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Physiological Responses to Two Different Models of Daily Undulating Periodization in Trained Powerlifters

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COLLEGE OF HUMAN SCIENCES

PHYSIOLOGICAL RESPONSES TO TWO DIFFERENT MODELS OF DAILY UNDULATING PERIODIZATION IN TRAINED POWERLIFTERS

By

MICHAEL CHRISTOPHER ZOURDOS

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Michael Christopher Zourdos defended this dissertation on March 26^{th}, 2012.

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The Graduate School has verified and approved the above-named committee members, and certifies that the dissertation has been approved in accordance with university requirements.

This dissertation is dedicated to my parents, Christopher and Deborah Zourdos, and my brother Peter Zourdos. My mother and father are my heroes and role models in life. What they have done, and continue to do is indescribable in a short dedication. Simply, I owe them everything. My brother Peter has inspired me in ways he likely doesn't even know. I've never known another individual to excel in so many different areas. His intelligence and ability to learn new skills is exceptional and amazes me every single day. These individuals are my family, and there absolutely is no better.

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LIST OF ABBREVIATIONS

1. LP – Linear Periodization
2. DUP – Daily Undulating Periodization
3. NLP – Non-Linear Periodization
4. FNLP – Flexible Non-Linear Periodization
5.WUP – Weekly Undulating Periodization
6. RLP – Reverse Linear Periodzation
7. APRE – Autoregulatory Progressive Resistance Exercise
8. TV – Total Volume
9. 1RM - One-Repetition Maximum
10. HSP - Hypertrophy, Strength, Power
11. HPS - Hypertrophy, Power, Strength
12. CSA – Cross-Sectional Area (of skeletal muscle)
13. USAPL - United States of America Powerlifting
14. IPF – International Powerlifting Federation
15. NSCA – National Strength and Conditioning Association
16. ROTC – Reserve Officers' Training Corps
17. NFL – National Football League
18. SAID – Specific Adaptations to Imposed Demands
19. CK - Creatine Kinase
20. LDH - Lactate Dehydrogenase
21. T/C Ratio – Testosterone to Cortisol Ratio
22. GH – Growth Hormone
23. IGF-1 – Insulin-Like Growth Factor-1
24. mPS – Muscle Protein Synthesis
25. MVC – Maximal Voluntary Contraction
26. EMG – Electromyography
27. ELISA – Enzyme Linked Immunosorbent Assays

ABSTRACT

Periodization refers to systematic variations to exercise intensity and volume across an entire training program in efforts to optimize performance for competition. Although multiple periodization models exist, linear periodization (LP), which does not encompass as many manipulations of volume and intensity as daily undulating periodization (DUP), has been prominently utilized in practical settings. However, DUP has recently shown promise as an effective resistance-training paradigm with respect to positive neuromuscular adaptations and performance gains. In contrast to LP, DUP is characterized by frequent, session-to-session alterations to volume and intensity across a complete training period. Previous research has demonstrated the efficacy of DUP in significantly increasing muscular strength, i.e. one-repetition maximum (1RM), to a greater extent than LP. Nevertheless, further investigation is necessary to improve the systematic programming of the DUP training model. Therefore, the primary aim of the present study was to examine the effects of two divergent DUP models (modified versus traditional) on maximum strength adaptations and total exercise volume in trained powerlifters. Furthermore, we investigated the temporal profile of anabolic and catabolic hormone responses across the DUP training protocols. Eighteen male, college-aged powerlifters (body weight: 82.55 ± 11.39 kg.) participated in this study and were assigned to one of two groups. Subjects underwent either: 1) traditional DUP training which employed a weekly training order of hypertrophy, strength, and power (HSP) or 2) modified DUP training which implemented a hypertrophy, power, and strength (HPS) training order for each week. The study spanned a total of eight weeks with each group assessed for pre-training 1RM during the first week, followed by 6 weeks of DUP training, and subsequent testing for post-training 1RM. Subjects specifically performed powerlifting exercises (squat, bench press, and deadlift) on testing and training days. During hypertrophy and power training sessions, subjects performed a fixed number of sets and repetitions, which progressed weekly. However, during strength training sessions, subjects were instructed to perform repetitions until volitional failure at a given percentage in order to measure total volume (TV) of exercise performed. Additionally, blood was collected 30 minutes prior to the strength training sessions each week to examine alterations in hormonal markers, testosterone and cortisol, in response to the DUP training protocols. Hormonal analysis was conducted using enzyme linked immunosorbent (ELISA) assay. For 1RM squat there was a main time effect ($p<0.05$); however, no difference existed between increases for HSP (+7.93%) and HPS (+10.48%). Regarding bench press, only HPS significantly increased 1RM by 8.13%, while HSP failed to exhibit significant improvements over the course of the study. There was a main time effect ($p<0.05$) for 1RM deadlift (HSP: +6.70%, HPS: +7.57%) and powerlifting total (HSP: 6.70%, HPS: +8.66%), but no difference existed between groups for either variable. Total Volume in HPS was significantly greater ($p<0.05$) than HSP for squat, bench press, and powerlifting total; however, for the deadlift there was no difference between groups ($p>0.05$). There was no group effect ($p>0.05$) for testosterone and cortisol levels. A main time effect ($p<0.05$) for testosterone concentrations was demonstrated as values were significantly less than pre-training levels during weeks 5 and 6 of training, while cortisol levels declined during training weeks 3 and 4. Both hormones recovered to pre-training levels in the following weeks. Our findings suggested that both traditional and modified DUP models are effective for improving muscular strength following 6 weeks of training in collegiate powerlifting athletes. Further, the modified DUP model (HPS) may produce greater maximum strength gains in the bench press over a 6-week training period possibly due to an increased TV of exercise.

CHAPTER I
INTRODUCTION

Periodization is a systematic approach to optimize an exercise-training program and involves time-sensitive manipulation of training volume and intensity in an effort to maximize performance before planned competition (1). On the other hand, non-periodized training does not include programmed variations to training variables (2). Currently, there are two main models of periodization used by athletes and coaches: linear periodization (LP) and non-linear periodization (NLP), also called undulating periodization (2). Each model takes a practical approach of altering training variables to achieve specific goals, while battling with the cumbersome concept of overtraining. Previous research has shown LP (1,3,4,5,9,38,43,45) and undulating periodization (8,9,10) to increase measures of muscular performance when compared to a non-periodized training program. Undulating periodization can be further broken down into weekly undulating periodization (WUP) and daily undulating periodization (DUP).

Numerous studies have compared LP vs. undulating periodization for possible differences in maximal strength gains (2,10,40,46,52,53). The current body of evidence, however, shows mixed results as some report no differences between training models (2,40,53), whereas others suggest undulating periodization as more advantageous for strength gains (10,46,52). An in-depth analysis of these studies unravels that no differences were found in untrained or recreationally trained individuals (2,40,53). Conversely, the studies showing greater strength gains with undulating periodization all utilized well-trained males and used a protocol of the DUP variety (10,46,52). These findings seem to suggest that there is no difference in maximal strength increases among untrained individuals when comparing undulating periodization and LP; however, well-trained athletes may gain additional strength benefits from DUP as opposed to LP. Even though DUP has produced greater strength gains in previously trained individuals, it is likely that the program design and practical implementation of DUP can still be improved upon. For example, a previous study (46), which reported significance in favor of DUP, utilized a weekly training order of hypertrophy, strength, and power training types (e.g. hypertrophy training on Monday, strength training on Wednesday, and power training on

Friday). Therefore, it is apparent that further investigation is necessary to revisit and advance the design of DUP.

The possible flaw in the existing DUP model is that it calls for strength training to be performed just 48 hours following hypertrophy training each week. One reason this may be disadvantageous is because of the three training types (hypertrophy, strength, and power), hypertrophy training results in the greatest amount of muscle damage (124), fatigue, and stress (159). Further, muscle damage has been shown to remain elevated 48 hours following high-volume training (76). Additionally, high levels of muscle damage, measured through enzymes creatine kinase (CK) and lactate dehydrogenase (LDH), have been correlated with a decrease in maximal strength performance (76). Therefore, it is likely that the magnitude of muscle structural damage (e.g. elevated blood CK and LDH) is greatest prior to a strength training session (which takes place 48 hours following hypertrophy training) in the current DUP model, possibly compromising total exercise volume that an individual can perform (Sets x Repetitions x Total-Weight-Lifted) during the strength training session. Secondly, hypertrophy training increases the catabolic hormone cortisol to a greater extent than strength or power training (159). Subsequently, an increase in resting cortisol levels has been associated with decreased weightlifting performance (69), whereas elevated resting testosterone concentrations are positively correlated with strength performance (11). After considering these factors, it is necessary for athletes to carefully design their DUP program to avoid training in a fatigued state during the strength training session of a given week. Thus, greater temporal separation between strength and hypertrophy training during each week of DUP might be more advantageous than the traditional configuration. For example, an experimental DUP model would comprise of weekly training sessions sequenced in the order of hypertrophy, power, and strength, which differs from the current traditional model (i.e. hypertrophy, strength, and power). To our knowledge no study has yet examined the physiological responses (strength, myofiber damage, anabolic and catabolic hormones) in well-trained athletes when using a different order of DUP during a given training week. The potential efficacy of the proposed model may be supported by previous evidence as McCaulley et al. (2009) showed that well-trained males lifted over 100% of their previously determined one-repetition maximum (1RM) when tested 48 hours following a session of power training. However, these subjects lifted between 97-98% of their 1RM 48 hours post hypertrophy training (159). Therefore, the proposed DUP model may allow greater total exercise volume to be performed during each strength training session of a given week when compared to the current model, thus eliciting greater strength gains following the completion of a training program. Moreover, the findings from the proposed study might further enhance the DUP protocol design for strength athletes.

Specific Aims

The specific aims of the proposed project were to: 1.A) examine the degree by which the modified DUP model altered 1RM strength in comparison to the traditional DUP model following a 6-week training protocol; 1.B) to determine the extent to which the modified DUP model influenced total training volume during its strength training sessions in comparison to the strength training sessions of the traditional model; and 2) to examine resting changes in anabolic and catabolic hormones as well as the hormonal levels prior to each week's strength training session. Specific Aims 1.A and 1.B were accomplished by assessing subjects' 1RM using the United States of America Powerlifting (USAPL) protocol for the squat, bench press, and deadlift 1RM testing (168) and the product of total performed sets and repetitions, as well as weight lifted (Total Volume = Sets x Repetitions x Total-Weight-Lifted) respectively. Specific Aim #2 was pursued by collecting 10mL of blood, 30 minutes prior to each training session and using enzyme linked immunosorbent assays (ELISA) to analyze testosterone (anabolic) and cortisol (catabolic) concentrations.

Research Hypotheses

It was hypothesized that over the 6-week training period, HPS would produce significantly greater increases in 1RM strength of the squat, bench press, and deadlift when compared to HSP. It was also anticipated that HPS would perform a greater total volume of exercise during the strength training sessions each week than HSP and it was hypothesized that following the six weeks of training both groups would see significant increases in resting levels of testosterone while concurrently experiencing decreases in resting cortisol concentrations.

Assumptions

The following assumptions for this study included

1. All laboratory equipment provided accurate results during the testing procedures and data analysis.
2. All subjects adhered to the conditions provided in the Informed Consent Form.
3. All subjects put forth their maximum effort and performed to their utmost potential in all testing sessions.
4. All subjects honestly completed their health history questionnaire, and activity and dietary logs.

Delimitations

The delimitations for this study included:

1. For inclusion into this study subjects must have been able to perform the squat and deadlift exercises with of at least 2 times their body weight and the bench press exercise with 1.5 times their body weight in accordance with the rules and conditions of United States of America Powerlifting (USAPL).
2. Subjects must have been currently engaged in a resistance-training program at least 3 times per week and must have been doing so for at least 2 years.
3. Subjects were instructed to refrain from any exercise additional to that of this project until they had completed all training and testing sessions.

Limitations

The limitations for this study included:

1. This study examined only two different conditions of daily undulating periodization.
2. Subjects were restricted to college-aged students (18-29 years).
3. This study utilized only male subjects.
4. The final major limitation is that this study used only trained subjects.

Operational Definitions

Linear Periodization (LP) – A systematic training program in which volume of training is decreased and intensity is increased in anticipation of a planned competition (3,21,25).

Non-Linear/Undulating Periodization – A training program that allows for the variation of volume and intensity within a microcycle (21,50). This approach allows for more frequent variation of training variables than LP.

Daily Undulating Periodization (DUP) – A sub-type of undulating periodization in which variation of training volume and intensity must occur each training session. Another variety of undulating periodization would be weekly undulating periodization, which calls for the fluctuation of training variables each week (2).

Testosterone – Testosterone is an anabolic hormone synthesized by the leydig cells of the testes. Testosterone acts in an anabolic nature by promoting protein synthesis and inhibiting protein breakdown (124).

Cortisol – Cortisol is a glucocorticoid and a prominent catabolic hormone secreted by the adrenal cortex. In addition, cortisol is released via the hypothalamic-pituitary-adrenal axis. Cortisol's catabolic effects are the opposite of growth hormone (GH) in that it decreases levels of protein synthesis, but increases levels of protein break down (124).

Total Volume (TV) – Total Volume is measured by the following equation: Total Repetitions X Sets X Total-Weight-Lifted (21,25). For example: If a subject performs the back squat exercise with 5 sets of 10 repetitions per set with 300 pounds then the calculation would be; 5X10X300 = 15000.

One-Repetition Maximum (1RM) – 1RM is the largest amount of weight that can be lifted for one repetition with proper and legal technique (3,21,25).

Powerlifting Total – In the sport of powerlifting, the powerlifting total, represents the sum of a lifter's best squat bench press and deadlift. For example if a lifter squatted 500lbs., bench pressed 300lbs., and deadlifted 500lbs. then there powerlifting total would be: 500 + 300 + 500 = 1300lbs.

United States of America Powerlifting (USAPL) – USAPL is the leading powerlifting organization in the United States.

International Powerlifting Federation (IPF) – IPF is the governing body of powerlifting internationally. The IPF is compromised of member federations (of which the USAPL is one) from eighty-three countries on six continents.

Wilk's Formula - The Wilk's formula is used by the USAPL and IPF to compare the strength of powerlifters who have different body weights. The individual who has the highest Wilk's at a USAPL or IPF competition is awarded the title of 'best lifter' (168).

CHAPTER II
REVIEW OF RELATED LITERATURE

TRAINING TYPE SPECIFIC AND ENDOCRINE ADAPTATIONS TO RESISTANCE TRAINING

Characterizing Strength and Power Training

The characterization of strength and power training may be different for untrained and trained individuals. When implementing a strength-training program for beginners the program should elicit optimal neural gains through attempting to optimize muscle tissue growth (65,67,125). Therefore, strength-training programs for beginners may utilize more moderate repetitions in contrast with the low repetitions characterized for maximal strength gains. One advantage of using moderate repetitions for strength gains among untrained individuals is that more repetitions mean more opportunity to perform the exercise and less risk of injury. The increased number of opportunities has been described by Peterson et al. (2004), whose meta-analysis recommends 8-12 repetitions for strength increases among beginners, as a greater chance for skill acquisition and adaptation of the nervous system (112).

When training for strength and power, an athlete is often training for a specific movement with the goal of becoming proficient at performing a movement for maximal strength like the one-repetition maximum (1RM) (120). As described earlier, after these trained individuals have received maximum hypertrophy training they may need to elicit further neural adaptations to allow for greater increases in strength. Deschenes et al. (1994) and Sale (1992) have suggested that athletes who have maximized their hypertrophy can bypass the size principle and recruit high-threshold fibers from the onset of muscle contraction. Therefore, it is reasonable to suggest that well trained athletes should utilize low repetitions and high loads when training for maximal strength increases (65,73). Performing these low repetitions will essentially enable an athletes' nervous system to become more efficient at coordinating all of the muscle fibers available in a contraction. This notion of low repetitions is confirmed by data from Anderson and Kearney (111). These authors reported that well trained athletes performing upper and lower body exercises for 8 weeks with 6 or less repetitions increased maximal strength (both upper and lower body) to a greater extent than subjects who performed 10-20 or 30-40 repetitions (111). In addition, this study found that the 10-20 repetitions group increased strength more than the 30-40 repetitions group, while the 30-40 repetitions group showed greater increases in muscular endurance than the other two training protocols (111). This study points to a ‘continuum of training effects’ suggesting that the less number of repetitions that are performed the greater adaptation for strength whereas the greater number of repetitions performed the greater adaptation for muscular endurance (111). Therefore, the characterization of training for maximal strength in well-trained athletes, are repetitions in the range of 1-6.

Increases in strength appear to correlate with the ability of an individual to produce power (113). True peak power seems to be elicited at extremely low loads of 30% 1RM (28,52,113,122,123), however, the execution of commonly used exercises (squat, bench press, and deadlift) is altered at such a low load when compared to a high load due to difficulty controlling the high load during the eccentric phase of the lift (114). Therefore, the recommendation of power training should utilize a load heavy enough, which allows an athlete to perform the movement with the same execution he or she would use in competition. For this reason Garhammer et al. (1979) suggested that single effort athletes (i.e. weightlifters, long jumpers, high jumpers, shot-putters etc.) should utilize 1-2 repetitions of 80-90% 1RM for power training while athletes who perform multiple bouts of high power output (i.e. 50m swim, basketball, and volleyball) may require 3-5 repetitions with 75-85% of 1RM (20). These recommendations are based on specificity to a particular sport and upon the training status of the athletes.

Another training variable, which can influence maximal strength gains are rest intervals between sets. A study by Robinson et al. found that trained male subjects who utilized a 3-minute rest interval between sets of the back squat and vertical jump had greater 1RM strength gains and increases in peak power during a 15-second maximal cycle after 5 weeks of training than those who rested 30 seconds between sets (volume was equated between groups) (115). The squat showed a 7% strength increase in the 3-minute group, which was statistically greater than the 2% increase in the group who rested 30 seconds. These findings suggest that rest intervals of at least 3 minutes should be used for strength and power training.

Characterizing Optimal Hypertrophy Training

Due to the recruitment of motor units based on the size principle it is important to perform a resistance-training routine, which, allows for the greatest recruitment of motor units in an effort to maximize hypertrophy. When performing resistance training we understand that the size principle recruits low threshold fibers first, therefore by the end of a set consisting of moderate repetitions (6-12), which approaches failure an increased number of motor units of the exercising muscle will be recruited (85,127).

Increases in anabolic hormones: GH, testosterone, and Insulin-like growth factor-1 (IGF-1) have been shown to be significantly higher in females (86) and males (71) after moderate repetition sets (lasting between 30-90 seconds) when compared to lower repetition sets. Lactic-acid, the by-product of glycolysis (71,72) also rises to a greater extent during moderate repetition sets causing greater acidity and a lower pH inside of the muscle than during low repetition sets (87). Furthermore, lactate build-up seems to be a factor stimulating the release of testosterone as male rats who were administered lactate increased testosterone production in a dose dependent fashion by acting directly on leydig cells (160). Lin et al. (2001) also reported that this effect on leydig cells increased the activity of the secondary messenger adenylyl cyclase and the L-Type Ca^{2+} channel (160). Because of these factors it is possible that time under tension is important for hypertrophy due to increase metabolite build-up and anabolic hormone release. Therefore, moderate repetition sets should last between 30-90 seconds to maximize lactate build-up and anabolic hormonal release.

Moderate repetitions are also superior to low repetitions for hypertrophy due to the blood pump mechanism. Moderate repetitions and an increased time under tension can cause a collapsing of veins which allows arteries to continually bring blood to the muscle causing extreme myofibrillar hydration (88,94). This increase of fluid in the muscle may cause a blunting of protein degradation and an increase in muscle protein synthesis (mPS) resulting in an anabolic protein turnover ratio (88,89,90). This increased protein turnover ratio is important to note as it has been suggested that muscle cell shrinkage as opposed to the cell swelling actually inhibits mPS (90,97). Therefore, hydration of the muscle, as a result of a training stimulus may yield a hypertrophic response.

Endocrine Adaptations to Training (Testosterone, GH, IGF-1, and Cortisol)

Hormones released from glands of the endocrine system are secreted in an effort to maintain homeostasis in the body (128). Fluctuations in these hormones can occur acutely in response to exercise or resting hormonal concentrations may be changed as an adaptation to a chronic training stress (129,130). Acutely, it is typical to see a sharp increase or decrease in hormonal levels, however smaller changes or a lack of change occurs in response to chronic training (131). The alterations in levels of the primary anabolic and catabolic hormones will be examined in this section.

Testosterone is an anabolic hormone that interacts with skeletal muscle tissue (131). Testosterone has direct effects on muscle tissue and can promote GH responses in the pituitary, which can in turn influence mPS (145). Additionally, testosterone can also influence muscle hypertrophy through its ability to affect the nervous system (132). The ability of testosterone to influence the nervous system is due to testosterone's interaction with receptors on neurons. This interaction serves to increase the amount of neurotransmitters released to increase force production (132). Therefore, based on these abilities and the capacity of testosterone to directly interact with androgen receptors of the cell nucleus (132,145) it is clear that testosterone can have an anabolic training effect. Acutely testosterone has been shown to be significantly increased post-resistance training in men (133,134). Gotshalk et al. (1997) examined hormonal responses in recreationally trained men for up to 60 minutes post-exercise who performed one-set or three-sets of a resistance training protocol (133). The authors reported that both groups significantly increased testosterone levels when compared to baseline at 0, 5, 15, 30, and 60 minutes post-exercise. Further, this study showed that the three-set group had greater levels of testosterone when compared to the one-set group at 5, 15, and 30 minutes post bout (133). These results not only demonstrate that testosterone is significantly elevated post-exercise bout, but also that the level of increase seems to be dependent on total volume performed. To parallel these findings, Kraemer et al. (1999) reported untrained young and old men to both have increased testosterone levels post-training (135). Moreover, these authors found greater increases in testosterone post bout after 10 weeks of training. These findings suggest that a training base may be necessary to yield a greater acute response of testosterone. In addition, McCaulley et al. (2009) reported trained male subjects to increase testosterone levels to a greater extent immediately post hypertrophy training when compared to immediately post strength or power training (159). Subjects performed hypertrophy, strength, and power training and all three groups increased testosterone over pre-training levels by 32.3, 19.6, and 10.7% respectively, however, there was no difference in testosterone concentrations at 60 minutes post-exercise among the three groups. Thus, this study demonstrates testosterone to elicit the greatest increase as a result of high volume training and shows testosterone's half-life to be less than 60 minutes and most likely the peak in testosterone is between 10-15 minutes post-exercise (124).

Young women have in some cases also been shown to increase testosterone immediately following exercise (136,137), but data also exist showing no change in testosterone levels among women following resistance training (138). Moreover, various studies have also reported no change in resting testosterone levels in both men and women following long-term resistance training programs (139,140,141,142). Specifically, Stoessel et al. (1991) indicated no differences in the resting testosterone levels of untrained women and elite female weightlifters (143) following one year of training. Possible conflicting evidence regarding changes in resting testosterone levels is available from Hakkinen et al. (1987) who reported no differences in resting levels after one year of training; however, the authors did note increases in resting testosterone following two years of training (144). These results suggest that changes in resting testosterone levels are time dependent. Although data are inconsistent regarding the effects of chronic resistance training on resting testosterone levels, it does seem clear that testosterone concentration will increase acutely, dependent on total volume, following a bout of resistance training. Therefore, exercise which increases testosterone would be beneficial for muscle hypertrophy and muscle force production due to the ability of testosterone to interact with androgen receptors, increase the amount of neurotransmitters, and possibly stimulate mPS (145).

GH is an anabolic hormone secreted by the somatroph cells of the anterior pituitary gland (124). Its release seems to be correlated with an increase in exercise volume and it acts in an anabolic nature by promoting protein synthesis and inhibiting protein breakdown (124). Similar to testosterone, the level of acute GH increase seems to be dependent upon volume as studies in men comparing multiple set to single set protocols all reported greater increases in GH with the multi-set protocol up to 30 minutes post-exercise (133,147,148). Furthermore, GH seems to increase in men at 5, 10, 15, and 30 minutes post-exercise bout, but returns to baseline levels by 60 minutes (133). The correlation between greater exercise volume and an increased GH response also seems to be accompanied by high blood lactate levels that occur during high volume training protocols (145). This correlation is supported by findings from Hakkinen and Pakarinen (1993) who showed blood lactate and GH to increase at the same rate with different training volumes among male athletes (148). The augmentation of GH may be due to the accumulation of H+ when lactate acidosis occurs (145). This theory is supported by Gordon et al. (1994), who demonstrated that cyclists who were induced with alkalosis pre-exercise attenuated their GH response, following high-intensity-cycling (149). Even though it cannot be determined from Gordon's results if lactate acidosis provides a direct causation for an augmented GH response, the findings warrant more research to determine if the causation exists. Furthermore, acidosis is again correlated with GH release as Hakkinen and Pakarinen showed a significantly greater increase in GH and blood lactate immediately post-exercise among male athletes following 10 sets of 10 repetitions of the back squat at 70% 1RM when compared to 20 sets of 1RM (148). Along with testosterone it appears that chronic resistance training does not affect resting levels of GH (145). Kraemer et al. (1999) showed no difference in resting GH levels after 10 weeks of training in both young and old men when compared to pre-training levels (135). In addition, similar resting GH concentrations have been found between Olympic weightlifters and recreationally trained athletes (150). In agreement, Hakkinen et al. (2000) reported no differences in resting GH levels after 6 months of heavy resistance exercise combined with explosive training in both middle-aged and elderly men and women (151). However, perhaps the most interesting finding from this study was that elderly women did not show acute increases in GH following heavy resistance training, which was in contrast with all the other training groups (151). Although elderly women do not seem to have an acute GH response to training other populations do, as previously cited; however, changes in resting GH levels after chronic training do not seem to exist in any population. Consequently, it would seem that a resistance training protocol of high volume would elicit the greatest acute response in post-exercise GH levels allowing the skeletal muscle to obtain the most anabolic benefit.

Insulin-Like Growth Factor-1 (IGF-1) is an anabolic hormone, which signals anabolic pathways, and has been shown to increase muscular hypertrophy (82) and mPS (91). It is also pertinent to examine IGF-1 as a hormonal response as it mediates many of the actions of GH (145). The acute response of IGF-1 to a bout of resistance training is still not entirely clear, as studies have shown no change (161,162,163) or an increase (164,165,166) in IGF-1 immediately following training. The lack of post-training increase in some studies may be due to the delayed secretion of IGF-1, because IGF-1 secretion follows GH-stimulated mRNA synthesis (153). In support of this theory, Chandler et al. (1994) reported that peak values in IGF-1 occurred 16-28 hours following GH release in men (161). Thus, even though some studies have demonstrated no immediate increase in IGF-1 following resistance training it seems that changes in IGF-1 concentrations are deferred until the secretion of GH has taken place from the liver (145). In regards to chronic changes in IGF-1 concentrations it has been reported that trained men have higher resting IGF-1 levels than untrained men (164) while women have also shown increases in resting levels following long-term training (158). Indeed, Borst et al. (2001) found that in a 25-week training study of previously untrained men and women resting IGF-1 increased by 20% after 13 weeks of training and remained elevated at 25 weeks (167). Concurrently, Marx et al. (2001) demonstrated increased resting levels of IGF-1 following 6 months of training in previously untrained women (158). Interestingly, just as GH and testosterone increase, Marx et al. showed IGF-1 to increase dependent upon volume as a single-set group in this study did not increase IGF-1 to the same magnitude as a group of women who performed multiple sets of each exercise (158). Therefore, similar to GH and testosterone, increases in IGF-1 seem to be dependent upon total training volume.

Contrary to testosterone, GH, and IGF-1, cortisol is a catabolic hormone and glucocorticoid, which is secreted by the adrenal cortex and released via the hypothalamic-pituitary-adrenal axis (124). Cortisol's catabolic nature provides the opposite effects of GH in that it decreases levels of protein synthesis and increases levels of protein break down. These catabolic effects initiate an increased release of lipids and amino acids into circulation (124). These catabolic functions seem to be the greatest in type II fibers (145), cortisol serves to attenuate hypertrophy and strength increases with training. However, just as testosterone and GH, cortisol increases to the greatest extent post-training bout when high volume exercise is performed with short rest intervals (124) and seems to peak between 10-15 minutes post-exercise (124). Studies have shown trained men (148,152), untrained men (135), untrained women (138), and trained women (153) to all elicit increases in cortisol concentration post-exercise when compared to pre-exercise levels. In contrast, the results from Kraemer et al. (1999) indicated no post bout increase in cortisol levels among both powerlifters and untrained individuals (154). However, these findings could be due to the fact that this study only utilized one set of 80% 1RM to failure on the leg press exercise. Conversely, Hakkinen and Pakarinen found 10 sets of 10 repetitions of the back squat at 70% 1RM to significantly increase post-exercise cortisol levels (148). These findings once again suggest that increases in post-exercise cortisol may be dependent on a sufficient total volume being performed. Furthermore, not only total volume important but shorter rest intervals seem to yield a greater increase in cortisol levels at post-exercise. This phenomenon is evident as Kraemer et al. (1996) reported 8 sets of 10RM on the leg press with 1-minute rest intervals to increase the acute cortisol response to a greater extent than the same protocol with 3-minute rest intervals (155). In response to chronic resistance training studies have reported either no change (152,151,156) or a decrease (157,158) in resting cortisol concentration. Due to the clear acute response that cortisol has to exercise and its correlation with volume and rest interval length it seems that this acute response is a sign of metabolic stress. However, the inconsistency in chronic adaptations may be a result of tissue homeostasis and protein metabolism (145).

Examining the Importance of Training Variation: A Rationale for Periodization

Previously discussed are the primary mechanisms causing hypertrophy, strength, and power adaptations along with recommended training guidelines. Even though each specific muscular adaptation has a certain protocol a variation between these protocols must be used to achieve optimal muscle performance. This variation sets up phases of training each based on one of the three main adaptations: hypertrophy, strength, and power.

After neural adaptations provide strength increases in the early phases of training the primary reason for strength gains seem to stem from muscular hypertrophy (65,112). Furthermore, as previously discussed, increases in strength seem to correlate with increases in power (113). It should also be noted that essential to maximizing power output, in addition to strength, is maximizing muscle cross sectional area (CSA) through hypertrophy gains. The relationship between muscle CSA and power output comes to light in a study from Jones and Rutherford (116) who demonstrated that after 12 weeks of lower body training three times per week, unilateral eccentric exercise increased isometric force by 15% with a 5% increase in quadriceps CSA. In the same study and subjects unilateral concentric exercise increased isometric force by 11% and CSA by 5% following the same 12 weeks of training three times per week. Even though there was no significant correlation between the increases in strength and CSA, the authors noted that perhaps the main change in these 12 weeks was an increase in force generated per unit cross-sectional area of muscle (116). The analysis above suggests that even when training for maximal strength it may not be optimal to always utilize low repetitions because optimal strength requires optimal hypertrophy to optimize strength per unit of CSA. By the same token power output is dependent on hypertrophy and strength factors as well. Therefore, a variation of volume and intensity may be necessary for optimal muscle performance. This variation of volume and intensity during the training cycle has been shown to increase desired muscular performance to a greater degree than when variation is not used during the training cycle (5,9,38,43,47). This theory of varying volume and intensity is known as periodization training and the remainder of this review will examine this theory in depth dating back to the origins and development of periodization.

THE ORIGINS AND THE THEORY OF PERIODIZATION TRAINING

According to older publications the concept of periodization first originated in the second century (14) in ancient Greece and Rome (15,16). The early idea of periodization in this part of the world may have stemmed from the strength success of Milo of Croton. Milo lifted a growing calf every day, thus as the calf grew larger with each passing day Milo was forced to lift more weight (17). Since this time the strength and conditioning world of coaches and athletes alike have used some form of periodization with varying load and intensities (18). LP, however, as we refer to it today seems to have been built around the foundation set by various individuals in the 1960s to 1980s.

Following the original ancient writings on periodization, the concept was not officially introduced or expanded upon until Soviet textbooks were written in the late 1920s to 1940s. The first textbook, which published the idea of periodization called for a division of training between general and specified training, in which volume and intensity would vary between the general and specialized phases (103). In the years following these original publications a few other textbooks picked up on the idea and developed periodized training programs for individual sports such as skiing (104), swimming (105), and track and field (106). Following these texts, in 1956, Selye, introduced the idea that systems in the body will adapt to changes that may be placed upon them (19), which seems to confirm the efficacy of periodization. Selye called this the general adaptation syndrome (GAS). Under the GAS theory the body initially responds to the shock of a bout of training by soreness and performance decrements (20), which can last more than a week. Following this "resistance phase" the body recovers from the shock of training to its normal state and may now regain the ability to handle additional stress placed on the body without falling back into a state of shock. Next, the individual may leave the resistance phase stronger and more fit as a result of being able to withstand stress and this is known as the supercompensation principle (5,21). This theory paved the way for the specific adaptation to imposed demands (SAID) principle, which suggests that strength will continue to increase as volume and intensity are increased due to the muscular and nervous systems adapting to the requirements of the changes in volume and intensity (22). A periodized training program utilizes this theory by altering the volume and intensity of training to invoke the overload principle to allow for greater neuromuscular and hypertrophic gains. This has been noted to be effective as the neuromuscular system seems to respond to the increased load and demands placed upon it with greater strength returns (10). This concept is supported by various publications noting that periodized training yields greater muscular performance when compared to non-periodized training (1,3,4,5,9,38,43,45).

Finally, in 1964, the first modern model of periodization as we know it today was designed by Leo Matveyev of Russia (23). A recent review by Issurin (2010) has even labeled Matveyev as the founder of traditional periodization (24). Issurin goes on to note that Matveyev's model of periodization, which contains subdivisions of an annual plan and breaks them into smaller cycles, are indispensible for training (24). Matveyev's design is deemed effective for increasing desired muscular performance as almost all of today's athletes and coaches utilize some type of training periodization as their mode of preparation.

THE TRADITIONAL LINEAR PERIODIZATION MODEL

In the traditional linear model of periodization volume is gradually decreased as intensity is steadily increased up to competition day (25). This process is accomplished through the use of different training sub-cycles called macrocycles, mesocycles, and microcycles, which occur within the four major periods of the linear model as proposed by Stone et al. (6): 1) Preparatory Period, 2) First Transition Period, 3) Competition Period, and 4) Second Transition Period. Stone's model is widely accepted today and slightly updated Matveyev's original model by adding "First Transition Period." Stone chose to implement the first transition period to initiate more recovery between the preparatory period and the competition period (6). The linear model is applicable for both sports performance and maximal strength and power acquisition and will be described as such beginning in the following section.

Design of the Linear Model for Sports Performance

Each period of the linear design decreases volume and increases intensity of training as the competition approaches in an effort to elicit maximal performance on competition day (1,5,24). A macrocycle is the largest phase of periodization usually referred to as a yearly cycle with distinct preparatory and competition periods, however, this phase may last up to 4 years such as in the cases for Olympic athletes (1,24). Next a mesocycle is a shorter phase within the macrocycle lasting a certain amount of weeks followed by microcycles (about one week), which are short training phases within a mesocycle (24). The mesocycles and microcycles are the stages that allow for variation of volume and intensity during the periodization plan (24). This variation is important for achieving peak skill or strength, however, the amount of time spent attributed to a skill should be determined by the competition schedule (1,5,21,24). Using this theory, when training for sport performance, the early part of a periodized routine would focus on high-volume non-sport specific activities and transition to low volume and high intensity sport-specific activities as the competition approaches (1,5,21,24). Originally, the traditional method has been discussed as a way to prevent overtraining (6,26) by offering "transition periods" and intensity variations as opposed to a non-periodized routine. However, it has been recently suggested that a model of LP may not protect against overtraining as it pertains to muscle performance (12). One of the suggestions for possible overtraining with the LP model indicates a lack of recovery during high volume phases of training (10) although no specific data have been collected on this issue making this notion purely speculative.

Preparatory Period: The preparatory period is reserved for general and preliminary work (6,24). It encompasses the longest time of the four major periods within a macrocycle and it occurs at a point of the training cycle when there are no competitions on the horizon (21,24,26). The preparatory period is designed to build a stable base of training to allow the athletes to get in better condition to tolerate the increased workload to come. The goal is to increase muscle mass during this phase to give the athlete an opportunity to reach his or her full strength potential (27). For strength training Stone and O'Bryant (1987) have laid out the order of hypertrophy, strength, and power training to occur (26). This trend of high volume to low volume during the preparatory period is based on two factors: 1. As discussed previously, the findings of Jones and Rutherford indicate a possible relationship between muscle CSA and force output (116) and 2. The high volume in the early stages should yield supercompensation. Supercompensation, an increase in desired performance following a training program, is apparent in a study by Mujika et al. (1996) who showed that high volume training by elite swimmers which was followed by a taper to yield increased competition performance over projected outcomes (117). This study may validate the use of a taper where volume is significantly reduced, but also demonstrates the effectiveness of high volume training during the preparatory period. Even though this study seems to show that the taper is an effective tool to increase performance, the projected measure used by Mujika is speculative and the comparison of the experimental group to a control group may have been a better design.

First Transition Period: The first transition period serves as a short break or taper in training between the preparatory period and the competition period. In other words, the period serves as a break between period of high-volume training and high-intensity training. During this period active rest or low intensity training is utilized to recover and prepare for the competitive period. It is interesting to note, that the original periodization model proposed by Matveyev did not have this first transition period (23), rather it was introduced in 1981 by Stone et al. (6). The addition of this period by Stone and others seems to have support in the literature. Mujika and colleagues (1996) reported that a taper after the preparatory period and before the competition significantly improved performance in elite swimmers over their projected training period (117). The elite swimmers in this study (10 male and 8 female) had 3 major competitions throughout the year and the study's protocol called for a 2-week taper before the 1st competition with 4-week and 6-week tapers before the 2nd and 3rd competitions, respectively. When averaging each individual swimmer's performance time across all three competitions, 17 swimmers performed better than their projected time ($p<0.05$) while only 1 swimmer did not exhibit significance improvement in favor of the taper (117). The projected performance time was calculated from an equation designed by Banister et al. (1975), which has been shown to accurately measure athletes' response to training (118). Therefore, when projecting a competition time Mujika et al. (1996) did not account for the taper as part of the training volume. The projection was solely based on training without a taper to act as a control (117). These findings suggest that utilizing a taper during the first transition period may be necessary to recover from the preparatory period in order to elicit supercompensation gains and maximize competition performance.

Competition Period: As noted in the previous section (the first transition period), the competition period utilizes training of an increased intensity with a decreased training volume from that of the preparatory period. This period focuses on sport-specific work (24). Now skill and technique become a central part of the training program in order to peak strength and power for maximal performance (21,24,26). A competition period will often last the entire length of a sports season. For example, the competition period for a National Football League (NFL) team would last from the beginning of September through at least December or possibly longer. This entire competition period keeps the athlete performing high-intensity and low-volume training throughout their season of competition (39). The National Strength and Conditioning Association (NSCA) recommends that strength training for this period remains at levels of at least 93% of 1RM with low volume (1-3 sets and 1-3 reps) to allow for peaking and maintenance during the competitive season (21). The recommendations of the NSCA are supported by Hoffman et al. (2003) who reported significant strength gains in 1RM squat among freshman collegiate football players in-season when following a LP protocol that abides by NSCA's in-season guidelines when compared to a NLP protocol (107). In this study, the LP group significantly increased squat 1RM over baseline measures by 7%. It should be cautioned, however, that freshmen often see little playing time in the sport of football on the collegiate level. Therefore, many of these athletes may not have been as fatigued as those playing significant game time, thus the ability to actually gain strength in season due to sufficient recovery was present with these athletes. Moreover, this period should also attempt to avoid overtraining at all costs to allow the athlete to perform under optimal conditions on competition day.

Second Transition Period: The second transition period, which is also commonly known among athletes and coaches as active rest, immediately follows the competitive phase and is defined by Issurin (2010) as a time for rehabilitation and recovery (24). During this time it is custom to perform non-sport specific activities at a low volume and intensity (28-30). This type of training is often known as cross training where for example, a soccer player may engage in other sports performed at low intensities as a form of active rest. It has also been reported that the active rest period gives athletes a chance to not only physically recover from injuries, but also recover mentally from the high intensity of the competitive period (28-30). Finally, this period may consist of a de-load, where resistance training is performed at a very light intensity. The de-load has been made popular among athletes through books and training manuals by coaches. Esteemed coaches Eric Cressey and Jim Wendler recommend the athlete to perform a de-load to avoid overtraining (31,32). Their training principles have been supported through the literature by Schulze et al. (2002) who reported that a 21 de-load or 'unload' maintained upper and lower body strength of previously trained men (108). In this study 16 trained male subjects performed 3 days of training of the knee extensors for 21 days at a low volume and high intensity as opposed to a control group who rested. After the protocol was completed, and to be expected, the experimental group was able to maintain their pre-study 1RM of the knee extensors with no significant change while the control group demonstrated a decline in their 1RM knee extension by an average of 17% from baseline measures. Furthermore, subjects who performed the de-load also reported that they felt rested and ready to embark on a new training plan. These findings suggest that a de-load is helpful for maintaining maximal strength as opposed to simply resting when attempting to recover (108).

Design of the Linear Model for Maximum Strength Gains

Improving maximal strength is important for sports performance as it can increase other conditioning factors associated with a particular sport (5,12). The three basic phases of strength training: hypertrophy, strength, and power take place during the preparatory period of the LP design. The details of how to optimally design training in each phase will be discussed in the following sections.

Hypertrophy Training: Hypertrophy training occurs earlier in the preparatory phase of a LP program and lasts 1-6 weeks (3). This phase is sometimes referred to as a hypertrophy/endurance phase. The characterization of hypertrophy training is that of high volume and low intensity.

The basis of hypertrophy resistance training is to increase muscle CSA in an effort to maximize strength potential (27,116) as the greater the muscle mass the greater potential there is for that individual to gain strength. Previously this review discussed the necessity to exhaust motor units to achieve hypertrophic adaptations. This exhaustion of motor units is referred to as the Corridor Theory of Strength Training as proposed by Zatisorsky (33). In his theory Zatisorsky notes that the only motor units, which are susceptible to physiological change are those that are both recruited and exhausted resulting in muscle fiber damage. As we know a certain level of muscle damage stimulates the cascade of the IGF-1 pathway, which in turn activates satellite cells to begin repairing muscle fibers (81-83) (thus the basis for Zatisorsky's theory). Furthermore, electromyography (EMG), which measures electrical activity in skeletal muscles, data indicate that all available motor units are more likely to be used at some point when more repetitions are performed (109,127). Thus to truly exhaust and fatigue all available motor units hypertrophy training must consist of moderate repetitions. This theory leads to traditional hypertrophy training in which moderate repetitions are performed with short rest intervals to maximize muscle damage and muscle growth. It is also equally important to utilize a rest interval short enough as it is to perform moderate repetition so that the recruited motor units do not recover. This lack of recovery will cause the subsequent training set to recruit new motor units to be exhausted. If the rest interval is too long, then the same motor units would be exhausted over and over leading to less of a hypertrophic adaptation. This theory is also supported by the findings of Rhea et al. (2002) who reported that 3 sets of resistance training induced greater strength gains than one set in recreationally trained individuals (34). The 16 men in this study trained with the bench press and leg press 3 days a week for 12 weeks. Eight subjects performed 3 sets of each exercise to failure each session, while the other 8 subjects only performed one set to failure each session. The group, which performed 3 sets increased leg press and bench press by 56% and 33%, respectively whereas the group who performed 1 set only increased each lift by 26% and 20%. Even though muscle CSA was not measured in this study, these subjects rested no more than 2 minutes, so that motor units could not fully recover so new motor units were recruited and exhausted each set. Therefore, the findings of Rhea et al. (2002) seem to support Zatisorky's theory that only motor units which are exhausted are those which undergo physiologically change.

Strength Training: Following the hypertrophy phase is the strength phase characterized by exercises of high intensity and moderate volume. As noted earlier the greater CSA of the individual the greater potential for strength gains that athlete will possess during this phase. It has been previously reported that optimal strength gains occur when performing repetitions of 6 or less (38,111) however, as cited previously variations in training volume and intensity are necessary to optimize strength gains. This concept is important for powerlifters and weightlifters that strive for 1RM strength as it may even be optimal for them to often perform repetitions in the 1-3 range.

An applicable model load when in a strength phase is Prilepin's Table (Table 1), which has been previously used in the literature (39) to determine a training protocol for college athletes. Prilepin's Table was created by, legendary Soviet weightlifting coach Alexandre Prilepin through his many years as coach of the Soviet Olympic weightlifting team (39). Charniga's textbook (1982) brought this table to the mainstream and it is now commonly used among weightlifters and powerlifters to develop maximal strength (119). The table provides an optimal total or total range of repetitions, which should be performed during a training session based on the load to yield maximal 1RM gains.

Table 1: Prilepin's Table (39)

INTENSITY	REPS PER SET	OPTIMAL TOTAL OF REPS	TOTAL RANGE OF REPS
BELOW 70%	3-6	24	18-30
70-79%	3-6	18	12-24
80-89%	2-4	15	10-20
90% AND ABOVE	1-2	7	4-10

The low repetitions with a moderate to high intensity performed in this strength phase utilize rest intervals from about 3-5 minutes. When rest intervals of this nature are used new motor units may not be exhausted each time resulting in less of a hypertrophy response that was described in the previous phase. However, Willoughby et al. (1993) point out that less volume and more weight, which is utilized in this phase, is better for strength gains than that of lighter resistance (5). This strength is found through recruiting as many fibers as possible (5), which is done with loads in excess of 90%. As previously reported by Anderson and Kearney, greater strength adaptations among previously trained individuals occur with lower repetitions (111), thus Prilepin's Table may give effective recommendations for strength as low repetitions are suggested (39).

Finally, a basic strength phase prepares the athlete not only for the high intensity power phase to come, but is also important for increasing power and force output. Hartmann et al. (2009) note that high weight loads of greater than 90% performed with maximum explosiveness are important to increase strength and power depending on the amount of muscle CSA available (27,116). Therefore, these strength and power gains also depend on the amount of hypertrophy achieved during the hypertrophy phase.

Power Training: The final resistance training phase to occur during the preparatory period of the linear model is the power phase, which is sometimes referred to as the "strength/power" phase since it involves loads of up to 95% used in this training phase. As described earlier, Hartmann et al. (2009) discuss the importance of loads in excess of 90% to be utilized for strength and power gains, which is extremely important at times in this phase (27). Even though true power output is maximized at about 30% 1RM, the recommendations of Hartmann are supported by Newton et al. (1996), who showed that power training at 90% 1RM allowed the athlete to utilize similar motor patterns during a maximal attempt (114). The authors went on to note that low loads such as 30% make it difficult to control the weight during the eccentric phase. Therefore, recommendations for power training range from 75-85% with 1-3 repetitions and loads of 90% with 1-2 repetitions (20). Applying these recommendations depends on the type of sport in which the athlete takes part. The first recommendation may be implemented for an athlete who participates in a sport requiring multiple power outputs such as: basketball, volleyball, or soccer. While the latter recommendation, may be utilized for athletes needing to produce only a single bout of high power output (powerlifters, high-jumpers, and shot-putters). As the intensity of weight training increases so does the intensity of anaerobic conditioning and a shift is being made toward more sport-specific movements. For a strength athlete, such as a powerlifter or a weightlifter, the sport specificity would be testing 1RM at the end of this phase just before the taper during the first transition period or perhaps performing a practice competition. At the end of the power phase the strength athlete would be sufficiently prepared for the planned competition as the sport athlete with a longer competition period would utilize an in-season maintenance program during the subsequent competitive period (3,21).

Findings, Analyses, and Mechanisms of the LP Model

When matched against a non-periodized routine a LP model seems to increase performance/strength in male reserve officers' training corps (ROTC) cadets (38) and collegiate women's tennis players (43). LP also seems to attenuate decreases in stride length in endurance athletes as opposed to non-periodized strength training or no strength training which has no effect on a runners' stride length (45). Furthermore, LP has been shown to increase 1RM strength and sport specific skills above baseline measures among NCAA Division I track and field athletes (44) and increase maximal upper and lower body strength among collegiate football players (41). Finally, LP simply increases maximal strength among trained males to a greater extent than non-periodized training (5). These data show the clear advantage of utilizing periodization when compared to a non-periodized program for muscle performance, and demonstrate the efficacy of periodization for both males and females, trained and untrained populations. The details of these studies will now be discussed.

There are nine total studies analyzed in this section, of which five are broken down in Table 2 (Note: only five are in the table because the other four either do not have strength as a main outcome or have no control group). Of the nine total studies analyzed two studies compared the effects of muscle performance outcomes in males between a LP and a non-periodized group, and both studies showed a significantly greater effects of the desired outcome in favor of the LP training (5,38). Three studies matched linear and non-periodized groups in females, with two studies (9,43) showing muscle performance increases of the desired outcome in favor of a LP group when compared to a non-periodized group, while one study found no differences between LP and non-periodized training as it relates to maximal strength among untrained women (47). Other studies utilized either males (41,42) or males and females (44), and showed significant increases in muscle performance outcomes with LP over baseline (note: these studies did not contain a non-periodized condition). The final study examined the effects of running specific periodized training versus running specific non-periodized training in trained runners to see the effects on stride length (45). This study yielded a greater attenuation of stride length in favor of the LP group. The results among males are remarkably consistent and strongly suggest the implementation of some sort of periodized training program. A classic study by Willoughby (1993) set the standard by showing LP to elicit greater 1RM bench press and squat increases when compared to non-periodized training over a 16-week training program in an extremely large population of 92 previously weight-trained college aged males (5). This study is unique because it matched four different training groups with one of the groups utilizing a LP model and the other three all using constant, but different set and repetition ranges. However, it is important to note that even though volume was not significantly different among groups ($p>0.05$), the author does acknowledge that the LP group performed the greatest amount of volume. Therefore, a slightly greater volume in the LP training group might have been partially responsible for the greater strength increases. Just two years later, Potteiger et al. (1995) were the first to expand on the Willougby's study (5) and apply LP to highly trained athletes by measuring strength, lean body mass, and sports specific activities in division I male and female collegiate track and field athletes (44). Potteiger not only reported significant strength increases with LP, but also significant increases in power (measured by vertical jump power), as well as increases in overhead shot put throw distance and kneeling shot put throw distance (44). This study however, did not have a non-periodized group to compare findings to. Potteiger et al. (1995), however in contrast with Willoughby (1993), did control for volume, and these findings support increasing muscle performance in terms of strength and power will lead to increased sport performance for both men and women (44).

Schiotz et al. (1998) continued to use highly trained individuals to investigate LP and studied 14 male ROTC cadets over 10 weeks of LP versus non-periodized training (38). First, it is interesting to point out that this study was the first to report significant decreases in body fat percentage with a 1.5% decrease only in the LP group whereas a non-significant 0.6% decrease was shown in the non-periodized group after 10 weeks. The findings of Potteiger et al. (1995) are in contrast with that of Schiotz, as Potteiger reported no significant decrease in body fat percentage over 24 weeks of training in highly trained men and women with a LP training protocol (44). These differences may not be surprising as Schiotz et al. (1998) also included 3 cardiovascular training sessions per week, in addition to resistance training in an effort to prepare the ROTC cadets for the Army Ranger Challenge. Schiotz et al. (1995) demonstrated that the 1RM bench press was significantly increased in the LP group as opposed to the non-periodized training group (38). Highly trained athletes were also the focus of the study by Wilder et al. (2002), who investigated the effects of LP in division I collegiate football players and reported significant increases in 1RM bench press (9%) and 1RM squat (14%) with LP over baseline measures after training 3 days per week for 10 weeks (41). It is difficult, however, to make recommendations as it pertains specifically to football players, as this study did not have a control group of non-periodized training. Also, the subjects in Wilder's study were supplemented with creatine, which may have inflated the strength increases of the subjects (41). The study also found that the football players decreased body fat percentage significantly by 1.3% (41). This appears to be similar to the study by Schiotz et al. (1995) who reported a significant decrease in body fat by 1.5% (38) after the same duration of 10-week training.

In addition, to the previously discussed findings, periodized training has not only been investigated in relationship to strength (42), but also endurance performance (45). Nunez et al. (2008) found that 12 weeks of periodized aerobic and strength training increased maximal strength, vertical jump height, and a soccer specific shuttle run known as the Probst test in professional soccer players (42). Again periodized training is increasing the desired muscular performance of a given sport, however, this study offers no control group or alternative of a non-periodized training group to compare results against (just as Wilder's study from above). Therefore, it is difficult to make a recommendation for the optimal strength and endurance training protocol for soccer based on these findings. Periodized training does gain further support as it pertains to endurance performance as Esteve-Lanao et al. (2008) investigated the effects of LP training vs. non-periodized training over 16 weeks in 18 well-trained and competitive male distance runners. Every 4 weeks volume and intensity of the strength and endurance training protocols were altered to follow traditional periodization guidelines, which yielded an attenuated loss of stride length (45). The authors suggest that attenuating the loss of stride length improves running economy and increases running endurance performance as longer strides can be maintained throughout a race. This study represents further evidence that LP evokes greater effects for desired muscular performance when compared to non-periodized routines in highly trained males.

As previously mentioned Potteiger et al. (1995) included females as well as males and demonstrated that both groups of highly trained track and field athletes increased strength, power, and sport specific task performance with a LP training protocol (44). Consistent with Potteiger's findings are those from Kraemer et al. (2000 and 2003), which reported increases in maximal strength and power of collegiate women's tennis players (9,43). These studies are quite unique in that their durations are the longest investigated to date as they each consist of 9 months of training. In the study by Kraemer et al. (2003), the authors simply measured strength and power differences between periodized and non-periodized training groups with the periodized group showing significant increases over the non-periodized training at each time point (3, 6, and 9 months) over the nine-month period (9). In their earlier study, however, Kraemer et al. (2000) took a slightly different approach by utilizing training protocols of differing volumes (43). This study matched a LP program (periodized and multiple sets) as opposed to a single set non-periodized protocol. As previously mentioned, the LP group in comparison showed significant increases in the outcome variables of strength and power, which was not only consistent with other findings on LP but with the findings by Rhea et al. (2003), who reported three sets of strength training to be superior to one set for maximal strength among trained individuals (34). The results of both studies conducted by Kraemer suggest that LP is superior to non-periodized training for trained women just as it is for men.

One study in contrast with others is that of Herrick and Stone (1996) who investigated the use of LP versus a non-periodized program in untrained women for 15 weeks (47). Their findings indicated that both groups had significant increases in 1RM squat and bench press when compared to baseline measures following the training with no significant differences between groups. These findings show that for untrained women periodized training may not be necessary, primarily due to neural adaptations involved with early phase resistance training. However, the LP group continued to make upper and lower body strength gains toward the end of the 15 weeks while the non-periodized group began to plateau resulting in slightly greater but non-significant gains (47). This analysis suggests that even though the early phase relies heavily on neural adaptations a longer training protocol may require the planned variation of LP to optimize success and desired muscle performance.

Table 2: Strength Gains in Studies Comparing LP vs. a Non-Periodized model

Study	Number & Training Status	Duration & Frequency	Training Protocol	Strength Tests	Strength Gains	Significance for LP over NP For Strength
Willoughby et al. 1993	92 Previously Weight Trained Males LP-23 NP1-23 NP2-23 C-23	All Groups trained 3 days/wk for 16 weeks	LP – Altered every 4 weeks: 5X10RM, 6X8RM, 3X6RM, 3X4RM NP1 – 5X10RM for 16 weeks NP2- 6X8RM for 16weeks C-Control, no training	1RM Bench Press and Squat	Not enough data to calculate percentage change	YES
Herrick and Stone 1996	20 Untrained College Women LP– 10 NP – 10	Each group trained 2 days/wk for 15 weeks	LP – 8 weeks of 3X10RM, 4 weeks of 3X4RM, 3 weeks of 3X2RM. NP – 15 weeks of 3X6RM	1RM Bench Press and Squat	Bench Press: LP – 9.4% NP – 7.9% Squat: LP – 23.6% NP – 22.2%	NO
Schiotz et al. 1998	14 Male ROTC Cadets LP - 7 NP - 7	Each group trained 4 days/wk for 10 weeks	LP – Wk 1,2: 5X10, Wk 3,4,6,5,6,7: 4X8, Wk 8,9,10: 2X5,2X3 NP – 4X6	1RM Bench Press and Squat	Bench Press: LP – 7.5% NP – 4.8% Squat LP – 11.3% NP – 13.1%	Yes, but only for the bench press

Table 2 - Continued

Study	Number & Training Status	Duration & Frequency	Training Protocol	Strength Tests	Strength Gains	Significance for LP of NP For Strength
Kraemer et al. 2000	24 Collegiate Women's Tennis Players LP – 8 NP – 8 C – 8	The LP and NP groups trained 2-3 days/week for 9 months. The control group performed no resistance training.	LP – Repetitions varied from 6, 8-10, and 12-15 every 4 weeks. NP – 1X8-10RM of all exercises in a circuit training fashion C – No resistance training	1RM Bench Press, Shoulder Press, and Leg Press	Not enough data to calculate	YES
Kraemer et al. 2003	30 Collegiate Women's Tennis Players LP– 10 NP – 10 C - 10	The LP and NP groups trained 3 days/wk for 15 weeks. The control group performed no resistance training.	LP – Rotated between 12-15RM, 8-10RM, and 4-6RM every 4 weeks NP – Constant loading of 8-10RM for duration of study C – No resistance training	1RM Bench Press, 1RM Leg Press, and 1RM Shoulder Press	Bench Press: LP – 23% NP – 17% Leg Press: LP – 19% NP – 17% Shoulder Press LP – 24% NP -18%	YES for bench press and shoulder press at 9 months. Also, leg press was significantly greater after 4 and 6 months.

Limitations of LP

Perhaps the main limitation of LP is that the athlete runs the risk of overtraining. Willoughby (1993) proposed that a biochemical, physiological, or psychological factor causing performance decrements or lack of improvement with a sufficient training stimulus as overtraining (5). This definition simply states that overtraining occurs when performance declines as a result of too much training. Previously it was thought that LP was an adequate method to avoid overtraining (48,49). However, more recent authors suggest that LP training puts an individual at a greater risk for overtraining when compared to a non-linear or undulating model of periodization (12,17). Furthermore, Poliquin notes that the overtraining with LP may stem from neural fatigue by remaining in the same training phase for too long of a period of time (50). McNamara et al. (2010) also suggest that LP may become stale for an athlete (17). These factors may be avoided with greater fluctuations throughout the periodized cycle that occur with non-linear or undulating periodization (to be discussed later in this chapter).

A second possible limitation of LP is the possible loss of training adaptations during different phases. With LP an athlete can spend up to 6 weeks or more in a single phase, which may cause a loss of training adaptations from another phase (1). An athlete who is in a competitive phase for 6 months may lose CSA or general endurance as the LP model does not call for hypertrophy training during the competition period. Moreover, the traditional LP model is lacking when it comes to preparing for multiple events during a short period of time. For example a tennis player who has a tournament every month would simply not have enough time to sort through an entire LP model to peak for each match, and this is one of the reasons that previous research recommends a non-linear or undulating model for tennis players (12). However, at this point these limitations may be speculative, which leads to the need to examine differences in training adaptations between LP and NLP.

THE NON-LINEAR OR UNDULATING PERIODIZATION MODEL

The non-linear (also referred to as undulating) model of periodization differs from the LP model in which it allows for fluctuations of load and volume of training within a microcycle (21). These fluctuations may occur each day or each week. The undulating model of periodization was introduced by Poliquin (1988), in an effort to improve upon

LP. Poliquin suggested that the alterations of volume and intensity made in the LP model were too gradual and that more frequent changes in the stimulus would enhance strength gains to a greater extent than LP (50). His original model of undulation varied the load and volume of training every two weeks, however in contrast to Poliquin's hypothesis, no difference was found in strength gains when Baker et al. (1994) first compared a weekly undulating periodization model against a LP training protocol (40).

Design of the Undulating Model

Since Poliquin's suggestion to investigate the undulating model, there have been a multitude of studies, which have developed protocols known as Weekly Undulating Periodization (WUP) (2,40), Daily Undulating Periodization (DUP) (10,46,51,52,53,60), and Non-Linear Periodization (NLP). NLP may constitute any of the undulating models, whereas WUP varies the volume and intensity between weeks, and DUP varies the volume and intensity each workout. For example, a DUP model of strength training may have the athlete perform high volume and low load during Monday's training, medium volume and medium load on Wednesday, and low volume and high load training on Friday. On the other hand the WUP model would have a strength athlete utilize 6 sets of 10 repetitions at 70% during week one of training followed by 5 sets of 6 repetitions at 80% the second week, and 8 sets of 3 repetitions at 90% the third week. Rhea et al. (2002) suggested that the neuromuscular system makes greater adaptations and elicits greater strength gains in response to an undulating model than it does as a result of LP due to more opportunities to recruit high-threshold motor units (10).

Findings, Analyses, and Mechanisms of the NLP/Undulating Model

There is evidence that undulating or NLP elicits greater strength or muscular endurance adaptations (10,46,51,52) when compared to LP, however, data from Baker et al. (1994) indicated no difference in maximal strength gains between a LP and WUP (40). It is important to note, however, that there are no data showing LP to elicit greater strength increases during training in the preparatory period when compared to an undulating model. Furthermore, the study from Baker et al. (1994) also contained a non-periodized training group. The authors also reported no differences in strength between the non-periodized group and both LP and WUP among recreationally trained subjects (40). This point is important because it is in agreement with previously discussed data from Herrick and Stone (1996) showing that no difference in strength gains exists between LP and non-periodized training protocols among novice trainees (47). An in depth analysis of the remaining studies on undulating periodization is in the following section.

The findings yielded by these studies (which are broken down in Table 3 below) become more interesting when analyzing the training level of the participants as well as the method of undulation. Of the seven studies analyzed below four out of the seven utilized truly trained lifters (10,46,52,60) while only 3 of the 7 studies yielded significant gains in favor of the undulating model, all three (10,51,52) were of this trained group. Furthermore, all of the significant findings utilized DUP protocols in males (10,46,52), while a study matching DUP vs. LP in untrained women found no significant difference between groups for maximal strength or muscle CSA after 12 weeks of training (53).

Among the studies using trained males, Rhea et al. (2002) and Monteiro et al. (2009) reported greater upper and lower body maximal strength gains with a DUP vs. LP model in strength trained men (10,52). In highly trained males, however, Peterson's protocol elicited significance in favor of the DUP group versus a LP group (46), while Hoffman found no differences among Division III collegiate football players when comparing DUP and LP (60). At first glance it seems surprising that Peterson and Hoffman yielded differing results, however, a more in depth analysis examines the difference in the protocols of the two studies. Peterson et al. (2008) found greater gains in a DUP group, which utilized the traditional hypertrophy, strength, and power phases in the training program design (46), while the collegiate football players always trained at a high intensity rather than using all three phases in their model of DUP (52). Furthermore, the participants in the Hoffman (60) study trained 4 days/week compared to 3 days/week training used by Peterson et al. (2008) and the other studies utilizing trained participants and a DUP protocol (10,46,52). Understanding these facts of each study makes it possible that the participants in Hoffman's study completed more total volume and training days than that of Peterson et al. (2008) and may have been overtrained in comparison simply due to the extra days of training. Furthermore, it may be beneficial to utilize all three traditional phases when implementing a DUP protocol with highly trained athletes rather than just varying the number of repetitions between workouts. All three studies mentioned above found significantly greater improvements in strength when using the undulating periodization among trained males using a three-day a week training routine and a DUP model.

The studies using untrained or recreationally trained individuals, men or women did not yield any significant findings in favor of the undulating periodization model (2,40,53). Buford et al. (2007) and Baker et al. (2004) both employed WUP protocols in recreationally trained males with no significant findings (2,40) when compared to LP. Kok et al. (2009) demonstrated that DUP was unsuccessful in yielding superior strength and CSA gains in untrained females when compared to a LP training group (53). The lack of significance in this study could very well be due to the novice training nature of the subjects, which seems consistent with that of Buford et al. (2007) and Baker et al. (2004), suggesting that there might be no different effects on muscle performance between undulating and LP in novice athletes (2,40). The untrained females did however, utilize a DUP protocol in which they trained in each traditional phase (hypertrophy, strength, and power), which puts these findings in contrast with that of Peterson et al. (2008) (46). However, as already discussed these studies used markedly different populations.

When comparing the data there are no significant findings that have been found in favor of the WUP or DUP vs. LP in recreationally trained or untrained individuals (2,40,53). It does seem apparent, however, that trained athletes seem to respond best to undulating periodization although more data on untrained and trained athletes are necessary to truly understand the applicability of the undulating model. It is important to point out that most studies using trained males do seem to favor DUP for strength gains. No studies have matched WUP vs. LP in trained individuals, therefore a comparison between WUP and LP cannot be made. However, the study from Buford et al. (2007) using recreationally trained subjects contained three groups: DUP, WUP, and LP (2). This study showed no difference among any of the groups, which demonstrates that all three groups had similar strength gains. Thus, Buford's study indicates that there is no difference in strength gains between DUP and WUP protocols in novice athletes. Further, it is currently unknown if there are differences in strength between DUP and WUP among trained individuals as no study to date has examined this. Additionally, no long-term training study during the competition period in trained or untrained individuals has ever reported significant strength gains in favor of LP training when compared to any undulating model. It is interesting to note that the only model of undulating periodization showing significance in untrained subjects of LP does not pertain to maximal strength. Rather, Rhea et al. (2003) showed that DUP enhanced muscular endurance among recreationally trained men and women to a significantly greater extent than a LP protocol (51).

TABLE 3: Strength Gains in Studies Matching a Non-Linear vs. a Linear Model

Study	Number & Training Status	Duration & Frequency	Training Protocol	Strength Tests	Strength Gains	Significance for NLP over LP For Strength
Baker et al. 1994	22 Recreationally Trained Male Athletes LP -8 WUP -5 NP-9	All Groups trained 3X a week for 12 weeks.	NP – 5X6 for 12 weeks LP – Altered every 4 weeks: 5X10, 5X5, and 3X3 WUP – Altered every 2 weeks: 5X10, 5X6, 5X8, 5X4, 5X6, 4X3	1RM Bench Press And Squat	Squat: NP – 26.1% LP – 27.7% WUP – 28.4% Bench: NP – 12.5% LP – 11.6% WUP – 16.4%	NO
Rhea et al. 2002	20 Trained men from college weight training classes. LP – 10 DUP – 10	All Groups trained 3X a week for 12 weeks.	LP – Altered every 4 weeks: 3X8RM, 3X6RM, 3X4RM DUP – Altered each workout: Day1: 3X8RM, Day2: 3X6RM, Day3: 3X4RM and then repeat each week.	1RM Bench Press and Leg Press	Bench: LP – 14.37% DUP – 28.78% Leg Press: LP – 25.61% DUP – 55.78%	YES

Table 3 – Continued

Study	Number & Training Status	Duration & Frequency	Training Protocol	Strength Tests	Strength Gains	Significance for LP of NP For Strength
Buford et al. 2007	30 College Aged Recreationally Trained classes: 20 men and 10 women LP – 9 WUP – 9 DUP – 10	All groups trained 3X a week for 9 weeks	LP – Altered every 3 weeks: 3X8, 3X6, 3X4 WUP – Altered every week: 3X8, 3X6, 3X4 DUP - Altered each workout: 3X8, 3X6, 3X4	1RM Bench Press and Leg Press	All groups increased 1RM bench press and leg press strength significantly from pre to post.	NO
Hoffman et al. 2009	51 NCAA Division III College Football Players NP – 17 LP – 17 NL – 17	All groups trained 4X a week for 15 weeks.	NP – 4X6-8 for 15 weeks LP – Altered at 4 weeks, 6 weeks, and 4 weeks: 4X9-12, 4X6-8, 5X3-5 NL – Altered each workout between 4X9-12 and 4X3-5.	Strength: 1RM bench press and squat.	Bench: NP – 6.7% LP – 5.6% NL – 6.4% Squat: NP – 11.3% LP – 13.6% NL – 9.9%	NO
Kok et al. 2009	20 untrained college females LP – 10 DUP – 10	Both groups trained 3X a week for 9 weeks	LP – Altered every three weeks: 3X10, 3X6, 3X3 DUP – Altered each workout: Day1: 3X10 Day2: 3X6 Day3: 3X3 and each week.	Strength: 1RM bench press and squat.	Bench: LP – 17.9% DUP – 22.1% Squat: LP – 25.9% DUP – 29.2%	NO

Table 3 – Continued

Study	Number & Training Status	Duration & Frequency	Training Protocol	Strength Tests	Strength Gains	Significance for LP of NP For Strength
Monteiro et al. 2009	27 strength-trained men. NP – 12 LP – 12 NL – 13	All groups trained 2-3 days a week for 12 weeks.	NP – 3X8-10RM for every training session LP – Altered every 3 weeks: 3X12-15RM, 3X8-10RM, 3X4-5RM, 3X12,8, 4RM NL – Altered each workout between 3X12-15RM, 3X8-10, and 3X4-5RM	Strength: 1RM bench press and leg press.	Bench: NP – NA LP – NA NL – 28% Leg Press NP – NA LP – NA NL – 43%	YES
Peterson et al. 2008	14 well-trained firefighters LP – 7 DUP – 7	Both groups trained 3X a week for 9 weeks.	LP – Altered every 3 weeks: 3X7-9, 3X3-5, 3X2-4 DUP altered each workout: Day1: 3X7-9, Day2: 3X3-5, Day3: 3X2-4 and then repeat each week.	Strength: 1RM bench press and squat.	Bench: LP – 9.1% DUP – 14.4% Squat: LP – 14.4% DUP – 17.1%	YES

One of the primary mechanisms in support of the undulating model is that LP may compromise strength gains due to a decrease in the ability of the neuromuscular system to recruit high-threshold motor units (53). Kok et al. (2009) showed just this as untrained women underwent either a 9-week LP model or a 9-week DUP model with biopsies taken every 3 weeks (53). This study reported that LP increased CSA by 9.5% over baseline measures after 3 weeks before seeing a plateau and measuring at 8.7% after the complete 9 weeks of the training protocol. On the other hand, the DUP group only showed a 4.1% increase in CSA at 3 weeks (a significantly less increase than the LP group at this time point) and finished the 9-week protocol with a 14.8% increase in CSA. The increase in muscle CSA from week 3 to week 9 was significant, and also the muscle CSA was significantly greater in the DUP group at week 9 when compared to the LP group at the same time point. It must be noted, however, that even though the DUP group exhibited increases in muscle CSA at later training points than the LP group, these differences (as previously noted) were not significantly different between groups. Therefore it would be interesting to see differences in CSA in previously untrained subjects throughout a longer training protocol.

In addition, a greater adaptation of the neuromuscular system with undulating periodization is also supported by Rhea and colleagues (10). In a 12-week study Rhea and colleagues reported that DUP significantly increased leg press strength when compared to a group of LP training in trained college aged men. Also, this study reported a 28.78% increase in bench press strength in the DUP group as opposed to a 14.37% increase in the LP after the duration of the study; however, this increase in bench press 1RM only approached significance (p=0.08). Rhea et al. (2002) utilized an 8RM training day on Monday, 6RM on Wednesday, and 4RM on Friday. It seems that over longer periods of time DUP yields greater results because the LP model causes the neuromuscular system to become accustomed to the periodized program, however, with DUP the neuromuscular system must adapt more quickly to recruiting high-threshold fibers. For example, it is possible that an athlete who performs only hypertrophy training for a long period of time will have a reduced ability to recruit high threshold motor units. However, an athlete who undulates his or her training and practices recruiting high threshold motor units on a regular basis may be more efficient at producing maximal force. The authors do caution, however, that it is possible that DUP was not necessarily directly responsible for the increases in strength over the LP group. The differences could be the result of changing the exercise program to DUP since all the trained men were already accustomed to LP training (10). However, Monteiro et al. (2009) also supported the DUP-induced neuromuscular adaptation by demonstrating greater strength gains in trained college aged males in response to NLP (Monteiro called the training in is study NLP, but it was in fact DUP as well) in comparison to LP (52). Monteiro et al. (2009) suggest that neural adaptations occur during the first few weeks of training in both NLP and LP, although the adaptation is maintained later in the training program with

NLP due to the more frequent use of low repetitions (52). It should also be noted that Monteiro only took performance measures, thus no definite determination can be given to why the NLP protocol elicited the greatest strength gains. Furthermore, it is suggested that that NLP places a greater physiological strain on the muscle making it superior to LP programs for increases in strength, power, and muscle CSA. (52).

It is possible that the greater neural adaptations during NLP/undulating periodization are a result of the constant change in motor unit recruitment (52). The greater fluctuation in motor unit recruitment may lead to the exhaustion of more and different units. Some fast twitch fibers seem to be recruited when working at loads of 70% maximal voluntary contraction (MVC) (25), but much more are recruited at higher loads allowing for the fluctuation. Finally, LP is more likely to lead to overtraining than non-linear periodization (12,17). This theory seems to support the previously discussed results, in which the undulating/NLP model is better for strength later in a training program. By avoiding overtraining due to more flexibility within microcycles, an athlete may limit fatigue, minimizing poor effects on technique and skill acquisition, and possibly even decrease the risk of injury (25). Obviously these aspects are key to allow the proper motor patterns to develop and remain healthy enough to train.

Application of the Undulating Model

Resistance training not only increases strength (54,57), but also running economy (55), tennis serve velocity (43), and jumping ability (56). Based on these findings it seems clear that resistance training is important for maximizing sports performance, but the question remains as to how to implement the undulating model. The debate over the application of the undulating model seems to be between using split routines and whole-body routines (10,12,52). A split routine for strength training separates muscle groups to be trained on different days, whereas a whole-body routine trains all major muscle groups during the same training session. It has been reported that athletes and coaches prefer split resistance training routines due to the belief that split routines maximize strength gains in advanced athletes when compared to whole-body routines (52). Non-linear periodization has been shown to increase strength to a greater extent than LP in split routines (52) and whole-body routines (10) among trained men. However, in disagreement with the current thinking of athletes and coaches the study utilizing a split routine did not increase strength to a greater extent than the whole-body routine. Monteiro et al., who implemented a split routine, reported strength increases in bench press and leg press strength at 28% and 43%, respectively (52), while the whole-body routine from Rhea and colleagues (10) increased the same indices of strength by 28.8% and 55.8%. Each of these studies used trained males over 12 weeks. Furthermore, Monteiro et al. (2009) only trained two days per week for 4 weeks (52) while Rhea e al. (2002) utilized 3 training days each week (10), thus there was likely a discrepancy in volume between the two studies. This comparison is warranted, however, as Monteiro's study is the only split-body DUP routine investigated to date. When using split routines the muscle groups are isolated and thus specificity to sport performance most likely declines. With this idea of muscle groups being isolated it might be beneficial to move away from the traditional thinking of utilizing split routines for athletes and recommend whole-body undulating periodization routines for the specificity of sport performance.

Limitations of the Undulating Model

It is extremely difficult to cite limitations in the NLP/undulating model due to limited data available. Although there is substantial research resulting in increases in strength, further data are warranted to formulate the optimal hypertrophy program using an undulating model. For example, even though 6 repetitions or less is the recommended training range for strength (38), it is clear that a LP program yields greater strength than always performing low repetitions during a non-periodized routine. Therefore, it is possible that the undulating model may need further research to provide the optimal program design for various muscle performance goals over the long-term.

A second limitation could be the application of the undulating model in-season. Even though a review by Marques (2005) has advocated for use of the undulating model in-season (12), these statements, are in contrast to the findings from Hoffman et al. (2003), which reported that freshman college football players significantly increased maximal lower body strength to a greater extent when using LP in-season when compared to DUP (107). The LP groups obtained a 7% increase in 1RM squat strength while the DUP group only obtained a 2.2% increase. These findings could possibly be due to the hypertrophy training of the undulating model causing excessive fatigue in-season. However, the implementation of Flexible Non-Linear Periodization (FNLP) (to be discussed later) may be a way for the undulating model to avoid this issue.

Finally, to date there has been no long-term training study showing undulating periodization to yield significant increases in muscle performance of any kind in untrained or recreationally trained subjects when compared to LP. This is in contrast with studies consisting of trained or highly trained subjects. The lack of significance in favor of DUP over LP for maximum strength gains among novice trainees may be due to the extreme rate, at which neural adaptations occur in novices. Thus, there may be no benefit beyond that of LP for the implementation of the undulating model in untrained individuals.

ALTERNATIVE TRAINING MODELS FOR STRENGTH GAINS

Aside from the LP and NLP models previously discussed there are alternative models in the literature, which are variations of the two main periodization models. These variations of periodization have relatively little data, however, they have been shown to be effective at increasing strength, which warrants their discussion in this review.

Reverse Linear Periodization

Reverse Linear Periodization (RLP) is similar to a LP model in which the intensity and volume are gradually changed. In a RLP model volume is gradually increased through the preparatory period, as intensity is gradually decreased opposite to those in a LP model. Over a 15-week study men and women significantly increased muscular endurance of the leg extensors with both RLP and LP over baseline measures by 19.5% and 16.2%, respectively with the RLP increase being significantly greater than the LP increase (51). RLP, however, does not seem to be nearly as effective for maximal strength gains as it does for muscular endurance. Prestes et al. (2009) reported that after 15 weeks of training previously trained women significantly increased strength of the leg extensors to a greater extent in a LP model (31.76% increase) when compared with a RLP model (18.71% increase) (59).

Flexible Non-Linear Periodization

A recent study by McNamara et al. (2010) has coined the term Flexible Non-linear Periodization (FNLP) (17). In this study, which brings new information to the field, 16 untrained college aged males were split into two groups of eight to make up a FNLP group and a NLP group, and both groups trained 3-days per week for 12 weeks. The NLP group undulated between 20, 15, and 10 repetitions workouts, whereas the FNLP group was able to choose which workout they wanted to perform upon entering the gym. The FNLP group yielded significantly greater increases in leg press strength after the 12-week training protocol (note: there is not enough data in the manuscript to calculate percentage changes). There were a total of 36 training sessions during this 12-week training program, which yielded 12 sessions of training protocol for the NLP. Therefore, even though the FNLP group was able to choose its workouts each day, the group had to perform each one exactly 12 times, therefore once subjects in the FNLP group performed a particular training protocol 12 times they no longer had that protocol as an option. Explanations for this phenomenon are that the athlete can choose a workout determined by his or her mental readiness, which in turn may limit injury and overtraining by not having the athlete perform a heavy workload when he or she is in a state of fatigue (17). Even though these data are interesting and new to the field there was no LP group for comparison. Therefore, this was simply a comparison of two varying NLP protocols in untrained subjects.

Autoregulatory Progressive Resistance Exercise

Autoregulatory progressive resistance exercise (APRE) has limited research, but it has been shown to produce significant strength improvements in the bench press and squat when compared to LP in Division I collegiate football players over 6 weeks of training (22). The APRE group significantly increased bench press and squat 1RM by 9.3% and 19.3%, respectively while bench press and squat improved by only 0.4% and 3.7% in the LP group. APRE makes adjustments to the training program on a week-to-week basis just like the WUP model, however, APRE allows the athlete to progress at his or her own pace (22). In APRE training the athlete's performance with a certain percentage of his or her 1RM determines the load used for the following week as opposed to using a planned percentage (22). For example, if an athlete is scheduled to perform 5 repetitions on the bench press with 85% of 1RM, but actually performs 8 repetitions adjustments will be made to use a new training max for the following week. With this method a higher 1RM will yield an increased load at a given percentage. To date this method of training has not been compared to an NLP/undulating model.

SUMMARIES AND FUTURE DIRECTION

This chapter has discussed the origins of strength training and periodization, progression and recently introduced methods, as well as examined the mechanisms and adaptations, which have been shown to occur in response to different models of resistance training. Overall, it is clear that resistance training improves muscle performance and periodization is necessary as a mode of training preparation in order to optimize an athlete' performance. Furthermore, it seems that the undulating model of periodization elicits greater strength gains for athletes and trained individuals when compared to a LP model. In contrast, there seems to be no significant difference as it relates to strength increases when comparing undulating periodization and LP in untrained or recreationally trained individuals.

Undulating periodization is a relatively new topic in the literature and it is unlikely that it is perfected at this point based on the new findings related to FNLP and APRE training protocols. Even though an undulating model may protect against long-term fatigue it does not protect against short-term fatigue and muscle damage from hypertrophy and high volume training. Although acute and short-term fatigue still exist, DUP often performs a high intensity workout just 48 hours following the high volume training (as seen by the training protocol designs in Tables 5 and 6 in Chapter III) and at this point it is unlikely that the athlete is recovered. Therefore, it is possible that the traditional order of periodization may be not suitable for DUP. It would be interesting to examine a DUP model, which performs a power workout with a lower percentage of 1RM, in the session following high volume training. This strategy may allow the athlete to optimally recover from the subsequent high intensity strength day without compromising the frequency of training. Therefore future research will be necessary to compare different models of non-linear/undulating periodization among trained athletes. Aside from comparing differing models of DUP it would also be interesting to compare WUP vs. DUP and LP in trained athletes for maximal strength as this comparison does not yet exist. These are just a couple examples of study designs, which can shed new light upon the effects of undulating periodization on maximal strength. Nevertheless, there are many possible ways to construct the undulating model and when proposing new versions of undulating periodization it is important to stress specificity of training. New proposals may differ from current models used in the literature by focusing on hypertrophy or power as the main outcome rather than strength. In this case a program may increase the ratio of hypertrophy or power type training compared to strength training to address the desired outcome. These proposals suggest that even though the undulating model is effective in trained athletes for strength increases, it is possible that undulating periodization needs to be tailored toward each athlete's individual goals as the existing model may not be optimal for all athletes.

CHAPTER III
RESEARCH DESIGN AND METHODS

Subjects

Eighteen college-aged powerlifters (specific subject characteristics can be seen in Table 4) were recruited for this study, primarily from The Florida State University's 2011 and 2012 United States of America Powerlifting (USAPL) state champion powerlifting team. For inclusion in the study, it was required that each subject be able to perform a 1RM back squat with a minimum poundage of 2 times body weight, a 1RM bench press with at least 1.25 times body weight, and a 1RM deadlift with at least 2 times body weight. Additionally, the following three criteria were required of subjects: 1. At least 5 years of resistance training experience, 2. Must have currently been performing a structured resistance-training program at least 3 times per week prior to the onset of the study for 1 or more years, and 3. Have been consuming a whey protein supplement on training days for at least the past 3 months. This study, was approved by The Florida State University Institutional Review Board (Appendix A) and all subjects signed an informed consent prior to taking part in the study (Appendix B). Subjects also completed a health history questionnaire (Appendix C) before the beginning of the study.

Table 4: Subject Characteristics (N=18)

Age (y)	Height (cm.)	Weight (kg.)	%BF
21.06 ± 1.89	177.81 ± 7.86	82.55 ± 11.39	9.29 ± 3.17

Values are means ± standard deviations
%BF = percent body fat, using the sum of 3 skinfold measurements

Overview of Experimental Design

The proposed study was designed to examine the physiological responses to two different 6-week training models of DUP in powerlifters. Subjects were assigned to one of these two groups: hypertrophy, strength, power (HSP) or hypertrophy, power, strength (HPS). After measuring subjects' pre-testing 1RM, subjects were counterbalanced to ensure that there was no difference in relative strength (168) or absolute strength, between groups, at pre-testing measurements.

Subjects reported to the laboratory a total of 22 days over 8 consecutive weeks to complete the study (see Table 5 for more details). Weeks 1 and 8 served as pre- and post-testing respectively. Pre-testing 1RM and blood collection were administered on day one of week one, followed by light training 72 hours later. Weeks 2-7 consisted of a 6-week DUP training program (HSP or HPS). Subjects engaged in resistance training three days per week on alternate days (e.g. Monday, Wednesday, and Friday sessions) during the 6-week program. Blood was collected 30 minutes prior to each week's strength training session, during the 6 weeks of DUP training. During week 8 subjects reported to the laboratory on two occasions. First, 96 hours following the completion of week 7 training, and again 72 hours later for a final 1RM and blood collection. Additionally, subjects were fed 30 grams of whey protein 30 minutes prior to and immediately after each training session and anthropometrics were administered on pre- and post-testing days.

As briefly described, this study consisted of two different DUP training groups (see Table 6 for more details). One group performed the traditional DUP model for 6 weeks consisting of 3 training sessions per week (example: Monday, Wednesday, and Friday) in the order of hypertrophy training on day 1, strength training on day 2, and power training on day 3 (HSP). The other group was configured in the order of hypertrophy, power, strength (HPS) each week for 6 weeks. Sets and repetitions were the same between the DUP training groups, but different between the training types: hypertrophy, strength, and power.

Each group performed 3 exercises during training: the squat, bench press, and deadlift. The squat and bench press were performed during every training session, while the deadlift was performed only during the strength training session of each week. During the first week of each DUP group, hypertrophy training consisted of 5 sets of 8 repetitions for the squat and bench press at 75% 1RM. During the second week of training both hypertrophy and power days consisted of the same sets and repetitions as they did in week 1. For training weeks three and four subjects performed 4 sets of 8 on the squat and bench press, while weeks 5 and 6 called for 3 sets of 8 repetitions for the squat and bench press. The load for hypertrophy progressed each week based on each subjects' individual adaptations (22). Power training was performed as follows: 5 sets of 1 repetition at 80% 1RM during weeks 1 and 2, 4 sets of 1 repetition at 85% in weeks 2 and 3, and 3 sets of one repetition at 90% in weeks 5 and 6. Strength training consisted of 3 sets of maximal repetitions at 85% 1RM on all three exercises during week 1. Following week 1, the load used on strength training days progressed from week to week as follows: week 2-87.5%, week 3-90%, week 4-90%, week 5-92.5%, and week 6-95%.

Specific Aim 1

1.A) We examined the degree by which the HPS (modified) training model altered maximum strength in comparison to HSP (traditional) following the 6-week training protocol; and 1.B) Determined the extent to which HPS influenced training volume during its strength training sessions in comparison to the strength training sessions of HSP.

Anticipated Outcome

1.A) We anticipated that HPS would elicit greater improvements in 1RM strength after 6 weeks of training than HSP. Additionally, a linear regression analysis was performed to determine any correlation between TV and post-testing 1RM. 1.B) Further, we predicted that HPS would perform a greater TV of exercise during strength training sessions than HSP.

Design for Aim 1

1.A) The design to examine changes in maximal strength between HSP and HPS was a 2 (group, HSP and HPS) X 2 (time; at pre- and post-training) repeated measures analysis of variance (ANOVA). At baseline and following 6 weeks of training subjects underwent 1RM testing for each of the three exercises performed. This testing was designed to demonstrate differences in maximum strength compared to baseline and between each condition. 1.B) The analysis to examine TV was a 2 (group) x 6 (time; 6 strength training sessions) ANOVA.

Specific Aim 2

Specific aim 2 was to examine the levels of blood indices of muscle anabolism (testosterone) and catabolism (cortisol) prior to each strength training session throughout 6 weeks of each DUP training protocol.

Anticipated Outcome

We anticipated that testosterone and cortisol levels would not change during training weeks. However, we predicted that at post-testing, in both groups, resting testosterone concentrations would be significantly elevated while cortisol levels would be significantly lowered compared to pre-testing.

Design for Aim 2

This aim was designed to examine weekly and resting changes of testosterone and cortisol concentrations. The design was a 2 (groups) X 8 (time; 8 blood draws) repeated measures ANOVA. Assay kits were used to analyze activity levels of the dependent variables (blood markers) at each time point.

Blood draws were administered 30 minutes prior to the strength training session of each week and as well as on pre- and post-1RM testing days, which totaled 8 blood draws per subject (6 strength training sessions and 2 1RM testing sessions). We collected 10mL of blood from the antecubital vein using sterile vein-puncture techniques. Blood was obtained in EDTA coated tubes. Next, blood sat at room temperature for 10 minutes before being centrifuged at 4°C for 15 minutes at 3,000 rpm. Following the centrifuge, plasma was separated and stored at -20 ^{o} C until analysis.

Testosterone and cortisol were measured in duplicate using enzyme linked immunosorbent assays (ELISA) kits (R&D Systems, Minneapolis, MN). All assays were carried out as instructed by the manufacturer's directions. Our coefficient of variation between duplicates was less than 5%.

Dietary Log and Body Fat Percentage

To control for diet, subjects were instructed to keep a record of their nutritional intake (all food and beverages) for each day prior to a resistance-training session (Appendix C). The diet logs were given to all subjects with the instructions to replicate their food consumption 24 hours prior to each resistance-training session. Further, subjects were instructed to cease any supplementation use at least 2 weeks prior to the study, and only partake of the supplement provided to them for the duration of the study. Body fat percentage was determined with skinfold calipers, by the sum of three sites (abdomen, front thigh, and chest). The same investigator took the skinfold measurements for each subject.

Physical Activity Questionnaire

To obtain greater background on subjects' exercise history and qualifications for this study, each subject completed a physical activity questionnaire during their initial visit to the laboratory (Appendix D). Subjects provided information on how many years they have been resistance training, a description of their previous training programs, what they estimated their current 1RM to be on the back squat, bench press, and deadlift exercises, and when they competed in their last powerlifting competition. Subjects were required to refrain from all additional physical activity for the duration of the study.

Health History Questionnaire

On the first visit to the laboratory, after signing an informed consent form, subjects completed a health history questionnaire (Appendix E). This questionnaire was designed to provide us with a health history and any current medications that the subject may have been taking. Further, the subjects' answers revealed if they had any contraindications to exercise such as, high blood pressure or any cardiovascular diseases.

One-Repetition Maximum (1RM) Testing

Subjects underwent 1RM testing on two different occasions during the study: pre-testing during week 1 and post-testing during week 8. The 1RM testing protocol was administered on the 3 powerlifts (back squat, bench press, and deadlift). For these sessions subjects had their blood drawn when entering the lab 30 minutes prior to both 1RM testing days. The powerlifts were performed under the rules set by USAPL (168). For the back squat 1RM test, subjects stood with their knees locked and the bar placed across the upper back/shoulders. Subjects then descended with a bending of the knees until the top of the leg at the hip joint was below the top of the knee. Finally subjects returned, on their own volition, to an erect standing position. During the bench press subjects laid on a weight bench with their feet flat on the ground and butt, shoulders, and head touching the bench at all times throughout the lift. Subjects took the bar out of the racks, with a partner-assisted lift-of if requested, and held it with there arms extended before beginning the lift. The bar was then lowered until it touched the chest, where it was then pressed until the arms were fully locked. In contrast to the squat and bench press, the deadlift began with the bar on the floor. Subjects bent down and stood up with the bar until their knees were in a locked position and they were standing completely erect. Subjects then lowered the bar back to the starting position on the floor.

Statistical Analysis and Sample Size Determination

The specific ANOVA models, to be used were noted with each specific aim in the preceding sections. Data were screened for normality and outliers. Wherever a significant F-value was found a Tukey post-hoc test was performed to locate the significance for multiple comparison purposes. Data were reported as means and standard deviations, and significance was set at $p<0.05$. The software Statistica was used to perform all statistical analyses.

The ultimate goal of this project was to examine the strength and hormonal changes in response to two different models of DUP in trained athletes. Thus, maximal strength in trained individuals was one of the primary outcomes of this study, and provided the basis for the sample size as determined by the G*Power analysis software. The rationale for our sample size was based on a study from Peterson et al. (46). These investigators found that 7 trained firefighter academy attendees significantly increased their 1RM squat by 16.82% following 9 weeks of daily undulating periodization training. Based on the effect size (0.88) of Peterson et al. 26 subjects (13 per groups) were needed. However, due to dropout during the study we concluded with 18 subjects in total (9 per group).

Resistance Training Protocol

Table 5: Resistance Training Protocol of the Study (N=18)

Training Day	**Exercise**	**Sets/Repetitions Week 1**	**% 1RM Used**	**Sets/Repetitions Week 2**	**% 1RM Used**
Hypertrophy	Back Squat	5X8	75%	5X8	IA
	Bench Press	5X8	75%	5X8	IA
Strength	Back Squat	3Xmax reps.	85%	3Xmax reps.	87.5%
	Bench Press	3Xmax reps.	85%	3Xmax reps.	87.5%
	Deadlift	3Xmax reps.	85%	3Xmax reps.	87.5%
Power	Back Squat	5X1	80%	5X1	80%
	Bench Press	5X1	80%	5X1	80%

Table 5 - Continued

Training Day	Exercise	Sets/Repetitions Week 3	% 1RM Used	Sets/Repetitions Week 4	% 1RM Used
Hypertrophy	Back Squat	4X8	IA	4X8	IA
	Bench Press	4X8	IA	4X8	IA
Strength	Back Squat	3Xmax reps.	90%	3Xmax reps.	90%
	Bench Press	3Xmax reps.	90%	3Xmax reps.	90%
	Deadlift	3Xmax reps.	90%	3Xmax reps.	90%
Power	Back Squat	4X1	85%	4X1	85%
	Bench Press	4X1	85%	4X1	85%

Training Day	Exercise	Sets/Repetitions Week 5	% 1RM Used	Sets/Repetitions Week 6	% 1RM Used
Hypertrophy	Back Squat	3X8	IA	3X8	IA
	Bench Press	3X8	IA	3X8	IA
Strength	Back Squat	3Xmax reps.	92.5%	3Xmax reps.	95%
	Bench Press	3Xmax reps.	92.5%	3Xmax reps.	95%
	Deadlift	3Xmax reps.	92.5%	3Xmax reps.	95%
Power	Back Squat	3X1	90%	3X1	90%
	Bench Press	3X1	90%	3X1	90%

IA = Individually Adjusted.

Complete Study Protocol

Table 6: Model of Subjects' Daily Activities in the Study. Note: This table shows training order in the HSP group. For the HSP group strength and power training days were switched.

	Week 1	**Week 2**	**Week 3**	**Week 4**
Monday	Pre-Testing Blood draw; Pre 1-RM	Hypertrophy Training	Hypertrophy Training	Hypertrophy Training

Table 6 - Continued

	Week 1	Week 2	Week 3	Week 4
Tuesday	No lab visit	No Lab Visit	No Lab Visit	No lab visit
Wednesday	No lab visit	Blood draw; Strength Training	Blood draw; Strength Training	Blood draw; Strength Training
Thursday	Taper Training	No Lab Visit	No Lab Visit	No lab visit
Friday	No lab visit	Power Training	Power Training	Power Training
Saturday	No lab visit	No Lab Visit	No Lab Visit	No lab visit
Sunday	No lab visit	No Lab Visit	No Lab Visit	No lab visit

	Week 5	Week 6	Week 7	Week 8
Monday	Hypertrophy Training	Hypertrophy Training	Hypertrophy Training	No Lab Visit
Tuesday	No Lab Visit	No Lab Visit	No Lab Visit	Taper Training
Wednesday	Blood draw; Strength Training	Blood draw; Strength Training	Blood draw; Strength Training	No Lab Visit
Thursday	No Lab Visit	No Lab Visit	No Lab Visit	No Lab Visit
Friday	Blood draw; Power Training	Blood draw; Power Training	Blood draw; Power Training	Blood draw; Post- 1RM TestingStudy Completed
Saturday	No Lab Visit	No Lab Visit	No Lab Visit	
Sunday	No Lab Visit	No Lab Visit	No Lab Visit	

CHAPTER IV

RESULTS

Subjects and Dietary Log

All subjects in this study were active members of The Florida State University's current state champion powerlifting team. Subjects had an average of 6.4 ± 2.1 years of training experience and there was no difference in years of training experience between groups. Due to minor injury one subject missed two squat sessions (hypertrophy and power) during week 5 for precautionary reasons, however, this subject did complete the bench press on these days. Therefore, subject data was included if at least 90% of the training protocol was completed. Additionally, as expected there was no difference in total caloric intake between groups.

1RM Strength

Mean values for pre- and post-training performance variables, for both groups, can be seen in Table 7.

Table 7: Changes in strength measures pre- to post-training in HSP and HPS (N=18)

Variables	HSP		HPS	
	Pre-Training	**Post-Training**	**Pre-Training**	**Post-Training**
1RM Squat (kg.)	162.03 ± 18.67	174.89 ± 18.18* (7.93% Increase)	173.12 ± 20.76	191.27 ± 25.26* (10.48% Increase)
1RM Bench Press (kg.)	130.28 ± 20.07	133.81 ± 21.58 (2.71% Increase)	133.31 ± 17.08	144.14 ± 20.19*# (8.13% Increase)
1RM Deadlift (kg.)	195.80 ± 27.54	216.97 ± 26.68* (6.70% Increase)	199.83 ± 27.53	221.00 ± 27.21* (7.57% Increase)
Powerlifting Total (kg.)	485.19 ± 62.00	517.60 ± 60.80* (6.70% Increase)	506.51 ± 58.96	550.36 ± 66.67* (8.66% Increase)
Wilk's Formula	328.08 ± 23.45	350.27 ± 21.37* (6.76% Increase)	342.74 ± 38.11	372.38 ± 41.66* (8.65% Increase)

Values are in means ± standard deviation.
*$p<0.05$, significantly different from pre-training
#$p<0.05$, significantly greater than HSP
HSP = Hypertrophy, Strength, and Power

HPS = Hypertrophy, Power, and Strength
1RM = One-Repetition Maximum

1RM Squat Strength

There was no group x time interaction for pre to post 1RM squat strength ($p>0.05$); however, as anticipated there was a significant time effect for both groups ($p<0.05$). The mean values (in kg.) in the HSP group increased from 162.03 ± 18.67 to 174.89 ± 18.18 (+7.93%), and in the HPS group from 173.12 ± 20.76 to 191.27 ± 25.26 (+10.48%). Mean values can be seen in Figure 1 with individual squat values plotted in Figure 2.

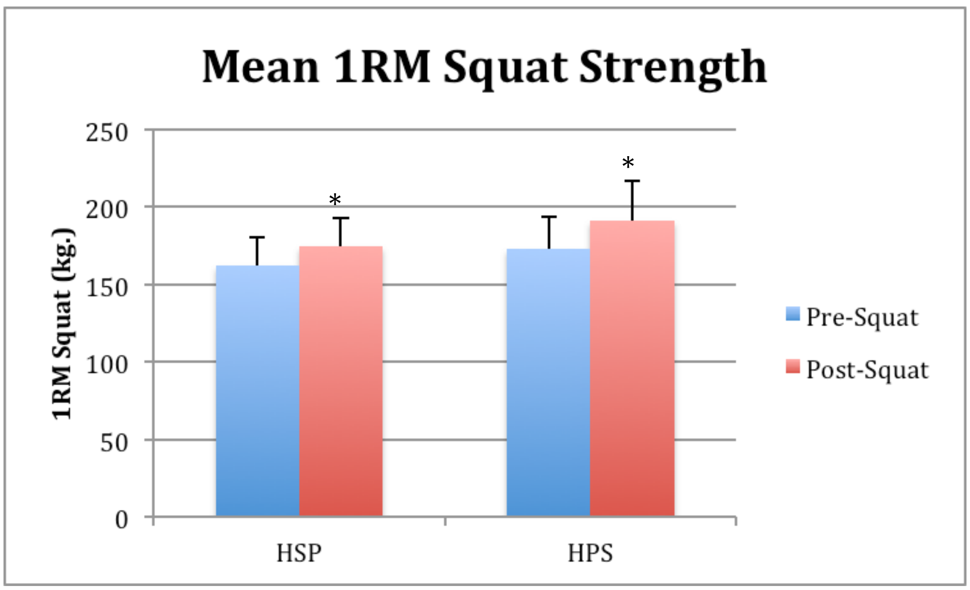


Figure 1: Comparison of mean pre to post squat strength between groups.
HSP = Hypertrophy, Strength, Power. HPS = Hypertrophy, Power, Strength. 1RM = One-Repetition Maximum. 1RM squat strength increased significantly in both groups compared to pre-training measures ($p<0.05$). *$p<0.05$, significantly different from pre-training. The HSP and HPS groups increased their 1RM squat 7.93 and 10.48%, respectively, from pre- to post-training. Values are reported in means ± standard deviation.

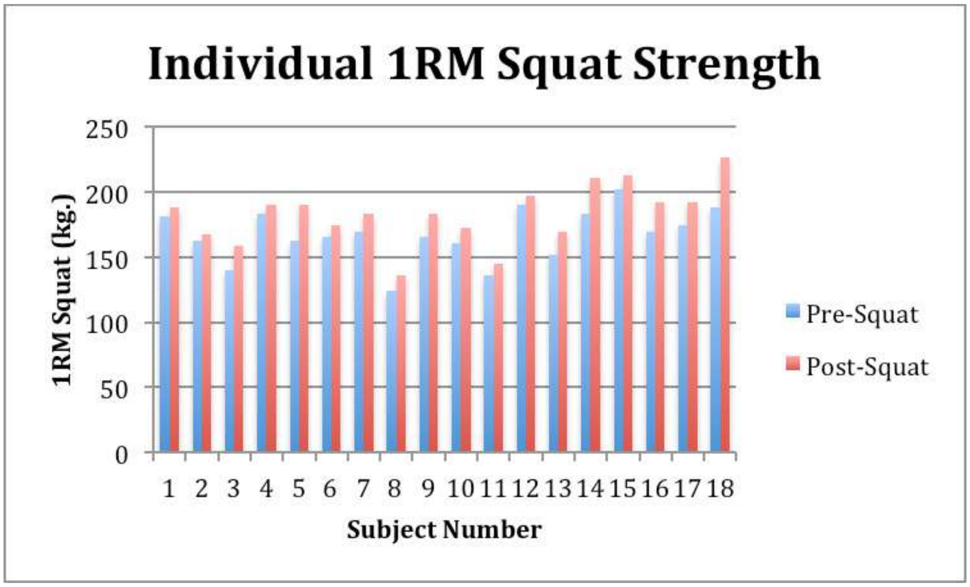


Figure 2: Individual increases in 1RM squat strength. N=18. 1RM = One-Repetition Maximum.

1RM Bench Press Strength

For pre to post 1RM bench press strength, there was a significant group x time interaction ($p<0.05$) indicating a significant increase in bench press 1RM observed only in the HPS group and not in HSP. The HSP group demonstrated no significant increase (130.28 ± 20.07 to 133.81 ± 21.58 kg.) while HPS showed a significant increase of 133.31 ± 17.08 to 144.14 ± 20.19 kg. (+8.13%). Mean values are in Figure 3 with individual values plotted in Figure 4.

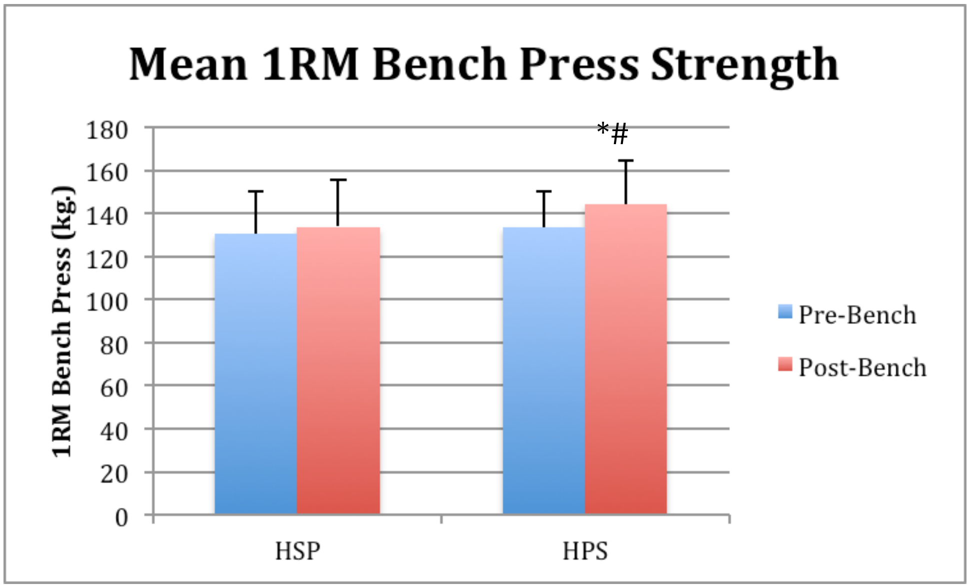


Figure 3: Comparison of mean pre to post bench press strength between groups. HSP = Hypertrophy, Strength, Power. HPS = Hypertrophy, Power, Strength. 1RM = One-Repetition Maximum. There was a group x time interaction for post-training bench press strength in the HPS group ($p<0.05$). Additionally, there was a time effect for HPS bench press strength ($p<0.05$). *$p<0.05$, significantly different from pre-training, #$p<0.05$, significantly different from post-training in the HSP group. Values are reported in means ± standard deviation.

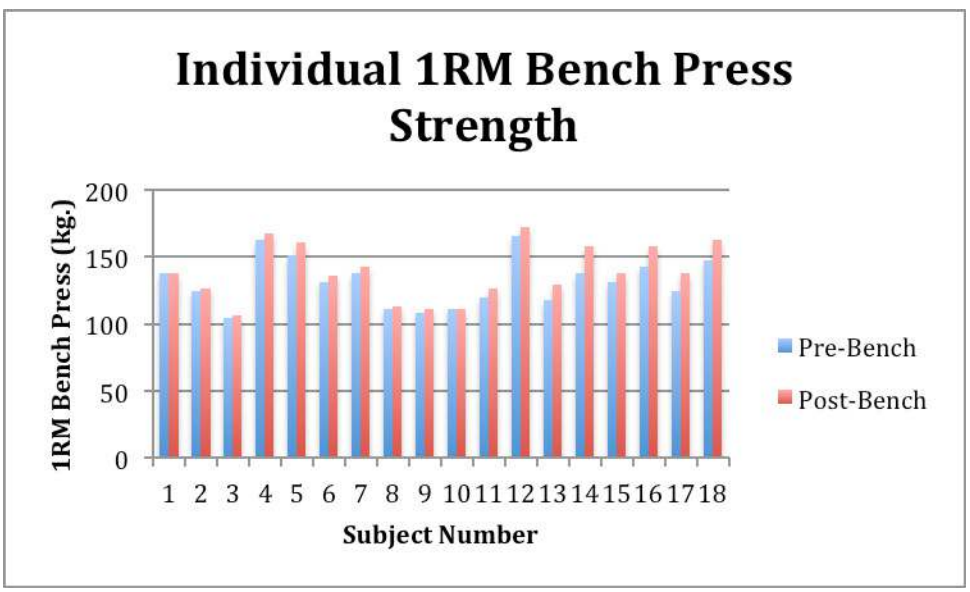


Figure 4: Individual increases in 1RM bench press strength. N=18. 1RM = One-Repetition Maximum.

1RM Deadlift Strength

There was no group x time interaction for pre to post 1RM deadlift ($p>0.05$); however, as anticipated there was a significant time effect for both groups ($p<0.05$). From pre- to post-training, HSP increased deadlift 1RM from 195.80 ± 27.54 to 216.97 ± 26.68 kg. (+6.70%), and HPS increased deadlift 1RM from 199.83 ± 27.53 to 221.00 ± 27.21 kg. (+7.57%). Mean values can be seen in Figure 5 with individual deadlift values plotted in Figure 6.

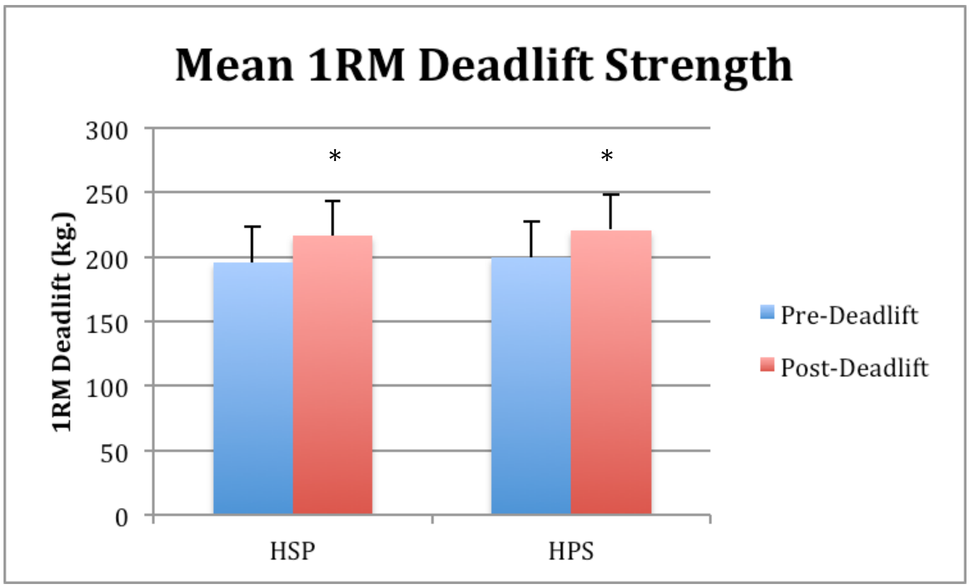


Figure 5: Comparison of mean pre to post deadlift strength between groups. HSP = Hypertrophy, Strength, Power. HPS = Hypertrophy, Power, Strength. 1RM = One-Repetition Maximum. 1RM deadlift strength increased significantly in both groups compared to baseline measures ($p<0.05$). *$p<0.05$, significantly different from baseline. The HSP and HPS groups increased their 1RM deadlift 6.70 and 7.57%, respectively, from pre to post-training. Values are reported in means ± standard deviation.

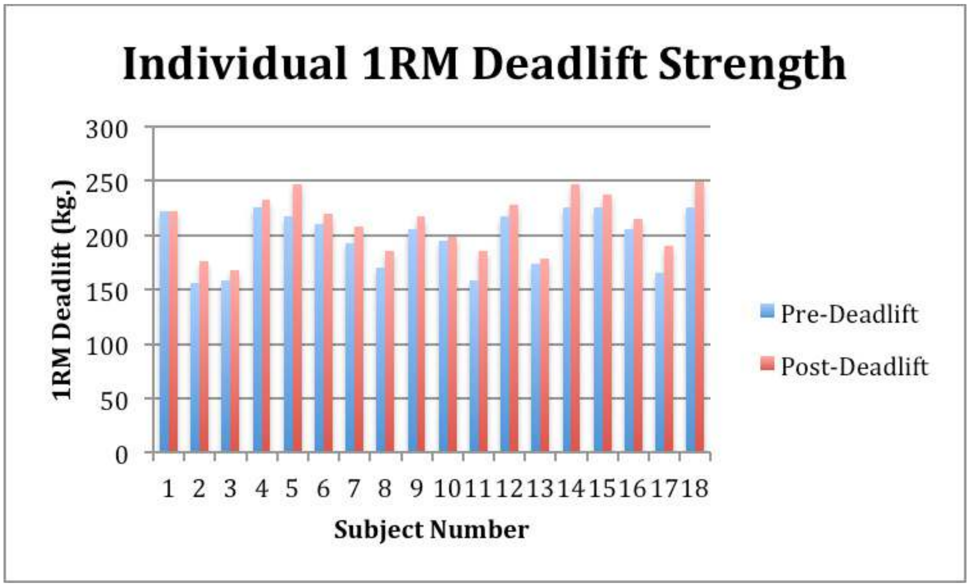


Figure 6: Individual increases in 1RM deadlift strength. N=18. 1RM = One-Repetition Maximum.

Powerlifting Total

There was no group x time interaction for pre to post powerlifting total (p>0.05); however, as anticipated there was an overall significant time effect for both groups (p<0.05). The mean values (in kg.) in the HSP group increased from 485.19 ± 62.00 to 517.60 ± 60.80 kg. (+6.70%), and in the HPS groups from 506.51 ± 58.96 to 550.36 ± 66.67 kg. (+8.66%). Mean values can be seen in Figure 7 with individual squat values plotted in Figure 8.

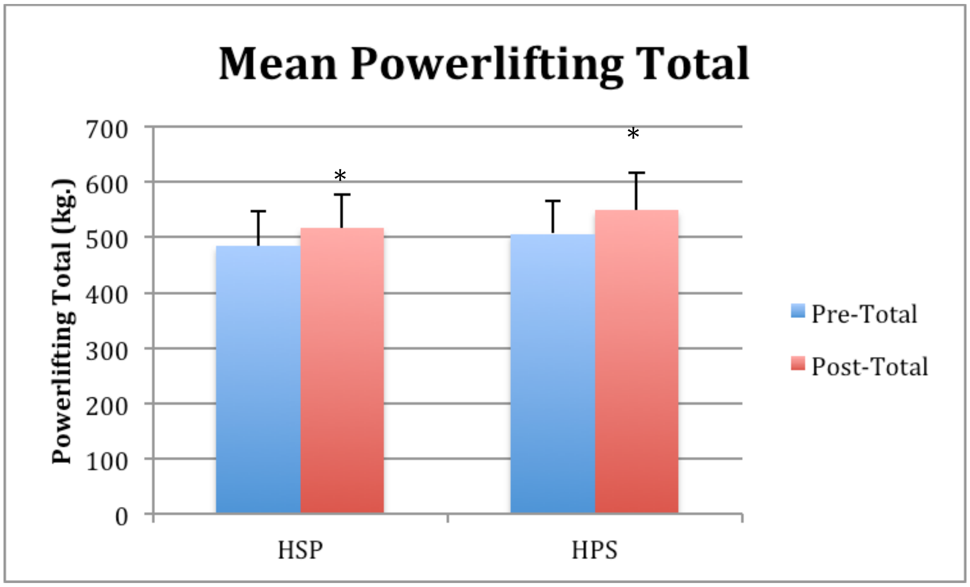


Figure 7: Comparison of mean pre to post powerlifting total between groups. HSP = Hypertrophy, Strength, Power. HPS = Hypertrophy, Power, Strength. Total increased significantly in both groups compared to baseline measures (p<0.05) with a combined increase of 7.70%. *p<0.05, significantly different from baseline. Individually HSP and HPS increased their total 6.70 and 8.66%, respectively, from pre- to post-training. Values are reported in means ± standard deviation.

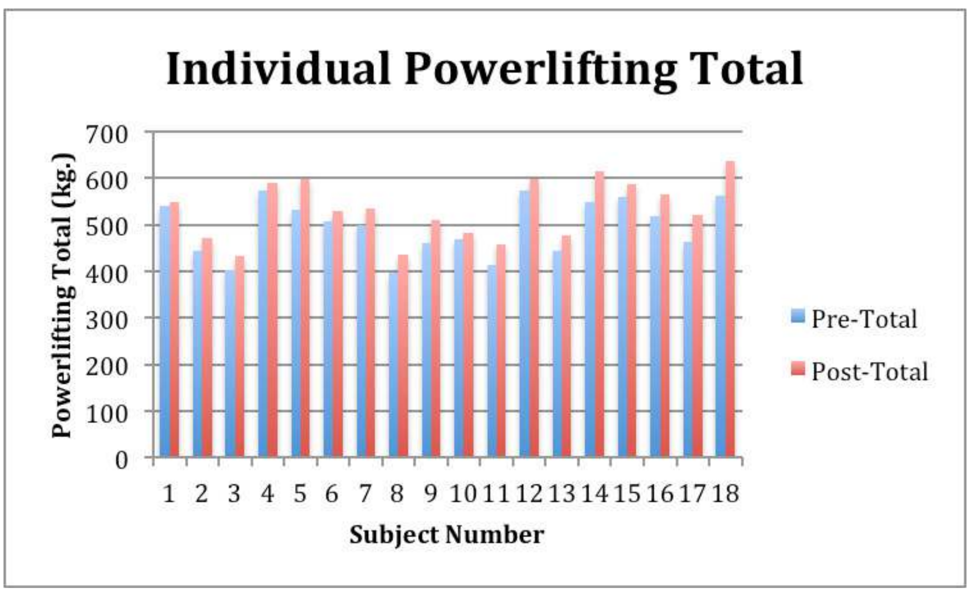


Figure 8: Individual increases in powerlifting total. N=18.

Wilk's Formula

There was a significant main time effect in Wilk's formula for both groups ($p<0.05$). The mean values in the HSP group increased from 328.08 ± 23.45 to 350.27 ± 21.37 (+6.76%), and in HPS from 342.74 ± 38.11 to 372.38 ± 41.66 (+8.65%).

Squat Total Volume (STV)

Squat total volume (STV) (Figure 9), performed was significantly greater in the HPS group (28261.45 ± 2720.17 kg.) compared to the HSP group (19280.62 ± 1504.94 kg.), which was noted by a significant group interaction ($p<0.05$). Even though STV was greater in the HPS group there was no group x time interaction ($p>0.05$) and no between group differences in individual week squat volumes.

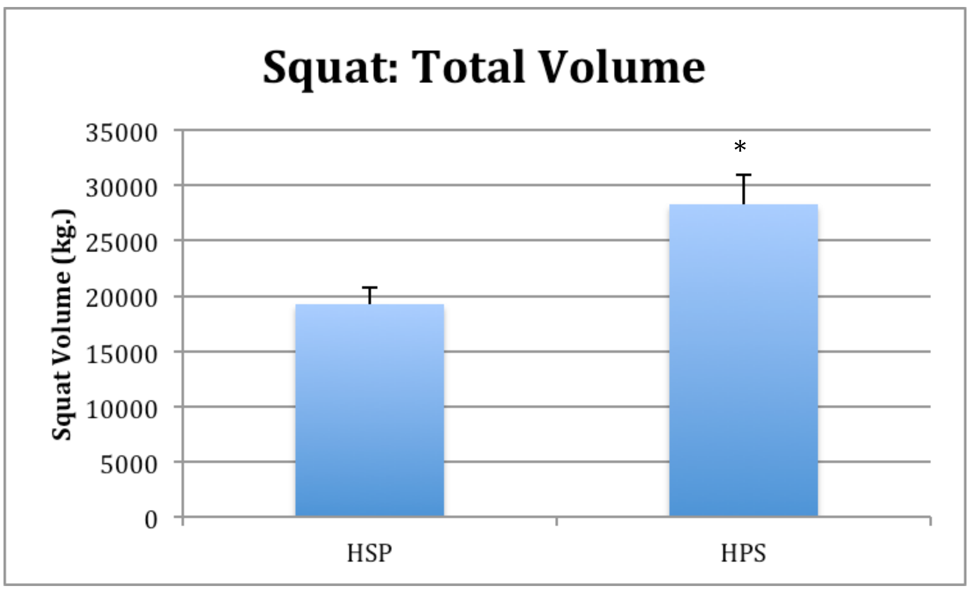


Figure 9: The combined STV of subjects in each group. HSP = Hypertrophy, Strength, Power. HPS = Hypertrophy, Power, Strength. There was a group effect ($p<0.05$), *$p<0.05$, significantly different from the HSP group. Values are reported in means ± standard deviation.

Bench Press Total Volume (BPTV)

Similar to STV there was a significant group effect ($p<0.05$) with HPS (16591.27 ± 1892.37 kg.) performing more total volume than HSP (10009.20 ± 1704.82 kg.). Additionally, there were also direct differences between individual week volume. In weeks 2,4, and 5 HPS performed greater BPTV than HSP (p<0.05). Overall BPTV can be seen in Figure 10, while weekly BPTV is plotted in Figure 11.

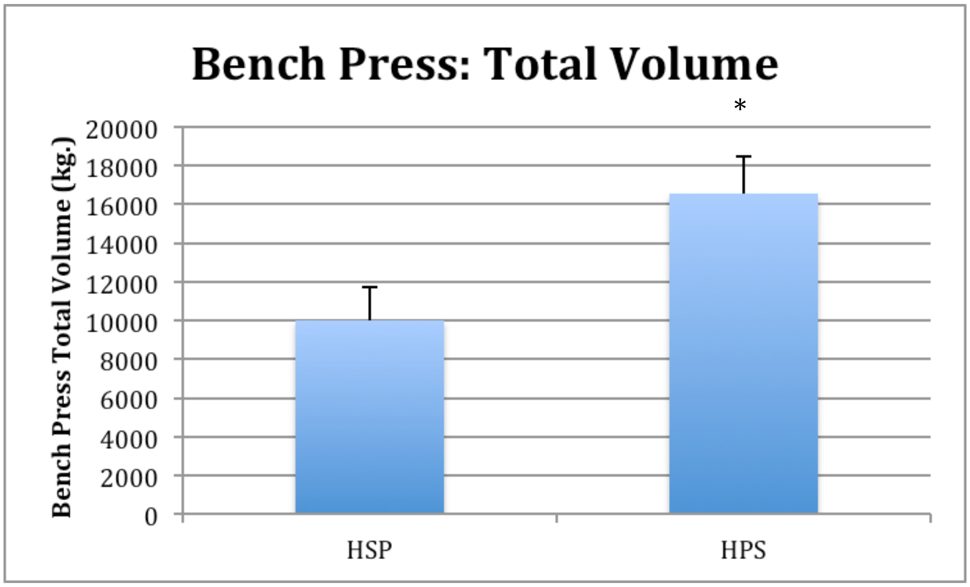


Figure 10: The combined BPTV of subjects in each group. HSP = Hypertrophy, Strength, Power. HPS = Hypertrophy, Power, Strength. There was a group effect (p<0.05), *p<0.05, significantly different from the HSP group. Values are reported in means ± standard deviation.

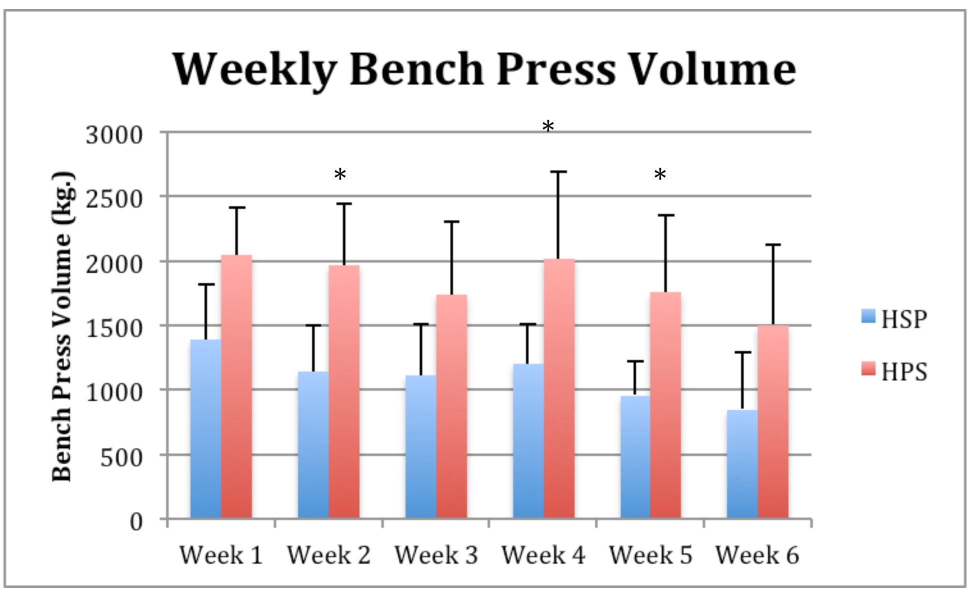


Figure 11: Comparison of mean weekly bench press volume between groups. HSP = Hypertrophy, Strength, Power. HPS = Hypertrophy, Power, Strength.

There were significant group effects at weeks 2,4, and 5 ($p<0.05$). *$p<0.05$, significantly greater than HSP group. Values are reported in means ± standard deviation.

Deadlift Total Volume (DLTV)

For DLTV, there was no significant group effect ($p>0.05$) between HPS (18130.48 ± 1590.74 kg.) and HSP (21339.74 ± 3312.70 kg.) (Figure 12) or group x time interaction ($p>0.05$). There was a significant main time effect ($p<0.05$) demonstrating the overall DLTV performed during week 6 to be lower than DLTV performed during weeks 1-4.

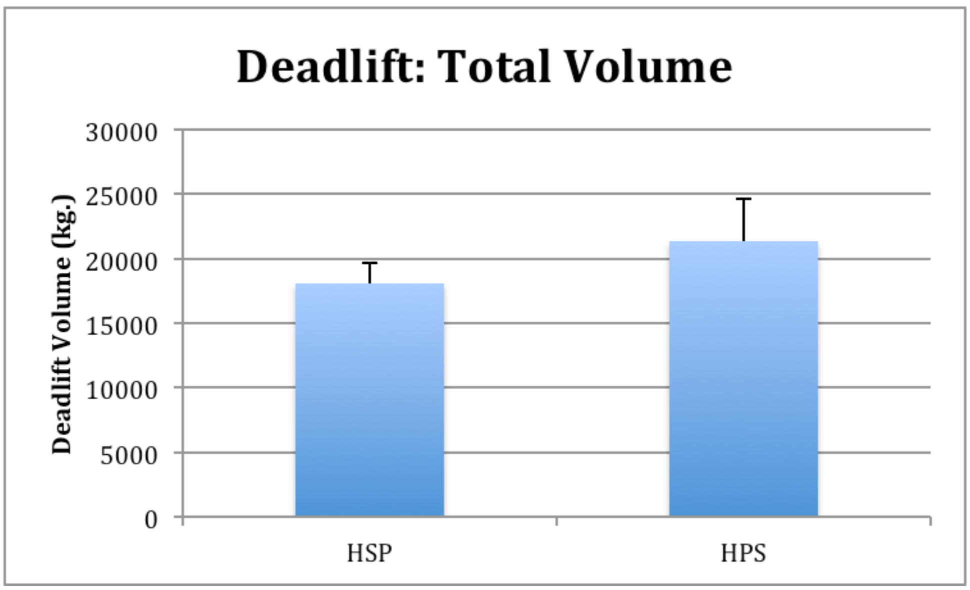


Figure 12: The combined DLTV of subjects in each group. HSP = Hypertrophy, Strength, Power. HPS = Hypertrophy, Power, Strength. There was no significant difference in DLTV between groups ($p>0.05$). Values are reported in means ± standard deviation.

Overall Total Volume (OTV)

The combined volume of squat, bench press, and deadlift (OTV) was significantly greater in HPS than in HSP ($p<0.05$). The mean OTV (in kg.) in HPS was 31566.02 ± 6708.38 compared to 44055.56 ± 8557.00 in HSP (Figure 13).

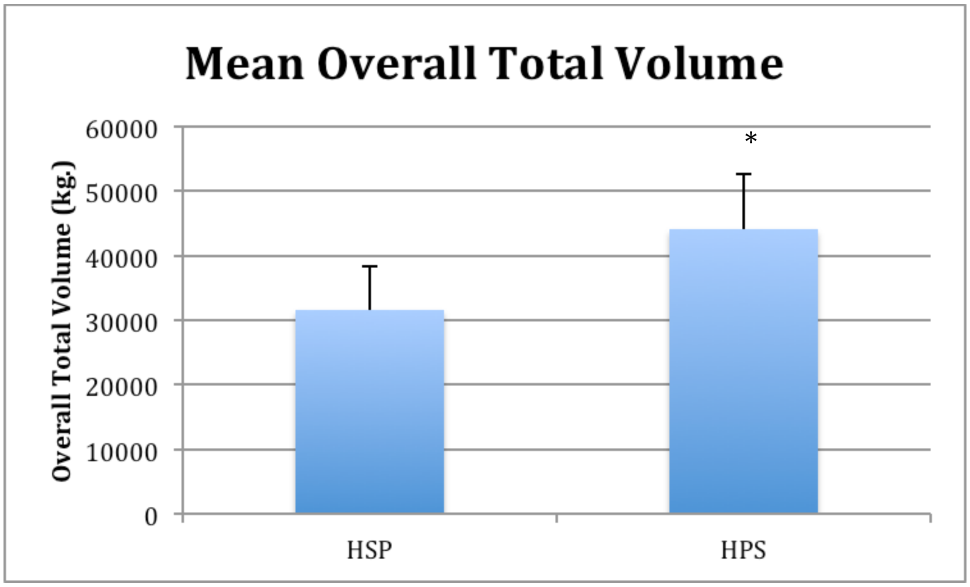


Figure 13: The mean OTV of subjects in each group. HSP = Hypertrophy, Strength, Power. HPS = Hypertrophy, Power, Strength. There was a significant difference between groups ($p<0.05$), *$p<0.05$, significantly different from the HSP group. Values are reported in means ± standard deviation.

Total Volume/Strength Relationship

Overall total volume was significantly correlated with post-training 1RM strength ($p<0.05$) with a t-value of 2.545 and an r square of 0.350; however, there was no group effect ($p>0.05$).

Total Repetitions

Data for total repetitions (sum totals and overall means) can be seen in Table 8, while weekly total repetitions and means can be seen in Table 9.

Table 8: Overall total repetitions and means in HSP and HPS

Total Repetitions: Sum Total and Means				
Variables	**HSP**		**HPS**	
	Sum Total	**Mean**	**Sum Total**	**Mean**
Squat Total Repetitions	805	134.16 ± 12.04	1100*	183.33 ± 19.23*
Bench Total Repetitions	536	89.33 ± 16.65	842*	140.33 ± 19.35*
Deadlift Total Repetitions	633	102.00 ± 12.37	742	118.80 ± 15.55
Overall Total Repetitions	1964	327.33 ± 35.29	2674*	445.67 ± 59.24*

Values are reported in means ± standard deviation
HSP = Hypertrophy, Strength, Power. HPS = Hypertrophy, Power, Strength.
*$p<0.05$, significantly greater than HSP

Table 9: Total repetitions, weekly totals and means in HSP and HPS (N=18)

Total Repetitions: Weekly Totals and Means				
Variables	**HSP**		**HPS**	
	Weekly Total	**Weekly Mean**	**Weekly Total**	**Weekly Mean**
Week 1 STR	139	15.44 ± 3.28	203	23.88 ± 5.55
Week 2 STR	129	14.33 ± 4.50	183	21.38 ± 5.24
Week 3 STR	121	13.44 ± 5.10	184	21.50 ± 5.40
Week 4 STR	155	17.22 ± 5.93	200	23.13 ± 5.72
Week 5 STR	126	14.00 ± 6.89	181	20.63 ± 4.57
Week 6 STR	135	15.00 ± 6.65	149	17.13 ± 5.29
Week 1 BPTR	115	12.78 ± 3.96	163	18.11 ± 2.32
Week 2 BPTR	93	10.33 ± 3.16	152*	16.89 ± 3.59*
Week 3 BPTR	88	9.78 ± 3.60	131	14.56 ± 4.56
Week 4 BPTR	95	10.56 ± 3.36	153	17.00 ± 4.97
Week 5 BPTR	80	8.89 ± 4.62	133	14.78 ± 4.35
Week 6 BPTR	65	7.20 ± 3.63	110	12.22 ± 4.79
Week 1 DLTR	123	13.67 ± 3.57	148	16.44 ± 5.36
Week 2 DLTR	117	13.00 ± 3.32	129	14.33 ± 4.18
Week 3 DLTR	107	11.89 ± 5.12	123	13.67 ± 3.12
Week 4 DLTR	102	11.33 ± 4.42	130	14.44 ± 4.33
Week 5 DLTR	101	11.22 ± 4.44	120	13.33 ± 4.00
Week 6 DLTR	83	9.22 ± 3.87	92	10.22 ± 4.58
Week 1 OTR	377	41.89 ± 5.62	514	57.11 ± 8.78
Week 2 OTR	339	37.67 ± 8.28	464*	51.56 ± 8.25*
Week 3 OTR	316	35.11 ± 11.62	438	48.67 ± 9.33
Week 4 OTR	352	39.11 ± 11.82	483	53.67 ± 10.78
Week 5 OTR	297	33.00 ± 11.58	434	48.22 ± 7.61
Week 6 OTR	283	31.44 ± 11.06	341	37.89 ± 9.55

Values are reported in means ± standard deviation
HSP = Hypertrophy, Strength, Power. HPS = Hypertrophy, Power, Strength.
STR = Squat Total Repetitions
BPTR = Bench Press Total Repetitions
DLTR = Deadlift Total Repetitions
OTR = Overall Total Repetitions (The sum of STR + BPTR + DLTR for that week)
*$p<0.05$, significantly greater than HSP

Squat: Total Repetitions (STR)

Squat total repetitions (STR), the sum of each individual week's total repetitions performed were significantly greater in the HPS group (1100 STR) compared to the HSP group (805 STR), which was noted by a main group effect ($p<0.05$). Even though STR was greater in HPS there was no group x time interaction ($p>0.05$) nor were there differences in week comparisons between groups. Additionally, there was an overall main time effect ($p<0.05$) with total repetitions performed being less in week 6 when compared to week 1.

Bench Press: Total Repetitions (BPTR)

Similar to STR there was a significantly greater amount of repetitions performed in HPS compared to HSP ($p<0.05$). However, there was also a direct difference between individual week BPTR in week 2 ($p<0.05$). Additionaly, a time point comparison at week 4 approached significance ($p=0.054$) in favor of HPS. In week 2, HPS performed an average of 16.89 ± 3.59 vs. 10.33 ± 3.16 BPTR for HSP, the total number of repetitions for week 2 was 152 vs. 93, respectively.

Deadlift: Total Repetitions (DLTR)

For DLTV there was a total of 742 DLTR performed by HPS and 633 DLTR performed by HSP. There was a main time effect ($p<0.05$) demonstrating the overall DLTR performed during week 6 to be lower than DLTR performed during weeks 1-4. However, there was no significant group effect ($p>0.05$) or group x time interaction ($p>0.05$).

Overall Total Repetitions (OTR)

The combined repetitions of squat, bench press, and deadlift (OTR) were significantly greater in HPS than in HSP ($p<0.05$), 2674 vs. 1964 OTR, respectively. A group x time interaction was also apparent when directly comparing total repetitions in week 2 between groups ($p<0.05$), in favor of HPS (51.56 ± 8.25 repetitions) vs. HSP (37.67 ± 8.28 repetitions).

Hormonal Markers: Testosterone and Cortisol

For testosterone there was no group effect or group x time interaction ($p>0.05$) for serum testosterone levels; however, there was an overall main time effect ($p<0.05$) (Figure 14). The time effect indicates that mean testosterone levels (in ng/mL) in both groups were lower during weeks 5 (9.00 ± 4.87) and 6 (8.60 ± 5.40) of training when compared to pre-training (13.12 ± 7.74) values.

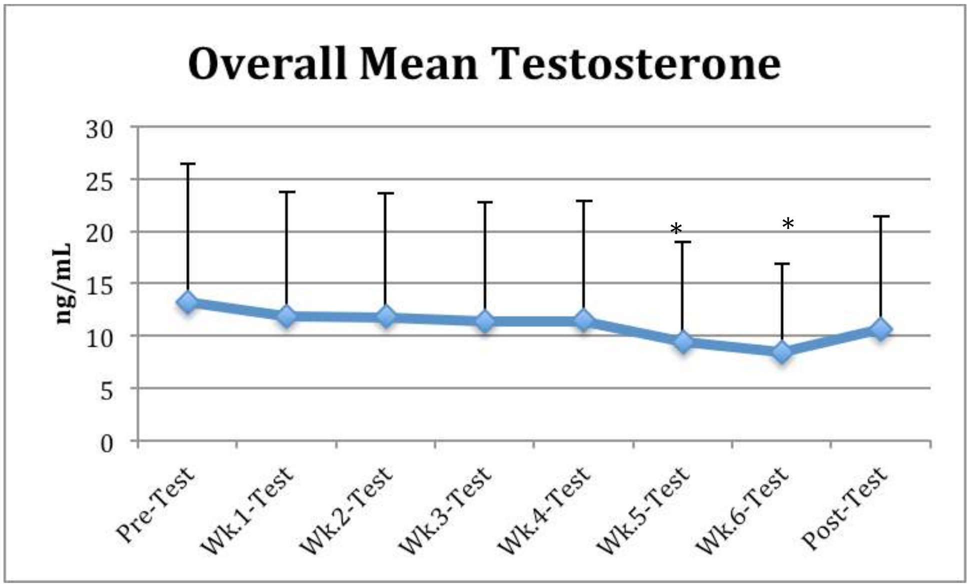


Figure 14: Overall mean testosterone values for all time points. Overall testosterone refers to all subjects, N=18. There was a significant overall main time effect ($p<0.05$). *$p<0.05$, significantly less than pre-training values. Values are reported in means ± standard deviation.

For cortisol analysis there was overall main time effect ($p<0.05$), as well as a significant group x time interaction ($p<0.05$). Cortisol concentrations (in ng/mL) at week 3 (31.03 ± 25.00) and week 4 (28.21 ± 15.80) of training were significantly lower than pre-training levels (41.74 ± 26.04) (Figure 15). Additionally, cortisol concentrations during week 6 of HSP (24.34 ± 21.89) were significantly lower than their pre-training levels (43.75 ± 27.84) (Figure 16).

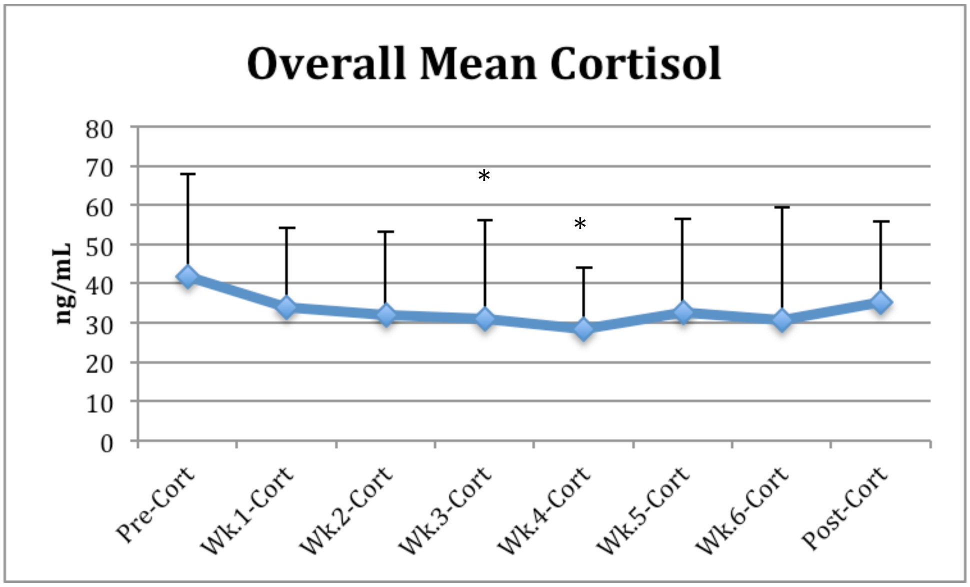


Figure 15: Overall mean cortisol values for all time points. Overall cortisol refers to all subjects, N=18. There was a significant overall main time effect ($p<0.05$). *$p<0.05$, significantly less than pre-training values. Values are reported in means ± standard deviation.

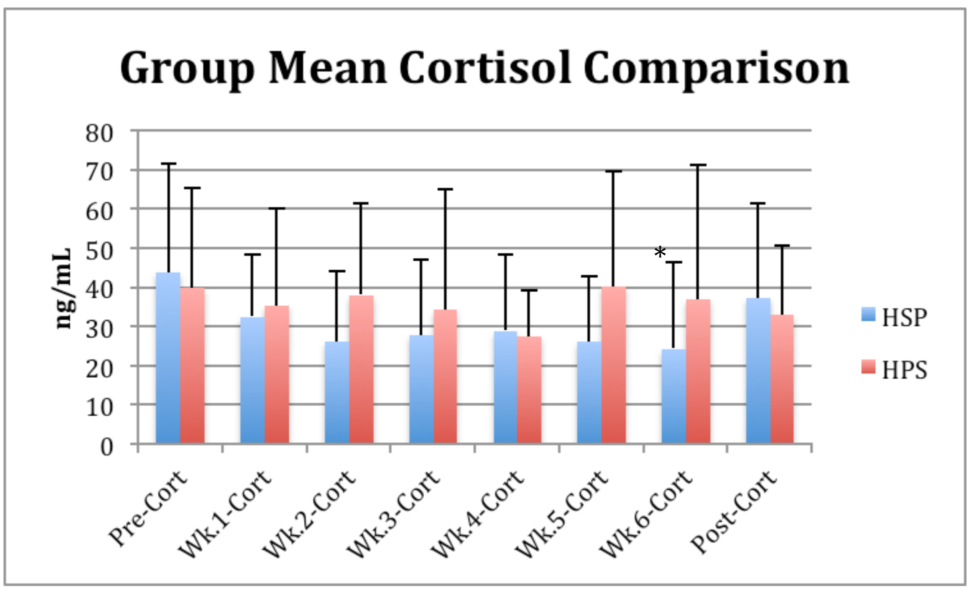
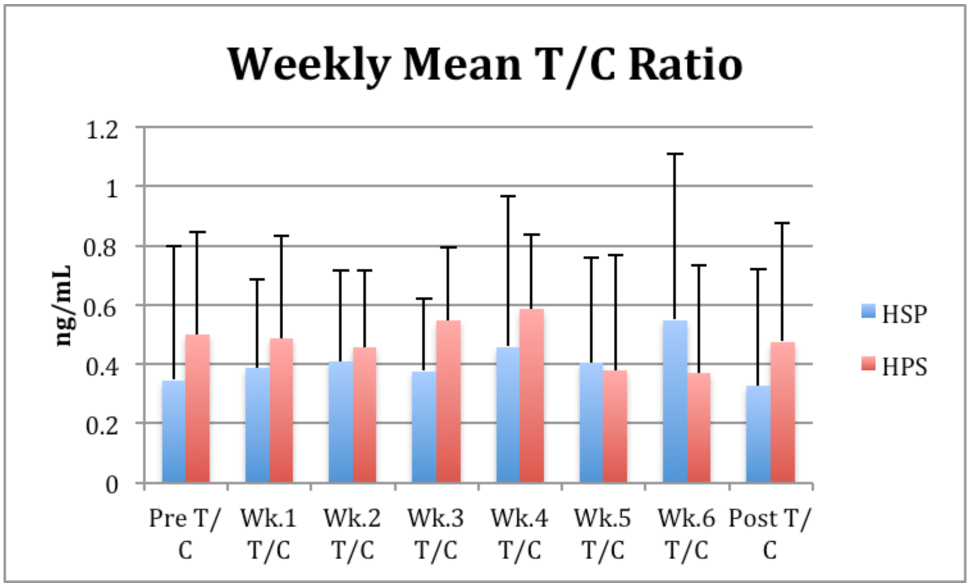


Figure 16: Comparison of mean cortisol values for each week between groups. HSP = Hypertrophy, Strength, Power. HPS = Hypertrophy, Power, Strength. There was no difference between groups at any time point. However, cortisol concentrations in HSP were significantly lower during week 6 of training than at pre-training ($p<0.05$). *$p<0.05$, significantly less than pre-training in HSP. Values are reported in means ± standard deviation.

Testosterone to Cortisol Ratio (T/C)

There was no group x time interaction, group effect, nor time effect for T/C ratio ($p>0.05$). Pre-training ratios were 0.39 ± 0.46 (HSP) vs. 0.50 ± 0.43 (HPS). Post-training ratios were 0.35 ± 0.41 (HSP) vs. 0.39 ± 0.32 (HPS). The comparison of weekly mean T/C Ratio between groups is plotted in Figure 17.



Figures 17: Comparison of mean T/C ratio for each week between groups. HSP = Hypertrophy, Strength, Power. HPS = Hypertrophy, Power, Strength. There was no difference between groups at any time point nor was there any time course change in ratio ($p>0.05$). Values are reported in means ± standard deviation.

CHAPTER V

DISCUSSION

The primary aim of the present study was to examine changes in powerlifting performance (as measured by squat, bench press, and deadlift 1RM) in response to two different models of daily undulating periodization in collegiate male powerlifters. The two DUP models, HSP (traditional – hypertrophy, strength, and power) and HPS (modified – hypertrophy, power, and strength), differed in training order throughout a week. We also compared the total volume of exercise performed and serum anabolic (testosterone) and catabolic (cortisol) hormone concentrations between the two training groups. The main findings were that both groups significantly increased 1RM for all lifts from pre-training to post-training with the exception of HSP in the bench press. This lack of increase in bench press 1RM for HSP may have been due to HSP performing significantly less total volume in the bench press than HPS. Furthermore, there were no significant differences between pre- and post-training hormonal responses within and between groups.

One-Repetition Maximum (1RM)

The present study is the first, to our knowledge, to demonstrate the efficacy of DUP in improving performance in well-trained powerlifters. Results indicated a significant difference from pre- to post-training for powerlifting total 1RM (i.e. 7.7%; +38.18 kg.); however, no difference was found between groups. These pre- to post-training changes in powerlifting total were attributable to significant increases of 9.29% and 7.13% in squat and deadlift 1RMs, respectively. Interestingly, there was no significant main time effect for bench press from pre- to post-training. However, HPS significantly increased their bench press strength over the course of the study by 8.13%, while HSP did not. Therefore, the lack of significance in overall bench press 1RM is likely due to HSP demonstrating no significant pre- to post-training changes in bench press 1RM.

Table 10: Overall changes in strength measures pre- to post-training

Variables	Pre-Training	Post-Training
1RM Squat (kg.)	159.81 ± 19.99	174.65 ± 22.94* (9.29% Increase)
1RM Bench Press (kg.)	125.81 ± 18.14	132.76 ± 20.96 (5.45% Increase)
1RM Deadlift (kg.)	188.82 ± 26.80	202.15 ± 26.33* (7.13% Increase)
Powerlifting Total (kg.)	495.80 ± 59.71	533.98 ± 64.15* (7.70% Increase)
Wilk's Formula	335.41 ± 31.61	361.32 ± 34.07* (7.73% Increase)

Values are in means ± standard deviation.
*p<0.05, significantly different from pre-training. N=18

The 1RM strength gains resulting from DUP training agree with previous research (10, 46). Rhea et al. (2002) reported a 28.8% increase in bench press strength with traditional DUP training and Peterson et al. (2008) demonstrated a 16% and 15% increase in squat and bench press 1RM, respectively. Despite the general consistency of these findings, a smaller degree of improvement in the squat (+9.29%) and bench press (+5.45%) was observed in the present study. Two factors may possibly account for the discrepancy in strength gains: 1) longer training protocols in previous studies (12 weeks) *vs.* the present study (6 weeks), and 2) recreationally trained subjects in previous studies (46,51) *vs.* competitive powerlifters in the present study. These factors are noteworthy as less-trained subjects with longer training programs would likely account for greater strength gains than well-trained subjects with shorter training programs. Nonetheless, our findings provide support for the effectiveness of DUP in enhancing strength in well-trained powerlifters.

1RM Squat Strength

Although increases in squat 1RM from pre- to post-training were observed in both groups, there was no significant difference between groups. These findings are in agreement with Hoffman et al. (2009), who reported that non-periodized, linear, or non-linear training increased squat 1RM to a similar degree in collegiate football players (60). The non-linear group had a pre-training 1RM squat (164.20 ± 23.20 kg.) similar to the present study (159.81 ± 19.99 kg.). Also similar to the present research, Hoffman et al. observed these changes after 7 weeks of training. The authors, however, did not observe differences from week 7 to week 15 of training and suggested the 15 weeks to be of insufficient length to detect between-group differences in maximum strength following a lay-off from training. Further, research needs to be conducted to validate this claim, however, it should be noted that significant strength differences between DUP and LP after training protocols of 9 weeks (46) and 12 weeks (51). In the current study, although there was no statistically significant difference between HSP (7.93% increase) and HPS (10.48% increase) squat 1RM, the 2.55% discrepancy between groups might suggest that a longer training period could produce greater gains with HPS.

1RM Bench Press Strength

In contrast to the squat and deadlift, only HPS demonstrated a significant increase in bench press 1RM (+8.13%) whereas HSP showed no significant change (+2.71%). These percent increases are comparable to Hoffman et al. who reported a 5.89% increase in bench press strength in collegiate football players after 7 weeks of non-linear periodization training (60).

Speculatively, HPS displayed greater gains solely in the bench press possibly due to a great amount localized fatigue and muscle damage in the smaller muscle groups of the upper body (e.g. pectoralis, deltoids, and triceps). On the other hand, walking, a lower body exercise, has been shown to result in more general fatigue of larger muscle groups (170). Consequently, the localized fatigue in small muscle groups of the upper body may require a longer recovery period than general fatigue in the lower body. Ultimately, HSP had a shorter recovery period before performing strength training, possibly accounting for the attenuated rate of bench press 1RM increase compared to HPS. This notion gains support from Gates and Dingwell (2010) who demonstrated that the pectoralis, shoulders, and triceps were most susceptible to localized fatigue when a upper body exercise was performed (169). One group of subjects in their study performed a fatiguing task similar to sawing, while a second group performed a lifting task similar to a front raise. Both tasks fatigued the entire upper body, as noted by maximal voluntary contraction (MVC) and EMG measurements; however, fatigue from the sawing task was much more localized to the pectoralis major, deltoids, and triceps brachii which are the prime movers of the bench press. Further, these findings are supported by Newton et al. (1996), who demonstrated the greatest EMG activity in the pectoralis major, anterior deltoid, and triceps brachii when compared to all upper body muscle groups, during a bench press variation in male subjects (177). Conversely, lower body exercise has been shown to induce generalized lower body fatigue not specific to any particular muscle group (170). Our results suggest that the bench press and upper body exercise in general may cause greater fatigue to specific muscle groups and smaller muscle groups, possibly requiring a longer recovery period than lower body exercise.

Previous authors have reported on the importance of using the proper attention style to master the powerlifting exercises (173). However, a previous study concluded that specific fatigue of a muscle group led to greater changes in muscle activation patterns and therefore improper utilization of motor patterns as opposed to when systemic fatigue was predominant (171). This may lead to muscle imbalances negatively affecting the stability of the muscle specific task (172). Moreover, it is possible that the shorter recovery period in HSP led to incorrect motor patterns being used during strength training in the bench press. Whereas, in HPS, the longer recovery period allowed for proper muscle activation during strength training, thus greater skill and neuromuscular adaptations were achieved in this group.

1RM Deadlift Strength

Regarding 1RM deadlift, there was a main time effect, however, results indicated no significant between HSP (+6.70%) and HPS (+7.57%). Over the course of resistance training research, the deadlift is utilized far less as a training exercise than the squat or bench press. This is possibly due to large variability of acceleration parameters exhibited by unskilled lifters (175), which may lead to an increased risk of injury. However, with our study utilizing trained powerlifters, not only did subjects have the necessary strength base to perform the deadlift, but were also highly experienced in the deadlift prior to the onset of the study.

In contrast to the squat and bench press, the deadlift was not performed in DUP fashion. Subjects performed the deadlift once a week on strength training sessions only. This programming tactic was implemented due to the high amount of central nervous system fatigue associated with the deadlift. Interestingly, the overall deadlift 1RM increase was 7.13%, which was very comparable to the overall squat (+9.29%) and bench press (+5.45%) increases, even though those lifts were performed three times a week. These results are unique in suggesting that powerlifters can achieve a similar rate of increase in deadlift 1RM to that of the squat and bench press even when performed with less frequency.

Total Volume and Repetitions

Previous research suggested that total volume (or total work) of exercise is primarily responsible for strength gains and hypertrophy, instead of inducing a significant amount of muscle damage throughout a training program (174). Thus, we found it important to measure total exercise volume as an outcome measure along with 1RM strength. Total exercise volume and repetitions performed were significantly greater with HPS compared to HSP for squat, bench press, and powerlifting total as predicted; however, there was no difference between groups for deadlift volume and repetitions. The significantly less volume performed in the HSP group corresponds well with that of Chen et al. (2005), who noted at least 30% decline in total volume for up to 72 hours following exercise induced muscle damage in male subjects (76). Further, Dolezal et al. (2000) has demonstrated that recovery from muscle damage occurs 96 hours after exercise in trained men (176). In the present study HPS had a 96-hour time period between hypertrophy training and strength training as opposed to only 48 hours in HSP, therefore HPS may have been sufficiently recovered at the onset of strength training accounting for the greater total volume and repetitions compared to HSP.

Previous research has concluded that strength is dependent upon total volume performed during a training program (174). In terms of bench press, our findings agree as HPS performed 39.67% greater volume, more total repetitions, and had greater strength gains compared to HSP. Additionally, not only total volume and repetitions were significantly greater in HPS, but also bench press total repetitions were significantly different from HSP in a direct comparison of week 2 training. Likewise, bench press total volume was significantly greater in HPS at weeks 2, 4, and 5. However, squat volume and repetitions were greater in HPS, yet there was no significant difference between the training protocols regarding 1RM squat strength, which seems to disagree with the previous findings. Although, further analysis reveals that the difference in squat volume (31.78% more volume in HPS) may correspond with our findings in 1RM strength. While there was a significant group effect for total squat volume and repetitions, there were no differences in individual week comparisons, unlike bench press, which did demonstrate individual week differences. The weekly bench press differences elicited a 5.42% greater increase in bench press 1RM for HPS, while the difference in squat 1RM was non-significant (2.55%). Therefore, even though the disparity in squat 1RM was not statistically significant, the rate of increase in each group does seem to be dependent upon total exercise volume as previous research suggests (174). To put the 2.55% difference in 1RM squat in a practical perspective, at the 2011 International Powerlifting Federation (IPF) world championships only a 1.63% difference in powerlifting total separated 1st and 3rd place in the 120kg. division, while only 2.56% separated 1st from 4th. Thus, the difference in 1RM squat between groups in our study could have significantly changed an athlete's standing in this competition. Consequently, it does seem that the greater squat volume in HPS played a significant role in the 2.55% difference in 1RM strength gains between groups in the squat.

Hormonal Markers: Testosterone and Cortisol

Quite often research has examined the acute responses of testosterone and cortisol to various training programs. The consensus of these studies has been that a hypertrophy-oriented bout of resistance exercise elicits the greatest acute elevations of these hormones (133,138,153,159), with a subsequent return to resting levels normally within 24 hours following the exercise bout (159). However, consistency in chronic adaptations of hormones in response to long-term training is less clear (145). Previous research has reported no change in testosterone levels in response to long-term resistance training programs (139-142), including no change following one-year of training (144,150). However, following 2 years of training, data have indicated increases in resting testosterone concentrations (144). Alterations in resting cortisol concentrations have also been shown to be inconsistent; studies have reported decreases (157,158) and no change (151,152,156) in cortisol values in response to long-term resistance training. Our study reported declines in hormone concentrations in the middle weeks of the training program, however, levels returned to baseline following a one-week taper. Therefore, it may require a longer training period than the present study (6 weeks) to significantly alter hormone concentrations at post-training from baseline levels.

To our knowledge, there is no study examining the time course of serum testosterone and cortisol responses during different DUP training models. However, Kraemer et al. (2003) reported a significant elevation in both testosterone and cortisol following a 9-month LP training protocol in collegiate women's tennis players (145). Even though there were no significant differences between pre- and post-training hormonal concentrations in our study, it is important to note that overall mean testosterone levels were lower than pre-training at weeks 5 and 6 while overall cortisol levels were significantly lower than pre-training at weeks 3 and 4. These alterations are interesting because although no changes were observed at post-training the differences found each week may be due to accumulated muscle fatigue resulting from the previous training sessions (145). Moreover, the declines in cortisol (weeks 3 and 4) and testosterone (during weeks 5 and 6) suggest muscle fatigue due to repeated intensive training sessions. Nevertheless, after decreasing in weeks 5 and 6, testosterone concentrations recovered to pre-training levels at post-training, likely due to the positive supercompensation effects of the taper following the training protocol. Therefore, these results suggest that training in a heavy state of fatigue may initially deplete hormone concentrations; however, this fatigue is beneficial for strength gains at the culmination of training once a taper and supercompensation has taken place. Further, the alterations in cortisol (weeks 3 and 4) and testosterone (5 and 6) in the present study were likely due to a current state of fatigue rather than real resting changes.

Conclusions

Structured or periodized resistance training programs are effective methods to increase maximal strength and overall muscle performance measures. With DUP being at the forefront of recent periodization research, it is imperative to expand upon the traditional model and strive to continue to move closer to the optimal periodized training protocol for maximal strength. Therefore, the objective of our study was to take the initial step in achieving a more effective DUP training program design. Our findings demonstrate that in certain exercises and muscle groups the modified DUP model (HPS) may augment strength gains when compared to the traditional DUP model (HSP). While our study only took a preliminary step to optimize DUP training, our modified DUP model induced significantly greater strength gains in the bench press following 6 weeks of training and a 2.55% greater increase in 1RM squat strength, which may hold great practical significance for competitive powerlifters. Our findings also indicated that greater total exercise volume and repetitions were performed in the bench press and squat exercises with HPS vs. HSP. Additionally, subjects in this study performed the powerlifts with a high frequency and demonstrated significant gains from pre- to post-training regardless of training group. These results show that DUP training is effective to increase maximal strength in a short period of time among well-trained powerlifters. Finally, to our knowledge, we are the first group to compare physiological responses to two different models of DUP in trained athletes, as previous studies using trained athletes have only compared DUP to LP or DUP to non-periodized training programs. Future research should incorporate measures of muscle hypertrophy and attempt to implement DUP for specific sports and goals. Ultimately, future research should investigate the comparison of additional modified DUP training programs against each other and against traditional DUP. This future analysis should include longer training programs, an effort to support DUP efficacy for sport specificity, and continue to examine hormonal changes and maximal strength adaptations.

APPENDIX A

HUMAN SUBJECTS APPROVAL LETTER

Office of the Vice President For Research
Human Subjects Committee
Tallahassee, Florida 32306-2742
(850) 644-8673 · FAX (850) 644-4392

APPROVAL MEMORANDUM (for change in research protocol)

Date: 7/11/2011

To: Michael Zourdos

Address: 1493
Dept.: NUTRITION FOOD AND MOVEMENT SCIENCES

From: Thomas L. Jacobson, Chair

Re: Use of Human Subjects in Research (Approval for Change in Protocol)
Project entitled: 1.1 Comparison of Two Different Models of Daily Undulating Periodization for Total Volume Performed, Hormonal Response to Exercise, and Maximal Strength Gains.

The form that you submitted to this office in regard to the requested change/amendment to your research protocol for the above-referenced project has been reviewed and approved.

If the project has not been completed by 5/9/2012, you must request a renewal of approval for continuation of the project. As a courtesy, a renewal notice will be sent to you prior to your expiration date; however, it is your responsibility as the Principal Investigator to timely request renewal of your approval from the Committee.

By copy of this memorandum, the chairman of your department and/or your major professor is reminded that he/she is responsible for being informed concerning research projects involving human subjects in the department, and should review protocols as often as needed to insure that the project is being conducted in compliance with our institution and with DHHS regulations.

This institution has an Assurance on file with the Office for Human Research Protection. The Assurance Number is FWA00000168/IRB number IRB00000446.

Cc: Jeong-Su Kim, Advisor
HSC No. 2011.6676

APPENDIX B

INFORMED CONSENT FORM

1. I voluntarily consent to be a participant in the research project entitled "Physiological Responses to Two Different Models of Daily Undulating Periodization". This research is being conducted by Michael C. Zourdos, MS and Jeong-Su Kim, Ph.D. Dr. Jeong-Su Kim, Ph.D. is a faculty member and Michael C. Zourdos, MS is a PhD candidate in the Department of Nutrition, Food and Exercise Sciences at The Florida State University.

2. The purpose of the proposed study is to examine physiological responses including total volume performed, hormonal responses, and maximal strength gains during 6 weeks of training of two different models of daily undulating periodization (DUP).

3. My participation in this project will require my attendance at The Florida State University Exercise Physiology Laboratory for a total of 22 different days over a period of 8 weeks. I will be performing one of two different DUP strength training programs (there are two groups of DUP) of which, each training session will last approximately 90 minutes: The DUP training program will last for six weeks, occurring during weeks 2-7, with weeks 1 and 8 serving as pre- and post-testing respectively. Week 1 day 1 will serve to establish baseline strength measures and a blood draw followed by a day of light training 72 hours later. From week 2 through 7 I will perform one of the two DUP training programs, which will require 18 visits to the laboratory split into 3 visits each week. Each of these visits will consist of resistance training with a blood draw 30 minutes prior to training. Finally, during week 8 I will report to the lab on two occasions. The first visit on during week 8 will be light training and will occur 96 hours following the end of week 7 training. The second visit on week 8 will be 72 hours later and will serve as a post-test for maximum strength and a final blood draw to complete the study.

On the first day of the study I will come to the Exercise Physiology Laboratory where I will sign an informed consent and answer questions on my medical history. I will also have my blood pressure measured. If I have high blood pressure (greater than 140/90 mmHg), or have any contraindications to maximal resistance training then I will not be able to participate in the study. After obtaining my consent I will have approximately 10 mL (3-4 tablepoons) of blood drawn by a trained phlebotomist. Then, I will perform a one-repetition maximum (1RM) on the back squat, bench press, and deadlift exercises using a free weight barbell. After a standard warm-up protocol I have three attempts to lift the maximum amount of weight possible on each exercise while maintaining proper technique. For the remainder of week 1 I will return to the laboratory 72 hours later to complete a low volume resistance training protocol to complete the first week of the study. Weeks 2-7 will consist of a 6-week DUP training program. I will complete one of the two following programs during this time: 1. Hypertrophy, Strength, and Power (HSP); or 2. Hypertrophy, Power, and Strength (HPS). During weeks 2-7 I will train 3 days a week on alternating days. For example: I may train Monday, Wednesday, and Friday with Saturday and Sunday as rest days. If I perform the HSP protocol I will perform hypertrophy training on Monday, strength training on Wednesday, and power training on Friday. If I perform the HPS protocol I will perform hypertrophy training on Monday strength training on Wednesday, and power training on Friday. The sets and repetitions for each training type (hypertrophy, strength, and power) will be the same for each program. For hypertrophy training of week 1 I will perform 6 sets of 8 repetitions for the back squat and bench press with a load of 75% 1RM. For power training during week 1 I will perform 5 sets of 1 repetition at 80% 1RM for both the back squat and bench press. The strength training session for week 1 will consist of 5 sets of maximal repetitions at 85% 1RM for the back squat and bench press and 3 sets of maximal repetitions at 85% for the deadlift. This means the bar will be loaded to 85% of my 1RM and I will be instructed to perform as many repetitions as possible until muscular failure. For the remaining weeks of the DUP training program I will follow the same sets and repetitions, however, the load I lift will be progressively increased each week based upon my personal adaptations. During week 8, the final week, I will only report to the laboratory on two occasions. The first lab visit of week 8 will be 96 hours following the completion of week 7 training, and will serve as light training. The second visit of the final week will take place 72 hours following the first and will be for final 1RM testing of all three lifts, which have been trained up to this point, and a final blood draw. Furthermore, I will have my blood drawn on 20 separate occasions: on day 1 of week 1 as described above, as well as each training day during the DUP training program, and before final 1RM testing during week 8. With these instructions I understand that I will report to the laboratory a total of 22 times while being instructed to refrain from any exercise other than that which is performed in the study. In addition, I will be given a dietary log to record my diet each day, as I will be instructed to keep my dietary intake consistent between days. I should also refrain from taking any pain or anti-inflammatory medicine (e.g. Aspirin, Tylenol, or Advil) ten days before and during the experimental period to avoid any external protection against exercise-induced inflammation or muscle soreness.

4. I understand that there is a possibility of a minimal level of risk involved if I agree to participate in this study. The risks will be minimized by using well-trained technicians and experienced trainers, and by teaching me proper techniques in testing and resistance training. I am also well aware of the potential risks, as I am experienced in resistance training. I will not be able to participate in the study if I have high blood pressure (greater than 140/90 mmHg), or smoke. I also should report any other conditions that may disqualify me from this type of physical exertion. During my interview or first visit to the laboratory I will provide my health history and current health status to the investigator. Therefore, I will complete the Health History Questionnaire to the best of my knowledge immediately following completion of the Informed Consent Form. Upon request, I am willing to provide my physician's contact information to the investigator, thus the investigator may contact my physician if necessary. The investigator will determine my participation based on the given information and schedule for further evaluations and tests if I am qualified.

5. I am aware that with a blood draw there are minimal risks involved. These risks include: moderate pain; slight bleeding, and mild swelling.

6. I am well aware of exercise-induced muscle soreness from strength testing and training protocols. Further, I understand that with resistance training there is also a risk of joint pain and fatigue. It is recommended that I limit additional strenuous daily activity and exercise training throughout the experimental period or as long as muscle soreness persists.

7. The results of this research study may be published but my name or identity will not be revealed. Information obtained during the course of the study will remain confidential, to the extent allowed by law. My name will not appear on any of the public record. If individual responses are needed, my confidentiality is granted. Confidentiality will be maintained by assigning each subject a code number and recording all data by a code number. The only record with the subject's name and code number will be kept by Dr. Jeong-Su Kim, in a locked drawer in his office. This record will be destroyed in 10 years.

8. If I develop health problems during the course of the study, The Florida State University will not provide compensation and will not provide medical treatment without charge for any medical charges as a result of this research investigation. However, the investigators will provide first aid if an injury occurs during testing.

9. I will not be paid for my participation in this research project. However, I will receive free fitness evaluations as indicated below with no cost to me (please see #11 for details).

10. Any questions I have concerning the research study or my participation in it, before or after my consent, will be answered by the investigators or they will refer me to a knowledgeable source. I understand that I may contact Michael C. Zourdos, [redacted] or Dr. Jeong-Su Kim, jkim6@fsu.edu, (850) 644-4795 regarding any questions that I may have about this research project or my rights. Group results will be sent to me upon request.

11. In case of injury, or if I have questions about my rights as a subject/participant in this research, or if I feel I have been placed at risk, I can contact the chair of the Human Subjects Committee, Institutional Review Board, through the Office of the Vice President for Research, at (850) 644-8633.

12. Benefits from this study include learning not only about fitness evaluations for maximal strength but also about how to optimally design a resistance-training program to improve strength performance. I will also be able to learn my own physiological responses during the two different DUP training models. These evaluations and practical education will be conducted at no cost to me.

13. The nature, demands, benefits, and risks of the project have been explained to me. I knowingly assume any risks involved.

14. I have read the above Informed Consent Form. I understand that I may withdraw my consent and discontinue participation at any time without penalty or loss of benefits to which I may otherwise be entitled. In signing this consent form, I am not waiving my legal claims, rights, or remedies. A copy of this consent form will be given to me.

____ (Subject) (Date)

FSU Human Subjects Committee Approved on 7/08/11. Void after 5/09/12. HSC# 2011.6676

APPENDIX C

DIETARY LOG

1. Use the Dietary Record Forms provided to record everything you eat or drink for each day of this study.
2. Indicate the name of the FOOD ITEM, the AMOUNT eaten, how it was PREPARED (fried, boiled, etc.), and the TIME the food was eaten. If the item was a brand name product, please include the name. Try to be accurate about the amounts eaten. Measuring with measuring cups and spoons is best, but if you must make estimates, use the following guidelines:

    Fist is about 1 cup

    Tip of Thumb is about 1 teaspoon

    Palm of the hand is about 3 ounces of meat (about the size of a deck of cards)

    Tip of Thumb is about 1 ounce of cheese

3. Try to eat what you normally eat and record everything. The project will only be useful if you are HONEST about what you eat. The information you provide is confidential.
4. MILK: Indicate whether milk is whole, low fat (1 or 2%), or skim. Include flavoring if one is used.
5. VEGETABLES and FRUITS: One average serving of cooked or canned fruits and vegetables is about a half cup. Fresh whole fruits and vegetables should be listed as small, medium, or large. Be sure to indicate if sugar or syrup is added to fruit and list if any margarine, butter, cheese sauce, or cream sauce is added to vegetables. When recording salad, list items comprising the salad separately and be sure to include salad dressing used.
6. EGGS: Indicate method of preparation (scrambled, fried, poaches, etc.) and number eaten.
7. MEAT / POULTRY / FISH: Indicate approximate size or weight in ounces of the serving. Be sure to include any gravy, sauce, or breading added.
8. CHEESE: Indicate kind, number of ounces or slices, and whether it is made from whole milk, part skim, or is low calorie.
9. CEREAL: Specify kind, whether cooked or dry, and measure in terms or cups or ounces. Remember that consuming 8 oz. of cereal is not the same as consuming one cup of cereal. 1 cup of cereal generally weighs about 1 ounce.
10. BREAD and ROLLS: Specify kind (whole wheat, enriched wheat, rye, etc.) and number of slices.
11. BEVERAGES: Include every item you drink excluding water. Be sure to record cream and sugar used in tea and coffee, whether juices are sweetened or unsweetened and whether soft drinks are diet or regular.
12. FATS: Remember to record all butter, margarine, oil, and other fats used in cooking or on food.
13. MIXED DISHES / CASSEROLES: List the main ingredients and approximate amount of each ingredient to the best of your ability.
14. ALCOHOL: Be honest. Record amounts in ounces. Specify with "light" or "regular" beer.

DIETARY RECORD FORM

Day of the Week: ________________

Date: ___________________

FOOD ITEM	AMOUNT	TIME

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

APPENDIX D

PHYSICAL ACTIVITY QUESTIONAIRRE

Think about all the exercise training including any vigorous activities, which take hard physical effort that you did in the last 7 days. Vigorous activities make you breath harder than normal and may include aerobic, heavy lifting, or fast bicycling. Think only about those physical activities that you did for at least 10 minutes at a time.

1. Do you compete on a regular basis? If so, how often?

Yes or No If so, _______________ times/year

2. How long have you been training for strength competitions?

_______________ years

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

_______________ miles/week

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

_______________ days/week Average_______________ times/day

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

_______________ % your maximum

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

Yes or No If so, _______________ times/week

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

1 2 3 4 5 6 7 8 9 10

Very Light Light Moderate Intense Very Intense

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

Yes or No If so, name:_______________ and when:________________

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

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

Event:________________________________

10. In your opinion, before you take part in an experimental session, do you believe that you will increase strength greater during the HSP or HPS condition?

HSP:________________ HPS:__________________ No Difference:__________________

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

APPENDIX E

HEALTH HISTORY QUESTIONAIRRE

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

2. Do you feel pain in your chest when you do physical exertion?

3. In the past month, have you had chest pain when you were not doing physical activity?

4. Do you lose your balance because of dizziness or do you ever lose consciousness?

5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?

6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

7. Do you know of any other reason why you should not do physical activity?

8. Please list all medications that you are currently taking. Please include vitamins or supplements.

9. Do you run at least 20 miles a week, and have previously competed in long distance running events (5K or longer)?

10. Do any of your immediate family/grandparents have a history of (check those applicable):

_ heart disease

_ heart surgery

_ high cholesterol

_ diabetes

_ heart attack

_ congenital heart disease

_ high blood pressure

_ stroke

_ premature death

If yes, please note relationship and age

11. Has there been a death in the family via heart attack, heart disease, or stroke?

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BIOGRAPHICAL SKETCH

MICHAEL CHRISTOPHER ZOURDOS

Michael was born on September 12th, 1985 in Silver Spring, Maryland to Christopher and Deborah Zourdos. With one older brother, Peter Zourdos, he grew up in the Washington D.C. suburb of Potomac, MD. Michael attended private school at The Bullis School, in Potomac, from fourth grade through his high school graduation, and later served as Strength and Conditioning Coach at Bullis. In December of 2006 Michael earned his Bachelor's of Science in Exercise Science from Marietta College (Marietta, OH.). He was a 4-year letterman on Marietta's NCAA Division III soccer team in the Ohio Athletic Conference (OAC) and he captained the squad in his final two seasons. Upon graduation from Marietta Michael began his Masters degree the next semester at Salisbury University (Salisbury, MD.). Michael graduated with his Masters of Science from Salisbury in the Spring of 2008. While at Salisbury Michael served as the Graduate Assistant Strength and Conditioning Coach, working all varsity teams at the University. Michael then began his Ph.D. training at FSU in the fall of 2008, where he immediately began working on human performance and skeletal muscle research under the guidance of Dr. Jeong-Su Kim. During this time Michael has served as a lecture and laboratory instructor of Anatomy and Physiology II. Along the way Michael became coach of FSU's Powerlifting team and competed with the team. The team has since won the 2011 and 2012 USAPL state of Florida open championships and 2011 Florida collegiate championships. In conjunction with the 2011 collegiate state championships Michael hosted the "Optimizing Performance Training and Nutritional Adaptations" symposium, which a large crowd of over 250 people. Through these endeavors Michael's research and publications have focused mainly on human athletic performance, increasing maximal strength, and improving endurance running. Michael will continue to compete and coach in powerlifting as well as continue his human performance research line and teaching as an Assistant Professor at Florida Atlantic University. Finally, Michael is recently engaged to Dr. Catherine Coccia.