyseal plate. In addition, all lifters should be advised not to perform the valsalva maneuver, as it can create excess intra-abdominal pressure and compressive force on the heart. Each of these risks can be prevented, however, with proper knowledge and safety guidelines.

Statement of Problem

The primary problem of this study was to compare the effectiveness of three models of periodization: linear periodization (LP), daily undulating periodization model (DUP), and weekly undulating periodization (WUP); on improving muscular strength in a college-aged population of both men and women.

The secondary problems of the study were, with group collapsed, to determine what improvements would be made in muscular strength and body composition following nine weeks of resistance training as well as to examine relationships of ratings of perceived exertion (RPE) to group over time.

Significance of the Study

Strength training is an area that needs scientific advances because, traditionally, research in this area has lagged because of a preoccupation with research on the aerobic energy system (50). Strength training has become an accepted, and in some arenas, necessary, part of a healthy lifestyle and has been even further emphasized as a necessity for athletic populations (2,38,50). As stated previously, there are many program variables that can be manipulated to provide adequate stimuli to produce muscular adaptations. Periodization has received much attention and now is almost widely accepted as a necessary part of a resistance training program (58). However, there have been few studies comparing periodized program models with equated volume and intensity. Equating volume and intensity helps to insure that differences between groups will come solely from the difference in workout design.

Knowledge gained through this study could help to make resistance training workouts more effective without having to alter volume or intensity. Thus, one could improve his/her workout without adding time or energy. In addition, no studies have been found comparing the three methods when examining sex as a variable. It may be possible to begin training women the same as men if they are found to respond to a periodized program in a similar fashion. All of these results will be primarily applicable to recreational trained lifters, but the knowledge could form a base for follow-up research to be completed on athletes.

Hypotheses

The null hypothesis for the primary problem of this study was that there would be no significant ($p<.05$) difference among periodization models in terms of strength gains during nine weeks of resistance training. The alternate hypothesis was that one of the periodized models would be significantly better at eliciting strength gains in the subjects.

Primary Hypothesis

Ho1: $\mu(LP)=\mu(DUP)=\mu(WUP)$

Ha1: $\mu(LP)\neq\mu(DUP)\neq\mu(WUP)$

The first null hypothesis for the secondary problem of the study was that no significant ($p< .05$) differences would be made in strength for across groups following nine weeks of resistance training. The alternate hypothesis was that strength would be significantly improved over the course of nine weeks.

Secondary Hypothesis #1

Ho2: $\mu(pre)=\mu(post)$

Ha2: $\mu(pre)\neq\mu(post)$

The second null hypothesis for the secondary problem of the study was that no significant ($p< .05$) differences would be exist in terms of body composition for all groups following nine weeks of resistance training. The alternate hypothesis was that body composition would be significantly improved, by skinfold and anthropometric analysis, over the course of nine weeks.

Secondary Hypothesis #2

Ho3: $\mu(pre)=\mu(post)$

Ha3: $\mu(pre)\neq\mu(post)$

The third null hypothesis for the secondary problem of the study was that no significant ($p< .05$) differences would be observed in RPE scores between groups during the course of the study. The alternate hypothesis was that RPE scores would significant differences would be observed between groups during the nine weeks.

Secondary Hypothesis #3

Ho4: $\mu(LP)=\mu(DUP)=\mu(WUP)$

Ha4: $\mu(LP)\neq\mu(DUP)\neq\mu(WUP)$

Operational Definitions

1RM (One Repetition Max)	The maximal weight that a person can lift one time with proper exercise technique; a true measure of absolute strength.
Concentric Muscle Action	Muscle action in which the force produced is greater than the resistance to be overcome.

Daily Undulating Periodization (DUP)	A form of undulating periodization in which changes in volume and intensity are made on a daily basis.
Eccentric Muscle Action	Muscle action in which the resistance to be overcome is greater than the force produced.
Exercise Volume	The total amount of weight lifted during a training session, calculated by multiplying the number of sets completed by the number of repetitions times the weight lifted per repetition (e.g. 3x8x100).
Frequency	The number of training sessions completed in a given time period.
Hypertrophy	Enlargement of muscle fibers due to trauma to muscle (stemming from muscular overload) followed by a period of regeneration causing an increase in the cross-sectional area of the fibers.
Intensity	Level of muscular activity that can be quantified in terms of power. In resistance training terms, intensity is generally given as a percentage of 1RM.
Isometric Muscle Action	Muscle action in which the force produced is equal to the resistance to be overcome, or

	the force to overcome is greater than force than can be produced. Thus, tension is produced but no movement occurs.
Isokinetic Exercise	An exercise in which the speed of the contraction is controlled and maintained at a constant rate.
Linear Periodization (LP)	Periodization model that follows a general pattern of decreasing training volume and increasing training intensity over a series of microcycles; also known as the classical model.
Macrocycle	Large training period usually constitutes one training year, but may be a period of months up to four years (for Olympic athletes).
Mesocycle	Training segment generally consisting of several weeks or months.
Microcycle	Segment of training that is generally one week, but could last as long as four weeks.
Overreaching	Short term decrement in performance capacity following intense training that is recovered from following several days or weeks of rest.

Overtraining Syndrome (OTS)	Long term performance decrement following intense training in which performance is not restored even after an extended rest period that is generally accompanied with a change in mood.
Periodization	A systematic process of planned variations in a strength-training program over a training cycle with specific objectives of maximizing strength gains and avoiding overtraining syndrome.
Progressive Overload	Gradual increase of stress placed upon the body during exercise training.
Power	Amount of work performed in a given time.
Resistance Exercise/Training	A specialized method of conditioning that involves the progressive use of resistance to increase one's ability to exert or resist force; also known as strength training.
Set	Group of repetitions performed continuously without resting.
Strength	Maximal amount of force a muscle or muscle group can generate in a specified movement pattern at a specified velocity.

Type I Fibers	Slow twitch fibers with low power and high aerobic capabilities.
Type II Fibers	Fast twitch fibers with high power and low endurance capabilities.
Undulating Periodization	Also known as non-linear periodization, this model calls for more frequent alterations in intensity and volume than the linear model.
Weekly Undulating Periodization (WUP)	A form of undulating periodization in which changes in volume and intensity are made on a weekly basis.

Assumptions

The following assumptions were made:

1. The subjects made an honest effort to comply with the intervention protocol according to their specific group.
2. The subjects made an honest effort in answering the medical history questionnaire, the PAR-Q, and the exercise self-efficacy instrument.
3. The subjects made an honest effort in completing the weekly exercise/activity logs.

Delimitations

1. This study was delimited to college aged subjects.

2. Although subjects had prior resistance training experience, this study was delimited to those who had not strength trained consistently (> once per week) in the two months prior to the study.
3. This study was delimited to apparently healthy subjects as noted by their medical history forms.
4. To maintain equal volume between subjects, this study was delimited to subjects who were performing no other resistance training concurrently.
5. To prevent additional improvements not attributable to the program design, this study was delimited to subjects taking no additional nutritional supplements outside of their regular diet.
6. Findings are only applicable to recreationally trained weight lifters.

Limitations

1. Nine weeks of training might have been insufficient training time to elicit significant strength changes in some subjects.
2. Rest periods were not standardized for all subjects.
3. Levels of aerobic endurance were not monitored. In some subjects with high aerobic exercise levels, strength gains may have been compromised

CHAPTER II

REVIEW OF LITERATURE

Basic Principles of Resistance Exercise

Designing the most effective resistance training program is an extremely difficult task, considering the many variables involved and the fact each person needs an individualized program because people respond differently to training stimuli (9,15,41). In addition to the resistance training program variables, many other physiological variables such as nutrition and/or the use of ergogenic aids will help determine the effectiveness of a resistance training program. While such factors are highly important, they are outside the scope of this research at this time.

Exercise Selection

Fleck and Kraemer (15) remark that “the number of possible joint angles and exercises is as limitless as the body’s functional movements.” This is undoubtedly true, however, often times resistance training programs are designed with a cookie-cutter type approach. To combat this, individuals who wish to strength train must focus on what their goals are, and then learn the proper way to train to achieve those goals. The first decision one must make is for what purpose is he/she exercising. If one were looking for muscular hypertrophy, for example, it would not be beneficial to use isokinetic training.

On the other hand, if speed training was the goal, isokinetic training would be an acceptable choice. The decision must first be made regarding whether training is for sports performance, health/fitness, or aesthetic value. Then one must decide whether muscular hypertrophy, strength, or endurance is preferred. Finally a program design has to define what muscles to specifically target, such as upper body/lower body or biceps and chest. It has been shown in women, however, that a total-body workout is more beneficial for improving strength as opposed to upper-body only or lower-body only training (37,40). In addition, it is important to stress agonist and antagonist strength ratios so as not to create a muscular imbalance that could lead to injury (e.g. only including quadriceps exercises and no hamstring exercises) (6).

One of the primary keys to a proper resistance training program is the ability to choose the correct exercise to address each training goal. Exercises will benefit only the muscle that is activated during that exercise, as muscle that develops no tension will not benefit from the exercise (15). Both multi-joint and single joint exercises have been shown to be effective in increasing muscular strength in targeted muscle groups (2,15,41). Multi-joint exercises (e.g. squat, power clean, and power snatch) have been shown to have the greatest impact on strength and power gains (2,6,15,41) because they activate the greatest amount of muscle mass. These exercises are necessary for athletic performance training because they teach neuromuscular coordination. In addition, exercises that involve large amounts of muscle mass have been shown to provide greater hormonal responses such as increased growth hormone and testosterone in both men and women, although to varying degrees (41,42). However, these exercises require more technical skill and may not be appropriate for beginning lifters. Single joint exercises (e.g. biceps curl, leg extension, leg curl) are used to target a specific muscle group and are generally safer because of the reduced skill involved (2,6,15,41).

Muscle Actions and Velocity of Contraction

Another aspect of exercise selection involves what type of muscle actions will be used. A well-rounded resistance training program should involve concentric and eccentric, and possibly isometric, contractions as well as various movement velocities for these muscle actions (2). If sport specific training is desired, the athlete must train with the movement patterns and velocities that are required by the sport (34,38,49). A football lineman for example, would benefit much more from isometric training than would a tennis player. Training a pitcher with heavy resistance and slow movement velocities would not be beneficial since pitching requires rapid shoulder movement.

Muscle tissue responds to electrical stimuli from the brain to produce force. The number of and degree to which the muscle fibers are stimulated determines what kind of action will be produced (38). Concentric actions are produced when the muscle shortens due to a greater force being generated than resistance to be overcome. In contrast, eccentric actions lengthen the muscle as less force is produced than the resistance to be overcome. Isometric exercises involve no joint movement because the force produced is exactly equal to the resistance or the resistance is greater than the force which can be produced. In many natural movements such as jumping or running, a concentric action is preceded by an eccentric action. This series, known as the stretch-shortening cycle, serves to stretch the muscle just prior to the concentric action and enhances force production (6,38).

Velocity of movements is perhaps the most overlooked aspect of resistance training programs, as many programs are often designed with no regard to velocity specific goals (33). The velocity of each repetition affects the neural, hypertrophic, and metabolic responses to resistance exercise (2,40). Evidence exists that the strength increases are specific to the velocity of training (2,15,33,34,41), however, claims to the contrary do exist (48,69).

Force production is a product of both the muscle action used and the velocity of the movement. In concentric actions, force capabilities are inversely related to the velocity of the movement (6,33). This simply means that muscles are unable to move heavier loads at the same rate as they can move lighter loads. However, force production increases as velocity increases in eccentric actions (6,14). Force capabilities in eccentric actions range from 120% to 160% of those of concentric actions (6). Thus, it is possible to train with much higher loads eccentrically than with concentric training only. Farthing and Chilibeck (14) reported that eccentric protocols have shown greater increases in strength and hypertrophy than concentric protocols. However, it has also been reported that there is no significant difference in strength gains between concentric and eccentric training (2,15,22,41). Brandenburg and Docherty (10) reported that eccentric training and concentric training were equally effective in increasing strength in the elbow flexors but claimed that eccentric training may be more effective in other muscle groups.

It has been reported that training at moderate velocities increases strength across all velocities (2,41). This claim, however, assumes that the moderate velocity will be accompanied by a corresponding moderate load. It has been shown that intentional slow-velocity contractions with sub-maximal loads produce less force than moderate velocity contractions (2,41). Jones (33) subsequently theorized that all loads should be maximally accelerated to produce the greatest force. It is reasonable to assume, then, that using moderate loads and trying to maximally accelerate them will produce the greatest strength increases across all movement velocities. Farthing and Chilibeck (14) directly compared eccentric and concentric actions at two different velocities with eight week training protocols. They reported that high-velocity eccentric training (180 degrees/sec) elicited significantly ($p<0.05$) greater increases in muscular hypertrophy than the other models, and that eccentric high-velocity training is the most effective training protocol for increasing strength and muscular hypertrophy. Since high velocities are shown to be warranted, and higher loads can be used at higher velocities it seems logical that high-velocity eccentric training would provide the greatest strength gains. This question needs to be examined further. However, medium loads and velocities are optimal for beginning lifters as they are the safest and easiest to control.

Exercise Order

In order to achieve the greatest possible strength gains with a workout program, it is necessary to pay attention to the order of the exercises within the program. There are several different general workout structures to choose from. If multi-joint exercises (e.g. Olympic lifts) are included in the workout program, it is advised that the multi-joint exercises be performed at the beginning of the workout to prevent fatigue from causing poor technique later in the session (2,6,15). This model may also be known as large muscle areas before small areas. Generally power exercises are followed by core exercises with assistance exercises near the end of a workout.

An opposing model discussed by Baechle (6) as well as Fleck and Kraemer (15) termed "pre-exhaustion" proposes that smaller group exercises be performed first to intentionally fatigue the small muscles. Theoretically, this would cause the large muscle groups to perform more work during a large muscle group exercise, yet it often results in lower resistances being used. The pre-exhaustion method warrants further research and is not recommended at this time.

Fleck and Kraemer (15) also describe a system, known as the priority system, which places the exercises that are most important to achieving the goals of the training program at the beginning of the workout. For example, if the goal were to improve pectoral strength or size then bench press may be placed near the beginning of every workout. Split routines may be used in which large muscle groups and small muscle groups are trained on alternate days or individual muscle groups are trained on alternate days. In this case it is still important to begin with multi-joint exercises. However, several other options for varying the workout order may help to recover in-between sets. These include alternating upper body and lower body exercises, push-pull exercises, or agonist-antagonist (6).

Training Volume and the Single Set/Multiple Set Controversy

In recent years there has been much controversy concerning the optimal training volume to elicit strength gains. Specifically, the issue has pertained to whether a one set protocol is just as effective as a multiple set approach. Single set advocates argue that those performing multiple sets on each exercise are wasting valuable training time and energy, and that single sets allow for a greater number of exercises to be performed.

Because of the ever increasing controversy over the matter, much literature exists on the matter. Kramer et al. (43) reported significant differences in multiple and single set programs on increasing 1RM squat in favor of multiple sets. Rhea et al. (54) reported a significant difference ($p < 0.05$) favoring multiple sets in the leg press and differences approaching significance in the bench press. Galvao and Taaffe (19) presented a review paper in 2004 which reported that all but one of the papers supporting single set equality were published prior to 1998. Some of the problems that exist in these papers include no pre-test measures, no mention of rest intervals between sets, and/or not equating volume and intensity between groups (54).

Several meta-analytic papers have been published recently to examine the literature through a wider lens. Wolfe et al. (72) performed a meta-analysis comparing the literature of single vs. multiple-set programs that were at least six weeks or more. Sixteen studies and 621 subjects were included, and their results showed that multiple set protocols generated significantly ($p < 0.001$) greater increases in strength. Meta-analyses from Peterson et al. (50) and Rhea et al. (56) examined the optimal training loads for strength gains. Each of these studies advocated multiple sets, although one study examined athletes and the other was applied to recreationally trained weight lifters. The former found 85% of 1 Repetition Max (1RM), 2 days/week, and 8 sets per muscle group to be the optimal "dose" for athletes while the latter reported 60% of 1RM, 3 days/week, and 4 sets per muscle group to be optimal for recreational weightlifters.

It is slowly becoming accepted that single set protocols are effective for novices, however, for continued progression multiple sets must be included (2,15,41). While some studies have reported a single set to be as effective as multiple sets over a short term in beginners, no studies have reported single set protocols to be superior to multiple sets. The faster rate of muscular strength with single sets initially can most likely be attributed to neural adaptations. Strength, lean mass, and muscular endurance can all be improved by use of a single set, but if maximal strength gains are the goal, multiple sets are more effective.

Intensity, Frequency, and Rest between Sets

Determining the optimal training load as well as the prime amount of time between sets is often a difficult task for many recreational weightlifters. These factors, along with training frequency, are large determinants of success of a program, yet are often inhibitory if managed improperly. Managing these factors within recreational strength training is often difficult. In the case of each of these program variables, it often can be easy to sell one or all of them short because of perceived difficulty or fatigue.

Frequency is perhaps the simplest of these three variables to implement into a program design. Training status is one important consideration when assigning training sessions per week (6,41). The NSCA and American College of Sports Medicine (ACSM) (2,6,49) recommend training 2-3 days per week for novices and increasing as training status increases. Recommendations also include allowing at least one day of rest in-between muscle group workouts, with no more than three.

Intensity can be defined as the relative resistance that the muscle is exercising against (38). Often, intensity is expressed as a percentage of 1RM. For example, one may train with 60% of 1RM for 6-8 repetitions or use a resistance that achieves an RPE of 8-9 on the last rep. There is an inverse relationship between intensity and repetitions that can be completed. For example, the intensity for 1-3RM sets would be much higher than for 8-10RM sets. Theoretically, there is a threshold which the intensity must be above for adaptations to occur. As one becomes more acclimated to training, absolute loads must increase to stay above this threshold. This idea is captured by the concept of progressive overload.

Identifying the intensity for any single session depends on training status and the goal for that training session. For example, a novice lifter may gain strength by using loads of 45-50%, whereas a more advanced lifter would need to increase the intensity to increase strength. As training status improves, heavier loads must be used to increase neural adaptations (41). ACSM recommends that novice to intermediate lifters begin by using 60-70% of 1RM for 8-12 reps (2). It is important for more advanced lifters to invoke a wider range of training adaptations; three distinct "training session types" exist according to Kraemer and Hakkinen (38). A "neural" session involves training with heavy resistance (80-100% 1RM) for a low number of repetitions (1-3) for the purpose of improving muscle fiber recruitment and firing rates. It is important to compliment neural training with "hypertrophic" sessions. It is important to implement hypertrophy training in order to continue to have the muscle mass needed to train "neurally". Otherewise the lifter will not have sufficient muscle mass to support the lifting of heavy weights nearer to their 1RM Max. Typically, hypertrophy sessions involve resistance of 60-80% and 6-12 repetitions per set. The last type of loading involves "explosive" training. Explosive training involves low resistances (30-60%) and maximal or near-maximal velocities.

It is generally agreed that maximal strength is best enhanced with long rest periods versus short periods (2,41,67). However, in practice it becomes important to maximize the gains from a workout. It is illogical to take 5 minutes of rest if 3 minutes will provide you with similar recovery. The optimal rest period between sets is currently under debate. It is known that various rest periods will affect the hormonal and metabolic responses to the exercise (2,41,67). For example, hypertrophy training with short to moderate rest periods will stress the adenosine triphosphate phosphor-creatine (ATP-PC) and glycolytic systems whereas neural training with long rest periods will directly affect only the ATP-PC system.

Willardson and Burkett (70) compared volume that could be completed on squat and bench press exercises with rest intervals of 1, 2, or 5 minutes in college-aged men. Volume was based on total number of repetitions that could be completed over 4 sets. In bench press, significant differences were revealed between all rest intervals. In the squat exercise, the 5 minute rest interval produced significantly greater volume than the 1 and 2 minute conditions. However, 1 minute and 2 minute rest intervals showed no significant difference between groups.

Richmond and Godard (59) compared rest periods of 1, 3, and 5 minutes in the same subjects on three different testing days for total work on the bench press. Only two sets were performed in the study. Total work was defined as repetitions x weight. These findings showed significantly greater work performed for 3 and 5 minute rest intervals versus a 1 minute rest interval. However, no significant difference was found between 3 and 5 minute rest intervals. Thus, the authors concluded that 3 minutes was sufficient rest between sets of 8-12 reps.

Ahtiainen et al. (5) performed a six-month crossover study including two different 3 month training periods with 13 recreationally trained men. The crossover design compared short rest (SR, 2 minutes) with long rest (LR, 5 minutes) in the unilateral right leg extension 1RM. No significant differences were found between the protocols. Further research is needed find optimal rest periods between sets.

Neuromuscular Adaptations

Certain neuromuscular adaptations are associated with resistance training that help to clarify the source of increased strength, power, or muscular endurance from training. These adaptations differ, however, between trained and relatively untrained subjects. Untrained subjects often experience strength gains with no corresponding muscle hypertrophy in the initial weeks of training, and these gains can be attributed to neural factors such as: 1) Increased motor unit recruitment, 2) Increased firing frequency, 3) Increased synchronicity of firing and/or 4) decreased co-contraction of the antagonist muscle (6,8,12,25,26,27,38).

Muscle fibers only become stronger if they are activated by an exercise. During the initial stages of training, the activation of agonist muscles is increased while the activation of the antagonists is decreased (38). This would allow for increased net strength of the agonist due to decreased co-contraction of the antagonist. Behm (8) refers to this as energy conservation derived from learning a task. Along with this learning comes improved synchronization of motor units, but the benefits remain unclear (8).

Neural Activity

Electromyographic (EMG) activity is one of the most accessible ways of measuring neural drive. EMG is a combination of the recruitment of motor units and their firing frequency (rate coding). Rate coding refers to the frequency of which any particular motor unit is activated. If it is activated once, little force is produced. However, successive activation increases the force as the twitches summate (6). Recruitment, on the other hand, is the process of activating more motor units in large muscle contractions. Rate coding seems to be more related to improved rate of force development than increased force production itself (8). An increase in EMG actvity suggests that the number of motor units recruited has increased, the motor units are firing at a faster rate, or some combination of both. The change in the relationship between maximal integrated EMG (IEMG) and force over a training period and the IEMG-time curve are demonstrated by figure 2.1.

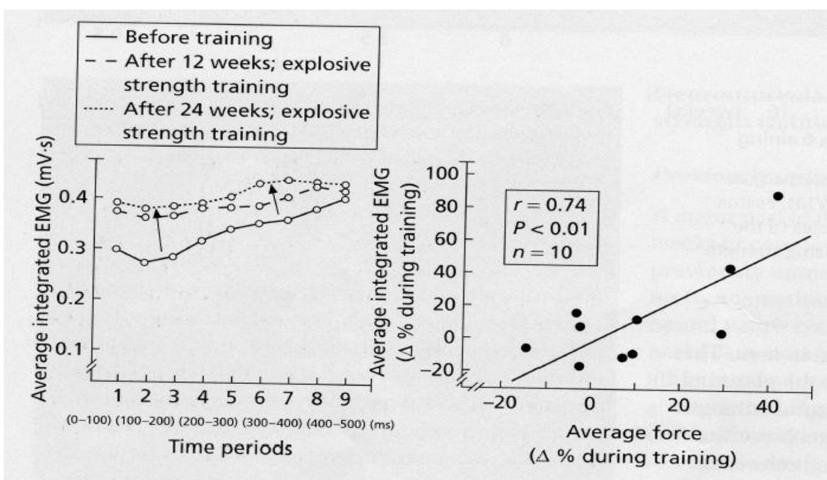


Fig. 2.1 Maximum IEMG-time curve of maximal isometric leg extension (left) and the relationship between changes in maximal IEMG and changes in average explosive force of the trained muscles (right). Reprinted from Kraemer and Hakkinen 2002 (38.)

Hakkinen et al. have reported increases in EMG activity from short (2-3 weeks) and moderate (16-24 weeks) length training (24,25). Hakkinen and Komi (23) however, did report a decrease in EMG following training and concurrent with strength gains in the quadriceps. This is perhaps due to an increased sensitivity of the muscle spindles.

Hakkinen et al. (27) reported significant increases in isometric force, cross-sectional area (CSA), and average IEMG of the leg extensor muscles following 3 weeks of intensive resistance training in women. Maximal force per muscle CSA increased significantly; meaning that force increased at a much higher rate than the muscle hypertrophied. This significant correlation between changes in IEMG and changes in force supports the notion of neural factors being prevalent in the early stages of training. In addition, the greatest IEMG activation was seen after the completion of the training period. This fact could be viewed in support of periodization, as rest and reduced training resulted in the maximal neural activation.

Kraemer and Hakkinen (38) reported that the time course of maximizing EMGs seem to differ between men and women, as maximum EMGs of trained muscles in women seem to plateau slightly earlier than in men. Force capabilities of muscle fibers in men and women are roughly equivalent per unit of CSA. In addition, relative increases in hypertrophy and neural adaptations are similar in men and women over a training period. However, absolute hypertrophy and strength development will be higher in males on average because of hormonal differences, specifically with the concentration of blood testosterone (38). It has been reported that when comparing strength between sexes, women's upper body strength lags further behind men's (55% of men) than does their lower body strength (72% of men) (37).

Hypertrophy

It has long been known that maximal strength is directly related to the CSA of a muscle (12,26). Prolonged strength training will result in further strength gains through muscular hypertrophy. Hypertrophy results from an increase in the CSA of the muscle fibers, not an increase in number. Hypertrophy is a product of increases in actin and myosin and an increase in the number of the myofibrils within a muscle fiber (6). Typically, type II fibers show a faster rate of growth than type I fibers because of greater recruitment due to higher force output and contraction velocities that are necessary in strength training.

Hypertrophy in men has been extensively studied, and is far more understood than hypertrophy in women because of the effect of testosterone. Hakkinen et al. (27) reported significant (yet significantly less than IEMG) increases in CSA of the quadriceps femoris in women following three weeks of training. However, these increases were highly variable between individuals. Some women showed increased muscle mass whereas others did not due to interpersonal differences in serum testosterone levels.

Kraemer et al. (40) analyzed muscle hypertrophy in women by using four treatment groups including upper-body or total-body training with either a "neural" or "hypertrophic" training range. Training was undergone for the course of 24 weeks. Hypertrophy was measured by examining CSA in muscles in the upper arms, quadriceps, and hamstrings. The principle of specificity was supported as CSA increased at all time points for all groups in the arm muscles, however, CSA in the leg muscles was only increased in the total-body training groups. Following week 4 (T2) and week 9 (T3), CSA in the thigh muscles of the total-body groups was significantly greater than the upper-body groups. These findings are converse to those of Chilibeck (12) who found increases in arm lean mass for only the first 10 weeks of training and increases in lean mass in the trunk and legs only for the second 10 weeks of training.

The Specificity Principle

One of the most basic concepts of resistance training is that of specificity. One must train in a specific manner to produce a specific training outcome. Achieving hypertrophy and strength gains through training require individual types of training. For example, a requirement to achieve hypertrophy is muscle tension for a sufficient duration to provide a signal for amino acid uptake and protein synthesis (38). Typical hypertrophic sessions include 4-6 sets of 6-12 repetitions with loads of 60-80% with short to moderate rest periods (6,38). Training for strength requires loads of 80-100% of 1RM with 1-3 repetitions, a high number of sets, and long rest periods (6,38). Whereas hypertrophic training increases muscular size to support the strength phase, "strength sessions" fatigue the nervous system as well as the muscles. This fact is supported by reductions in EMG, force, and a shift in the force-time curve following a heavy session (see figures 2.2-2.3).

Hakkinen and Keskinen (26) demonstrated this concept of specificity by comparing strength trained athletes (SA), sprinters (SPA), and endurance trained athletes (EA) in terms of cross-sectional area (CSA), maximal isometric force, and force-time characteristics. SA demonstrated the greatest CSA and maximal isometric force production. SPA showed the shortest times to produce equal force levels as would be expected from athletes training in explosive sprint and jumping type situations. EA fell significantly behind in all of these categories as would be expected via their training method. Interestingly, when force was related to CSA, SA still demonstrated greater values and SPA, and both were significantly greater than EA.

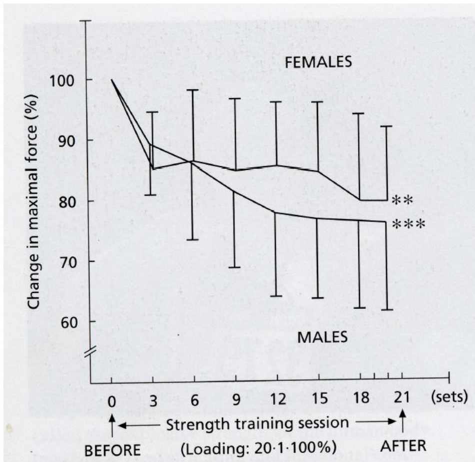
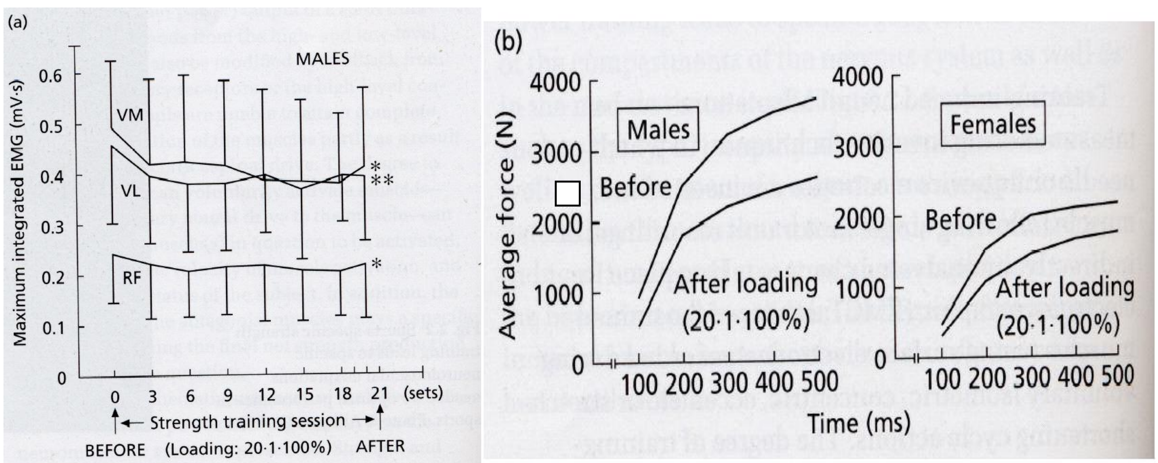


Fig. 2.2 Mean Relative changes (± SD) in maximal isometric bilateral leg extension force during a heavy resistance loading session in male and female athletes. (From Kraemer and Hakkinen 2002 (38.)

Fig. 2.3 (Below) (a) Mean (± SD) maximum IEMGs of the quadriceps muscles during a heavy loading session in males. (b) Average force-time curves of the leg extensors during the maximal isometric leg extension in male and female strength athletes before and after the heavy resistance loading session. (From Kraemer and Hakkinen 2002 (38.)



Hormonal Adaptations

The hormonal changes that occur with resistance training are an important factor in the development of strength and muscle mass. The intricacies of endocrine adaptation are beyond the scope of our work here, but it is important to mention a few of the hormones that may affect the utility of a strength training program design. There are four general classes of hormonal adaptations that can occur with resistance training (42): 1) acute changes during and post-resistance exercise, 2) chronic changes in resting concentrations, 3) chronic changes in the acute response to a resistance training stimulus and 4) changes in receptor content. In short, hormonal adaptations can occur when levels of circulating hormones are raised and there are adequate numbers of binding receptors to interact with and begin cellular changes. Several factors have been reported to affect the level of testosterone response to a training session, including muscle mass involved, intensity, volume, training experience, and nutritional intake (42). Large muscle group exercises such as the Olympic lifts have been shown to produce the largest elevations in testosterone. Higher intensities have generally been reported to produce greater testosterone increases than lower intensity workouts (4,42), however, Ahtiainen et al. (5) reported no difference in testosterone response between two protocols of varied intensity.

As stated previously, the primary hormonal influence, as well the largest source of the gap between hypertrophy ability in sexes, is that of testosterone. Many other hormones have been suggested to play a role in hypertrophy and strength gains, such as growth hormone binding protein, insulin-like growth factors, cortisol, and insulin; however, only testosterone warrants discussion for our purposes. The primary difference in the ability to produce hypertrophy, and therefore the greatest strength gains, between men and women is the presence of higher levels of testosterone in men. A review by Kraemer et al. (42) reports that most studies have shown resistance exercise to acutely increase total testosterone in men, while no change or slight elevation may take place in women. In fact, Hakkinen et al. (27) reported a high variability among women in testosterone levels, but no significant increases during short-term training. Basal concentrations, however, remain more difficult to adjust (3,42). The primary long-term adaptation of resistance training on testosterone appears to be the increase in level of response to an acute bout.

Monitoring a Resistance Training Session

It has been reported previously that directly monitoring a resistance training program can increase the musculoskeletal adaptations to that program because of a greater rate of increase in training load (47). It is possible that the presence of a supervisor during training enhances competitiveness and motivation, if not merely accountability. It has also been anecdotally observed that many novices begin resistance training programs but do not continue because of lack of enjoyment due to initial difficulty. It has been theorized that using Ratings of Perceived Exertion (RPE) during strength training may lower drop-out rates (21).

In addition, RPE may serve to help prevent OTS (13,66). Day et al. (13) and Sweet et al. (66) hypothesized that using RPE to monitor a resistance training session is integral to the success of a periodized program because of the importance of not training to heavy on light days or visa versa. RPE could potentially be a better indicator of proper training load than a percentage of 1RM.

Traditionally, RPE has been associated with aerobic exercise (13,21,66). However, RPE can also be a useful tool for monitoring resistance training. Lagally et al. (45) suggest that RPE is related to relative exercise intensity, which, in terms of resistance training would be a percentage of 1RM. Traditionally, the Borg 15-category scale (table 2.1) has been applied to estimate exercise intensity. It has been shown to be a valid method for assessing exercise intensity in resistance training (20,21,45,66). An alternative to the Borg scale is the CR-10 RPE scale (table 2.1). This scale simplifies RPE by using a 1 to 10 scale and has also been shown to be valid (13). RPE for resistance training is generally noted in terms of session RPE, or the overall difficulty of the training session. This measurement is generally assessed thirty minutes following the session to prevent difficult or easy elements near the end of the session from skewing the overall rating (66). In addition, Sweet et al. (66) suggested assessing RPE for each set to minimize the effect that long rests may have on the overall session and to more accurately assess the accuracy of the training load.

Table 2.1 A comparison of Borg-15 point and CR-10 RPE scales.

Borg 15-point	CR-10 RPE	Description
6	0	Complete Rest
8	1	Very, Very Easy
10	2	Easy
12	3	Moderate
14	4	Somewhat Hard
15	5	Hard
16	6	
17	7	Very Hard
18	8	
18.5	9	
19	10	Extremely Hard (almost maximal)
20	*	Exhaustion

Concurrent Resistance and Endurance Training

The question of the compatibility of aerobic training and resistance training in regard to gaining strength has long been of interest to investigators. While resistance training and aerobic training are both necessities for sport performance or general health, if strength or power gains are the sole objective, it appears that endurance training can interfere with strength gains (6,31,35). Kraemer et al. (35) reported that combining the two training methods decreased strength by producing increases in cortisol that lead to catabolic effects in muscle tissue. Strength training alone, however, reduced cortisol, and in turn increased the testosterone-cortisol ratio. It has also been suggested that the aerobic conditioning varies the adaptation mechanisms of the muscle fibers. However, reports to the contrary have been published, including Hakkinen et al. (28), which reported no difference in strength gains between strength only or concurrent strength and endurance training groups. Power production was impaired in the bi-modal training group. Further research to support these findings is pertinent, as the incompatibility of the two training methods when training for strength is a long held tenet.

Overtraining

In the past, research on overtraining has primarily focused on the aerobic exercise. However, the necessity of creating periodization models reveals a need for study of anaerobic overtraining. In addition to maximizing strength gains, the other primary purpose for using periodization in a training program is to prevent staleness. The General Adaptation Syndrome (GAS) provides a theoretical framework for understanding Overtraining Syndrome (OTS), yet the true cause of the condition remains disputed. Diagnosing the condition has proven equally as difficult, as many of the signs and symptoms of overtraining are variable between aerobic and anaerobic overtraining (17). While overtraining has generally been a problem with athletic populations, it is possible that recreational lifters who become experienced may push themselves to a point of overtraining. In this case, as opposed to athletes, there is no coach there to watch over the lifter to see signs of OTS.

The effects of OTS can be devastating to one's mental and physical health. Of these effects, possibly the most devastating can be the effects on one's psyche. Baechle (6) reports that the major effect of anaerobic resistance overtraining is a loss of desire to train and a change in mood state. This change in mood is thought to be the first indication of impending OTS (63). However, it is the decline in performance that usually presents the idea that the OTS is present (63). While specific physiological effects of OTS require more research, the exact physiological cause of OTS is even more unclear. While it is known that the condition stems from excess training volume and intensity (6,17,38,63) and that the GAS theory applies, it is uncertain why the body responds in this manner. One of the new primary theories proposed by Lucille Smith (63) is that OTS is due to tissue trauma and an excess of cytokine molecules in the body. Essentially, the body is worked so hard that it feels it is suffering injury or illness, and the cytokines are released for injury or repair. However, an increase in cytokines coincides with altered hormone levels, such as increased cortisol or decreased hypothalamus activity, that might account for altered mood states or a decrease in strength and muscle mass. We suggest continuing further research in this area.

In addition to finding the cause of OTS, the condition remains difficult to diagnose correctly. It has been stated that the critical piece of diagnosing overtraining syndrome is a decreased performance capacity (44), not simply a manifestation of signs and symptoms. Kraemer and Hakkinen (38) claim, however, that the condition most likely occurs less than some might think, as it may be easier to blame sub-par performance on OTS than on mistiming of or improper training. In either case, these decrements may occur too late to stop the effects of OTS. It is also difficult to distinguish overreaching from overtraining, and Halson and Jeukendrup (29) claim that there is no evidence to confirm the continuum idea that overreaching will develop into overtraining (see figure 2.4).

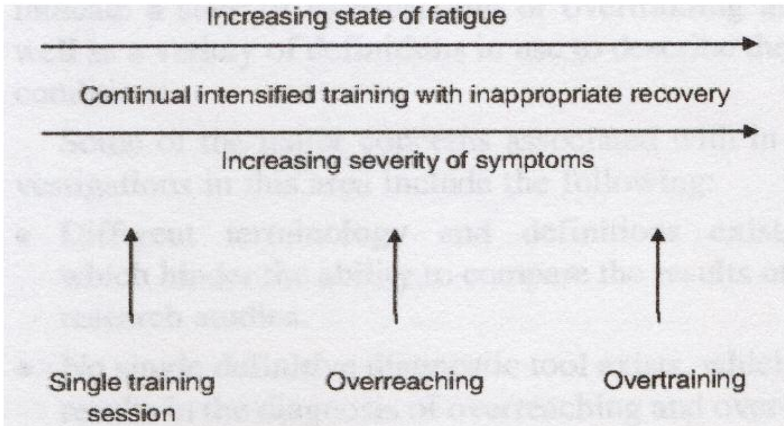


Fig. 2.4 A model of the continuum idea of overtraining. From Halson and Jeukendrup 2004 (29).

In 2002, Urhausen and Kindermann (68) reported that tools available in diagnosing overtraining (both aerobic and anaerobic) had not improved much in recent years. Suggested tools for diagnosing anaerobic OTS include sport specific testing, examining any loss of desire to train or change in mood state, as well as excessively high acute ephinephrine and norepinephrine levels. Other neuroendocrine factors (see table 2.2) have been implicated as having possible associations with overtraining, but evidence is currently lacking to support conclusive findings (17). Finding new tools may prove difficult as it is unethical to induce a state of overtraining for research (29) and subsequently much research is possibly being done on overreaching subjects instead (17,29). We propose that it is most likely easier to invoke periodization and variation of acute exercise variables in a training program to prevent OTS than it would be try to decipher and back off the fine line that separates extreme overreaching and OTS.

Table 2.2 Suggested tools for diagnosing OTS. Reprinted from Urhaussen and Kindermann 2002 (69).

Tool		Changes in OTS	Suitability
Sports-specific performance	(Sub)maximal exercise	↓	Gold standard; regular testing problematic (in most sports)
Ergometric performance	Anaerobic threshold	(↑)	Does not diagnose OTS, but targets other training errors
	Maximal exercise	↓ or ↔	Incremental graded tests less sensitive than tests-to-exhaustion (or time-trials)
Neuromuscular excitability	At rest	↓	Difficult method; needs more data
Mood profile	At rest	↓	Very sensitive; may be manipulated
Subjective complaints	At rest, submaximal exercise	↑	'Heavy legs': very common; sleep disorders: less common; may be manipulated
Borg-scale	Submaximal exercise	(↑)	Small changes
Heart rate	At rest	↔	↑ may indicate other problems (infection)
	Variability	?	Insufficient data
	Maximal exercise	(↓)	Rather small changes
Respiratory exchange ratio	(Sub)maximal exercise	↓	Limited data
Lactate	Submaximal exercise	(↓)	Does not diagnose OTS, but excludes other training errors
	Maximal exercise	↓	Typical change, but probably not in every sport
CK, urea	At rest	↔	↑ may indicate muscular overuse or prolonged carbohydrate depletion
Testosterone	At rest	↔	↓ may indicate high physiological strain?
Cortisol	At rest	↔	↑ may indicate high physiological strain
	Maximal exercise	(↓)	Differentiation between intensive training and OTS may be questionable
ACTH	Maximal exercise	↓	Very sensitive, differentiation between intensive training and OTS may be questionable
Catecholamines	Excretion (urine)	↓	Marked ↓ as late indicator of OTS
	Maximal exercise (plasma)	↓ or ↔	Parallels changes of lactate

ACTH = adrenocorticotropic hormone; **CK** = creatine kinase; ↓ = decreased; (↓) = slightly decreased; ↔ = unchanged; ↑ = increased; (↑) = slightly increased; ? = not established.

Background of Periodization

Periodization is thought to have been first theorized and practiced by coaches in the former Soviet Union and other Eastern European countries (6,15,38,49,64). Specifically, Russian scientist Leo Matveyev is credited as the first to propose periodization (6,64). Initially, periodization was used for athletes seeking to peak once or twice a year for competitions (e.g. competitive weight lifters). However, periodization has now become an established part of resistance training programs. The main foci of periodization are the maximization of strength gains and the prevention of OTS.

Periodization has been closely linked with the concept of the General Adaptation Syndrome (GAS) developed by Dr. Hans Seyle (6,11,38,62,64). The GAS theory did not originally relate to strength training, but it was rather a theory on how the body responds to all types of stressors. Seyle defines a stress reaction as “a nonspecific response of the body to any demand” (62). In addition, he states that “all stress reactions are essentially defensive”, and that these reactions may cause more problems for the body than the outside agent itself. Resistance training, and the body’s response to it, are initially quite traumatic for the body and should be monitored closely for novice lifters. Thus, the concept of progressive overload must be adopted. Progressive overload simply means that the program design will gradually increase intensity and give the body sufficient time to adapt to the more intense stimuli.

Garhammer (18) first applied the GAS concept to resistance training by linking the three stages of GAS to the stages of training. The first phase is the shock/alarm phase (11). In this phase of training, new or more intense stress is placed on the body and is forced to respond to the stimulus. At this point, the body will most likely experience soreness and performance will most likely suffer decrements. This adaptation period is often known as necessary overreaching. The breakdown of muscle tissue that occurs during the first stage is necessary to recruit what is known as super compensation (11). When super compensation occurs, the body moves into the resistance phase, which also correlates to the preparation period of training (64). During the resistance phase, the body adapts to the stresses placed on it by making neurological adjustments; which in turn, lead to increased performance (6). However, if the training regiment is too demanding and lacks variation or rest periods, the body will fall into the exhaustion phase and lose the ability to fight the stress (OTS). Simply stated, the theory behind periodization is that prescribing variations in intensity and volume will promote maximal strength gains and prevent staleness by always staying one step ahead of the body's adaptive mechanisms.

The inception of periodized programs was accompanied by terminology to describe training periods (6,38,64). The largest of these time periods was generally a calendar year and is known as a macrocycle. The macrocycle would then be broken down into smaller sections known as mesocycles (several months) and microcycles (a few weeks) which would be aimed at more specific training goals. Matveyev's initial model of periodization involved three major divisions of training: preparatory, competition, and transition (46). Stone, O'Bryant, and Garhammer (65) later added a "first transition" period between the preparatory and competition periods to create the conventional model of periodization. This model, as depicted by Figure 1.1, illustrates a model that is appropriate for novice or relatively untrained subjects (6).

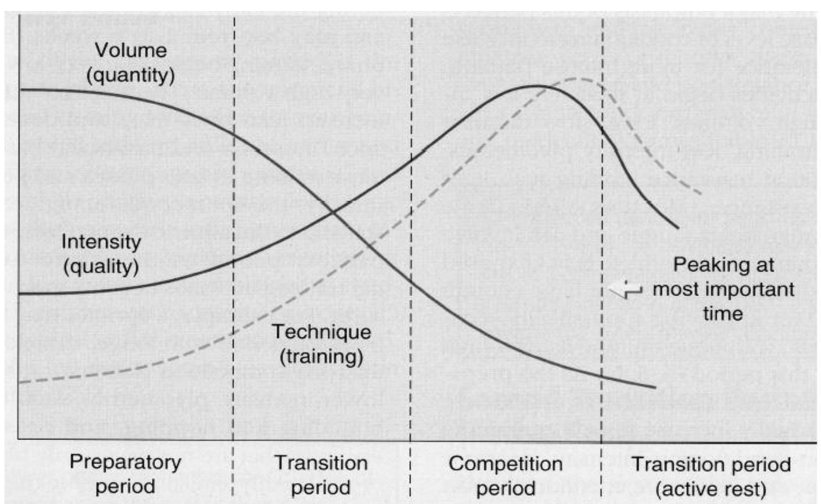


Figure 2.5 Matveyev's model of periodization. Reprinted from Baechle and Earle 2000 (6).

Each of these periods has a specific targeted muscular adaptation. The preparatory period is designed to elicit hypertrophy and strength in the muscles that will allow for maximal loads during later training. During this phase, total volume is high, while intensity is kept at a low to moderate level. The preparatory phase sequentially consists of base conditioning, hypertrophy training, strength training, and power (table 1.2).

Table 2.3

A Periodization Model for Resistance Training

Period	Preparation ⟶ First transition			Competition			Second transition (active rest)
Phase / Variable	Hypertrophy/ endurance	Basic strength	Strength/ power	Peaking	O R	Maintenance	
Intensity	Low to moderate	High	High	Very high		Moderate	Recreational activity (may not involve resistance training)
	50-75% 1RM	80-90% 1RM	87-95% 1RM† 75-90% 1RM‡	≥ 93% 1RM		≈80-85% 1RM	
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	

Reprinted from Baechle and Earle 2000 (6).

The first transition period involves technique training and serves literally as a “transition” from high volume to high intensity training. During the competition phase the goal is either peaking or maintenance depending on the sport and the number of competitions per season. Finally, the second transition period provides a time of rest and restoration for the athlete in which common recreational activities are performed to keep a level of general conditioning but also allow the athlete to recover from the season. This traditional model is known as linear periodization and involves progressively increasingly intensity over several microcycles. An alternative to linear periodization developed by Poliquin (53) is known as undulating periodization. Undulating periodization calls for more frequent variations in volume and intensity on a daily or weekly basis. The theory behind the undulating model is that linear intensification will create neural fatigue and leaves little time for regeneration (6,53). Undulating periodization on the other hand, provides more frequent alterations in stimuli to stimulate the neuromuscular system. This type of periodization model was developed to allow for athletes with long seasons to train throughout the season.

Periodization Models and Maximizing Strength Gains

It is now generally agreed that some form of periodization is needed for maximal strength gains to occur (9,15-16,41,46,49,52,55,58,71), although a few studies claimed periodization to be no better than a non-periodized program (7,60). In 2004, Rhea and Alderman (58) performed a meta-analysis of studies involving periodized programs versus non-periodized programs with a purpose of finding a specific magnitude of the strength increases. Eleven different studies met the inclusion criteria. They reported that periodized programs elicited 0.25 standard deviations greater strength or power than non-periodized programs.

Few studies have directly examined the effectiveness of linear and undulating periodized programs. Ivanov et al. (32) compared a non-periodized program to undulating periodization and found the undulating model to be superior in producing strength gains in 1RM bench press and squat. However, since no linear program was included, this can only be assumed to be due to the fact that periodization is simply more effective than models with no alterations in intensity.

Kraemer et al. (36) compared the effectiveness of an undulating periodized program to a single-set circuit training protocol over a nine month period in collegiate female tennis players. The study evaluated various performance variables including strength and found that that the periodized group demonstrated significant increases in bench press, shoulder press, and leg press 1RM at 4, 6, and 9 months. The single set group only significantly increased strength at 4 months. This is the only study found to include an undulating program for females, but it does not directly compare the program to a linear program. It is possible that the results may be due to the superiority of a periodized program over a single-set program.

Baker et al. (7) compared linear periodization (LP), undulating periodization, and a non-periodized model for 12 weeks and found no significant differences between groups for 1RM squat, 1RM bench press, or vertical jump. The undulating model used by Baker varied the intensity and volume on a biweekly basis. While no significant differences were found between groups, the undulating model did show greater percentage increases in strength than the other protocols.

Rhea et al. (54,57) conducted two studies directly comparing LP and Daily Undulating Periodization (DUP). One of these studies (54) examined effect of the protocols on strength gains, while the other (57) examined the effect of LP, DUP, and reverse linear periodization (RLP) on strength and endurance. Each of the studies included recreationally trained lifters from college weight training classes. In addition, both studies equated volume and intensity for all subjects in order to attribute differences between groups directly to the program design. Rhea et al. (57) reported no significant differences in strength gains between groups, but it is most likely due to the fact that the training sessions included extremely high repetitions (15-25) aimed at improving muscular endurance. The study aimed at improving strength (53), however, showed DUP groups to experience significantly greater percent gains in strength for both exercises, and significant absolute gains for the leg press.

In summary, periodization has is noted in the literature as an effective means of preventing OTS and maximizing strength gains when applying a strength training program. The literature is mixed, however, on the determination of what type of periodized program is most effective for increasing strength. Therefore, further research needs to be done in the area of periodization (39), especially in terms of comparing undulating and linear models (15,16,38) as well as different types of undulating periodization (54).

CHAPTER III

METHODOLOGY

Methods

Purpose

The purpose was to expand the findings of Rhea et al. (54) by adding a weekly undulating periodization (WUP) group and by including female subjects in the study. This may be the first study to compare LP, DUP, and WUP programs as well as compare these protocols to each other with the inclusion of female subjects. Total volume and intensity were equated for all groups throughout the training period. Equating these variables allowed the attribution of differences in strength gains or body fat losses to program design only and not to higher levels of volume or intensity. Maximal bench press and leg press measurements allow for a proper measurement of upper- and lower-body strength in a recreational weightlifting population because little skill is required to perform these exercises. Skinfold measurements and anthropometric measures (chest and thigh circumference) were taken to examine any changes in body composition through the training period. Furthermore, RPE was examined throughout the training program in order to determine if one workout structure is significantly different from the others. It has been theorized that significantly higher RPE's may be an indicator of impending OTS.

Subjects

Twenty men and ten women were recruited from college weight-training classes. Subjects were required to sign an informed consent form, which was approved by an Institutional Review Board prior to participation in the study. In addition, all subjects completed a medical history form including prior history of strength training. Subjects had prior weight training experience, but no subjects reported consistent training within the six months prior to the study. Subjects agreed to abstain from any additional resistance training during the course of the study. Subjects were informed that they must attend 90% of the training sessions to be included in the study. Three absences disqualified a participant from the study. Two subjects withdrew from the study for unrelated reasons. This resulted in a total of twenty-eight subjects who completed the study. Subject characteristics are listed in Table 3.1.

Table 3.1 Subject characteristics: group means ± SD.*

Group	LP	DUP	WUP
N	9 (5m, 4f)	10 (7m, 3f)	9 (6m, 3f)
Age (y)	22.67± 3.61	23.90± 5.11	20.11± 1.54
Weight (kg)	155.17± 24.22	167.40± 30.06	159.89± 33.56

*m=men, w=women; LP=linear periodization, DUP=daily undulating periodization, WUP=weekly undulating periodization.

Testing

Subjects were tested pre, mid, and post-training. Mid-testing was conducted following four weeks of training. The testing consisted of body weight, body composition testing using skinfold calipers, thigh and chest circumference measurements, and 1RM testing on both bench press and leg press exercises. Body composition testing was performed with a seven-site skinfold test using Lange Calipers. The seven sites chosen for the test were pectoral, thigh, subscapular, suprailiac, abdominal, midaxillary, and triceps. Thigh and chest circumferences were taken using standard tape measurers. Thigh circumference was measured on the subject's dominant leg. Bench and leg press testing was done on standard free-weight stations. For 1RM testing, all subjects were required to warm up and perform light stretching before performing 10RM with a light resistance (40-60% of 1RM) for each exercise. The load was then increased to an amount estimated to be less than the subject's 1RM. The resistance was progressively increased until the subject could only perform 1RM. The amount of each increase was based on the perceived difficulty of the preceding 1RM by the subject.

Before the first testing session, subjects were familiarized with the Borg C-10 scale for determining RPE. Each of the testing sessions was performed at the same time of day to account for diurnal changes in strength as well as following the same number of days of rest. In addition, all tests were conducted by the same researcher during each of the three test dates to maintain test-retest reliability.

Training Protocol

Following testing, males and females were separated and randomly assigned to one of three training groups: LP (N=9), DUP (N=10), WUP (N=9) and began a 9-week resistance training program. Subjects trained 3 days per week with a minimum of 48 hours in-between sessions. Exercises performed are listed in table 3.2. The exercises performed each day were identical for each group. Training volume and training intensity were altered contrarily for each group, but were equated over the course of the study. The numbers of repetitions performed per set are defined in table 3.3.

The Borg CR-10 scale was used to monitor subjects' perceived intensity of each exercise set and exercise session. After each set of exercise and 30 min post-exercise subjects were asked to give an RPE for the difficulty of each exercise set and training session. A rating of "0" on the RPE scale represents rest or no effort and a rating of "10" represents maximal effort or most stressful effort performed. For bench press and leg press, a percentage of 1RM from the most recent testing session was figured to determine the resistance to be used for each training session (table 3.2). For all other exercises, subjects were instructed to achieve an RPE of "8" or "9" on the final repetition of each set.

Table 3.2 Schedule of Exercises Performed by Day.

MONDAY	WEDNESDAY	FRIDAY	8RM= 80%
			6RM= 85%
Bench Press	Bench Press	Bench Press	4RM= 90%
Leg Press	Leg Press	Leg Press	
Seated Row	Lat Pulls	Upright Rows	
Lunges	Leg Extension	Leg Curls	
Preacher Curls	Standing Calves	Triceps Extension	
Incline Sit-Ups	Back Extension	Knee Raises	

Table 3.3 Schedule of Exercise Volume by Group. Sets x Reps.

LP Group	**Weeks 1-3**	**Weeks 4-6**	**Weeks 7-9**
	3x8	3x6	3x4
Incline Sit-ups, Back Ext., Knee Raises	3x15	3x12	3x10
DUP Group	**Monday**	**Wednesday**	**Friday**
	3x8	3x6	3x4
Incline Sit-ups, Back Ext., Knee Raises	3x15	3x12	3x10
WUP Group	**Weeks 1,4,7**	**Weeks 2,5,8**	**Weeks 3,6,9**
	3x8	3x6	3x4
Incline Sit-ups, Back Ext., Knee Raises	3x15	3x12	3x10

Statistical Analyses

The statistical analysis of the data was accomplished by using a 3x3 analysis of variance (ANOVA) with repeated measures (group x time). A subsequent repeated measures ANOVA was then conducted for each gender, with "group" collapsed. Tukey's post-hoc tests were conducted where appropriate. An alpha of .05 was used to determine significance for all analyses. All values were reported as mean $\pm$ SD.

CHAPTER IV

RESULTS & DISCUSSION

Results

Primary Hypothesis

Ho1: No significant ($p<.05$) difference will exist among periodization models in terms of strength gains during nine weeks of resistance training.

There was no significant ($p > .05$) difference between groups (LP, DUP, WUP) for either bench press 1RM or leg press 1RM at all time points. Percent increases in 1RM in DUP were lower than the other two protocols for both bench press and leg press, but these differences were non-significant. These changes are summarized in table 4.1.

Table 4.1 Strength measures results: group means ± SD.

Group				
Bench Press				
	T1	T2	T3	%Δ T1-T3
LP	131.11± 52.07	146.67± 56.57	162.78± 58.42	24.2
DUP	154.50± 74.18	170.0± 71.99	181.50± 70.52	17.5
WUP	145.0± 40.85	162.22± 45.15	180.56± 43.33	24.5
Leg Press				
	T1	T2	T3	
LP	370.0± 116.30	500.0± 122.68	685.56± 165.16	85.3
DUP	399.50± 139.77	554.0± 151.82	715.0± 160.78	79
WUP	355.56± 89.32	517.78± 118.40	710.0± 152.97	99.7

LP= Linear Periodization; DUP= Daily Undulating Periodization; WUP= Weekly Undulating Periodization.

Figure 4.1

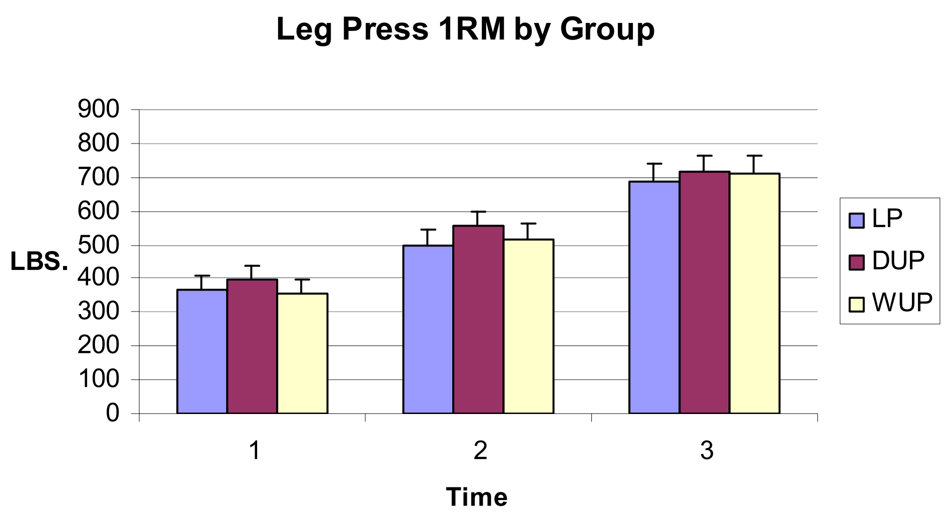
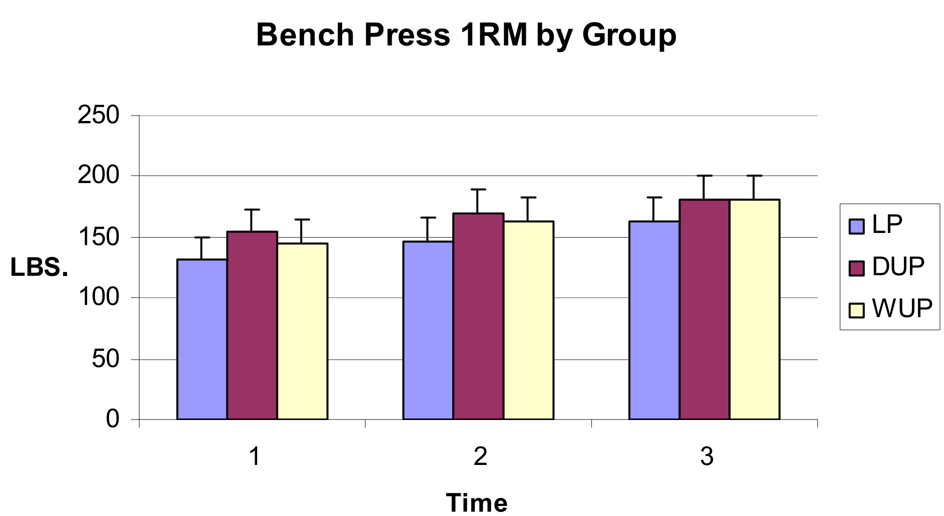


Figure 4.2



<u>Secondary Hypothesis 1</u>

Ho2: No significant ($p < .05$) differences will be made in strength for across groups during nine weeks of resistance training.

Ha2 was actually true, as bench press and leg press strength was significantly ($p < .05$) greater across time for each gender. For bench press, 19% and 32% increases from

T1-T3 were seen for males and females, respectively. In regard to leg press, males demonstrated an 80% increase over the course of the study, while females increased 108%. For males and females, mean bench press and leg press 1RM's were significantly ($p < .05$) greater between all time points. These results are summarized in Table 4.2.

Table 4.2 Strength measures with group collapsed: mean ± SD.

Exercise				
Bench Press	[lbs.]			
	T1	T2	T3	%Δ T1-T3
Males	176.11± 43.20	194.17± 41.10*	209.44± 38.73*	18.93
Females	86.0± 18.97	98.50± 20.15*	113.50± 22.24*	31.98
Leg Press	[lbs.]			
	T1	T2	T3	
Males	435.0± 97.57	598.33± 95.32*	783.33± 133.68*^	80.08
Females	269.50± 46.57	393.0± 56.77*	561.00± 48.01*^	108.16

* Significantly ($p < .05$) different from T1.
^ Significantly ($p < .05$) different from T2.

Figure 4.3

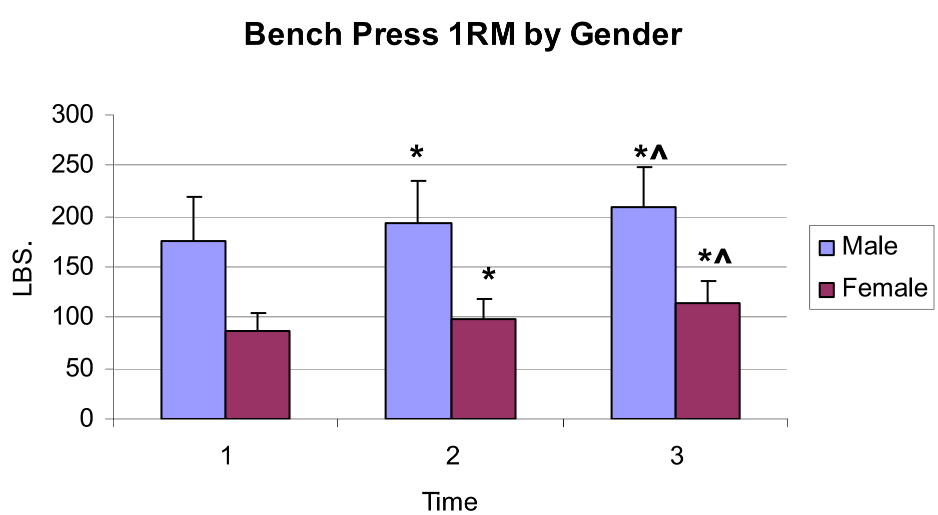
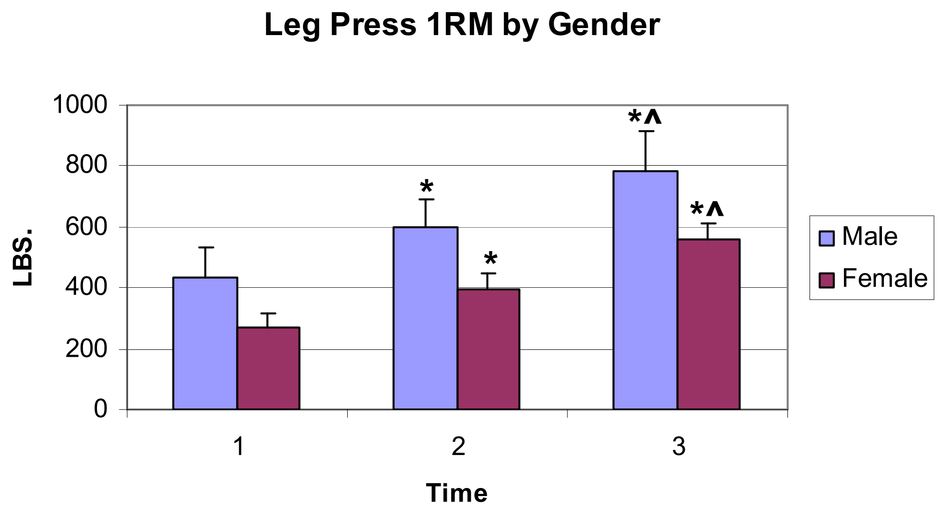


Figure 4.4



Secondary Hypothesis 2

Ho3: No significant (p< .05) differences will exist in terms of body composition for all groups following nine weeks of resistance training.

Changes in body composition were observed over the course of the training. Significant decreases in body fat percentage were observed from T1-T2 and T1-T3 and non-significant decreases were observed from T2-T3 when groups were collapsed. Mean chest circumference for all subjects decreased from 94.53cm to 93.73cm from T1-T2, and then increased from 93.73cm to 95.48cm at T3. Chest circumference changes reached the significant level from T2-T3, but not from T1-T2 or T1-T3. Mean thigh circumference increased at all time points (T1-T3) for all subjects. Thigh circumference increased from 50.57cm to 52.94 cm from T1-T2 and from 52.94 to 53.48cm from T2-T3. The increases in thigh circumference were significant from T1-T2 and T1-T3 with no significant difference observed from T2-T3.

Table 4.3 Body composition results: group means ± SD.

Group				
Body Fat %				
		T1	T2	T3
LP		24.90± 9.27	23.97± 9.02	23.65± 8.73
DUP		21.09± 7.53	19.90± 7.84	19.69± 7.74
WUP		21.57± 11.24	20.71± 10.47	20.74± 9.81
Chest Circum.	[cm]			
		T1	T2	T3
LP		91.94± 7.28	92.22± 8.76	93.78± 7.61
DUP		96.75± 9.91	94.70± 10.02	96.95± 9.74
WUP		94.89± 9.49	94.27± 7.56	95.72± 8.19
Thigh Circum.	[cm]			
		T1	T2	T3
LP		49.44± 4.65	52.78± 5.44	52.72± 5.40
DUP		51.90± 4.45	53.40± 4.98	53.80± 5.37
WUP		50.22± 5.31	52.61± 4.77	53.89± 3.79

LP= Linear Periodization; DUP= Daily Undulating Periodization; WUP= Weekly Undulating Periodization.

Secondary Hypothesis 3

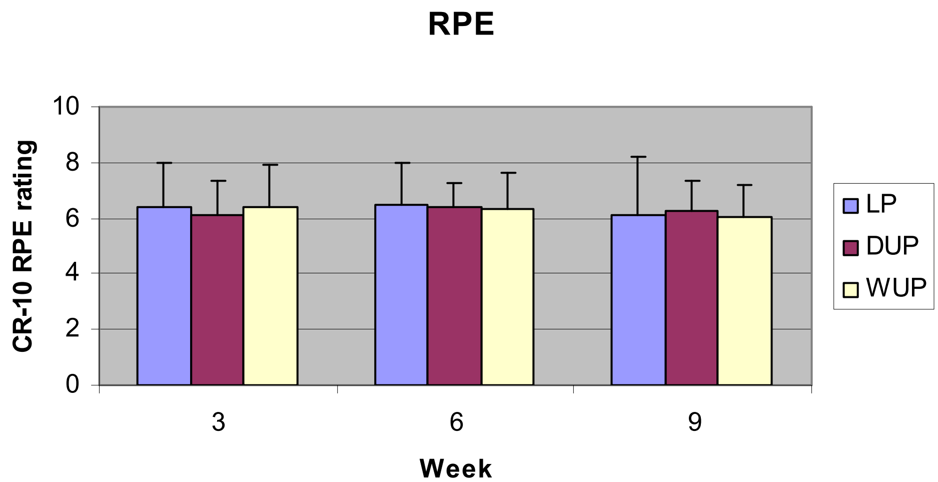
Ho4: No significant ($p < .05$) differences will be observed in RPE scores between groups during the course of the study.

Ho was correct, as no significance was observed in mean RPE between groups at any time point. Linear and weekly undulating periodization models showed an overall non-significant decrease in mean RPE from T1-T3, while daily undulating periodization actually showed a 3.5% non-significant increase from T1-T3. These results are summarized in Table 4.4.

Table 4.4 Ratings of Perceived Exertion results: group means ± SD.

RPE				%Δ T1-T3
	T1	T2	T3	
LP	6.43± 1.54	6.48± 1.54	6.08± 2.14	-5.4
DUP	6.08± 1.27	6.42± 0.86	6.29± 1.03	3.5
WUP	6.41± 1.47	6.30± 1.29	6.02± 1.16	-6.1

Figure 4.5



Discussion

The purpose of this study was to determine the effectiveness of three periodization protocols for improving strength and also to determine if any one of these methods is more effective than the other two. While no significant differences were observed between groups, each of the three models proved effective in increasing bench press and leg press strength over the course of nine weeks. In addition, these models were applied to both men and women, and strength gains were observed in both genders.

The changes in body composition indicate that strength increases during those time points were not solely due to neural factors. Body fat was reduced while increases in chest and thigh circumference were observed. Caution must be used in interpreting the chest circumference, however, no significant differences were seen from T1-T3, yet significant differences were indicated from T2-T3. While the T2-T3 change was found to be significant, it may not be all that meaningful as a difference of less than 2 cm existed.

While muscle cross-sectional area (CSA) was not measured, it is likely that these changes in chest and thigh circumference were due to an increase in muscle fiber size (hypertrophy).

It is interesting to examine the mean session RPE ratings for each group. There was no significant difference in RPE between groups; this may be due to insufficient training time or workload. Most likely, these recreationally trained non-athletes could train for an extended period before experiencing overtraining syndrome compared to better trained lifters. Therefore, in this particular study, the RPE readings are not of use in determining which protocol is more efficient at battling the effects of overtraining syndrome. The RPE measurement does provide, however, a measure of reliability for using a percentage of 1RM as a measure of intensity. Since there was no significant difference in mean RPE over the course of the study, we can infer that using percentage of 1RM was effective in controlling intensity between subjects.

In comparison to studies using only males, few resistance training studies have been conducted using females. Studies have demonstrated that women respond to resistance training and can experience strength gains (12,36,37,39,40), yet few studies have directly examined the effect of periodization on females (36,39). To our knowledge, this is the first investigation to use women as subjects in comparison of multiple periodization models. Female subjects were extremely responsive to all models, showing mean increases of 32% and 108% for bench press and leg press, respectively, when groups were collapsed. A recent investigation by Peterson et al. (51) reports that the effort to benefit ratio varies among untrained, recreationally trained, and athletic populations. Thus, an optimal training effect can not be achieved by using one model for all populations. Therefore, it is recommended that these methods be replicated with both untrained and athletic populations.

CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS, & RECOMMENDATIONS

Summary

In conclusion, nine weeks of periodized weight training produced increases in strength in recreationally-trained subjects, yet there was no difference in strength gains among linear periodization, daily undulating periodization, and linear periodization. There was also no significant difference in mean session RPE between groups. All periodization models were effective at improving strength in both genders. In the future, we recommend further studies with extended training duration as well as research with untrained and athletic populations. For recreationally trained lifters over the course of nine weeks, any of the three periodization models examined may be used to foster strength gains in the bench press and leg press exercises.

Findings

1. No significant differences existed between training groups at any time point during the course of nine weeks in terms of strength.

2. All training groups significantly increased bench press and leg press 1RM's over the course of nine weeks.

3. Both male and females showed significant improvement in bench press and leg press 1RM's during the training.

4. Significant decreases in body fat were observed from T1-T2 and T1-T3.

5. Signifcant increases in chest circumference were observed from T2-T3.

6. Significant increases in thigh circumference were observed from T1-T2 and T1-T3.

7. No significant differences were observed in mean RPE between groups.

Conclusions

The most effective application from this study is that any of these periodization models are effective in improving strength in recreationally trained or detrained subjects of both genders. Our data indicate that there is no difference between the protocols in terms of ability to promote strength gains in the bench press and leg press exercises. However, this belief is only valid for a recreationally trained population over a period of no more than nine weeks.

Over the course of nine weeks, it does not appear that these protocols are significantly different in altering mean RPE or body composition in a recreationally trained population. Most likely, a longer training duration would be needed to see changes in these variables.

In order to further examine differences between the protocols, several adjustments may be made for future research. First, nine weeks may be insufficient time to elicit major differences between the protocols. Ideally, a full macrocycle would be examined as periodization was first implemented in terms of year-long training (46). Secondly, it would be beneficial to examine the protocols with athletes as subjects. This could be somewhat of a challenge, however, as convincing a coach to allow players to train in a way in which some of them may receive inferior training may prove difficult. Lastly, it may be necessary to acclimate all subjects to one protocol (for a period of six weeks for example) and then change the protocol for the other two groups to see whether further adaptations occur.

Recommendations for Future Research

1. The study should be replicated with a longer training duration.

2. The protocols should be examined in multiple populations (e.g. athletes, untrained).

3. LP, DUP, and WUP should be compared when rest periods and aerobic exercise training are equated for each subject.

4. An investigation should be conducted in which subjects perform the same training for a period (e.g. six weeks) and then switch them into different periodization protocols.

REFERENCES

1. American Academy of Pediatrics. Strength training by children and adolescents. *Pediatrics* 107(6): 1470-1472. 2001.

2. American College of Sports Medicine. Position Stand: Progression models in resistance training for healthy adults. *Med. Sci. Sports Exerc.* 34(2):364-380. 2002.

3. Ahtiainen, J.P., A. Pakarinen, M. Alen, W.J. Kraemer, and K. Hakkinen. Muscle hypertrophy, hormonal adaptations, and strength development during strength training in strength-trained and untrained men. *Eur. J. Appl. Physiol.* 89: 555-563. 2003.

4. Ahtiainen, J.P., A. Pakarinen, W.J. Kraemer, and K. Hakkinen. Acute hormonal responses to heavy resistance exercise in strength athletes versus nonathletes. *Can. J. Appl. Physiol.* 29(5): 527-543. 2004.

5. Ahtiainen, J.P., A. Pakarinen, M. Alen, W.J. Kraemer, and K. Hakkinen. Short vs. long rest period between the sets in hypertrophic training: Influence on muscle strength, size, and hormonal adaptations in trained men. *J. Strength and Cond. Res.* 19(3): 572-582. 2005.

6. Baechle, T.R. and R.W. Earle. *Essentials of Strength Training and Conditioning, 2nd Ed.* Champaign, IL. 2000.

7. Baker, D., G. Wilson, and R. Carolyn. Periodization: The effect on strength of manipulating volume and intensity. *J. Strength and Cond. Res.* 8(4):235-242. 1994.

8. Behm, D.G. Neuromuscular implications and applications of resistance training. *J. Strength and Cond. Res.* 9(4): 264-274. 1995.

9. Bompa, T.O. *Periodization: Theory and Methodology of Training.* Champaign, IL. Human Kinetics. 1999.

10. Brandenburg, J.P. and D. Docherty. The effects of accentuated eccentric loading on strength, muscle hypertrophy, and neural adaptations in trained individuals. *J. Strength and Cond. Res.* 16(1): 25-32. 2002.

11. Brown, L.E. and M. Greenwood. Periodization essentials and innovations in resistance training protocols. *Strength and Conditioning Journal.* 27(4): 80-85. 2005

12. Chilibeck, P.D., A.W. Calder, D.G. Sale, and C.E. Webber. A comparison of strength and muscle mass increases during resistance training in young women. *Eur. J. Appl. Physiol.* 77: 170-175. 1998.

13. Day, M.L., M.R. McGuian, G. Brice, and C. Foster. Monitoring exercise intensity during resistance training using the session RPE scale. *J. Strength and Cond. Res.* 18(2): 353-358. 2004.

14. Farthing, J.P. and P.D. Chilibeck. The effects of eccentric and concentric training at different velocities on muscle hypertrophy. *Eur. J. Appl. Physiol.* 89: 578-586. 2003.

15. Fleck, S.J. and W.J. Kraemer. *Designing Resistance Training Programs.* Champaign, IL. Human Kinetics. 1997.

16. Fleck, S.J. Periodized strength training: a critical review. *J. Strength Cond. Res.* 13(1):82-89. 1999.

17. Fry, A.C. and W.J. Kraemer. Resistance exercise overtraining and overreaching. *Sports Medicine.* 23(2): 106-129. 1997.

18. Garhammer, J. Periodization of strength training for athletes. *Track Tech.* 73: 2398-2399. 1979.

19. Galvao, D.A., and D.R. Taaffe. Single- vs. multiple-set resistance training: Recent developments in the controversy. *J. Strength and Cond. Res.* 18(3): 660-667. 2004.

20. Gearhart, R.F. Jr., F.L. Goss, K.M. Lagally, J.M. Jackicic, J. Gallagher, and R.J. Robertson. Standardized scaling procedures for rating perceived exertion during resistance exercise. *J. Strength and Cond. Res.* 15(3): 320-325. 2001.

21. Gearhart, R.F. Jr., F.L. Goss, K.M. Lagally, J.M. Jackicic, J. Gallagher, K.I. Gallagher, and R.J. Robertson. Ratings of perceived exertion in active muscle during high-intensity and low-intensity resistance exercise. *J. Strength and Cond. Res.* 16(1): 87-91. 2002.

22. Hakkinen, K. and P.V. Komi. Effect of different combined concentric and eccentric muscle work on maximal strength development. *J. Human Movement Studies* 7: 33-44. 1981.

23. Hakkinen, K. and P.V. Komi. Changes in neuromuscular performance in voluntary and reflex contraction during strength training in man. *Int. J. Sports Med.* 4: 282-288. 1983.

24. Hakkinen, K. and P.V. Komi. EMG changes during strength training and detraining. *Med. Sci. Sports Exerc.* 15:455-460. 1983.

25. Hakkinen, K. and P.V. Komi. Training induced changes in neuromuscular performance under voluntary and reflex conditions. *Eur. J. Appl. Physiol.* 55:147-155. 1986.

26. Hakkinen, K. and K.L. Keskinen. Muscle cross-sectional area and voluntary force production characteristics in elite strength- and endurance-trained athletes and sprinters. *Eur. J. Appl. Physiol.* 59: 215-220. 1989.

27. Hakkinen, K., A. Pakarinen, and M. K. Kallinen. Neuromuscular adaptations and serum hormones in women during short term intensive strength training. *Eur. J. Appl. Physiol.* 64:106-111. 1992.

28. Hakkinen, K., M. Alen, W.J. Kraemer, E. Gorostiagia, M. Izquierdo, et al. Neuromuscular adaptations during concurrent strength and endurance training versus strength training. *Eur. J. Appl. Physiol.* 89:42-52. 2003.

29. Halson, S.L. and A. Jeukendrup. Does overtraining exist? *Sports Med.* 34(14): 967-981. 2004.

30. Herrick, A.B. and W.J. Stone. The effects of periodization versus progressive resistance exercise on upper and lower body strength in women. *Journal of Strength and Conditioning Research* 10(2): 72-76. 1996.

31. Hickson, R.C. Interference of strength development by simultaneously training for strength and endurance. *Eur. J. Appl. Physiol.* 45: 255-263. 1980.

32. Ivanov, L., V. Krugily, and V. Zinchenko. Individualized strength development for throwers. *Leg. Atl.* 11(12). 1977. Reproduced in *Soviet Sports Rev.* 14: 138-139. 1980.

33. Jones, K., P. Bishop, G. Hunter, and G. Fleisig. The effects of varying resistance-training loads on intermediate- and high-velocity specific adaptations. *J. Strength and Cond. Res.* 15(3): 349-356. 2001.

34. Kawamori, N. and G.G. Haff. The optimal training load for the development of muscular power. *J. Strength and Cond. Res.* 18(3): 675-684. 2004.

35. Kraemer, W.J., J.F. Patton, S.E. Gordon, E.A. Harman, M.R. Deschenes, K. Reynolds, R.U. Newton, N. Travis Triplett, and J.E. Dziados. Compatability of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. *J. Appl. Physiol.* 78(3): 976-989. 1995.

36. Kraemer, W.J., N.A. Ramatess, A.C. Fry, T. Triplett-McBride, L. P. Koziris, J.A. Bauer, J. M. Lynch, and S.J. Fleck. Influence of resistance training volume and periodization on physiological and performance adaptations in collegiate women tennis players. *The American Journal of Sports Medicine* 28(5):626-633. 2000.

37. Kraemer, W.J., S.A. Mazzetti, B.C. Nindi, L.A. Gotshalk, J.S. Volek, et al. Effect of resistance training on women's strength/power and occupational performances. *Med. Sci. Sports Exerc.* 33(6): 1011-1025. 2001.

38. Kraemer, W.J. and K. Hakkinen. *Strength Training for Sport.* Ames, IA. 2002.

39. Kraemer, W.J., K. Hakkinen, N. Travis Triplett-McBride, A.C. Fry, L.P. Koziris, N.A. Ramatess, J.E. Bauer, et al. Physiological Changes with periodized resistance training in women tennis players. *Med. Sci. Sports Exerc.* 35(1): 157-168. 2003.

40. Kraemer, W.J., B. Nindl, N. Ramatess, L. Gotshalk, J. Volek, S. Fleck, R. Newton, and K. Hakkinen. Changes in muscle hypertrophy in women with periodized resistance training. *Med. Sci. Sports Exerc.* 36(4): 697-708. 2004.

41. Kraemer, W.J. and N.A. Ramatess. Fundamentals of resistance training: Progression and exercise prescription. *Med. Sci. Sports Exerc.* 36(4): 674-688. 2004.

42. Kraemer, W.J. and N.A. Ramatess. Hormonal responses and adaptations to resistance exercise and training. *Sports Med.* 35(4): 339-361. 2005.

43. Kramer, J.B., M.H. Stone, H.S. O'Bryant, M.S. Conley, R.L. Johnson, D.C. Nieman, D.R. Honeycutt, and T.P. Hoke. Effects of single vs. multiple sets of weight training: Impact of volume, intensity, and variation. *J. Strength and Cond. Res.* 11(3): 143-147. 1997.

44. Kreider, R.B., A.C. Fry, and M.L. O'Toole. Terms, definitions, and prevalence. In: *Overtraining in Sport.* Kreider, R.B., A.C. Fry, M.L. O'Toole, eds. Champaign, IL: Human Kinetics Publishers, Inc., 1988. pp. vii-ix.

45. Lagally, K.M., S.T. McCaw, G.T. Young, H.C. Medema, and D.Q. Thomas. Ratings of perceived exertion and muscle activity during the bench press exercise in recreational and novice lifters. *J. Strength and Cond. Res.* 18(2): 359-364. 2004.

46. Matveyev, L. *Fundamentals of Sports Training.* Moscow: Progress, 1981.

47. Mazzetti, S.A., W.J. Kraemer, J.S. Volek, N.D. Duncan, N.A. Ramatess, et al. The influence of direct supervision of resistance training on strength performance. *Med. Sci. Sports Exerc.* 32(6): 1175-1184. 2000.

48. Palmieri, G. Weight training and repetition speed. *J. Appl. Sport Sci. Res.* 12: 6-38.1987.

49. Pearson, D., A. Faigenbaum, M. Conley, and W.J. Kraemer. The National Strength and Conditioning Association's basic guidelines for the resistance training of athletes. *Strength and Conditioning Journal.* 22(4): 14-27. 2000.

50. Peterson, M.D., M. Rhea, and B. Alavar. Maximizing strength development in athletes: A meta-analysis to determine the dose-response relationship. *J. Strength and Cond. Res.* 18(2): 377-382. 2004.

51. Peterson, M.D., M. Rhea, and B. Alavar. Applications of the dose-response for muscular strength development: A review of meta-analytic efficacy and reliability for designing training prescription. *J. Strength and Cond. Res.* 19(4): 950-958. 2005.

52. Plisk, S.S. and M.H. Stone. Periodization strategies. *Strength and Conditioning Journal.* 25(6): 19-37. 2003.

53. Poliquin, C. Five steps to increasing the effectiveness of your strength training program. *NSCA Journal* 10(3): 34-39. 1988.

54. Rhea, M.R., B.A. Alvar, S.D. Ball, and L.N. Burkett. Three sets of weight training superior to 1 set with equal intensity for eliciting strength. *J. Strength and Cond. Res.* 16(4): 525-529. 2002.

55. Rhea, M.R., S.D. Ball, W.T. Phillips, and L.N. Burkett. A comparison of linear and daily undulating periodized programs with equated volume and intensity for strength. *Journal of Strength and Conditioning Research* 16(2): 250-255. 2002.

56. Rhea, M., B. Alvar, L. Burkett, and S. Ball. A meta-analysis to determine the dose-response relationship for strength. *Med. Sci. Sports Exerc.* 35: 456-464.2003.

57. Rhea, M.R., S.D. Ball, W.T. Phillips, and L.N. Burkett. A comparison of linear and daily undulating periodized programs with equated volume and intensity for local muscular endurance. *J. Strength Cond. Res.* 17(1): 82-87. 2003.

58. Rhea, M.R. and B.L. Alderman. A meta-analysis of periodized versus nonperiodized strength and power training programs. *Research Quarterly for Exercise and Sport* 75(4): 413-423. 2004.

59. Richmond, S.R. and M.P. Godard. The effects of varied rest periods between sets to failure using the bench press in recreationally trained men. *J. Strength and Cond. Res.* 18(4): 846-849. 2004.

60. Schiotz, M.K., J.A. Potteiger, P.G. Huntsinger, and D.C. Denmark. The short-term effects of periodized and constant-intensity training on body composition,

strength, and performance. *Journal of Strength and Conditioning Research* 12(3):173-178. 1998.

61. Seguin, R. and M.E. Nelson. The benefits of strength training for older adults. *Am. J. Prev. Med.* 25: 141-149. 2003.

62. Seyle, H. Stress and distress. *Comprehensive Therapy* 1(8): 9-13. 1974.

63. Smith, L.L. Tissue trauma: The underlying cause of overtraining syndrome? *J. Strength and Cond. Res.* 18(1): 185-193. 2004.

64. Stone, M.H., H. O'Bryant, and J. Garhammer. A hypothetical model for strength training. *J. Sports Med. Phys. Fitness* 21:342-351. 1981.

65. Stowers, T., J. McMillan, D. Scala, V. Davis, D. Wilson, and M. Stone. The short-term effects of three different strength-power training methods. *Natl. Strength Cond. Assoc. J.* 5:24-27. 1983.

66. Sweet, T.W., C. Foster, M.R. McGuigan, and G. Brice. Quantitation of resistance training using the session rating of perceived exertion method. *J. Strength and Cond. Res.* 18(4): 796-806. 2004.

67. Tan, B. Manipulating resistance training program variables to optimize maximum strength in men: A review. *Journal of Strength and Conditioning Research* 13(3):289-304. 1999.

68. Urhausen, A. and W. Kindermann. Diagnosis of overtraining: What tools do we have? *Sports Med.* 32(2): 95-102. 2002.

69. Wenzel, R. and E. Perfetto. The effects of speed versus non-speed training in power development. *J. Appl. Sport Sci. Res.* 62:82-87. 1992.

70. Willardson, J.M. and L.N. Burkett. A comparison of 3 different rest intervals on the exercise volume completed during a workout. *J. Strength and Cond. Res.* 19(1): 23-26. 2005.

71. Willoughby, D. S. 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(1):2-8.1993.

72. Wolfe, B.L. and P.J. Cole. Quantitative analysis of single- vs. multiple-set programs in resistance training. *J. Strength and Cond. Research* 18(1): 35-47. 2004.

APPENDICES

APPENDIX A: SUBJECT INFORMATION FORMS

Script for Periodization Study

Thank you for your participation in the research project observing effects of opposing models of periodization for strength training.

The purpose of this study is to investigate whether daily undulating periodization model, a weekly undulating periodization model, or a linear periodization model is most effective in improving strength during strength training. We intend to design your training program for nine weeks and compare groups using the two different models in terms of strength gains. We will also do 1RM max testing for the bench press and leg press at three different time points: pre, mid, and post-training. We will also obtain skinfold measurements for body fat percentage at each of the three time-points. For research purposes, we ask that you please do not participate in any other resistance training than what is done for the study.

If you choose to participate in the study, you will review and sign medical history and informed consent forms. This data collection sheet provides a summary of the tasks you will be asked to complete as a research participant. We suggest that you keep this sheet to remind you of the tasks we would like you to complete.

Instructions for Research Subjects:

- **Step One:** Read, fill out, and sign medical history and informed consent forms.
- **Step Two:** Complete 1RM max testing for bench press and leg press prior to beginning workout program. In addition, have skinfold testing done to determine body fat percentage.
- **Step Three:** Complete designed workout programs on Monday, Wednesday, and Friday of each of the nine weeks during assigned class time. 90% of the workouts must be completed for inclusion in the study.
- **Step Four:** Do not participate in any additional strength training. If at some time you do, please report it on the form provided. Also, consume your regular diet and do not use any ergogenic aids.
- **Step Five:** Complete 1RM max and skinfold testing following week 5.
- **Step Six:** Complete 1RM max testing and skinfold tests following completion of training.
- **Step Seven:** Follow all rules and procedures for the weight room.

Benefits for Subjects:

- **Gaining knowledge about proper exercise technique and program design from certified professionals**
- **Essentially, gaining free personal training**
- **Possibly improving neuromuscular efficiency, muscle size and strength, and increasing lean body mass**

Once again, thank you for your willingness to participate in the research project. We hope that it will be beneficial to you as well as to our research.

OKLAHOMA STATE UNIVERSITY
HARRISON HUMAN PERFORMANCE LABORATORY
Personal Medical History Survey

Complete the front and back of this form.

Name:____ Date:______________

Address:______________________________ City/State:____________________ Zip:______________

Phone:_________________________ E-mail Address: ______________________

Age:_______________Sex:________ Weight:___________ Height:_________

1. Have you ever been diagnosed as having: (check all that apply)

	In the past	**Presently**
A. Heart disease	______	______
B. Rheumatic fever	______	______
C. High blood pressure	______	______
D. Other vascular disorders	______	______
E. Diabetes	______	______
F. Kidney disease	______	______
G. Asthma	______	______
H. Allergies	______	______
I. Chronic bronchitis	______	______
J. Other respiratory illness	______	______
K. High serum lipids (cholesterol)	______	______
L. Anemia	______	______
M. Low blood sugar	______	______
N. Neuro-musculo-skeletal disease	______	______
O. Sores in mouth	______	______
P. Cavities in teeth	______	______
Q. Gum disease	______	______
R. "Strep" throat	______	______
S. Other oral infections	______	______

2. Please indicate any surgery that you have undergone and the approximate date(s).

____

____

3. Please indicate recent illnesses or major injuries that you have had. Also list approximate dates.

____

____

4. Do you smoke? __________ Packs per day? __________

Do you use smokeless tobacco (chew or dip)? ___________ How often?________

5. Please list all medications or supplements (prescription and non-prescription) that you are presently taking.

Medication Dosage Duration

____

____

____

____

____

6. Have you ever performed resistance training? Yes_____ No_____

7. On a scale from 1-10 (1 being novice, 10 being expert) rate your experience with using resistance training.

____

8. Describe exercise or activity program during the last 6 months. (Please include: the activity, amount per day, days per week, and length of time you have been exercising at this level)

Activity minutes/day days/week
weeks of exercise

____

____

Signature Date

RESEARCH PARTICIPANT CONSENT FORM

"A Comparison of Periodization Models with Equated Volume and Intensity for Strength"

Principal Investigators

Thomas W. Buford, CSCS; Douglas B. Smith, PhD., Stephen J. Rossi, M.S., CSCS

Oklahoma State University

Department of Health, Leisure, and Human Performance

The present research project will examine the effect differing models of program design for strength training. Linear periodization involves increasing intensity and lowering volume in weekly cycles while undulating periodization involves varying intensity and volume within the weekly workout. Two types of undulating models will be used: daily and weekly. Daily undulations change volume and intensity each day of training, while weekly changes the volume and intensity each week. You have been selected because you are enrolled in LEIS 1342, Weight Training. You will be asked to resistance train following a prescribed program for nine weeks and do 1RM testing of bench press and leg press pre, mid, and post-training. Skingfold measurements for body fat will also be taken at each of the three time-points.

Purpose of Research

I understand that the purpose of this research is to determine the most effective program design among linear periodization, daily undulating periodization, and weekly undulating periodization for strength.

Procedures

I understand that the tasks required of me are as follows:

1. Complete medical history and informed consent forms.
2. Complete skinfold testing prior to beginning the training program.
3. Complete 1RM testing prior to beginning training program for bench press and leg press.
4. Complete 9 week strength training program designed by primary investigators. Three workouts per week will be required. Intensity and volume will be equated for both groups, but groups will differ on the periodization model. 90% attendance is required for inclusion in the study.
5. Report any additional resistance train done outside of the scope of the research project.
6. Complete skinfold and 1RM testing in during week on assigned day following week five for bench press and leg press.
7. Complete skinfold and 1RM testing following the nine week training period for bench press and leg press.
8. Follow all rules and procedures for the weight room.

Duration of Participation

Participants will be involved in the training for a period of nine weeks, three days per week. The training will take place during their scheduled class time. In addition, three testing sessions will be required. These sessions will be pre, mid, and post testing. In all, thirty days of involvement will be required of the subjects.

Benefits to the Individual

Subjects will essentially receive free personal training as they are instructed on proper exercise technique and program design methods by professionals. Maximal muscular size and strength should be enhanced. In addition, neuromuscular efficiency should be enhanced along with increased in lean mass.

Risks of Participation

I understand that no exercise program is without inherent risks regardless of the care taken. I realize that when participating in resistance training, especially with 1RM testing, there is a slight chance of injury. The risks associated with a strength training program primarily deal with muscle soreness, and possibly musculoskeletal strains and sprains. In addition risk for losing control of the weight increases possibility of various injuries. Risks for the 1RM testing will me minimized by instructing all participants to refrain from holding their breath while lifting, in addition to spotters being required for all exercises involving resistance above the head, resistance loaded on the spine, and exercises using near maximal loads. Personnel administering tests are certified in first aid and CPR and either ACSM H-FI or NSCA CSCS certified.

Medical Liability

I understand the risks associated with this study and voluntarily choose to participate. I certify that to the best of my knowledge I am in good physical condition and able to participate in the study. I understand that in case of injury or illness resulting from this study, emergency medical care is available through community health care providers by dialing 911. In addition, the Oklahoma State University Health Services Center is available for all OSU students. I understand that no funds have been set aside by Oklahoma State University to compensate me in event of illness or injury.

Confidentiality

All data will remain confidential and will be available only to the Human Performance Lab personnel. All data will be reported as means and standard errors. For added protection, the OSU IRB has the authority to inspect consent records and data files to assure compliance with approved procedures.

Compensation

No compensation will be offered for this study.

Voluntary Nature of Participation

I understand that participation in this research project is voluntary and I can withdraw my involvement in the project at any time.

Human Subject Statement
For any questions or concerns that you may have about this research project, contact Thomas W. Buford at (405) 744-9373. If you have any concerns dealing with subjects' rights, contact Dr. Sue Jacobs, IRB chair, 415 Whitehurst Hall, Oklahoma State University, 405-744-1676.

Signatures
I have read and fully understand the consent form. I sign it freely and voluntarily. A copy of this form has been given to me.

__________________________ ________________ ________________
Signature of Participant Date Date of Birth

I certify that I have personally explained this document before requesting that the participant sign it.

__________________________ ________________
Signature of Researcher Date

APPENDIX B: TABLE OF RAW DATA

Subject	M/F	Group	Age	B1	B2	B3	LP 1	LP 2	LP 3	BF 1	BF 2	BF 3	WT1	WT2	WT3	CC1	CC2	CC3	TC1	TC2	TC3
1	2	1	20	75	85	110	270	390	540	34.38	32.49	30.61	160	148	148	91	85.5	89	51	54	53
2	1	2	21	155	175	205	410	630	770	7.09	6.93	6.77	151	153	154	93.5	93.5	95	46.5	48	48.5
3	2	2	27	95	110	125	370	500	590	20.94	21.09	23.88	135	139	137	83.5	82	86	50.5	50	52
4	1	3	22	185	200	215	380	540	740	10.28	8.3	8.3	128	128	129	94.5	91	88	48.5	49.5	50.5
5	1	1	21	175	200	215	510	680	1010	23.58	22.71	23.15	194.5	196	196	99	103.5	104.5	54.5	60.5	60
6	1	2	35	145	170	190	330	460	740	24.2	23.29	24.88	203	202	204.5	106	103	111	54.5	60.5	61.5
7	2	3	20	70	80	105	230	360	560	28.63	26.41	27.53	126	127	127.5	87	83.5	84.5	48	49.5	49
8	1	3	18	175	185	205	450	680	800	32.13	32.13	31.2	237	238	243.5	117	112	113.5	63	64.5	61.5
9	2	1	21	75	85	95	250	320	540	32.68	30.86	29.02	130	129.5	127.5	82	84.5	82.5	45	49	52
10	1	1	26	225	245	265	550	630	770	20.58	21.3	20.94	176	178	178.5	99	99	99	57.5	61	61
11	1	2	30	145	170	180	400	600	810	25.13	25.5	21.81	174	176	178	109	106.5	106	51.5	53	49
12	2	2	22	75	85	90	230	360	520	31.87	28.61	29.15	137	138	138.5	91	85	88.5	45.5	45.5	47
14	2	3	22	95	100	115	270	400	600	41.7	37.42	35.62	170	160	159	102	94	98.5	53.5	49	54
15	1	1	22	155	185	205	430	590	860	22.28	19.82	20.42	165	162	163	98.5	100	99	49.5	51.5	49
16	2	1	21	95	115	130	300	430	650	32.67	32.92	32.68	152	149	147	88	89.5	91	47.5	52	53
17	1	2	21	305	315	315	630	720	880	21.58	20.53	18.7	201	200	196	110	107	108.5	58.5	56	57.5
18	1	3	19	145	185	205	380	570	920	18.32	18.57	19.19	157.5	157.5	160	91	93.5	96	50	53.5	58
20	1	2	21	175	180	185	410	600	630	14.07	11.93	12.08	160	160	158	92	91	90.5	51	51	50.5
21	1	3	20	145	165	185	280	440	540	16.52	15.72	16.78	177.5	181	189	94.5	95	99	47.5	53	53.5
22	1	1	31	155	165	185	450	560	650	27.52	25.32	25.42	168	172	173	100	102	102	48.5	53	52.5
23	1	2	21	140	155	165	370	540	720	22.49	22.38	21.47	178	181	188	94	92	97	53.5	56	56.5
24	1	3	18	175	195	215	500	700	950	10.53	10.24	11.99	150	155.5	159	88.5	94	94	45	51	53.5
25	2	2	19	65	85	95	215	320	490	29.51	29.24	28.3	127	127.5	123	84	82	84	49	53.5	53.5
26	1	1	20	140	145	155	320	500	630	3.92	3.59	3.26	122	120.5	123	83.5	84	86	42	43.5	43
27	1	2	22	245	255	265	630	810	1000	14.05	9.53	9.83	208	202	202	104.5	105	103	58.5	60.5	62
28	2	3	21	130	145	165	310	450	600	26.18	27.03	26.04	143	142.5	142	87.5	90.5	92	49	53	53
29	1	3	21	185	205	215	400	520	680	9.86	10.6	10.01	150	156	156	92	95	96	47.5	50.5	52
30	2	1	22	85	95	105	250	400	520	26.52	26.68	27.37	129	130.5	131	86.5	82	91	49.5	50.5	51

APPENDIX C: IRB APPROVAL FORM

Oklahoma State University Institutional Review Board

Date:	Tuesday, July 05, 2005
IRB Application No	ED05128
Proposal Title:	A Comparison of Periodization Models with Equated Volume and Intensity for Strength
Reviewed and Processed as:	Expedited

Status Recommended by Reviewer(s): Approved Protocol Expires: 7/4/2006

Principal Investigator(s

Thomas Buford 194 Colvin Rec. Center Stillwater, OK 74078	Stephen J. Rossi 194A Colvin Center Stillwater, OK 74078	Douglas Smith 187 Colvin Center Stillwater, OK 74078

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

☒ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval.
2. Submit a request for continuation if the study extends beyond the approval period of one calendar year. This continuation must receive IRB review and approval before the research can continue.
3. Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of this research; and
4. Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Beth McTernan in 415 Whitehurst (phone: 405-744-5700, beth.mcternan@okstate.edu).

Sincerely,

Sue C. Jacobs

Sue C. Jacobs, Chair
Institutional Review Board

VITA

Thomas Wayne Buford

Candidate for the Degree of

Master of Science

Thesis: A Comparison of Periodization Models with Equated Volume and Intensity for Strength

Major Field: Applied Exercise Science

Biographical:

Personal Data: Married to the former Stacy Dutt on December 27, 2004.

Education: Graduated from Bethel High School in Bethel Acres, OK in May 2000; received Bachelor of Science in Education from Oklahoma Baptist University, Shawnee, OK in May 2004. Completed the requirements for Bachelor of Science with a major in Applied Exercise Science at Oklahoma State University in May 2006.

Experience: Employed by Oklahoma State University Health and Human Performance department as graduate teaching/research assistant, 2004 to present.

Professional Memberships: National Strength and Conditioning Association (NSCA), American College of Sports Medicine (ACSM), United States Weightlifting (USAW).

Name: Thomas Wayne Buford Date of Degree: May, 2006

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: A COMPARISON OF PERIODIZATION MODELS WITH EQUATED VOLUME AND INTENSITY FOR STRENGTH

Pages in Study: 78 Candidate for the Degree of Master of Science

Major Field: Applied Exercise Science

ABSTRACT

PURPOSE: The purpose of the present investigation was to determine if significant differences exist among three different periodization programs in eliciting changes in strength. **METHODS:** Twenty-eight recreationally trained college-aged volunteers (mean $\pm$ SD; 22.29 $\pm$ 3.98) of both genders were tested for bench press, leg press, body fat %, chest circumference, and thigh circumference during initial testing. Following initial testing, subjects were randomly assigned to one of three training groups: 1) Linear Periodization (LP) (n=9), 2) Daily Undulating Periodization (DUP) (n=10), or 3) Weekly Undulating Periodization (WUP) (n=9). The training regimen for each group consisted of a 9 week, 3 day per week program with volume and intensity equated for all groups. Training loads were assigned as heavy (90%, 4RM), medium (85%, 6RM), or light (80%, 8RM) for bench press and leg press exercises. Subjects were familiarized with the CR-10 RPE scale, and instructed to achieve an 8 or 9 on the final repetition of each set for all other exercises. Subjects were then re-tested following four weeks of training. Training loads were then adjusted according to the new 1RM. Subjects were then re-tested following five more weeks of exercise. A 3x3 analysis of variance with repeated measures was conducted to examine differences between groups and to examine changes in each variable between T1 and T3. **RESULTS:** No significant differences ($p > .05$) were observed between groups for bench press, leg press, body fat %, chest circumference, or thigh circumference at all time points. Groups were then collapsed, and significant ($p < .05$) increases in bench press and leg press strength were demonstrated at all time points (T1-T3). Body fat decreased, while thigh circumference increased significantly ($p < .05$) from T1-T2 and T1-T3 with no significant change between the second two testing sessions. Chest circumference was significantly ($p < .05$) increased from T2-T3. **CONCLUSION:** No significant differences were observed between groups, however, each of the three models proved effective in increasing bench press and leg press strength over the course of nine weeks.

ADVISOR'S APPROVAL: ____________________