2010

A Comparison of Training Modalities on Vertical Jump Performance in Recreationally Trained College Males

Katie Alexis Jackson

A COMPARISON OF TRAINING MODALITIES ON VERTICAL JUMP PERFORMANCE IN RECREATIONALLY TRAINED COLLEGE MALES

By
Katie Alexis Jackson

A thesis submitted to the faculty of The University of Mississippi in partial fulfillment of the requirements of the Sally McDonnell Barksdale Honors College.

Oxford
May 2010

Approved by

Advisor: Assistant Professor John C. Garner III

Reader: Assistant Professor Hugh S. Lamont

Reader: Associate Dean Teresa Carithers, School of Applied Sciences

DEDICATION

This thesis is dedicated to Daddy, Mama, Laura, and Eric who believed in me, supported me, pushed me, and encouraged me to finish what I started.

ACKNOWLEDGEMENTS

I would like to thank Dr. Jay Garner for his willingness to take me on as an Honors student and advise me in the thesis-writing process. He endured countless knocks on the door, questions, and emails, but he guided me through the entire process.

I would like to thank Chris McDonald for developing this research study and doing all the preliminary work. He was a great help throughout the research and writing process. I would like to thank him for trusting and granting me permission to study and analyze part of his project and for providing access to all of his methodological and procedural information involved with the study.

I would like to thank Dr. Hugh Lamont for his assistance throughout the entire research and writing process and for his willingness to serve on my thesis committee.

Lastly, I would like to thank the Sally McDonnell Barksdale Honors College administration, faculty, and staff for their continued support and guidance.

ABSTRACT

KATIE ALEXIS JACKSON: A Comparison of Training Modalities on Vertical Jump Performance in Recreationally Trained College Males
(Under the direction of Dr. Jay Garner)

Vertical jumping ability is a vital component of superior athletic performance. The purpose of this study was to compare the effects of six weeks of resistance training (RT), plyometric training (PT), and complex training (CT) on vertical ground reaction forces in vertical jump measures in college-aged males. Thirty participants were divided into three training groups: RT (n=11), PT (n=9), or CT (n=10). The participants trained two days a week for six weeks and participated in pre-testing, mid-testing, and post-testing sessions for a total study period of nine weeks. The testing sessions consisted of a 1RM back squat, Romanian Deadlift, standing calf raise, and three countermovement vertical jumps that were performed on a force plate in order to obtain average peak ground reaction force. A 3 x 3 (Group by Time Point) ANCOVA with body weight as the covariate revealed a significant group difference. A follow-up Bonferroni Post Hoc Test revealed no group by time point interaction, but a trend towards an applied effect appeared between complex training and resistance training. Across all three training protocol groups, there was a significant improvement in post-testing measures compared to pre-testing measures. Data in this study suggest that complex training was more effective than resistance training in improving vGRF in the vertical jump in recreationally trained college-aged males. However, there were no statistical or applied differences between complex and plyometric training or between plyometric and resistance training.

Table of Contents

Chapter I ... 4

Introduction ... 4

Purpose ... 11

Hypotheses ... 11

Limitations ... 12

Delimitations ... 13

Chapter II ... 14

Review of Literature ... 14

Resistance Training ... 15

Plyometric Training ... 22

Complex Training ... 27

Chapter III ... 35

Methods ... 35

Participants ... 36

Instrumentation ... 37

Grouping ... 38

Testing ... 39

Training ... 40

Analysis ... 47

Chapter IV ... 48

Results ... 48

Participant Characteristics ... 48

General Descriptive Statistics ... 49

Group Comparison Statistics ... 49

Chapter V ... 50

Discussion ... 50

Hypothesis Results ... 55

Conclusions ... 55

Future Research Considerations ... 56

List of References ... 58

List of Tables

Table 1. Timing for Training Protocols 41

Table 2. Resistance Training Protocol 43

Table 3. Plyometric Training Protocol 45

Table 4. Complex Training Protocol 46

Table 5. Group Descriptive Statistics 49

List of Figures

Figure 1. Training Timeline 36

Chapter I

Introduction

Even though some athletes possess what could be deemed "natural ability," there is still a certain level of time and effort that must be invested by anyone hoping to achieve high levels of performance within certain skills or sports. An abundance of training regimens exist that are related to the realm of exercise and sports training and can be employed by athletes to garner maximal performance improvements within their specific skill area. However, resistance training is a popular and well-established method of training used to some extent by nearly all athletes. While resistance training is commonly interchanged with the term "weight training," resistance training actually encompasses a much broader area within the strength and conditioning field. Newton (1999) broadly defines resistance training as performing exercise under any type of resistance. It can include modes such as heavy-load power training, plyometrics, isometric training, or different forms of combination training. Many forms of resistance training have been used in programs to improve performance measures such as one repetition maximum scores, agility, rate of force development, and vertical jumps. Two of the most important training outcomes of interest to athletes are strength and power development. The goals of the athlete must be taken into consideration to determine exactly which mode of resistance training should be incorporated into his training protocol.

For the sake of this study, the term "resistance training" will be used throughout the remainder of this paper to delineate one specific type of training, while plyometrics and forms of combination training will be referred to by those specific terms. Therefore, the training methods of main focus in this study include resistance training, plyometric training, and complex training, which is a form of combination training.

Resistance training is a common method of training used in both athletic and recreational settings. The exercises utilized may be considered isometric or dynamic. Regardless, specificity of movement and speed are important during exercises for enhancing the transfer of training effect from training to the actual performance (Harris et al., 2000; Stone et al., 1998; Stone et al., 2000). Across different training settings, it has been shown to induce health related changes to the body, prevent and rehabilitate injuries, and increase strength, hypertrophy, muscular power, and muscular endurance (Spennewyn, 2008; Wolfe et al., 2004; Stone et al., 2000; Miranda et al., 2007). Generally, relatively heavy loads are used for strength and power training, moderate loads are used for hypertrophy, and lighter loads are used for muscular endurance training (Fleck & Kraemer, 2003; Stone et al., 1982). Manipulation of variables such volume, intensity, frequency, exercise order, rest period lengths, type of muscle action, and movement velocity may help achieve training adaptations (Candow & Burke, 2007; Gonzalez-Badillo et al., 2005; Jackson et al., 2007; Miranda et al., 2007; Ronnestad et al., 2007; Spreuwenberg et al., 2006; Wolfe et al., 2004). The cyclic manipulation of these variables is called periodization, which is used to divide training macrocycles into smaller periods of time (Buford et al., 2007; Plisk & Stone, 2003). Resistance training is only a division of the general field of strength and conditioning, but proper use of available information can aid in performance improvement.

Another mechanism of training available to athletes today is plyometric training which improves power through force and velocity production. Plyometric exercises allow athletes to utilize gravity to store potential energy within the elastic structures of muscles and tendons that can be converted to kinetic energy (Chu, 1984). This increases both the amount of work done and potential force and allows for an explosive-reactive movement (Chu, 1984). This form of training utilizes the stretch-shortening cycle (SSC), which occurs when the active muscle switches from a rapid eccentric muscle action to a rapid concentric muscle action with a very short amortization phase. In the eccentric phase, the muscle is stretched and preloaded. The amortization phase is the time from the end of the eccentric phase to the initiation of the concentric muscle action (Chu, 1984; Kutz, 2003; Stem & Jacobson, 2007). Its timeframe should be kept to a minimum to avoid losing the effects of the stretch reflex. In the concentric phase, stored elastic potential energy in the muscles is converted to kinetic energy. The elastic strength of muscle-tendon tissue allows for quick and repeated rebounding from a surface with maximal height or distance (Chu, 1984). Jensen and Ebben (2007) propose that plyometric intensity could be evaluated through variables such as the rate of force development, ground reaction force, and joint reaction force.

By combining traditional resistance and plyometric training, athletes can establish a combination training protocol. One specific type of combination training is complex training in which biomechanically similar high load weight training exercises and plyometric exercises, deemed a complex pair, are alternated, set for set, within a single workout session (Ebben, 2002). Baker (2003) explains that the enhanced neural activity gained from heavy resistance exercises carries over to subsequent lighter resistance exercises and creates a greater power output than would have occurred without the prior heavy-load set. Neuromuscular factors can be seen as powerful physiological adaptation mechanisms of complex training because they may increase motor neuron excitability and reflex potentiation in addition to forcing greater motor unit recruitment (Ebben & Watts, 1998; Docherty et al., 2004; Jones & Lees, 2003). The adaptations caused by complex training can be described by an acute aftereffect phenomenon referred to as postactivation potentiation (PAP) (Hodgson et al., 2005; Robbins, 2005; Sale, 2002). An article by Docherty et al. (2004) reports that PAP is based on the assumption that the explosive capability of muscle is enhanced after it has just been subjected to maximal or near-maximal contractions. Ebben (2002) suggests that complex training is as equally effective or superior in comparison to other forms of combination training.

While there are many abilities and characteristics an athlete must obtain to achieve performance success, vertical jumps are vital to superior performance in a variety of sports. Baker (1996) writes that jumping ability is critical in sports ranging from diving to football. Some of the most popular mechanisms of training used to elicit superior improvements in vertical jumps include the three types previously mentioned—traditional resistance training, plyometric training, and complex training.

Countermovement vertical jumps are those preceded by a rapid stretch-shortening cycle (Baker, 1996). Baker (1996) states that a countermovement adds more height to a vertical jump compared to a squat jump, in which there is no pre-stretch, because of elastic energy utilization and neural augmentation to the muscles. Countermovement jumps create greater flight height than squat jumps because the ground reaction force in the upward phase of the jump is already greater than body weight, which allows the jumper to perform more work early in the upward phase of the jump (Linthorne, 2001). The transfer of training effect also applies to vertical jumping; therefore, the training protocol and exercises chosen should imitate the action of the vertical jump. There have been many research studies conducted on the effects of different training protocols on vertical jump improvements.

Vertical jumping is distinguished from other maximal strength measures because it produces high force in a short time (Baker, 1996). Fatouros et al. (2000) report several factors used as determinants of vertical jumping performance that include force developed by the hip, knee, and ankle joints; the rate of force development produced by these muscles; and the neural coordination of the movement. They also suggest that strength status affects vertical jumping ability in that low-strength subjects exhibit greater improvements following training than do strength-trained subjects (Fatouros et al., 2000).

For the purpose of this study, vertical ground reaction forces (vGRF) are used as a measure of vertical jump improvement because of their correlation with vertical jump height. Impulse is defined as the product of vGRF and the time of contact with the force plate (Hanson et al., 2007). Increasing either the vGRF or time variable results in a greater net impulse which then produces a change in the momentum of the body (Hanson et al., 2007; Linthorne, 2001). Increasing the propulsive force through acceleration or change in momentum allows jump height to be estimated from the net impulse (Hanson et al., 2007; Schilling et al., 2008). Increasing net impulse improves jump performance by increasing take-off velocity, which allows for greater jump heights (Hanson et al., 2007). Therefore, the largest net impulses reflect the greatest jump heights (Hanson et al., 2007). Because an increase in the time component decreases power output, as large a force as possible should be imposed on the ground to maximize both power and impulse (Hanson et al., 2007).

When applied practically, the use of different resistance training protocols can effect the development of skills such as the vertical jump (Baker, 1996). Another study by Perrine and Edgerton (1978) showed significant increases in vertical jump with dynamic resistance training. Baker (1996) concluded through his studies that various forms of resistance training can act together to improve vertical jumping ability through different physiological mechanisms. In a study comparing high force weight training, high power weight training, and combination training protocols, vertical jump measures significantly improved in the high power and combination training groups (Harris et al., 2000).

Miller et al. (2006) report that research has shown that plyometrics combined with a periodized strength-training protocol can help improve vertical jump performance. Research performed by Rimmer & Sleivert (2000), Stemm & Jacobson (2007), and Vissing et al. (2008) shows that effectively utilizing the SSC through plyometrics may improve performance in power-based events such as vertical jumps and bounds. Luebbers et al. (2003) report that a rapid prestretch and maximal effort during the concentric phase of the plyometric exercise has been effective at increasing muscle power output and vertical jump performance (Luebbers et al., 2003). Recent research conclusions support the enhancement of acceleration, power, muscular strength, vertical jump, and speed through plyometric training (Stemm & Jacobson, 2007). In a study by Vissing et al. (2008) that compared conventional resistance training and plyometric training, the plyometric protocol increased maximal countermovement jump height and power and maximal power in the ballistic leg press. Another plyometric study by Gehri et al. (1998) compared a countermovement jump protocol and depth jump protocol to a control group and found significant improvement in vertical jumping ability in both training groups. Other studies by Burgess et al. (2007), Gehri et al. (1998), Luebbers et al. (2003), and Potteiger et al. (1999) have shown the ability of plyometric training to increase vertical jump height, vertical jump power output, anaerobic power, and rate of force development.

Some research suggests the equal effectiveness or superiority of complex training compared to other combination training modalities shown through increased medicine ball throwing power, superior acute jumping performance, and improved vertical jump performance in response to a chronic complex training stimulus (Ebben and Watts, 1998). Mihalik et al. (2008) compared the effects of short-term complex training and compound training, another form of combination training, programs on vertical jump heights and power production and reported significant improvements in vertical jump height and power output in both training groups during the study. In another related study by Adams et al. (1992) the researchers concluded that a combined squat-plyometric training program increases power production in vertical jump measures significantly more than either a squat or plyometric program alone. Lyttle et al. (1996) compared a maximal power training program and a combined weight and plyometric program and found that the training groups improved significantly over the control group in vertical jump measures. Similarly, Fatouros et al. (2000) found that a combined plyometric and weight training protocol group performed significantly better than a weight training-only group and plyometric training-only group in vertical jump height, jumping mechanical power, and flight time. Additional studies from Jones and Lees (2003) and Jensen and Ebben (2003) indicate that complex training does not cause disadvantageous effects and may exhibit advantages in training measures.

Purpose

The purpose of this research was to perform a six week study comparing the effects of resistance training, plyometric training, and complex training on vertical ground reaction forces in vertical jump measures in college-aged males.

Hypotheses

H_{01}: There will be no change in vertical ground reaction forces in vertical jumps as a result of resistance training, plyometric training, or complex training.

H_{A1}: There will be an increase in vertical ground reaction forces in vertical jumps as a result of resistance training, plyometric training, or complex training.

Studies by Linthorne (2001), Hanson et al. (2007), Schilling et al. (2008), and Cormie et al. (2009) all provide information based on the impulse-momentum theory that supports the relationship that exists between vertical ground reaction forces and improvements in vertical jump heights. Increased force results in a change in acceleration and momentum via a change in net impulse, which can then be used to determine changes in vertical displacement, or height, of vertical jumps. Studies by Mihalik et al. (2008), Adams et al. (1992), Fatouros et al. (2000), and Lyttle et al. (1996) all showed improvements in vertical jump measures as a result of participation in different training protocols.

H_{02}: There will be no difference in vertical ground reaction forces in vertical jumps between the resistance training, plyometric training, and complex training protocols.

H_{A2}: There will be a greater increase in vertical ground reaction forces in vertical jumps as a result of complex training compared to either resistance training or plyometric training.

Research that indicates improvements in vertical jumps often report jump height which can be correlated with ground reaction forces to gauge changes in performance. A study from Mihalik et al. (2008) reported significant improvements in vertical jump height and power output as a result of a complex training protocol. Studies by Adams et al. (1992) and Lyttle et al. (1996) both concluded that a combined weight and plyometric training program significantly increased vertical jump performance measures. Similarly, Fatouros et al. (2000) concluded that a combined resistance and plyometrics protocol group performed significantly better the resistance-only and plyometrics-only protocol groups in vertical jump height, jumping mechanical power, and flight time. Jensen and Ebben (2003) also concluded that complex training has no disadvantageous effect on ground reaction forces in plyometric jumps performed one to four minutes after heavy-load resistance training. Baker (1996) stated that combined methods of training seem to offer the greatest training stimulus for improving vertical jumping ability.

Limitations

1. Participants were recruited from the University of Mississippi and surrounding Oxford, Mississippi community.
2. Thirty-four (34) recreationally trained, apparently healthy, college-aged males between the ages of 18 – 30 were used in the study.
3. The participants' responses to questionnaires were accepted as true.
4. There was a lack of complete control over participants' diets.

5. There was a lack of complete control over participants' levels of physical activity independent of the training protocols performed in the study.

Delimitations

1. Any participants classified as sedentary, as having a history of cardiovascular or respiratory disease, or as having had a traumatic injury or surgery to the lower extremities within two years prior to the study were excluded.
2. Reliable and valid equipment was used for all testing measurements obtained.
3. All participants had at least six months of recreational resistance training experience.
4. All pre-, mid-, and post-testing measures were obtained by the same researcher.
5. Only male participants were included in the study to allow for easier analysis of data and eliminate confounding effects of gender on the results.
6. Intention to treat analysis was used to account for any statistical change in the number of participants in order to keep the power the same.

Chapter II

Literature Review

The purpose of this section is to review and examine existing literature pertaining to three different training methods including resistance training, plyometric training, and complex training. As indicated by their abundance in literature, different protocols involving these training modes have been utilized by athletes to develop and improve performance measures across a wide spectrum of skills. While these three disciplines are not exhaustive training measures for performance enhancement, they will be the main focus within this review.

Within a season of training, athletes undergo multiple stages that each possesses different training goals aimed at eliciting a maximal performance outcome from the athlete. In order to meet the different goals within each phase, various methods of training can be undertaken. One of the most popular and traditional methods of training is resistance training. Because it has been established over the years as an effective training method, resistance training has become a regular mode of training for both athletes and the recreationally trained. Another type of training program commonly utilized in addition to resistance training is plyometric training. Plyometric training is a novel way to challenge the body because it employs different physiological mechanisms than resistance training that allow for an increase in force and power production and in performance measures like vertical jumping (Luebbers et al., 2003; Rimmer & Sleivert, 2000).

The variable of interest within this study is vertical ground reaction forces in a vertical jump. There are different ways to gauge improvements in vertical jumps. Most often in literature, vertical jump improvement is measured according to changes in vertical displacement, or height. However, for the purpose of this study, vertical ground reaction forces (vGRF) are used as a measure of vertical jump improvement because of their correlation with vertical jump height. The determination of either the net impulse or the vertical displacement of a jump allows for the calculation of the other value.

Both resistance and plyometric training have been established individually as successful and beneficial methods of training in the realm of athletic strength and conditioning. Therefore, combining the two individual methods into a single training protocol could possibly elicit even greater training effects than either method performed alone. The joining of both resistance training and plyometric training into one single training protocol is known as combination training. There are different forms of combination training, but the type under review in this study is known as complex training. In complex training, biomechanically similar high load weight training exercises and plyometric exercises are alternated, set for set, within a single workout session (Docherty et al., 2004; Duthie et al., 2002; Ebben, 2002; Ebben & Watts, 1998; Ebben & Blackard, 1997; Jensen & Ebben, 2003; Jones & Lees, 2003; Mihalik et al., 2008). Complex training is examined in this review because of its increasing prevalence in existing literature and growing popularity in athletic training settings.

Resistance Training

Resistance training is a common training mechanism used in most practical settings. It is often prescribed as a method to improve health and fitness, aid weight loss, improve athletic conditioning, and prevent and rehabilitate injuries (Spennewyn, 2008; Wolfe et al., 2004). It may also induce health-related changes such as improved endocrine and serum lipid adaptations, insulin sensitivity, increased lean body mass, decreased fat mass, increased tissue tensile strength, and decreased physiological stress (Stone et al., 2000). In terms of performance variables, resistance training can bring about increases in strength, hypertrophy, muscular power, and muscular endurance (Miranda et al., 2007). Changes that occur in these variables are related to improvements in athletic performance activities such as 1-repetition maximum strength measures, vertical jumps, sprint times, distance-running times, and agility (Buford et al., 2007; Candow & Burke, 2007; Humburg et al., 2007; Stone et al., 2000).

There are different approaches to resistance training that include static and dynamic training. Static, or isometric, training occurs when there is no change in muscle length because the contractile force is equal to the force of resistance. In dynamic training, there is an active lengthening or shortening of the muscle as seen in isotonic training, which includes concentric and eccentric muscle actions. Stone et al. (2000) report that isometric training can increase the rate of peak force development and velocity of movement but had only a minor effect on dynamic explosive-force production. In a study by Ball et al. (1963) isometric training was shown to have no effect on vertical jump performance, while another study by Perrine and Edgerton (1978) showed significant increases in vertical jump with dynamic training. Baker et al. (1994) contribute the differences between isometric and dynamic vertical jump training to variations in the structural, neural, and mechanical characteristics of each. Another form of training found in literature is the use of isokinetic devices which maintain a constant velocity, and thus allow a maximum effort to be exerted with each repetition (Kelly et al., 2007; Stone et al., 2000). Morrissey et al. (1994) report that comparisons between weight training and isokinetic exercise revealed the superior effects of weight training on lifting performance, no difference in training effects between the two types of training, the superiority of weight training on isokinetic strength, and the superiority of isokinetic training on isokinetic strength. Therefore, most literature suggests that much more research be done on the subject (Kelly et al., 2007; Morrissey et al., 1994; Stone et al., 2000).

A resistance training program consists of multiple variables that must be manipulated to elicit optimal training adaptations. These variables include volume, intensity, frequency, exercise order, rest period lengths, type of muscle action, and movement velocity (Candow & Burke, 2007; Gonzalez-Badillo et al., 2005; Jackson et al., 2007; Miranda et al., 2007; Ronnestad et al., 2007; Spreuwenberg et al., 2006; Wolfe et al., 2004). Performance gains may be garnered through the careful planning of changes in training volume, intensity, and exercise selection (Stone et al., 1998). The actual training regimen can be performed using either free weights or resistance machines. Stone et al. (2000) describe a free weight exercise as one in which a freely moving body, such as a barbell, dumbbell, or body mass, applies resistance and challenges the lifter to focus on the control, direction, and stability of the movement. In exercises performed with machines, resistance application is guided or restricted, allowing fewer challenges with movement direction, control, and stability (Stone et al., 2000). The development of an optimally designed resistance training program has the potential to benefit health and enhance performance.

Resistance training protocols can be manipulated in order to achieve different goals such as strength, power, hypertrophy, muscular endurance. These goals are characterized by the percentage of a one repetition maximum and the numbers of repetitions performed. Generally, an athlete should use relatively heavy loads for strength and power training, moderate loads for hypertrophy, and lighter loads for muscular endurance training (Fleck & Kraemer, 2003; Stone et al., 1982). As the training load increases, the goal number of repetitions typically decreases. A literature review by Fleck and Kraemer (2003) and Tan (1999) concluded that either 2-5 sets or 3-6 sets caused the greatest strength gains. To maximize power training, exercise volume is reduced through fewer goal repetitions and lighter loads with a recommendation of 3-5 sets of power exercises (Garhammer, 2007; Herrick & Stone, 1996; Kraemer and Koziris, 1992; Stone & O'Bryant, 1987; Stone et al., 1982). Higher training volumes can be used to induce muscular hypertrophy through programs included moderate to high repetitions, 3-6 sets per exercise, and three or more exercises per muscle group (Fleck & Kraemer, 1987; Hedrick, 1995; Herrick & Stone, 1996; Ostrowski et al., 1997; Tesch, 1992). Training programs of 2-3 sets of twelve or more repetitions emphasize muscular endurance (Fleck & Kraemer, 2003; Kraemer & Koziris, 1992; Stone et al., 1982). When applied practically, the use of different protocols can effect the development of skills such as the vertical jump, which is a necessary and vital skill in sports performance (Baker, 1996). Baker (1996) concluded through his studies that various forms of resistance training can act together to improve vertical jumping ability through different physiological mechanisms.

Strength can be defined as the capacity of a muscle to exert maximal force at a certain velocity (Knuttgen and Kraemer, 1987). Power, however, is the mathematical product of force and velocity at any speed. Stone et al. (1998) report that high-power weight training increases the rate of force production, velocity, and power of movement, while traditional heavy-weight training increases maximal strength. The training goals of strength and power overlap in terms of loads and repetitions. Schmidtbleicher (1992) proposes that maximum strength effects power in an ordered manner with diminishing influence as the external load decreases to a point at which force development takes precedence. It was also found that the relationship between maximum strength and power increased as additional resistance was added to a movement (Stone et al., 2003). In a study by Harris et al. (2000), low speed/high force weight training resulted in maximum strength gains and equal or superior gains in power and speed compared to light weights, while high speed/high power training resulted in superior gains in power output. They also suggested that a combination of those two methods may produce superior strength and power performance measures (Harris et al., 2000).

Power training is often employed by athletes because of its similarity to sports-related movements. Maximal power output gains are produced with the lifting of moderate loads at intermediate velocities (Knuttgen & Kraemer, 1987; Newton et al., 1996). For performance enhancement, characteristics such as peak force, rate of force development, and power development must transfer to the skill (Harris et al., 2000). Specificity of movement pattern and the speed of movement are also important for enhancing the transfer of training effect from a training exercise to the actual performance (Harris et al., 2000; Stone et al., 1998; Stone et al., 2000). Peak power output has been shown to occur at 30-40% of peak isometric force and 40-80% of 1-RM (Garhammer, 1993; Harris et al., 2000; Kraemer & Koziris, 1992; Newton et al., 1994; Stone et al., 1998; Stone et al., 2003). Training within this range provides gains in dynamic movements and influences neural and contractile mechanisms (Harris et al., 2000).

Another important training concept associated with resistance training is the idea of periodization. Periodization is used to elicit maximal training adaptations through the deliberate, cyclic manipulation of training variables, such as those previously mentioned (Buford et al., 2007; Plisk & Stone, 2003). It also manages fatigue and prevents stagnation and overtraining (Plisk & Stone, 2003). A periodization model divides a training program into specific time periods including a macrocycle, or the largest division signifying a training year; two or more mesocycles, each lasting weeks to months, within the macrocyle; and two or more microcycles, each lasting several weeks, within each mesocycle (Cargina et al., 1986; Cargina et al., 1987; Fleck & Kraemer, 2004; Fleck & Kraemer, 1988; Stone & O'Bryant, 1987; Stone et al., 1982). The two primary models of periodization found in most literature include a classic, or linear, model and an undulating model (Buford et al., 2007). The classic model was first proposed by Leo Matveyev and later modified by Stone, O'Bryant, and Garhammer to include the four distinct periods of preparatory, first transition, competition, and second transition (Matveyev, 1977; Matveyev, 1972; Stone & O'Bryant, 1987; Stone et al., 1981). In this linear model, exercise intensity and volume are varied across several mesocycles (Buford et al., 2007; Stone & O'Bryant, 1987). Because of naturally existing monthly biocycles, Matveyev (1972) suggests training cycles that last approximately one month in duration with 3-6 subcycles lasting about one week each in order to garner cumulative training effects. The undulating model, proposed by Charles Poliquin, consists of frequent variations in exercise volume and intensity on a daily, weekly, or biweekly basis, in contrast to the linear model's mesocyle-based alterations (Poliquin, 1988). Studies by Baker et al. (1994) and Rhea et al. (2002) found that the undulating model showed greater increases in strength in a 1-RM squat, 1-RM bench press, and vertical jump than the linear model and nonperiodized model. Plisk and Stone (2003) assert that the use of terms like "linear" or "nonlinear" is misleading because periodization, by definition, involves nonlinear variation in training parameters.

Another aspect of resistance training that should be considered is the comparison of single-set versus multiple-set programs. Wolfe et al. (2004) report that multiple set programs show greater gains in strength, power, hypertrophy, athletic performance, and muscular endurance in both trained and untrained individuals than single-set programs. Stone et al. (1998) state that a single set performed to failure does not provide an optimal training stimulus and thus does not increase muscle hypertrophy like a multiple-set program. Training to muscular failure is the inability to complete a muscle action because of temporary fatigue (Stone et al., 1998). Stone et al. (1998) provide the rationale that a single set fatigues motor units and allows additional motor units to be trained for greater gains in hypertrophy and strength, but they also express the practical inefficiency of this method for eliciting those gains. Fleck and Kraemer (1987) suggest that performing one set to failure enables the neuromuscular system to adapt to the strength stimulus so that a multiple-set program then provides a superior stimulus after the initial adaptation. Stone et al. (1998) report that muscle fatigue increases the risk of injury and reduces maximum force, peak rate of force production, power, and speed. Some research suggests that multiple sets of large-muscle mass exercises will produce greater changes in body composition compared to single sets (Kraemer et al., 1995; Marx, 1998). Stone et al. (1998) also report that multiple sets have shown superior strength gains to single sets. It has been concluded that multiple sets, optimally 3-5, produces superior results compared to a single-set program (Stone et al., 1998).

Through the proper manipulation of associated variables, resistance training protocols can be used to elicit superior gains and achieve the specific training goals of an athlete. In addition, resistance training has been shown as an effective mechanism for providing health benefits, improving physiological variables, and increasing athletic performance (Buford et al., 2007; Candow & Burke, 2007; Humburg et al., 2007; Miranda et al., 2007; Stone et al., 2000). The three basic principles of resistance training include overload of a stimulus; variation of intensity, velocity, volume, and exercise selection; and specificity of training for greater transfer (Stone et al., 2000). By utilizing all available information regarding the various aspects of resistance training, programs can be specially developed and personalized to an individual for superior benefits.

Plyometric Training

Plyometric training is a type of training mechanism employed by athletes to improve power through force and velocity production. Plyometric exercise trains muscles to do more work in a shorter amount of time, thereby improving power output and increasing explosiveness (Luebbers et al., 2003). Rimmer and Sleivert (2000) describe plyometrics as a type of training that develops the ability of muscles to produce force at high speeds and thus produce power in dynamic movements. This training method allows athletes to utilize gravity to store potential energy within the elastic structures of muscles and tendons that can be converted to kinetic energy (Chu, 1984). Miller et al. (2006) report that research has shown that plyometrics combined with a periodized strength-training protocol can help improve vertical jump performance, acceleration, leg strength, muscular power, increased joint awareness, and overall proprioception.

Plyometric exercise can also be defined as a quick, powerful movement using a prestretch, or countermovement, that involves the stretch-shortening cycle (SSC) (Wilk et al., 1993). This cycle occurs when the active muscle switches from a rapid eccentric muscle action to a rapid concentric muscle action with a very short amortization phase. The eccentric movement creates a stretch reflex in the muscle that is capable of producing a more forceful concentric muscle action than could be generated from rest because of the conversion of stored elastic potential energy to kinetic energy within the muscle action (Luebbers et al., 2003).

The SSC involves three distinct phases. As previously mentioned, the first phase is the eccentric phase where the muscle is stretched and preloaded which causes stimulation of the muscle spindles and series and parallel elastic components of the muscle (Kutz, 2003; Stemm & Jacobson, 2007). McNeely (2007) states that muscle spindles sense changes in the amount of stretch within a muscle and elicit the stretch reflex to contract the muscle that was stretched. The amortization phase is the time from the end of the eccentric phase to the initiation of the concentric muscle action (Chu, 1984; Kutz, 2003; Stem & Jacobson, 2007). Chu (1984) explains that the shorter the amount of time spent in contact with the landing surface before rebounding, the greater the neuromuscular reaction to the ground contact stimulus. McNeely (2007) writes that if the amortization phase is too long, the stretch reflex, as well as the plyometric effect, will be lost because of a resetting of the muscle length by the spindles. The stored energy may then dissipate as heat (Cavagna, 1977). The third and final phase is the concentric phase. The stored elastic potential energy in the muscles is converted to kinetic energy which leads to an increase in the amount of work done and an increase in potential force, allowing for an explosive-reactive movement (Chu, 1984). The utilization of the mechanical energy being stored as elastic potential energy is the key to increasing force output following a muscle stretch (Blakey & Southard, 1987). Effective utilization of the SSC through plyometrics has the potential to improve performance in power-based events such as vertical jumps and bounds (Rimmer & Sleivert, 2000; Stemm & Jacobson, 2007; Vissing et al., 2008).

In addition to utilizing the SSC, plyometric exercise can be an effective mechanism to improve skill components and evaluate performance variables. Chu (1984) describes elastic strength as those properties of muscle-tendon tissue that allow it to be stretched rapidly and therefore increase internal tension and lead to a rapid forceful shortening of the muscle. It allows quick and repeated rebounding from a surface with maximal height or distance (Chu, 1984). Factors that may affect elastic energy storage and increase the contractile force of muscle include minimized time between muscle stretch and contraction, smaller movement amplitude, and increased muscle stiffness (Blakey & Southard, 1987; Burgess et al., 2007; Cavagna, 1977). A more forceful stretch prior to a vertical jump may occur through a decrease in distance (amplitude) to reduce vertical velocity to zero or through a decrease in time that prevents stored energy from dissipating as heat (Blakey & Southard, 1987). Force developed is the product of tendon stiffness and the length that it is stretched. Therefore, an increase in tendon stiffness improves the rate of force development and causes a more rapid force transmission from muscle to bone (Burgess et al., 2007). Luebbers et al. (2003) point out that true plyometric training requires a rapid prestretch and maximal effort during the concentric phase. They also report that this type of training has been effective at increasing muscle power output and vertical jump performance (Luebbers et al., 2003). Jensen and Ebben (2007) propose that plyometric intensity could be evaluated through variables such as the rate of force development, ground reaction force, and joint reaction force. Recent research conclusions support plyometric training's enhancement of variables including acceleration, power, muscular strength, vertical jump, and speed (Stemm & Jacobson, 2007).

In a study by Vissing et al. (2008), conventional resistance training (CRT) and plyometric training (PT) were used to compare changes in muscle strength, power, and morphology. Fifteen untrained, healthy male participants, divided into CRT and PT groups, performed tests before and after the 12-week study including 1RM incline leg press, 3 RM knee extension, 1 RM knee flexion, countermovement vertical jump (CMJ), ballistic incline leg press, MRI, and muscle biopsy (Vissing et al., 2008). The CRT exercises were performed at a controlled, self-selected pace. The PT program emphasized performing the ground-contact phase as quickly as possible. The results showed that muscle strength increased through CRT, while PT increased maximal CMJ height and power and maximal power in ballistic leg press. Gross muscle size increased with both PT and CRT, but only CRT increased muscle fiber cross sectional area. Gains in maximal muscle strength were similar between the two groups, but muscle power increased almost exclusively with PT (Vissing et al., 2008).

In another plyometric-based study, Gehri et al. (1998) examined the effects of different training techniques on vertical jump performance and energy production. Twenty-eight college students (14 males, 14 females) who were engaged in regular aerobic exercise without any jumping activities were assigned one of three groups: control, countermovement jump (CMJ), or depth jump (DJ). Subjects were tested before and after the 12-week training study by performing 3 maximal vertical jumps under CMJ, DJ, and SJ (squat jump) conditions. They were instructed to flex their knees 30-60° and rebound upward in a maximal vertical jump for both the CMJ and DJ and to execute a maximal vertical jump from 60° of flexion with no prior downward movement for the SJ (Gehri et al., 1998). Training twice per week, the subjects performed 2 sets of 8 repetitions the first two weeks and progressed to 4 sets of 8 repetitions the remaining 10 weeks with 5 seconds between each repetition and 1 minute between each set. The results showed significant improvement in vertical jumping ability in both training groups, but there were no significant differences in jumping height between them. DJ training significantly improved positive energy production in all three conditions and was found to be superior to CMJ training. There were no significant differences in utilization of elastic energy (Gehri et al., 1998).

Through its utilization of stored elastic energy, plyometric training has the potential to increase power through force and velocity production and thus improve athletic performance. The stretch-shortening cycles allows the muscle to move from a rapid eccentric muscle action, through a short amortization phase, to a forceful concentric muscle action (Chu, 1984; Kutz, 2003; Luebbers et al., 2003). Studies have shown the ability of plyometric training to increase vertical jump height, vertical jump power output, anaerobic power, and rate of force development (Burgess et al., 2007; Gehri et al., 1998; Luebbers et al., 2003; Potteiger et al., 1999). It can thus be seen as a beneficial training mechanism with practical applications.

Complex Training

Complex training is an increasingly popular training mechanism in which biomechanically similar high load weight training exercises and plyometric exercises are alternated, set for set, within a single workout session (Docherty et al., 2004; Duthie et al., 2002; Ebben, 2002; Ebben & Watts, 1998; Ebben & Blackard, 1997; Jensen & Ebben, 2003; Jones & Lees, 2003; Mihalik et al., 2008). Two biomechanically similar exercises performed together, such as a set of squats (resistance exercise) followed by a set of squat jumps (plyometric exercise), have been termed a "complex pair" (Docherty et al., 2004; Ebben, 2002; Ebben & Blackard, 1997). Chu (1996) describes complex training as a combination of strength work and speed work designed for an optimal training effect. Masamoto et al. (2003) report that positive effects may occur if high-load strength training exercises are performed prior to plyometric exercises. Ebben and Watts (1998) also account for research that suggests the equal effectiveness, or superiority, of complex training compared to other combination training modalities shown through increased medicine ball throwing power, superior acute jumping performance, and improved vertical jump performance in response to a chronic complex training stimulus.

The purpose of complex training is to improve performance by maximizing power development and output through muscular and neurological adaptations (Adams et al., 1992; Docherty et al., 2004; Ebben, 2002; Ebben & Blackard, 1997; Ebben & Watts, 1998; Lyttle et al., 1996; Mihalik et al., 2008). Mihalik (2008) reports that complex training is believed to be more effective at improving power production than other training program designs because of an enhanced neuromuscular environment. Baker (2003) explains that the enhanced neural activity gained from heavy resistance exercises carries over to subsequent lighter resistance exercises and creates a greater power output than would have occurred without the prior heavy-load set. Adams et al. (1992) states that bridging the gap between strength and speed can optimize power production in athletes. Because it trains both force and velocity components that are necessary for achieving maximum power, complex training may be considered a practical, and possibly optimal, training strategy to produce maximal results in sports performance (Ebben & Blackard, 1997; Ebben & Watts, 1998).

The success of many sports depends on the expression and power production capacity of the body's musculature (Lyttle et al., 1996). Muscle contractions performed with heavy resistances may lead to adaptations in tension-dependent neural mechanisms that inhibit motor neuron excitation in voluntary maximal contractions (Ebben & Watts, 1998; Fleck & Kontor, 1986). Mihalik et al. (2008) concluded that the combination of resistance and plyometric training can maximize power output by increasing muscle fiber hypertrophy and neuromuscular adaptations. Ebben & Watts (1998) point to neuromuscular factors as possibly being the most powerful physiological adaptation mechanisms of complex training. These factors can be seen through the effect of high-load resistance training on subsequent plyometric exercise. It may increase motor neuron excitability and reflex potentiation in addition to forcing greater motor unit recruitment (Ebben & Watts, 1998; Docherty et al., 2004; Jones & Lees, 2003).

Much research has been done in an attempt to explain the rationale behind the physiological adaptations of complex training. The basis of the adaptations caused by complex training, which can be described as alternating stretch-shortening cycle (SSC) tasks with heavy resistance exercises within the same session, is an acute aftereffect phenomenon referred to as postactivation potentiation (PAP) (Hodgson et al., 2005; Robbins, 2005; Sale, 2002). An article by Docherty et al. (2004) reports that PAP is based on the assumption that the explosive capability of muscle is enhanced after it has just been subjected to maximal or near-maximal contractions. It also proposes two theories. One theory that has been proposed to explain PAP is that prestimulation enhances motor neuron pool excitability through greater motor unit (MU) recruitment, better MU synchronization, a decrease in presynaptic inhibition, or greater central input to the motor neuron. A second theory involves the phosphorylation of the myosin light chain (MLC). Muscle stimulation increases sarcoplasmic calcium which activates MLC kinase (MLCK), which in turn makes more ATP available to increase the rate of actin-myosin cross-bridge cycling (Docherty et al., 2004). Similarly, Duthie et al. (2002) report that there is a twitch-tension increase following high-intensity voluntary contractions and that maximal voluntary contractions produce short-term increases in explosive force attributable to neuronal post-tetanic potentiation effects. Moving from the physiological rationale of PAP to its integration into training protocols has been affected by the consideration of factors including magnitude and mode of preload activity, the length of the rest period between preload and outcome measures, and the training status of the participants (Docherty et al., 2004).

In a study from the University of North Carolina, Mihalik et al. (2008) compared short-term complex and compound training programs. They investigated the differences in gains in vertical jump heights and power production and the rate at which those gains occurred between the two programs. Thirty-one college-aged volleyball players (20 women and 11 men) were divided into either a complex or compound training group and trained 2 days per week for 4 weeks. Prior to the study, they participated in practice twice a week and jumping activities for 3 months. The resistance exercises performed included squats, single leg lunges, and deadlifts. The plyometric exercises included depth jumps, split squat jumps, and double leg bounds. The complex group (10 women and 5 men) performed plyometric and resistance exercises on both training days each week, while the compound group (10 women and 6 men) performed resistance exercises on the first training day and plyometric exercises on the second. Mihalik et al. (2008) reported significant improvements in vertical jump height and power output in both training groups during the study, no significant difference in gains between the two programs, and no significant difference in the rate at which gains were achieved within the two groups (Mihalik et al., 2008).

A related study from Oregon State University investigated the effect of a squat program, a plyometric program, and a squat-plyometric program on power production improvement in the hip and thigh during vertical jump measures (Adams et al., 1992). In this study, 48 male subjects, who had a minimum of one year of recreational lifting experience with little or no power training or plyometrics exposure, were divided into four groups—squat, plyometric, squat-plyometric, or control—and trained twice per week for six weeks. The squat training group began with 4 sets of 8 repetitions at 70% of their parallel-squat measured 1RM in the first week and advanced to 2 sets of 2 repetitions at 100% of their 1RM in the sixth week. The plyometric training group performed depth jumps, double-leg hops, and split squats during their sessions for a prescribed number of sets and repetitions with one to two minutes of rest between sets (Adams et al, 1992). The squat-plyometric group performed squats first on the first training day and plyometrics first on the second training day at the same intensity as the other groups but at a reduced work volume. Adams et al. (1992) concluded that a combined squat-plyometric training program increases power production in vertical jump measures significantly more than either the squat or plyometric program alone.

Another study by Fatouros et al. (2000) compared the effects of plyometric training, weight training, and a combined protocol of plyometrics and weights on vertical jump height, mechanical power, flight time, and maximal leg strength. Measurements were taken in 41 untrained male participants before and after 12 weeks of training designed to overload the muscles used in vertical jumping. The men were divided into a plyometric training group, a weight training group, a plyometric plus weight training group, or a control group. The weight training protocol consisted of barbell squats, leg presses, leg curls, and standing calf raises during the first 8 weeks and barbell jump squats, cleans, snatches, and push presses in the last 4 weeks. Front and side lunges, step ups, sitting calf raises, and dead lifts were used during all 12 weeks. The plyometric training protocol consisted of squat jumps, jumps over cones and benches, repeat triple jumps, single- or double-leg hops, alternate leg bounds, depth jumps, and box jumps.

The plyometric intensity began with 80 foot contacts in the first 2 weeks, and for the last 10 weeks, the intensity was 220 foot contacts on the first training day of the week, 150-170 foot contacts on the second, and 120 foot contacts on the last. The combined program included weight training exercises performed 180 minutes after plyometric exercises. Fatouros et al. (2000) concluded that the combined protocol group performed significantly better than the other two training groups in vertical jump height, jumping mechanical power, and flight time. It also had significantly higher improvement in leg strength compared to the plyometric group but not the weight training group.

In a study by Blakey and Southard (1987), a combination of plyometric depth drops and weight training was investigated for its effects on dynamic leg power and strength. This 8-week study enrolled 31 college-age males currently taking beginner-level university weight training classes three days a week where they attempted 3 sets of 8 repetitions of upper body exercises and leg presses. Depth jump training was performed prior to resistance training on the first and third training day (Blakey & Southard, 1987). They were divided into three groups according to depth jump heights of 1.1 m, 0.4 m, and no height. Both resistance and depth jump training intensity increased throughout the study. Blakey and Southard (1987) concluded that an 8-week combined program of resistance and plyometric exercise will increase leg strength and power.

Related research from Southern Cross University in Australia compared the effectiveness of two training protocols on enhancing dynamic performance measures (Lyttle et al., 1996). Thirty-three male participants, who had played various regional sports but had not performed resistance training, were randomly assigned to either a maximal power training program, a combined weight and plyometric program, or a nontraining control group. Participants underwent performance testing before and after the 8-week training program that included sprints, a seated shot put throw, a seated medicine ball throw, 1 RM bench press and squat, vertical jumps, explosive push-ups, and a 6-sec cycling test. The two training groups trained twice a week with sets and repetitions equated for both groups (Lyttle et al., 1996). The power training group performed weighted squat jumps and bench-press throws. The combined training group performed squats and bench presses along with rebound depth jumps and drop medicine ball throws. Lyttle et al. (1996) found that in all performance measures, both training groups showed significantly greater improvement over the control group with no significant difference between the two training groups.

Through its growth as a popular training mechanism, complex training has been compared in research and experimental studies to other protocols and has been found to have implications on multiple variables of athletic performance. In complex training, plyometric and resistance exercises that are biomechanically similar are alternately performed set for set within the same workout session (Docherty et al., 2004; Duthie et al., 2002; Ebben, 2002; Ebben and Watts, 1998; Ebben & Blackard, 1997; Jensen & Ebben, 2003; Jones & Lees, 2003; Mihalik et al., 2008). Complex training has been shown to be a beneficial training mechanism for variables such as vertical jump height, strength, power production, and other performance variables (Adams et al., 1992; Blakey & Southard, 1987; Fatouros et al., 2000; Jones & Lees, 2003; Lyttle et al., 1996; Mihalik et al., 2008). However, there are research studies in which improvements were seen but were not always significant (Duthie et al., 2002; Jones & Lees, 2003; Lyttle et al., 1996; Mihalik et al., 2008). Even if a result is not considered significant in clinical terms, it can still indicate performance improvement in a practical setting and show the beneficial impact that this mechanism of training can have on athletes.

Chapter III

Methods

In this section, the methods used to perform this research study will be given through a description of the participants involved and their respective roles in the study, the instrumentation used, the general procedures used, and the statistical analysis of the study. The main purpose of this study was to compare the effectiveness of a complex training protocol to a resistance-only training protocol and a plyometric-only training protocol. A group of college-aged, recreationally trained male participants completed a 9-week training period. Within this time frame, there was one week of pre-testing and procedure familiarization (W1) and two additional weeks of testing during the study that included mid-testing (W5) and post-testing (W9).

The participants were randomly assigned to one of the three following training groups: resistance-only training group (RT), plyometric-only training group (PT), and a complex training group (CT). Because the CT protocol was a combination of both the RT and PT protocols, comparisons could be made against each of the individual training modes. Therefore, there was no control group used in this study.

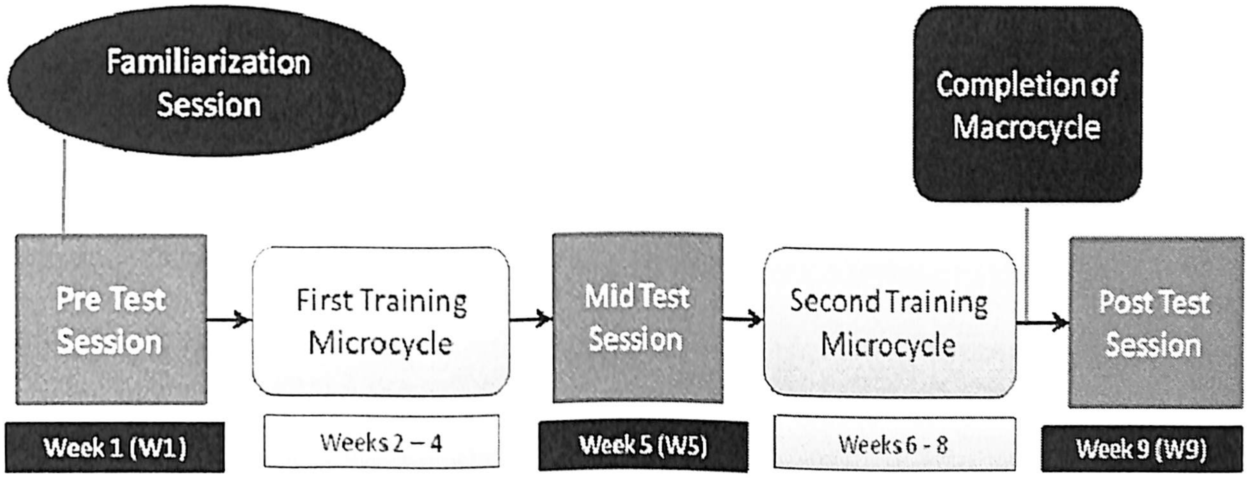

Figure 1. Training Timeline

Training Timeline Across the 9-Week Study Duration of Testing and Training

Participants

The participants recruited for this study were college-aged males ranging in age from 18 to 30 years. All participants were recreationally trained with a resistance training background of at least six months in length. Ebben and Watts (1998) deem functional strength a prerequisite to plyometrics and suggest that an athlete use weight training to prepare for a plyometric program in order to prevent injury, build a strength base, and prepare the body for high-impact forces. Therefore, any individuals classified as sedentary prior to the study were not included. In addition, participants presenting with a history of either cardiac or respiratory disease or with the occurrence of a traumatic event or surgery to the lower extremities within the past two years were excluded from the study.

Based on a comprehensive review of the literature, it was estimated the training protocol would elicit a large effect size (0.50). Coupled with a power $(1 - \beta) = 0.80$ and an alpha (α) level = 0.05, it was determined that 30 participants, allowing for 10 participants in each group, are needed to detect a 1.5 standard deviation (Hinkle, Wiersma, & Jurs, 2003). Therefore, the goal of this study was to include 39 participants, allowing for 13 participants in each training group. An intention to treat analysis was also used to adjust for any extensive dropout from the study and still keep the same power. This number of participants was also used in similar research. Adams et al. (1992), Mihalik et al. (2008), and Blakey and Southard (1987) used 48 participants in 4 groups, 31 participants in 2 groups, and 31 volunteers assigned into 3 groups, respectively.

This study was approved by the University of Mississippi Institutional Review Board (IRB), and all participants included in the study gave informed consent to participate prior to the beginning of the study.

Instrumentation

Instrumentation used for this study included various resistance training equipment, testing devices, and participation forms. To obtain the body weight of the participants, an SECA digital scale (Lafayette Instrument Co., Lafayette, Indiana) was used.

Various weight-training and plyometric equipment was used for the resistance training protocols in the study. A Jones Machine (The Jones Max Rack 3D, Body Craft, Sunbury, Ohio) was used for the back squat and straight leg calf raise (Calf Raise, Power Systems, Knoxville, Tennessee) exercises to allow for proper technique and to reduce any learning effects of the exercises. The Romanian Deadlift was performed with a 20-kg Power Lifting bar (Power Systems, Power Systems, Knoxville, Tennessee) that utilized additional plate-loading to increase the resistance. Hampton weighted plates (Venture, California) were used to increase the resistance for exercises performed on both the Jones

Machine and with the free-weight bar. Assorted plyometric exercises used in the training protocol were performed on plyometric boxes (Power Systems, Knoxville, Tennessee) of the following heights: 15.24 cm (6 in), 30.48 cm (12 in), and 45.72 cm (18 in). In addition, some exercises employed the use of 15.24 cm (6 in) and 30.48 cm (12 in) hurdles (Gorilla Speed Hurdles, Ann Arbor, Michigan). For the warm-up protocol, a Monark 828 E Pendulum Ergometer (Monark Sports & Medical, Varberg, Sweden) was used. All vertical jump testing measures in the procedure were performed on an AMTI (Advanced Mechanical Technology, Inc. – Watertown, MA) OR6-7.

Participation forms were incorporated into the procedural aspect of the study to ensure both consent and readiness prior to beginning. Included in these forms were the following: a health, fitness, and demographic questionnaire; a health and lifestyle questionnaire; and an exercise questionnaire to gauge participants' ability to perform required testing and training activities for the duration of the study. A University of Mississippi-approved consent form was given to all participants that contained all information regarding their rights and responsibilities during the study and all possible outcomes of the study in reference to their participation. All forms used were approved by the University of Mississippi Institutional Review Board (IRB).

Grouping

The participants were randomly assigned to one of the three following training groups: resistance-only training group (RT), plyometric-only training group (PT), and a complex training group (CT).

Testing

Participants were asked to engage in no strenuous aerobic or anaerobic activity for 24 hours prior to the pre-training session in order to prevent residual fatigue from any physical activity that could affect the outcome of testing measurements. Participants were also asked not to consume any caffeine for 4 hours prior to the pre-training session (Lamont, 2006). Because caffeine acts as a stimulant to the central nervous system, a heightened state of excitation in the body could negatively affect the results of this study by providing an alternative method of cause for the results obtained.

The test measures performed included the following: 1 repetition maximum (1RM) assessment of the back squat exercise, Romanian Deadlift (RDL), and the standing calf raise (SCR). The 1RM and SCR were performed in the Jones Machine, and all three were recorded in kilograms. National Strength and Conditioning Association (NSCA) guidelines were followed as the protocol for the lifts (Baechle & Earle, 2000). Participants were allowed to attempt a 1RM at a particular weight two times. If unable to lift the weight, the participant was allowed to attempt a lighter weight or to use the previous weight lifted as their 1RM. The 1RM measures were not always measured exactly as 1RM scores because multiple-RM measures were allowed if the weight values were too heavy to be safely attempted. The multiple RM values were then used in the following prediction equation from Brzycki (1993):

$$Predicted\ 1\ RM = \frac{Weight\ Lifted}{1.0278 - .0278X}$$

Weight Lifted = total weight lifted for the multiple repetition maximum

1.0278 = scaling coefficient

.0278 = scaling coefficient of the number of repetitions performed

X = number of repetitions performed

All of these tests were repeated during the mid-testing (W5) and post-testing (W9) sessions. In addition to these tests, vertical jump testing measures were performed during the pre-testing, mid-testing, and post-testing sessions. Each participant performed three countermovement vertical jump trials on the force plate. The average peak ground reaction force from the three trials during each testing session was calculated and recorded.

Training

The three training groups participated in six weeks of a specified training protocol and three non-training weeks in which pre-testing (W1), mid-testing (W5), and post-testing occurred (W9). The total timeframe for the study was nine weeks. The training protocol consisted of two 3-week microcycles that combined to form one 6-week macrocyle. The pre-testing session was held the week prior to the start of training (W1). The mid-testing session was held after third week of training (W5). The post-training session was held after the sixth and final week of training (W9).

Ebben and Blackard (1997) report the importance of a recovery period when performing a complex training protocol in order to reduce fatigue and allow consistent focus on work performance. The participants followed a protocol requiring two days of training in the lab per week for all six weeks of the study. Ebben and Blackard (1997) recommend at least 48 hours of recovery between sessions. Therefore, participants in all three training groups had rest periods of at least two days between subsequent sessions in order to normalize timing between the groups. Rest intervals between sets within a single complex training session are also important because of the timeframe needed to replenish anaerobic energy stores (Ebben and Blackard, 1997). Because of the recommended rest period of 2 to 5 minutes between sets in complex training, the CT, RT, and PT groups were allowed 3 minutes of recovery between sets in order to normalize recovery across the groups (Ebben and Blackard, 1997). Ebben and Blackard (1997) also suggest minimal rest of up to 30 seconds between exercises within a complex pair. However, some research suggests a rest period 3 to 4 minutes in length between exercises in a complex pair in order to allow for partial recovery but still utilize increased stimulation in the muscles introduced by heavy-load resistance training (Comyns et al., 2006; Ebben, 2002). Therefore, the rest period between complex pair exercises for the CT group was 30 seconds during the first microcycle (W2-W4) and 180 seconds during the second microcycle (W6-W8). Also, participants in the RT and PT groups were allowed 4 minutes of recovery between different exercises, while the CT group rested 4 minutes between different complex pairs.

Table 1. Timing for Training Protocols

Timing for All Training Protocols Between Sessions, Exercises, Sets, Repetitions, and Complex Pairs (where applicable)

Timing For Training Protocols					
	Timing Between:				
Training Protocol	**Sessions**	**Exercises**	**Sets**	**Repetitions**	**Complex Pair**
RT	≥ 48 hours	4 minutes	3 minutes	N/A	N/A
PT	≥ 48 hours	4 minutes	3 minutes	N/A	N/A
CT	≥ 48 hours	4 minutes	3 minutes	N/A	up to 30 seconds or 3 minutes

The twice-per-week, six-week training period was chosen based on research from Adams et al. (1992). They suggest that four to six weeks of power training provides optimal stress without excessive fatigue on the central nervous system (Adams et al., 1992). It has been reported that the neuromuscular adaptations that contribute to explosive power may occur within the first two to four weeks of a power cycle (Adams et al., 1992). Also, power athletes generally follow a standard format of performing squats and plyometrics twice a week to allow for adequate recovery (Adams et al., 1992). One week of testing was held after the completion of each microcycle. Following research by Buford et al. (2007), this allowed for a reevaluation of the 1RM prior to the second microcycle in order to optimize the opportunity for improvements in performance measures.

In the initial improvement in untrained individuals after short-term training can generally be attributed to neural adaptations. However, in this study, a combination of six-weeks of training and recreationally-trained participants of at least six months was used. With previously trained participants, the study aims to bypass the contribution of neural gains to the explanation of the data. Also, the length of the study provides that the participants are able to overcome any short-term hormonal adaptations that may contribute to physiological changes other than those being sought specifically by the training protocols.

A specific warm-up protocol utilizing a Monark Ergometer was followed by all the participants in each of the three training groups prior to each testing and training session. They pedaled at 50-60 revolutions per minute with .5 kilopound of resistance for 5 minutes. After this warm-up, members of the RT and PT groups also performed six repetitions of a back squat with resistances of both their body weight and 50% 1RM.

The training protocols for the CT, RT, and PT training groups were not equal in volume and intensity. However, the protocols for both RT and PT were equated as much as possible with regards to volume and intensity. Because the CT protocol is a combination of the RT protocol and the PT protocol, it is greater in total volume than either RT or PT individually. The total volume of a protocol is determined by multiplying the load, number of sets, and number of repetitions (load x sets x repetitions). This combination of protocols can be seen in research by Fatouros et al. (2000).

Training volume fluctuated between the two training days during each week. The purpose of this fluctuation can be attributed to overloading and the idea of mixed methods training. By having one "light" day and one "heavy" day each week, the protocol can effectively bring about physiological stress to the participants' bodies. Altering the load between days causes a progressive overload that requires the body to adapt quickly. In addition, the load fluctuation also allows for the training of different goals during the same time period. Power training includes both a force, or strength, component and a time component. Lifting heavier loads on the first training days emphasizes the strength component, while the lighter-load second training day allows for a greater lifting velocity and emphasizes the rate at which that force is produced. Therefore, both power and strength can be targeted during the same week.

The RT group performed the following exercises: Jones Machine back squat, RDL, and SCR. The participants in both the CT and RT groups performed these exercises over the course of both microcycles, which lasted six weeks. Following a linear progression periodization model, there was a steady increase in percentage of the participants' one repetition maximum score (Buford et al., 2007; Stone et al., 1981). The prescribed loads and repetitions lifted per set fluctuated between both training days each week. As stated previously, there was a 3-minute rest period between sets and a 4-minute rest period between exercises. The participants were instructed to move each load with maximum movement intent.

Table 2. Resistance Training Protocol

Resistance Training Protocol for Both Training Days over Both Microcycles

Resistance Training Protocol					
		Training Day 1		Training Day 2	
		% 1RM	Repetitions	% 1RM	Repetitions
Week 1	Pre-Test				
Week 2	1	75%	3 x 6	60%	3 x 6
Week 3	2	80%	3 x 5	65%	3 x 5
Week 4	3	82%	3 x 5	67%	3 x 5
Week 5	Post-Test				
Week 6	1	85%	3 x 4	55%	3 x 4
Week 7	2	88%	3 x 3	50%	3 x 3 *
Week 8	3	90%	3 x 3	45%	3 x 3 *
Week 9	Post-Test				

*Speed squats

The PT group performed the following exercises: lateral jumps (LJ), depth jumps (DJ), and box jumps (BXJ). Lateral jumps help develop the ability to move and change direction laterally (Chu, 1984). To perform the LJ, or lateral double leg hops, the participant hopped laterally over a distance of 35 cm while attempting to minimize ground contact time. The DJ utilize gravity and body weight to exert force against the ground and develop elastic strength (Chu, 1984). Based on work by Chu (1984), the DJ began as a double leg stance on a 30.48 cm box. With one foot leading, participants stepped off the box and landed with both feet making ground contact simultaneously.

With an "active-reactive" movement, the participants immediately explode off the ground and jump as high as possible vertically (Chu, 1984). Repetitions were performed in 5-second intervals from foot contact upon landing. Participants performed the BXJ by standing on both legs atop a box 30.48 cm in height, dropping off the back of the box, rebounding as quickly as possible off both legs, returning to the top of the box, and repeating the jump. Ground contact time was minimized.

The previous exercises mentioned were performed during the first microcycle of training. During the second microcycle, the participants progressed to more advanced exercises in order to provide opportunity for maximal improvements in testing measures. The LJ progressed to lateral jumps spanning 35 cm in distance with a 30.48 cm barrier (LJB). The performance of the exercise remained unchanged with the exception of adding a barrier to be cleared. The DJ box height increased to 45.72 cm. The BXJ advanced to a single leg jump exercise with an increased box height of 15.24 cm.

As previously stated, there was a 3-minute rest period between sets and a 4-minute rest period between exercises. Participants were instructed to move with maximum movement intent. Similar to a study by Fatouros et al. (2000), training volume fluctuated between the two training days each week. The rest period length and volume fluctuations served to aid in recovery both during and between training sessions.

Table 3. Plyometric Training Protocol

Plyometric Training Protocol for Both Training Days over Both Microcycles

Plyometric Training Protocol			
		Training Day 1	Training Day 2
		Repetitions	Repetitions
Week 1	Pre-Test		
Week 2	1	3 x 7	3 x 6
Week 3	2	3 x 6	3 x 5
Week 4	3	3 x 5	3 x 4
Week 5	Post-Test		
Week 6	1	3 x 5	3 x 4
Week 7	2	3 x 4	3 x 3
Week 8	3	3 x 3	3 x 3
Week 9	Post-Test		

The CT group performed a protocol that combined exercises from both the RT and the PT protocols in specific time intervals. The following complex pairs were performed as a set: the back squat and LJ, the RDL and DJ, and the SCR and BXJ. These exercises were paired based on their biomechanical similarities. As stated previously, the total volume performed by the CT group was not equated to the volume performed by either the RT group or the PT group.

Table 4. Complex Training Protocol

Complex Training Protocol for Both Training Days over Both Microcycles

Complex Training Protocol								
		Training Day 1			Training Day 2			
		Resistance Exercises		Plyo Exercises	Resistance Exercises		Plyo Exercises
		% 1RM	Repetitions	Repetitions	% 1RM	Repetitions	Repetitions
Week 1	Pre-Test						
Week 2	1	75%	3 x 6	3 x 7	60%	3 x 6	3 x 6
Week 3	2	80%	3 x 5	3 x 6	65%	3 x 5	3 x 5
Week 4	3	82%	3 x 5	3 x 5	67%	3 x 5	3 x 4
Week 5	Post-Test						
Week 6	1	85%	3 x 4	3 x 5	55%	3 x 4	3 x 4
Week 7	2	88%	3 x 3	3 x 4	50%	3 x 3*	3 x 3
Week 8	3	90%	3 x 3	3 x 3	45%	3 x 3*	3 x 3
Week 9	Post-Test						

*Speed Squats

As in the previous two groups, participants in the CT group had a 3-minute rest period between sets with a 4-minute rest period between sets, or complex pairs. The participants were instructed to perform movements with maximum intent during resistance exercises and to minimize ground contact time during plyometric exercises. The numbers of repetitions and sets used in the CT protocol was based on research by Fatouros et al. (2000).

After both microcycles of training were completed (W2-W4, W6-W8), all participants performed a post-training session (W9). The participants had also performed a mid-testing session between microcycles (W5). These testing sessions allowed for the analysis of the training effects on each participant after the first microcycle, the second microcycle, and the entire six-week microcycle. The measures taken were the 1RM in the back squat, RDL, SCR, and body weight. Also, participants performed vertical jumps on the force plate to obtain ground reaction forces. As in the pre-testing session, participants were instructed to engage in no strenuous aerobic or anaerobic activity within twenty-four hours of the post-testing session. They were also asked to consume no caffeine within four hours of testing (Lamont, 2006).

Analysis

A 3 (Group – Resistance, Plyometric, Complex) x 3 (Time Point – Pre, Mid, Post) ANCOVA with body weight as the covariate was run to assess main effect for group effect. Group by time-point interactions were assessed utilizing a follow up Bonferroni correction for multiple comparisons. A Bonferroni Post Hoc Test was utilized to highlight the nature of any within and between group differences. A comparison-wise error rate (α) of 0.05 was set a priori. All analyses were run with SPSS 16.0.

Chapter IV

Results

The purpose of this study was to compare the effects of resistance training, plyometric training, and complex training on vertical ground reaction forces in vertical jump measures in college-aged males during the course of a six-week study. Results for this study will include the following: participant characteristics, general descriptive statistics, and group comparison statistics. All data is expressed as mean group values $\pm$ standard deviation (SD).

Participant Characteristics

Thirty-nine (39) participants met all initial qualifications for the study. Thus, thirteen (13) participants were placed in each of the following groups: resistance training (RT), plyometric training (PT), and complex training (CT). Prior to beginning the study, all participants completed and signed the following forms: an IRB-approved informed consent, health, fitness, and demographic questionnaire; a health and lifestyle questionnaire; and a pre-participation exercise readiness questionnaire. Based on information provided on the forms, participants that met the criteria of the study began the testing protocol. Nine (9) subjects dropped out of the study for personal reasons. Therefore thirty (30) participants completed the nine-week study consisting of testing and training protocols. There were eleven (11) participants in the RT group, nine (9) participants in the PT group, and ten (10) participants in the CT group.

General Descriptive Statistics

The mean value of peak vertical ground reaction forces (vGRF) was calculated from the three vertical jump trials performed by each participant during each testing session. These scores were then used to calculate the mean value of peak vGRF for each group (RT, PT, and CT) during the pre-testing session, mid-testing session, and post-testing session and are illustrated in Table 5.

Table 5. Group Descriptive Statistics

Mean Peak vGRF Values of Each Training Group for Each Testing Session

Vertical Ground Reaction Forces (N)				
Group	**N**	**Pre-testing**	**Mid-testing**	**Post-testing**
RT	11	2003.95 ± 414.18	2057.49 ± 404.36	2083.80 ± 393.67
PT	9	2111.26 ± 371.66	2188.75 ± 326.75	2186.88 ± 346.96
CT	10	2274.97 ± 406.70	2351.66 ± 382.21	2375.44 ± 318.57

Group Comparison Statistics

A 3 (Group – Resistance, Plyometric, Complex) x 3 (Time Point – Pre, Mid, Post) ANCOVA with body weight as the covariate revealed a significant group difference ($p = 0.047$). A follow-up Bonferroni Post Hoc Test revealed no group*time interaction, but a trend towards an applied effect appeared between complex training and resistance training ($p = 0.069$).

Chapter V

Discussion

As stated previously, the purpose of this six-week study was to compare the effects of traditional resistance training and plyometrics training to complex training on vertical ground reaction forces in vertical jumping in recreationally-trained college-aged males.

In the analysis of the present study, the results revealed a significant group difference. Measurements obtained during post-testing were found to be significantly greater than those obtained in pre-testing in all three groups. However, when body weight was taken into account in the data analysis, there were no significant differences found between the groups. Even though there were no statistical or applied differences seen between complex and plyometric training or between plyometric and resistance training, an applied trend was found between complex training and resistance training. This trend indicates that complex training was more effective than resistance training in improving vGRF in the vertical jump in the participants of the present study. Mean differences among groups are presented in Table 5.

Support for the superiority of complex training over resistance training can be found across multiple studies in recent literature. Fatouros et al. (2000) reports that while plyometric, resistance, and combination training methods have been shown to improve vertical jump performance, the combination training protocol elicited significantly greater performance than either single protocol (Fatouros et al., 2000). While it was not a true "complex" protocol, the methods of combination training can still be seen as comparable.

The combination protocol included exercises from both individual protocols with resistance exercises occurring three hours after plyometrics (Fatouros et al., 2000). In that study, plyometric training led to a slightly greater improvement, though statistically insignificant, in jump performance than resistance training. Therefore, dynamic power-based exercises, which have a plyometric-like velocity factor, may be added to a resistance protocol to improve vertical jumps (Fatouros et al., 2000). The combination training reduced the amortization phase because of a better utilization of stored elastic energy (Fatouros et al., 2000). Plyometrics were incorporated into both the combination protocol (Fatouros et al., 2000) and complex protocol from the present study, whereas the heavy-load resistance protocols did not contain any stretch-shortening cycle, or plyometric, movements.

While jump performance is often measured in terms of jump height, the present study focused on the evaluation of vertical ground reaction forces (vGRF) which correlates with jump height through the net impulse of the vertical jump. A study by Jones and Lees (2003) found a trend, though not significant, for peak GRF to increase in CMJ following heavy-resistance exercise and thus concluded there was no disadvantage in performancing complex protocols.

The present study only involved six weeks of training, but Fatouros et al. (2000) suggest a 12-week training period is adequate for improving vertical jump performance. With a longer training period in the present study, more significant differences may have been seen within and between the different training protocols. Mihalik et al. (2008) found improvements in vertical jump performance after a 3-week period of complex and compound training, yet they considered those gains neural in nature and suggest future studies span a longer period of time. Buford et al. (2007) suggest nine weeks as an appropriate length of time to elicit strength gains through heavy resistance training only. There are multiple research studies that support the use of complex or compound training programs from six weeks up to 16 weeks to elicit improvements in vertical jump performance (Clutch et al., 1983; Ford et al., 1983; Harris et al., 2000; Lyttle et al., 1996; Polhemus et al., 1980; Santos & Janeira, 2008; Verkhoshansky & Tatyan, 1973).

More evidence for the superiority of complex training can be found in an 8-week study by Lyttle et al. (1996) that led to the conclusion that combined training protocols lead to superior performances in stretch-shortening cycle movements because the dynamic nature of plyometric movements may enhance the ability to perform SSC actions. Through the examination of different protocols, Baker (1996) concluded that combined methods of strength training offer the best stimulus by training contractile and neural/elastic components. Adams et al. (1992) also found that a 6-week combined squat and plyometric program significantly increased vertical jump ability more than either single protocol alone. They suggest that resistance training increases strength in jumping muscles while plyometrics develop explosiveness, allowing for optimal power production and the ability to jump higher (Adams et al., 1992). Duthie et al. (2002) designed a study to compare contrast and complex methods of training. The contrast protocol was comparable to the present study's complex protocol with heavy and light exercises alternated set for set, while in the complex protocol, all sets of resistance exercises were followed by all sets of lighter exercises (Duthie et al., 2002). They found a trend, though not statistically significant, for the contrast training method to elicit superior effects in jump height, peak power output, and maximal force achieved in a jump squat (Duthie et al., 2002).

The main difference between the complex and resistance protocols within the present study was the lack of plyometric movements within the resistance training protocol. The plyometric effect occurs when stored potential energy is converted to kinetic energy and leads to explosive-reactive movements. This lack of plyometric activity within the resistance protocol may have led to a deficiency in training specificity with regard to the vertical jump. There was no applied effect found between complex training and plyometric-only training in the present study; this can probably be contributed to the similarity of SSC movements and training specificity within each protocol.

The basis of complex training is often contributed to neuromuscular adaptations and postactivation potentiation (PAP), which allows the performance of additional work at high intensities (Docherty et al., 2004; Ebben & Watts, 1998; Hanson et al., 2007). In the present study, resistance intensities in the complex protocol were not consistently held at 80% of 1RM or higher, which Hanson et al. (2007) recommends as the optimal level to achieve PAP and offer benefit to subsequent high-velocity movements. Similar to Fatouros et al. (2000), Hanson et al. (2007) also suggests the addition of jump squats to stimulate greater PAP by increasing power and impulse. This would add a plyometric effect to resistance training, similar to what occurs in complex training, and allow for greater jump performance. A 9-week study by Harris et al. (2000) compared a high-force protocol (80-85% 1RM), a high-power protocol (30% peak isometric force), and a combination training protocol. Only the high power and combined protocols improved significantly in the vertical jump (Harris et al., 2000). Though the design of the study was different from the present study, it provides that a light-load protocol and a combined light and heavy-load protocol increases vertical jumps more than heavy-load resistance training alone.

Another topic that has been addressed in several studies and may have affected this study includes rest intervals and recovery periods. In the present study, the following protocol was followed: 30-second intracomplex rest interval (W2-W4), 180-second intracomplex rest interval (W6-W8), 3 minutes between sets, and 4 minutes between different complex pairs. Hanson et al. (2007) suggests a recovery period of 3-5 minutes or longer after heavy-load exercises. Longer rest periods for loads of 60% 1RM or less may result in dissipation of PAP before subsequent exercise performance (Hanson et al., 2007). In a study by Comyns et al. (2006), a reduction in GRF was seen with a 30-second intracomplex rest interval. Intracomplex rest intervals of up to 4 minutes were shown to be optimal in several studies (Ebben, 2002; Evans et al., 2000; Jensen and Ebben, 2003; Radcliffe and Radcliffe, 1996; Young et al., 1999). Therefore, extending the rest intervals from 30 seconds (W2-W4) and 180 seconds (W6-W8) as seen in the present study may prove to be beneficial as well. Comyns et al. (2006) and Duthie et al. (2002) both suggest the importance of individualizing time periods in complex training because high interindividual differences can exist. For optimal effectiveness, Güllich and Schmidtbleicher (1996) express the necessity of determining the most advantageous interval for each individual.

Hypothesis Results

H_{A1}: There will be an increase in vertical ground reaction forces in vertical jumps as a result of resistance training, plyometric training, or complex training.

Result: Based on the results of this study, the alternative hypothesis is accepted and the null hypothesis is rejected. The results showed a significant group difference in vGRF after training (p=0.047). The data showed a significant improvement in post-testing measures compared to pre-testing measures.

H_{A2}: There will be a greater increase in vertical ground reaction forces in vertical jumps as a result of complex training compared to either resistance training or plyometric training.

Result: Based on the results of this study, the data could not fail to reject this hypothesis. Therefore, this alternative hypothesis is rejected. The results showed no significant group*time interaction. However, the data did reveal an applied trend that complex training was more effective than resistance training in increasing vGRF in vertical jumps.

Conclusion

Although there was no significant difference in increase in vertical ground reaction forces in the vertical jump between training protocols, there was an overall significant improvement as a result of training. The results do suggest the effectiveness of complex training versus resistance-only or plyometric-only training in improving vertical jump performance. The applied trend found in the data suggests a possible superiority of complex training. Through adjustments to the training protocol or other aspects of the study, more significant results may be revealed. Because of this trend, complex training can be seen as a practical training modality worthy of incorporation into athletic strength and conditioning programs. Complex training offers more variety than either single-method protocol because of its multiple exercise inclusions. This may provide an improved training stimulus and allow for more efficient use of time within training sessions. In addition to strength and conditioning programs for athletes, complex training may also be beneficial for practical use in recreational settings.

Future Research Considerations

Because of the discrepancy in literature regarding complex training, more research may be necessary to determine the precise workload including numbers of sets and repetitions and intensity to be used within a complex training protocol to elicit optimal improvement. Adjustments to the recovery periods used within the present study may also lead to changes in the results because of the optimization of PAP and reduction of fatigue. Another modification to the present study for future consideration is the extension of the overall training period from 6 weeks to an 8-12 week study in order to possibly elicit more significant improvements and results in regard to testing measures. Because this group allowed each protocol group to serve as its own control, a true control group could also be added to future studies.

Another consideration may be the addition of upper-body heavy-load resistance, light-load resistance (in place of plyometrics), and complex training protocols to the present study to compare results between the upper-body and lower-body. The training level of subjects is a point of interest in most complex training literature. Because this study utilized recreationally trained college-aged males, it could be reproduced to compare the three training protocols (resistance, plyometric, and complex) in highly trained athletes or in gender-based studies with women as the subjects. Also more care could be taken in future studies to control possible confounding variables during the course of the study such as dietary intake or physical activity performed in addition to the training sessions. Controlling or assessing these variables could provide more insight into the data revealed in the study.

References

Adams, K., O'Shea, J., P., O'Shea, K., L., & Climstein, M. (1992). The Effects of Six Weeks of Squat, Plyometric and Squat-Plyometric Training on Power Production. *Journal of Applied Sport Science Research, 6*(1), 36-41.

Baechle, T. R., & Earle, R. W. (2000). *Essentials of Strength Training and Conditioning.* Champaign, IL: Human Kinetics.

Baker, D., Wilson, G., & Carlyon, R. (1994). Generality versus specificity: A comparison of dynamic and isometric measures of strength and speed-strength. *European Journal of Applied Physiology, 68,* 350-355.

Baker, D. (1996). Improving Vertical Jump Performance Through General, Special, and Specific Strength Training: A Brief Review. *Journal of Strength and Conditioning Research, 10*(2), 131-136.

Baker, D. (2003). Acute Effect of Alternating Heavy and Light Resistances on Power Output During Upper-Body Complex Power Training. *Journal of Strength and Conditioning Research, 17*(3), 493-497.

Ball, J. R., Rich, G. Q., & Wallis, E. L. (1963). Effects of Isometric Training on Vertical Jumping. *Research Quarterly for Exercise and Sport, 35*, 231-235.

Blakey, J. B., & Southard, D. (1987). The Combined Effects of Weight Training and Plyometrics on Dynamic Leg Strength and Leg Power. *Journal of Applied Sport Science Research, 1*(1), 14-16.

Brzycki, M. (1993). Strength Testing: Predicting a One-Rep Max from Reps-to-Fatigue. *Journal of Health, Physical Education, Recreation, and Dance, 64*, 88-90.

Buford, T. W., Rossi, S. J., Smith, D. B., & Warren, A. J. (2007). A Comparison of Periodization Models During Nine Weeks With Equated Volume and Intensity for Strength. *Journal of Strength and Conditioning Research, 21*(4), 1245-1250.

Burgess, K. E., Connick, M. J., Graham-Smith, P., & Pearson, S. J. (2007). Plyometric vs. Isometric Training Influences on Tendon Properties and Muscle Output. *Journal of Strength and Conditioning Research, 21*(3), 986-989.

Candow, D. G., & Burke, D. (2007). Effect of Short-Term Equal Volume Resistance Training with Different Workout Frequency on Muscle Mass and Strength in Untrained Men and Women. *Journal of Strength and Conditioning Research, 21*(1), 204-207.

Cavagna, G. A. (1977). Storage and Utilization of Elastic Energy in Skeletal Muscle *Exercise and Sport Science Reviews, 5*, 80-129.

Chargina, A., Stone, M., Peidmonte, J., O'Bryant, H., Kraemer, W. J., Gambetta, V., Newton, H., Palmeri, G., & Pfoff, D. (1986). Periodization Roundtable. *NSCA Performance Training Journal, 8*(5), 12-23.

Chargina, A., Stone, M., Peidmonte, J., O'Bryant, H., Kraemer, W. J., Gambetta, V., Newton, H., Palmeri, G., & Pfoff, D. (1987). Periodization Roundtable. *NSCA Performance Training Journal, 8*(6), 17-25.

Chargina, A., Stone, M., Peidmonte, J., O'Bryant, H., Kraemer, W. J., Gambetta, V., Newton, H., Palmeri, G., & Pfoff, D. (1987). Periodization Roundtable. *NSCA J, 9*(1), 16-27.

Chu, D. A. (1984). Plyometric Exercise. *NSCA Journal, 5*(6), 56-63.

Chu, D. A. (1996). *Explosive Power and Strength: Complex Training for Maximal Results*. Champaign, IL: Human Kinetics.

Clutch, D., Wilton, M., McGown, C., and Bryce, G.R. (1983). The Effect of Depth Jumps and Weight Training on Leg Strength and Vertical Jump. *Resistance Quarterly for Exercise and Sport, 7*(4), 11-12.

Comyns, T. M., Harrison, A. J., Hennessy, L. K., & Jensen, R. L. (2006). The Optimal Complex Training Rest Interval for Athletes from Anaerobic Sports. *Journal of Strength and Conditioning Research, 20*(3), 471-476.

Cormie, P., McBride, J. M., & McCaulley, G. O. (2009). Power-Time, Force-Time, and Velocity-Time Curve Analysis of the Countermovement Jump: Impact of Training. *Journal of Strength and Conditioning Research, 23*(1), 177-186.

Docherty, D., Robbins, D., & Hodgson, M. (2004). Complex training Revisited: A Review of its Current Status as a Viable Training Approach. *Strength and Conditioning Journal, 26*(6), 52-57.

Duthie, G. M., Young, W. B., & Aitken, D. A. (2002). The Acute Effects of Heavy Loads on Jump Squat Performance: An Evaluation of the Complex and Contrast Methods of Power Development. *Journal of Strength and Conditioning Research, 16*(4), 530-538.

Ebben, W. P. (2002). Complex Training: A Brief Review. *Journal of Sports Science and Medicine, 1*, 42-46.

Ebben, W. P., & Blackard, D. O. (1997). Complex training with combined explosive weight training and plyometric exercises. *Olympic Coach, 7*, 11-12.

Ebben, W. P., & Watts, P. B. (1998). A Review of Combined Weight Training and Plyometric Training Modes: Complex Training. *Strength and Conditioning, 20,* 18-27.

Evans, A. K., Hodgkins, T. D., Durham, M. P., Berning, J. M., & Adams, K. J. (2000). The Acute Effects of a 5RM Bench Press on Power Output [Abstract]. *Medicine & Science in Sports & Exercise, 32,* S311.

Fatouros, I. G., Jamurtas, A. Z., Leontsini, D., Taxildaris, K., Aggelousis, N., Kostopoulos, N., et al. (2000). Evaluation of Plyometric Exercise Training, Weight Training, and Their Combination on Vertical Jumping Performance and Leg Strength. *Journal of Strength and Conditioning Research, 14*(4), 470-476.

Fleck, S., & Kontor, K. (1986). Complex Training. *NSCA Journal, 8*(5), 66-68.

Fleck, S. J., & Kraemer, W. J. (1987). *Designing Resistance Training Programs.* Champaign, IL: Human Kinetics.

Fleck, S. J. & Kraemer, W. J. (2003). *Designing Resistance Training Programs,* 3rd ed. Champaign, IL: Human Kinetics.

Fleck, S. J., & Kraemer, W. J. (2004). *Designing Resistance Training Programs,* 3rd ed. Champaign, IL: Human Kinetics.

Fleck, S. J., & Kraemer, W. J. (1988). Resistance Training: Exercise Prescription. *The Physician and Sportsmedicine, (16),* 69-81.

Ford, H.T., Puckett, J.R., Drummond, J.P., Sawyer, K., Gantt, K., and Fussell, C. (1983). Effects of Three Combinations of Plyometric and Weight Training Programs on Selected Physical Fitness Test Items. *Perceptual and Motor Skills, 56,* 919-922.

Garhammer, J. (1993). A Review of Power Output Studies of Olympic and Powerlifting: Methodology, Performance Prediction, and Evaluation Tests. *Journal of Strength and Conditioning Research, 7*(2), 76-89.

Garhammer, J. (2007) Personal communication. In: *Essentials of Strength Training and Conditioning,* 3rd ed. Baechle & Earle, eds. Champaign, IL: Human Kinetics.

Gehri, D. J., Ricard, M. D., Kleiner, D. M., & Kirkendall, D. T. (1998). A Comparison of Plyometric Training Techniques for Improving Vertical Jump Ability and Energy Production. *Journal of Strength and Conditioning Research, 12*(2), 85-89.

González-Badillo, J. J., Gorostiaga, E.M., Arellano, R., & Izquierdo, M. (2005). Moderate Resistance Training Volume Produces More Favorable Strength Gains Than High or Low Volumes During a Short-Term Training Cycle. *Journal of Strength and Conditioning Research, 19*(3), 689-697.

Gullich, A., and Schmidtbleicher, D. (1996). MVC-induced Short-term Potentiation of Explosive Force. *New Studies in Athletics, 11,* 67-81.

Hanson, E. D., Leigh, S., & Mynark, R. G. (2007). Acute Effects of Heavy- and Light-Load Squat Exercise on the Kinetic Measures of Vertical Jumping. *Journal of Strength and Conditioning Research, 21*(4), 1012-1017.

Harris, G. R., Stone, M. H., O'Bryant, H., Proulx, C. M., & Johnson, R. (2000). Short term performance effects of high speed, high force and combined weight training. *Journal of Strength and Conditioning Research, 14*, 14-20.

Hedrick, A. (1995). Training for Hypertrophy. *Strength and Conditioning Journal, 17*(3), 22-29.

Herrick, A. R., & Stone, M. H. (1996). The Effects of Periodization versus Progressive REsistance Exercise on Upper and Lower Body Strength in Women. *Journal of Strength and Conditioning Research, 10*(2), 72-76.

Hinkle, D. E., Wiersma, W., & Jurs, S. G. (2003). *Applied Statistics for the Behavioral Sciences.* Boston, MA: Houghton Mifflin Company.

Hodgson, M., Docherty, D., & Robbins, D. (2005). Post-activiation Potentiation: Underlying Physiology and Implications for Motor Performance. *Sports Medicine, 35*(7), 585-595.

Humberg, H., Baars, H., Schröder, J., Reer, R., & Braumann, K. (2007). 1-Set vs. 3-Set Resistance Training: A Crossover Study. *Journal of Strength and Conditioning Research 21*(2), 578-582.

Jackson, N. P., Hickey, M. S., & Reiser, R. F., II. (2007). High Resistance/Low Repetition vs. Low Resistance/High Repetition Training: Effects on Performance of Trained Cyclists. *Journal of Strength and Conditioning Research, 21*(1), 289-295.

Jensen, R. L., & Ebben, W. P. (2003). Kinetic Analysis of Complex Training Rest Interval Effect on Vertical jump Performance. *Journal of Strength and Conditioning Research, 17*(2), 345-349.

Jensen, R. L., & Ebben, W. P. (2007). Quantifying Plyometric Intensity via Rate of Force Development, Knee Joint, and Ground Reaction Forces. *Journal of Strength and Conditioning Research, 21*(3), 763-767.

Jones, P., & Lees, A. (2003). A Biomechanical Analysis of the Acute Effects of Complex Training Using Lower Limb Exercises. *Journal of Strength and Conditioning Research, 17*(4), 694-700.

Kelly, S. B., Brown, L. E., Coburn, J. W., Zinder, S. M., Gardner, L. M., & Nguyen, D. (2007). The Effect of Single Versus Multiple Sets on Strength. *Journal of Strength and Conditioning Research, 21*(4), 1003-1006.

Knuttgen, H., & Kraemer, W. J. (1987). Terminology and measurement in exercise performance. *Journal of Applied Sport Science Research, 1*(1), 1-10.

Kraemer, W. J., & Koziris, L. P. (1992). Muscle Strength Training: Techniques and Considerations. *Physical Therapy Practice, 2,* 54-68.

Kraemer, W. J., Newton, R. U., Bush, J., Volek, J., Triplett, N. T., & Koziris, L. P. (1995). Varied multiple set resistance training program produces greater gain than single set program. *Medicine and Science in Sports and Exercise, 27,* S195.

Kutz, M. R. (2003). Theoretical and Practical Issues for Plyometric Training. *NSCA Performance Training Journal, 2*(2), 10-12.

Lamont, H. S. (2006). *The Effect of Whole Body Vibration Induced Post Activation Potentiation Upon Indices of Isometric and Dynamic Force/Power Production During, and Following a Six Week Periodized Smith Machine Back Squat Protocol* Unpublished Dissertation, University of Oklahoma, Norman, Oklahoma.

Linthorne, N. P. (2001). Analysis of Standing Vertical Jumps Using a Force Platform. *American Journal of Physiology, 69*(11), 1198-1204.

Luebbers, P. E., Potteiger, J. A., Hulver, M. W., Thyfault, J. P., Carper, M. J., & Lockwood, R. H. (2003). Effects of Plyometric Training and Recovery on

Vertical Jump Performance and Anaerobic Power. *Journal of Strength and Conditioning Research, 17*(4), 704-709.

Lyttle, A. D., Wilson, G. J., & Ostrowski, K. J. (1996). Enhancing Performance: Maximal Power Versus Combined Weights and Plyometrics Training. *Journal of Strength and Conditioning Research, 10*(3), 173-179.

Marx, J. O. (1998). The Effect of Periodization and Volume and Resistance Training in Women [Abstract]. *Medicine & Science in Sports & Exercise, 30*(5), S194.

Masamoto, N., Larson, R., Gates, T., & Faigenbaum, A. (2003). Acute Effects of Plyometric Exercise on Maximum Squat Performance in Male Athletes. *Journal of Strength and Conditioning Research, 17*(1), 68-71.

Matveyev, L. (1972). *Periodisierung Des Sportlichen Trainings.* Moscow: Fizkultura i Sport.

Matveyev, L. (1977). *Fundamentals of Sports Training.* Moscow: Fitzkultura i Sport.

McNeely, E. (2007). Introduction to Plyometrics: Converting Strength to Power. *NSCA's Performance Training Journal, 6*(5), 19-22.

Mihalik, J. P., Libby, J. J., Battaglini, C. L., & McMurray, R. G. (2008). Comparing Short-Term Complex and Compound training Programs on Vertical Jump Height and Power Output. *Journal of Strength and Conditioning Research, 22*(1), 47-53.

Miller, M. G., Herniman, J. J., Ricard, M. D., Cheatham, C. C., and Michael, T. J. (2006). The Effects of a 6-Week Plyometric Training Program on Agility. *Journal of Sports Science and Medicine, 5,* 459-465.

Miranda, H., Fleck, S. J., Simão, R., Barreto, A. C., Dantas, E., & Novaes, J. (2007). Effect of Two Different Rest Period Lengths on the Number of Repetitions

Performed During Resistance Training. *Journal of Strength and Conditioning Research, 21*(4), 1032-1036.

Morrissey, M. C., Harman, E. A., & Johnson, M. J. (1995). Resistance training modes: specificity and effectiveness. *Medicine and Science in Sports and Exercise,* 648-658.

Newton, R. U., & Kraemer, W. J. (1994). Developing Explosive Muscular Power: Implications for a Mixed Methods Training Strategy. *Strength and Conditioning Journal, 16*(5), 20-31.

Newton, R. U., Kraemer, W. J., Hakkinen, K., Humphries, B. J., & Murphy, A. J. (1996). Kinematics, Kinetics, and Muscle Activation During Explosive Upper Body Movements. *Journal of Applied Biomechanics, 12*, 31-43.

Ostrowski, K. J., Wilson, R., Weatherby, P. W., Murphy, P. W., & Lyttle, P. D. (1997). The Effect of Weight Training Volume on Hormonal Output and Muscular Size and Function. *Journal of Strength and Conditioning Research, 11*(3), 148-154.

Perrine, J. J., & Edgerton, V. R. (1978). *Medicine & Science in Sports & Exercise, 10*(3), 159-166.

Plisk, S. S. & Stone, M. H. (2003). Periodization Strategies. *NSCA's Strength and Conditioning Journal, 25*(6), 19-37.

Polhemus, R., Burkherdt, E., Osina, M., and Patterson, M. (1980). The Effect of Plyometric Training with Ankle and Vest Weights on Conventional Weight Training Programs for Men. *Track and Field Quarterly Review, 80*(4), 59-61.

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

Potteiger, J. A., Lockwood, R. H., Haub, M. D., Dolezal, B. A., Almuzaini, K. S., Schroeder, J. M., & Zebas, C. J. (1999). Muscle Power and Fiber Characteristics Following 8 Weeks of Plyometric Training. *Journal of Strength and Conditioning Research, 13*(3), 275-279.

Radcliffe, J. C., & Radcliffe, J. L. (1996). Effects of Different Warm-up Protocols on Peak Power Output During a Single Response Jump Task [Abstract]. *Medicine & Science in Sports & Exercise, 28,* S189.

Rhea, M. R., Ball, S. D., Phillips, W. T., & Burkett, L. N. (2002). A Comparison of LInear and Daily Undulating Periodized Programs with Equated Volume and Intensity for Strength. *Journal of Strength and Conditioning Research, 16,* 250-255.

Rimmer, E., & Sleivert, G. (2000). Effects of a Plyometrics Intervention Program on Sprint Performance. *Journal of Strength and Conditioning Research, 14*(3), 295-301.

Robbins, D. (2005). Postactivation Potentiation and its PRactical Applicability: A Brief Review. *Journal of Strength and Conditioning Research, 19*(2), 453-458.

Rønnestad, B. R., Egeland, W., Kvamme, N. H., Refsnes, P. E., Kadi, F., & Raastad, T. (2007). Dissimilar Effects of One- and Three-Set Strength Training on Strength and Muscle Mass Gains in Upper and Lower Body in Untrained Subjects. *Journal of Strength and Conditioning Research, 21*(1), 157-163.

Sale, D. G. (2002). Postactivation Potentiation: Role in Human Performance. *Exercise and Sports Sciences Reviews, 30*(3), 138-143.

Santos, E. & Janeira, M. (2008). Effects of Complex Training on Explosive Strength in Adolescent Male Basketball Players. *Journal of Strength and Conditioning Research, 22*(3), 903-909.

Schilling, B. K., Falvo, M.J., and Chiu, L. (2008). Force-velocity, impulse-momentum relationships: Implications for efficacy of purposefully slow resistance training. *Journal of Sports Science and Medicine, 7,* 299-304.

Schmidtbleicher, D. (1992). Training for Power Events. *Strength and Power in Sport.* P. V. Komi, ed. London: Blackwell Scientific Publications, 381-395.

Spennewyn, K. C. (2008). Strength Outcomes in Fixed Versus Free-Form Resistance Equipment. *Journal of Strength and Conditioning Research, 22*(1), 75-81.

Spreuwenberg, L., Kraemer, W. J., Spiering, B. A., Voler, J. S. Hatfield, D. L., Silvestre, R., Vingren, J. L., Fragala, M. S., Hakkinen, K., Newton, R. U., Maresh, C. M., & Fleck, S. J. (2006). Influence of Exercise Order in a Resistance-Training Exercise Session. *Journal of Strength and Conditioning Research, 20*(1), 141-144.

Stemm, J. D., & Jacobson, B. H. (2007). Comparison of Land- and Aquatic-Based Plyometric Training on Vertical Jump Performance. *Journal of Strength and Conditioning Research, 21*(2), 568-571.

Stone, M. H., Collins, D., Plisk, S. S., Haff, G., & Stone, M. E. (2000). Training Principles: Evaluation of Modes and Methods of Resistance Training. *Strength and Conditioning Journal, 22*(3), 65-76.

Stone, M. H. & O'Bryant, H. (1987). *Weight Training: A Scientific Approach.* Minneapolis: Burgess.

Stone, M. H., O'Bryant, H., & Garhammer, J. (1981). A Hypothetical Model for Strength Training. *Journal of Sports Medicine and Physical Fitness, 21*, 342-351.

Stone, M. H., O'Bryant, H., Garhammer, J., McMillan, J., and Rozenek, R. (1982). A Theoretical Model of Strength Training. *NSCA J 4*(4), 36-40.

Stone, M. H., O'Bryant, H. S., McCoy, L., Coglianese, R., Lehmkuhl, M., & Schilling, B. (2003). Power and Maximum Strength Relationships During Performance of Dynamic and Static Weighted Jumps. *Journal of Strength and Conditioning Research, 17*(1), 140-147.

Stone, M. H., Plisk, S. S., Stone, M. E., Schilling, B. K., O'Bryant, H. S., & Pierce, K. C. (1998). Athletic Performance Development: Volume Load - 1 Set vs. Multiple Sets, Training Velocity and Training Variation. *NSCA's Strength and Conditioning Journal 20*(6), 22-31.

Tan, B. (1999). Manipulating Resistance Training Program Variables to Optimize Maximum Strength in Men. *Journal of Strength and Conditioning Research, 13*(3), 289-304.

Tesh, P. A. (1992). Training for Bodybuilding. *The Encyclopedia of Sports Medicine: Strength and Power in Sport,* 1st ed., P. V. Komi, ed. Malden, MA: Blackwell Scientific, 370-380.

Verkhoshansky, Y. & Tatyan, V. (1973). Speed-strength Preparation of Future Champions. *Legkaya Atletika, 2*, 12-13.

Vissing, K., Brink, M., Lonbro, S., Sorensen, H., Overgaard, K., Danborg, K., et al. (2008). Muscle Adaptations to Plyometric vs. Resistance Training in Untrained Young Men. *Journal of Strength and Conditioning Research, 22*(6), 1799-1810.

Wilk, K. E., Voight, M. L., Keirns, M. A., Gambetta, V., Andrews, J. R., & Dillman, C. J. (1993). Stretch-Shortening Drills for the Upper Extremities: Theory and Clinical Application *Journal of Orthopedic Sport Physical Therapy, 17*, 225-239.

Wolfe, B. L., LeMura, L. M., Cole, P. J. (2004). Quantitative Analysis of Single- vs. Multiple-set Programs in Resistance Training. *Journal of Strength and Conditioning Research, 18*(1), 35-47.

Young, W. B., Jenner, A., & Griffiths, K. (1999). Acute Enhancement of Power Performance from Heavy Load Squats. *Journal of Strength and Conditioning Research, 12*, 82-84.