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Effects of Unilateral Versus Bilateral Squat and Plyometric Training Upon Athletic Performance Outcomes

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EFFECTS OF UNILATERAL VERSUS BILATERAL SQUAT AND PLYOMETRIC TRAINING UPON ATHLETIC PERFORMANCE OUTCOMES

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The purpose of this study was to compare two lower body, unilateral and bilateral, training styles on the development of athletic performance variables. Twenty-one division two collegiate swimmers (age 20.38 ± S.D.1.3), who were split into two groups, completed the training program. An eight week training program that utilized a modified single leg squat (MSLS) and unilateral plyometrics (n=11) or a bilateral back squat (BBS) and bilateral plyometrics (n=10) was used to train the athletes. The volume of training was equal across groups. Pre-post test assessments included a 5RM squat test, bilateral and unilateral jump height, a T-test, and goniometry, as differences were assessed. Significance was found after comparing the 5RM squat posttest (p=.043) and hip extension as measured by goniometry (p=.036) with the BBS group performing better when evaluated relative to the MSLS group. No significant differences were found in any of the other variables.

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CHAPTER ONE

INTRODUCTION

Resistance training is a method used by many athletes to increase force production and power in their clients (Zink, 2006). Strategies to increase muscular strength, power, agility, and flexibility, along with the ability to assess those measures have been topics of great interest for sport coaches and researchers (Zink, 2006). Many important adaptations occur in the nervous, muscular, connective tissue, endocrine, and cardiovascular systems through resistance training that can aid in athletic improvement (Baechle & Earle, 2008). Additionally, the gains in strength, power, agility, and flexibility have resulted from mechanical, neuromotor, metabolic, and endocrine activities produced through resistance training (Ahtianen, 2005).

Strength and conditioning professionals are faced with many decisions when implementing a periodized resistance-training program. These decisions have an impact on the planning and implementation of the training cycles within a season to enhance the performance of their athletes. The specific adaptations from the training are related to the variables of training volume, movement velocity, intensity, and specificity of the exercise. A major decision related to specificity of exercise selection is to determine an exercise that will either provide a base for future training or to determine an exercise that will translate to a sport specific skill.

To best achieve desired adaptations, athletes must perform training at a load and velocity that best corresponds to competitive movement (Rahmani, 2001). In addition, the exercises should be biomechanically relevant to competition and help guide the athlete to apply force in a way that can be directly translated into sport performance (McCurdy, 2005). Most athletic skills are completed through a unilateral, single-leg, movement or with the athlete's center of mass moved predominantly through the force applied by a single leg while in a two-leg stance

(McCurdy, 2005). Therefore, it is important to evaluate the usefulness of single-leg training on performance outcomes compared to two-leg (bilateral) training.

The squat is an exercise that requires the exerciser to activate muscles that are instrumental to sport activities (Morrissey, 1998). The bilateral back squat (BBS) is a movement that is performed with the use of both legs and loaded with a barbell placed on the upper back. It is commonly utilized to develop general strength and also provides a broad biomechanical base for future lower body exercises. Bilateral exercises have been thoroughly researched to determine outcomes related to strength and power development (McCurdy, 2005). Consistent use of the BBS has elicited improvement in lower-body strength as well as power in male and female collegiate athletes (Jones, 2012).

A bilateral back squat can conceal some bilateral deficit, which is when an individual exerts less force per limb during a two leg exercise than they would using only a single leg. This bilateral deficit is present in most individuals (Bobbert, 2006), and potentially hinders training adaptations as well as athletic performance. In addition, this exercise can obscure strength differences between limbs, allowing an individual to overcompensate by using the dominant leg to override deficiencies in the weaker leg. When taking sport specificity into account, this exercise may be lacking in terms of translating resistance training into a specific sport skill because many sport movements rely upon performance based primarily off of one leg’s output.

The modified single leg squat (MSLS), which is performed in a split squat position with the rear leg elevated on a surface behind the individual, is another lower body exercise that is utilized in strength and conditioning programs. As evidenced by electromyography (EMG), the MSLS actively engages the hamstring as well as the gluteus medius more than the BBS due to producing force differently through their bases of support (McCurdy, 2010). The selection of the

MSLS may enhance performance in athletic testing due to an increase in the activation of stabilization musculature and proprioceptive control over that of the BBS. Additionally, the MSLS has been shown to improve unilateral jump height and force production when compared to the bilateral back squat in untrained individuals (McCurdy, 2005). Also, the MSLS may increase flexibility due to the greater range of motion that is inherent to the exercise and the additional range of motion that occurs in the rear leg, which may occur to a lesser extent in the barbell back squat. A potential drawback of the MSLS is the added amount of training time that it takes to perform the exercise on both sides of the body. Despite the lack of specificity that the bilateral back squat provides, it has been proven that there is a significant elevation in muscle activation for this squat in the quadriceps when compared through EMG with the MSLS (McCurdy, 2010). A comparison of the bilateral back squat and the modified single leg squat has been conducted on an untrained population through an eight week training period (McCurdy, 2005) and the two squat types have been compared through EMG to detect muscle activation in an untrained population (McCurdy, 2010). It was found that when trained with the MSLS versus the BBS, the athletes significantly improved upon unilateral performance outcomes, while performing similarly on the bilateral performance outcomes. The MSLS is a more specific exercise and is able to improve upon performance outcomes that are applicable to many sport skills.

In addition to resistance training, most strength and conditioning programs utilize plyometric exercise in their programming. Plyometrics are rapid, power movements in which the exerciser is attempting to exert the highest muscular force in the shortest amount of time (Baechle & Earle, 2008). The effects of plyometric training on vertical jump height can be displayed after four weeks of implementing the program (Baechle & Earle, 2008). As with other types of exercise, plyometrics should be utilized on a progressive basis, in which the exerciser uses simple movements early in training and progresses towards more complex movements. Athletes of intermediate plyometric experience are advised not to experience more than 100 to 120 foot contacts per session as they begin a plyometric program (Baechle & Earle, 2008). Recommendations suggest that 48 to 72 hours of rest are needed between sessions to allow proper muscular recovery. In accordance with resistance training, a wealth of research exists concerning the use of plyometrics in general but does not have extensive data regarding unilateral versus bilateral plyometrics.

Statement of the Problem

There is a lack of research comparing the effects unilateral versus bilateral lower body resistance and plyometric training upon athletic performance outcomes. A comparison between unilateral and bilateral lower body training on a previously resistance trained collegiate athletic population, could yield information that could assist with program design. It could also aid in the selection of exercises that are most specific and useful for translation into applicable sport skills. The purposes of this study were to determine if there were differences in strength, power, agility, and flexibility outcomes for individuals who trained bilaterally (using the bilateral back squat and bilateral plyometrics) versus those who trained unilaterally (using the modified single leg squat and unilateral plyometrics).

Research Question

1. Does unilateral (single leg) training result in greater improvement of athletic performance outcomes when compared to bilateral (two leg) training over 8 weeks in a group of trained collegiate swimmers?

Hypotheses

1. Relative change in muscular strength, assessed by a bilateral 5RM, will not be significantly different between unilaterally trained versus bilaterally trained athletes.
2. When testing muscular power, athletes who trained unilaterally would show a significantly greater relative increase in their bilateral and unilateral countermovement jump height when compared to bilaterally trained individuals.
3. When testing agility, athletes who trained unilaterally would show a significantly greater relative decrease in T-test time when compared to bilaterally trained individuals. This test assessed agility.
4. When testing flexibility, athletes who trained unilaterally would show a significantly greater relative increase in joint range of motion as assessed with goniometry when compared to bilaterally trained individuals.

Limitations

1. Having a sample size of potentially fewer than 30 participants may result in low statistical power.
2. Most strength and conditioning programs use a combination of unilateral and bilateral training. The success of the unilateral group in the current study would only suggest an increase in the incorporation of unilateral exercises into programs.
3. Eight weeks is the minimum amount of time for a resistance-training program to produce visible training adaptations. A relatively short training period of eight weeks may not show the full extent of training outcomes that are possible through a change in training protocol.

4. To determine maximum power output for the participants the principal investigator assessed the countermovement jump. Although this is not the gold standard for assessing power output, it is a reliable and valid measure.

Definition of Terms

1. Agility- the skills and abilities needed to explosively change movement velocities or modes (Baechle & Earle, 2008).
2. Bilateral deficit- the force produced when both limbs are contracting together is less than the sum of the forces they produce when contracting unilaterally (Baechle & Earle, 2008).
3. Electromyography (EMG) – a common research tool used to examine the magnitude of neural activation following training (Baechle & Earle, 2008).
4. Flexibility- a measure of range of motion, the degree of movement that occurs at a joint, and has static and dynamic components (Baechle & Earle, 2008).
5. Macrocycle- a specified time period in periodization that typically constitutes an entire training year but may also be a period of many months up to four years (for Olympic athletes). This is generally the longest period in a periodization model (Baechle & Earle, 2008).
6. Mesocycle- a portion of periodization that is several weeks to several months long, that is used to more specifically address training needs than the macrocycle and takes into account, training competitions within the time frame (Baechle & Earle, 2008).

7. Microcycle- a time period in periodization that lasts typically one to four weeks and focuses on daily and weekly training variations. Multiple microcycles make up each mesocycle (Baechle & Earle, 2008).
8. Modified Single Leg Squat (MSLS)- a squat performed by supporting the toes of the rear foot on a stable structure placed behind the body. (McCurdy, 2010)
9. Muscle activation- when a motor unit fires an impulse or action potential, all of the muscle fibers that it serves are simultaneously activated and develop force (Baechle & Earle, 2008)
10. Muscle hypertrophy- muscular enlargement resulting from training, primarily owing to an increase in the cross-sectional area (CSA) of the existing fibers (Baechle & Earle, 2008).
11. Periodization- the planned distribution or variation in training means and methods on a periodic or cyclic basis (Baechle & Earle, 2008).
12. Power- the time and rate of doing work, which is the product of the force exerted on an object and the distance the object moves in the direction in which the force is exerted (Baechle & Earle, 2008).
13. Proprioception- an afferent response to stimulation of sensory receptors in skin, muscles, tendons, ligaments, and the joint capsule, that contributes to the conscious and unconscious control of posture, balance, stability and sense of position (Baechle & Earle, 2008).
14. Resistance Training- a grand umbrella term referring to any consistent method or form of exercise requiring one to exert force against a resistance. Characterized by training with

free weights and machines, implements, medicine balls, bands/tubing, manual resistance, water, or any object that provides resistance to movement (Ratamess, 2012).

15. Specificity- the method whereby an athlete is trained in a specific manner to produce a specific adaptation or training outcome (Baechle & Earle, 2008).
16. Strength- the maximal force that a muscle or muscle group can generate at a specified velocity (Baechle & Earle, 2008).

CHAPTER TWO

REVIEW OF LITERATURE

This chapter includes a review of literature addressing the following topics a) adaptations associated with resistance training; b) variable manipulation in resistance training; c) previous research regarding unilateral and bilateral training; and d) athletic performance testing and its validity/reliability.

Adaptations to Strength Training

There is a multitude of research available concerning acute as well as chronic resistance training and the adaptations that each entails. Research by Izquierdo (2006), found that strength gains occurring acutely in the first few weeks of initiating a new resistance training program are largely due to associated neural factors. As training continues, there is a progressively higher contribution from hypertrophy of muscle fibers (Izquierdo, 2006). Some of these early phase neural adaptations include an increase in the number of motor units that can be recruited, an increase in motor unit synchronization, and a lower threshold for type II motor units to be activated (Lamont, 2008). In turn, the neural changes increase the amount of muscle recruitment, the speed at which a muscle is able to fire and the pattern of muscular contraction at higher intensities (Baechle & Earle, 2008). It is important to realize that most resistance training programs will elicit these early phase strength gains due to neural adaptation. However, this is only as long as an appropriate stress is placed upon the musculature to be affected through training.

Additionally, acute resistance training has been shown to increase anabolic hormone levels in the blood for young men immediately after a resistance training session (Ahtiainen, 2003). It has been hypothesized by Ahtiainen (2003) that increases in anabolic hormone levels may increase the total number of hormone receptors, which may facilitate changes in neuromuscular function as well as an increase in muscular size. Furthermore, a study completed by Jones et. al (2012) found that testosterone responses were similar between a single bout of unilateral and bilateral squat exercises despite a lesser amount of absolute work that was performed in the unilateral squat. When considering the similar testosterone responses between the two types of exercise, this information lends itself to the incorporation of unilateral training into resistance training programs.

Muscle hypertrophy, or the enlargement of muscle fiber, occurs through resistance training on a more chronic basis (McCall, 1996). Hypertrophy is also believed to be a byproduct of heightened hormonal levels from resistance training sessions over time (Ahtiainen, 2003). Ultimately, an increase in muscle size, due mainly to a larger cross sectional area, has a linear relationship with muscular strength (Baechle & Earle, 2008). Interestingly, despite the correlation between muscle hypertrophy and muscle strength, the repetition ranges for each outcome are different. For hypertrophy, it is recommended to use multiple sets with a fairly high number of repetitions along with short rest periods, whereas for strength development it is most practical to train at higher loads with longer rest periods (Ahtiainen, 2005). As noted in Sooneste (2013), it takes at least six weeks for muscular hypertrophy to become noticeable.

When resistance training with concurrent endurance training, the muscular adaptations of each may be antagonistic to one another depending on the frequency of either type of training (Gergley, 2009). For the best chance at developing muscular strength and size, it is advised that the athlete avoid endurance training with the targeted muscle group (Gergley, 2009). Since swimming is an endurance activity, the contribution of the concurrent training on resistance training outcomes should be considered, whether that contribution positively or negatively affects resistance training goals.

To ensure that the desired adaptations are achieved through the resistance-training program, it is important that the program is periodized specifically to the desired adaptation. The exercises selected must be biomechanically similar to the sport skill and must be loaded appropriately so that competitive movement can be enhanced. Factors that are necessary for proper periodization are discussed in the following section.

Variable Manipulation in Resistance Training

Overview of Variables and Periodization

When designing a program, the strength and conditioning professional must assess a number of training variables including sets, repetitions, rest periods, and exercise intensity (Campos, 2002) to find the appropriate combination to elicit the desired training outcomes for the athletes. The combination of variables is selected after assessing the athlete's needs, the sport specific movements, and the experience of the athlete (Baechle & Earle, 2008). Using this assessment strategy is very important to ensure that athletes gain the most from their program and are able to do so safely.

Periodization refers to the manipulation and sequencing of training variables over a predetermined time period (Herodek, 2012). In periodization, the athlete will become acclimated to the training through the general adaptation syndrome (GAS). The GAS process is composed of an alarm phase, during which the athlete experiences a new stress on the body, a resistance phase, in which the athlete's body adapts as a result of the new stressor and an exhaustion phase which can occur if the stressor persists over an extended time frame (Baechle & Earle, 2008). If a program is designed properly to an individual or group of individuals, the specific performance outcomes will be achieved without the exhaustion phase being reached. All variables must be accounted for to ensure that specificity in training is achieved.

As referenced in (Herrick, 2008), a study by Fleck and Kraemer showed that prevention against overtraining can best be established through a periodized program. Also, when compared with other types of training, the variation in workload, intensity and sets yielded significantly better training outcomes when compared with other strength programs (Herrick, 2008). Effects of periodized training are usually evident after an entire season, or macrocycle, whereas a program of eight weeks in length may just begin show a smaller magnitude of changes. Studies by (Herrick, 2008; Moraes, 2013) did not detect differences of training outcomes in periodized programs versus nonperiodized programs but these results were attenuated to their short time frame of fifteen and twelve weeks respectively.

Training Volume's Effect on Performance Outcomes

Overall, training volume is made up of the repetitions, sets, and training load used throughout a particular training session. Also, the volume of a training session is referenced as the amount of work performed. According to the repetition maximum continuum (Baechle & Earle, 2008) and as is referenced in Campos (1998) through a study by Anderson and Kearney (1982), high resistance and low repetition training, specifically less than six repetitions will result in greater strength gains. It has been evidenced that training with a high intensity of approximately 80-100 percent of a one repetition maximum with a substantial total volume, is most effective in increasing maximal strength (Izquierdo, 2006). There is an inverse relationship between the weight of a load and the number of repetitions that can be completed with that load (Baechle & Earle, 2008).

Research has shown that gains in muscular strength can be established through a single set of eight to twelve repetitions but that further gains are attributed to additional sets (Baechle & Earle, 2008). A study by Marshall (2011) in which the squat exercise was compared through 1,4, and 8 sets, showed that there was a change in all groups after a ten week training period. However, the group that performed eight sets improved 12.3% more than did the one set group ($p<0.05$) (Marshall, 2011). The eight set group also improved more than did the four set group. Depending on the type of exercise or the sport specific metabolic demands, the number of sets can be manipulated to fit each athlete.

Rest Periods

Since strength and power related gains are both linked to a high intensity of exercise, it is easy to fathom that the rest periods to help elicit these gains are longer than endurance or hypertrophy training. Rest periods of two to five minutes are commonly used for strength and power exercises (Baechle & Earle, 2008). These longer time periods allow for increased recovery and the ability to maintain the high intensity of training throughout multiple sets (Rahimi, 2005). Physiologically, longer rest periods are useful to establish normal blood flow, to help remove built up lactic acid, to replace energy stores, and to regain the ability to produce maximal force (Larson Jr., 1997). A common rest ratio during resistance training is 1:3, work to rest (Larson Jr., 1997). The amount of rest planned is related to training goal, the training status of the athlete and the amount of weight being lifted (Rahimi, 2005).

Training Age

One of the major concerns for participants, in terms of training age, is the ability to complete the exercises prescribed with sound technique and a low risk for injury. For the squat exercise it is important that the participant can complete the movement with a flat-to-arched back, without unnecessary trunk lean and a back that is not rounded (Morrissey, 1998). A lack of resistance training experience with a certain exercise can be counterbalanced through "familiarization sessions" (Lamont, 2008) to instruct the participants on sound technique before initiation of a training program.

Specificity

One common theme throughout successful resistance-training programs is the development of a plan that is specific to the athlete's needs. As was mentioned in terms of periodization, a needs analysis, which takes into account both the sport requirements as well as the athlete's attributes (Baechle & Earle, 2008), is very important to include before developing a program. In order to achieve a higher level of performance, athletes should train exercises that are biomechanically relevant to the sport skill (McCurdy, 2005). Additionally, the exercises performed should be specifically loaded to be performed at a velocity that relates well to the muscular requirements of competition (Rahmani, 2001).

A major task for strength and conditioning professionals is to advocate for the selection of a particular exercise over another exercise. Whether the suggested exercise is more specific, biomechanically and metabolically, or allows for a higher enhancement in sport performance, the professional is responsible for utilizing it in their programs. Due to the demands of many sport activities requiring the production of lower body force off a single leg, the MSLS training relates directly to the Specific Adaptation to Imposed Demands (SAID) principle. The SAID principle states that the type of demand placed on the body directs the type of training adaptations that will occur (Baechle & Earle, 2008). Unilateral exercises tend to be underutilized in most training programs (McCurdy, 2005) although they are more directly applicable to sport skills. A study by Jones (2012) stated that although there is a decrease in absolute load when comparing the bilateral squat to the unilateral squat, by increasing the force development off one leg independently might increase sport specific strength gains. In McCurdy (2010), it related unilateral exercises in implications for practical use by stating the benefits of joint stabilization and strength.

Specificity does not only relate to the selection of specific exercises. It can be applicable to the training load, velocity of training, and intensity that will elicit specific performance gains relative to training goals (Rahmani, 2001). This is one of the most crucial concepts in program periodization and is the basis for why the strength and conditioning field exists today. No matter the goals or needs of an individual, a program specific to those outcomes will be most effective in progressing that individual to their desired endpoint. Due to the variety of movement in athletic performance, from running to leaping to changing direction, many of the sport movements are completed through a unilateral weight-bearing phase (McCurdy, 2005). Athletes aim for any small improvement to reach their goals, and specific unilateral training could be part of the answer.

Previous Research Regarding Unilateral and Bilateral Training

Much of the research related to unilateral training has been performed through short-term training studies, with most of the studies concluding in less than five training sessions. Focus has been placed on muscle activation (McCurdy, 2010), outcomes over a training period (McCurdy, 2005), effects on the contralateral limb (Munn, 2005), hormonal responses (Jones, 2012), and gender differences (Stephens II, 2007). The specificity of single leg training has been a topic of interest in the field of strength and conditioning despite a lack of depth in the research.

The largest influence in the literature has come from McCurdy, who conducted an eight-week training study on untrained individuals (2005). This study found that the unilaterally trained group fared significantly better in unilateral performance outcomes than did the bilaterally trained group. In addition, the bilateral performance outcomes including maximum strength and power showed no significant difference between training groups. The outcomes were assessed through a variety of pre testing and post testing that included a 5RM back squat, unilateral height jump, bilateral height jump, and Margaria-Kalamen test. Both men and women were used in this study and the strength gains in both groups were similar between genders.

Another study completed by McCurdy (2010) compared electromyography (EMG) activity, of the gluteus medius, the hamstrings and the quadriceps between the two-leg squat and the modified single leg squat (MSLS) in a group of collegiate female athletes. This study only measured what was determined as the dominant leg during both types of exercise. It was found that the MSLS had a significantly higher activation in the gluteus medius and hamstring musculature ($p<.05$). The two-leg squat has a significant increase in quadriceps activation ($p<.05$) and also quadriceps to hamstring ratio ($p<.01$). It was found that there was a higher quadriceps to hamstring ratio in the two-leg squat (4.87) than in the MSLS (1.67) ($p<.01$) which is related to injury prevention in female athletes. This means that the quadriceps were heavily outworking the hamstrings in the two-leg squat while there is a better balance in the relationship between the two muscle groups in the MSLS. These increases in stabilization musculature in the MSLS can be attributed to the reduced base of support when compared to the two-leg squat.

A study by Jones et. al (2012) which compared hormonal responses between unilateral and bilateral lower body training found that there was no significant difference between testosterone levels when performing the two types of exercise at the same relative intensity.

Another study, completed by Munn (2005) found that unilateral training, although only using a single limb and muscle group (the arm and biceps), produced small increases in contralateral strength. This means that the limb and muscle group not used in training gained strength from the opposite limbs work.

Despite finding a strong relationship (r=0.064) between lifting group, unilateral or bilateral, and gender, McCurdy (2005), there does not seem a substantial difference in the literature when comparing men and women training unilaterally. As evidenced by Witmer (2010) and McCurdy (2005) differences in performance outcomes are only different between men and women when measured as absolute values. Measuring outcomes on a relative basis allows the researcher to assess each individual's improvement relative to their own previous performance rather than against the group as a whole.

Athletic Performance Testing and its Validity/Reliability

Using both valid and reliable tests to assess training outcomes throughout a resistance-training program is essential for many purposes (Markovic, 2004). Testing can help to assess talent, examine future training needs, and serve as a motivational tool for athletes. Although most tests are not sufficient predictors of athletic performance, their use can help identify specific characteristics that will help develop an athletic profile. Despite the numerous tests that are available, there are certainly more reliable and valid tests than others.

The 1RM measurement or estimation is important for determining future training load for resistance-training programs (Baechle & Earle, 2008). If an exercise is not deemed appropriate for a 1RM or if a young training age makes an individual ineligible for a 1RM, a multiple repetition maximum can be used to estimate a 1RM. As evidenced in a study by Morales (1997), a multiple repetition maximum that best corresponds to a 1RM is eighty percent of the one repetition maximum or approximately eight repetitions. One drawback of a multiple repetition maximum is the reliance on a chart to predict 1RM and then the translation of that prediction into a training load for a designated number of repetitions. This could potentially limit training outcomes if the estimation is inaccurate (Morales, 1997) or possibly develop a different aspect of fitness than desired.

In terms of testing lower body power output, jump height has been commonly used (Markovic, 2004). The most reliable, consistent, tests have been proven to be to be the squat jump (SJ), which is performed from a static squat position, and the countermovement jump (CMJ), which allows the athlete to perform a countermovement downward before propelling themselves off of the ground. The test-retest reliability for these two tests is (0.97) and (0.98) respectively. These two jump types are most accurate when using a contact mat or force plate in unison with measuring jump height (Markovic, 2004). The CMJ showed the most validity by having the highest relationship with explosive power (r=0.87). The countermovement jump alone is still a reliable and valid measure of lower body power.

When considering agility testing, it is important to realize that agility encompasses various skills and abilities that allow an athlete to change the speed as well as the direction of movement (Baechle & Earle, 2008). Also, depending on the agility test selected, different aspects of agility may be brought to light. The T-test measures agility in four directions as well as the ability to maintain body control through rapid changes in direction (Pauole, 2000). It was the purpose of a study by Pauole (2000), to find the reliability and validity of the T-test in terms of leg speed, leg power, and agility, which are all important relative to athletic performance. Reliability for the T-test was (0.98). Through the Pauole study, it was found that leg speed, which accounted for 32% of the variability of T-test results for women and 21% for men, had the highest correlation to the T-test. Also, the T-test is significantly correlated with other field tests, so it can be widely applicable to the strength and conditioning community. The three attributes assessed, leg speed, leg power and agility account for less than 50% of variability in the T-test in men and 62% in women (Pauole, 2000).

In addition to selecting appropriate tests, another factor that is influences success of your program is the frequency of reassessment of performance measures, in particular the 1RM, which will allow for accurate progression of training load (e.g. increasing training load at the correct rate) (Baechle & Earle, 2008). Training studies vary in their frequency of reassessment from every three weeks (McCall, 1996 and Gergley, 2009), to every four weeks (Moraes, 2013 and Sooneste, 2013) to every seven weeks (Ahtianen, 2003). The more frequent the reassessment, the more likely it becomes that the individual will be completing training specific to their needs.

CHAPTER THREE

METHODOLOGY

Participants

The study population consisted of the members of the Indiana University of Pennsylvania men's and women's varsity swim team. Overall, there were 21 participants who completed the study (MSLS n=11, BBS n=10). Each individual selected had previous resistance training experience, as each individual followed similar in-season and off-season weight training programs for 6 months prior to the beginning of the present study. Previous training leading up to the present study included three sessions per week that involved a full body focus, rather than emphasizing a particular muscle group each day. A wide variety of exercises were incorporated into the swimmers' training program due to the complex movement associated with competitive swimming. During the previous training period the athletes completed their competitive season and the exercises for the current study were a segment of their offseason training program. The age of participants was 20.38 ± S.D.1.3 years. Additional inclusion criteria were the ability to perform a five repetition maximum squat test safely and also the ability to demonstrate proper technique of the BBS and the MSLS throughout the initial instructional sessions. Exclusion criteria were any previous or existing injuries that could compromise data collection or the safety of the potential participant. Any athlete who was injured leading up to participation in the present study or had been in the process of rehabilitation was required to obtain clearance from the athletic training staff to participate in the training sessions. In addition, before being considered for the study, each individual completed a health history (see Appendix A) that detailed medical conditions, any current medications, for safety purposes, and other pertinent information. Additionally, each participant was asked to avoid any additional squat or lower body plyometric training during the 8-week period of the study. During the time frame of the study, the participants completed other forms of resistance training, as their offseason would dictate but no other training outside the offseason program was completed. The current study replaced any squat or lower body plyometric training that would have been used for their offseason. For example, the athletes completed the same upper body training and the same additional lower body resistance exercises but the only squat training completed by the study population was through the study's training protocol. An attendance of 75% was attained for the data of an individual to be included in the final analysis.

Procedures

Subject Recruitment

Recruitment was completed through permission from the men's and women's swimming head coach to recruit the athletes for the study, an informal team meeting explaining the requirements for participation to the athletes, and their subsequent agreement to participate in the study on a completely voluntary basis. Through a detailed informed consent form (Appendix B), that provided a chance for the athletes to read over any risks involved, the principal investigator obtained a signature confirming an individual's participation before any training sessions were initiated. Afterwards, the principal investigator collected the informed consent forms from the individuals and personally met with each person who agreed to participate in the study. During this time, the principal investigator completed an overview of the study details and provided handouts to instruct the athletes on the types of testing that would take place in the second session. Any questions on behalf of the participants were answered before any physical work was completed.

This study involved two training groups, the first used a traditional bilateral back squat and bilateral plyometrics. The second group used a modified single leg squat (MSLS) and unilateral plyometrics. Both legs were trained in unilateral training as well. Each group completed a training protocol that was eight weeks in length and comprised of nineteen total sessions. These sessions began with an instructional session to teach proper technique, continued with a pretest session to gather baseline data for each participant, then sixteen training sessions where load and volume of training are manipulated daily and finally a posttest session where any changes in performance outcomes were assessed. The same relative intensity was used for both types of squat training throughout the program. Participants were notified in the initial meeting that they were to be randomized into groups if upon agreeing to participate in the study. To ensure compliance to their designated group, each participant was notified that if they did not complete 75% of the training sessions or failed to complete the exercises in three consecutive sessions that their participation in the study would be discontinued.

Instructional Session

Before the pretesting began, there was a day of instruction to ensure that each individual was able to complete the bilateral and unilateral squat with appropriate technique. Before being considered for inclusion the participant was required to a) complete the full range of motion of both types of squat so that the hamstrings were parallel with the ground at the lowest depth, without pain, b) maintain a neutral spine throughout the both squat movements and c) understand proper breathing patterns during both phases of movement. During this instructional session, each athlete performed 3 sets of ten of a BBS with bodyweight only, 3 sets of ten repetitions of a BBS and 3 sets of ten of the MSLS with bodyweight only. Additionally, each athlete demonstrated the ability to perform the baseline plyometric exercises for both programs.

Once the individual completed an instructional session and completed an informed consent form, each participant was randomized into one of two groups, and initiated either a unilateral (MSLS/unilateral plyometrics) or a bilateral (BBS/ bilateral plyometrics) training program. As previously mentioned, no physical activity was completed without a returned and signed informed consent form.

Pretesting

Pretesting included baseline measures of hip flexion/extension through goniometry, T-test, bilateral vertical jump, unilateral vertical jump and 5RM BBS in that order as would be standard for the National Strength Conditioning Association (NSCA) sequencing of tests to be administered. Each of these tests was administered to all participants and was completed during one session and was performed in the order listed above with adequate rest periods in between each test for recovery. The testing protocol for a 5RM BBS is included in Appendix C. All participants were given an outline during their instructional session so they were familiar with the procedures for each test that was to be administered. Included as Appendix D, the data collection sheet designated an area to record each pretest result and the units associated with each test. Each pretesting session took approximately 40 minutes per athlete.

Training Sessions

Once pretesting was completed, there was a time span of at least 48 hours between the pretest session and the first training session so that there was ample time to recover to prevent injury as well as to promote effective muscle rebuilding. Both randomized groups met 16 times in total over an 8-week training period. The unilateral and bilateral training groups experienced the same training volume and at the same relative intensity through each stage of the training period. Each session lasted approximately 45 minutes.

When first arriving at a training session each individual, regardless of training group, performed a specific warm up protocol, which included 5 minutes of cardio on a spinning bike, a brief dynamic stretching period, and a warm up set that was equal to half of the training load for the day. For the training loads throughout the program, the 5RM of the unilateral or bilateral squat depending on group, which was found at an earlier session, was used by following the NSCA's repetition maximum training chart (Baechle & Earle, 2008), to estimate the 1RM for that individual. An appropriate percentage of the estimated 1RM was used for the number of repetitions designated for the specific training day by using the NSCA's repetition maximum training chart (Appendix E). Additionally, the group that was unilaterally trained by using the MSLS completed a five-repetition maximum for each leg prior to the initiation of training so that appropriate loading and intensity was established to mimic the BBS protocol. Tracking of weights used and progression by individual for each session was accomplished by using the load estimation char in Appendix F.

Rest periods between sets varied between days depending on the training load for the specific day, with longer rest periods corresponding with the heavier loads lifted and shorter rest periods with lighter loads lifted. On each training day, the repetition range dictated that the individual is training for strength, hypertrophy or muscular endurance, the rest period followed NSCA procedures according to the specific training goal for the day. Training with bilateral and unilateral exercises required a slight manipulation in rest periods between the two to ensure that the rest time is consistent between groups. The bilateral group followed the NSCA recommendations, for example three minutes of rest, while the unilateral split the three minutes between legs. For this specific time, the unilateral group performed work with the right leg, rested for one minute and thirty seconds, work with the left leg, rested for one minute and thirty seconds, and then repeated. This protocol ensured that either leg in the unilateral group had the full three minutes rest before it was repeated as the prime mover, just as in the bilateral group. Specific rest periods for all training goals are outlined in Appendix G.

The first four training sessions served to progress the athletes to train with multiple sets of their 5 repetition maximum (RM). Through these sessions, the participants completed their designated squat exercises with a progressive increase in load and a decrease in number of repetitions. The same relative intensity was used for the MSLS group as the BBS group. The next twelve training sessions included an undulating periodization model since these athletes were previously resistance trained. Undulating periodization involves varying volume and load of an exercise on a daily basis. This could involve increasing or decreasing a variable daily rather than a traditional periodization scheme, which progressively increases throughout the program. Appendix H outlines the progression that was used for both programs. In overview, for each session either sets of ten or sets of five were used for each squat exercise and they were performed at an intensity of 75% or 87% respectively. As the sessions progress, the total volume of resistance training was increased by adding to the number of sets per session. Periodically, after the first four sessions, a recovery session was included which was three sets of fifteen repetitions at a 50%. These recovery sessions were interspersed between the repeating sessions of sets of ten or sets of five.

Plyometrics were started in the fifth session and varied inversely with the squat training. For example, on a high intensity day of squat training, the plyometric volume was low and on a day with low intensity squat training, the plyometric volume was increased. The plyometric training progressed from simple to complex throughout the program. The simpler, less taxing, plyometrics were utilized earlier on and the complex, more difficult, plyometrics were initiated after the simpler exercises are mastered. Plyometrics were always performed before the squat training on each day. The progression for unilateral plyometrics began with single leg push off from a box, the second exercise was a split squat jump, in which the individual had contact on the ground with both feet but applied force with a single leg, and the third exercise was a repeated single leg vertical jump. The progression for bilateral plyometrics began with a double leg vertical jump, moved to a double leg vertical jump with a leg tuck, and advanced to a squat box jump, in which the exerciser landed on a box after the jump.

As the periodization schedule moved forward, each individual had ample rest periods between sessions so that the designated training volume for the day could be completed. In the event that an individual was unable to complete a set or a number of repetitions with their assigned daily load, the progression chart was utilized in reverse. For example, as the progression chart (Appendix I) lists that an individual should increase their weight by 2 kg as to progress, an individual who did not complete their daily repetitions decreased by the 2kg so that they were able to complete their sets and repetitions. As recommended through the NSCA for athletes with intermediate experience, the number of ground contacts ranged from 100-120 per session.

In addition to the training that the athletes completed for this study, they participated in their regularly scheduled offseason training. This included upper body resistance training three times per week, that included a full body emphasis each session rather than only including specific muscle groups each day. Also, the swimmers took part in thirty-minute intensity based swim practices four days per week, with an additional hour and a half technique based pool session once per week. The concurrent training that took place was constant throughout all participants included in the study.

Throughout the eight-week training plan, the athletes were periodically assessed on their 5RM BBS, or 5RM MSLS to ensure that they were lifting the appropriate percentage of their predicted maximal lift. This occurred every two weeks during a designated recovery session, in that the overall intensity of the lifts for that day was lower than the surrounding days. By using these days for the reassessment, it allowed the athletes to provide a best effort to complete their best 5RM for either lift to be used to determine their training load for the following two weeks.

The posttest consisted of the same tests that were used for the pretest (goniometry, unilateral vertical jump, bilateral vertical jump, t-test, and 5RM back squat). A reminder of how each test is performed was explained to each participant before administration. These tests were replicates of the tests used for the pretest, so that accurate comparisons can be made between the two testing days. Posttesting occurred approximately one week after the final training session.

Instrumentation

Vertec Jump System

The Vertec system is used to assess the maximum jump height of an individual. It is a tall adjustable steel frame equipped with vanes at the top that are able to be moved around the axis of the frame. At the start of this test, each participant stood beneath the frame with one arm fully extended above the head with the feet flat on the ground. The participant touched the highest vane that could be reached from a standing position. Once this measure was completed, the adjustable portion of the frame was raised to the appropriate height. Afterwards, the participant performed a countermovement jump and reached the highest vane possible. This height was recorded and the jump height was the difference between the standing height and the jumping height. For this system, each participant completed three trials of the bilateral jump as well as three trials unilaterally. Each unilateral jump ended with the athlete landing on two feet. The maximum values were recorded for each jump type. The height was recorded to the nearest half inch.

5 RM Squat Test

The five repetition maximum squat test was performed using a power rack, a barbell and accompanied weights that were added for extra resistance. A power rack is equipped with safety bars that prevent the weight from falling down upon an individual in the case of the athlete being unable to complete a repetition. Additionally, there are two liftoff bars that are used to rack the weight before and after completion of the squat exercises. The barbell that was used is a standard 45 pound barbell used in many facilities. A protocol from the NSCA was used to detect the five-repetition maximum (Appendix C).

T-test

The T-test is an agility test used to assess an athlete's movement in the forward, lateral and backward planes of motion. This test was completed in a gymnasium for both trials to control for different types of surfaces. Equipment that was needed to perform this test was four small orange cones and a tape measure to spread the cones in the appropriate "T" shape. During the test the athlete ran forward 10 yards to the cone A, shuffled to either side 5 yards to a cone B, shuffled the opposite direction past cone A to cone C, shuffled back to the center to cone A, and finally backpedaled to the starting position. Each participant performed two trials of this test and the fastest time was recorded. The final time was recorded to the nearest 0.1 second.

Goniometry

Goniometry is a technique used by health and fitness professionals to assess range of motion of a joint of the body. A goniometer is a measure device, which consists of two measurement arms (a stationary and movement arm) that are anchored at a central point. The measurement was completed by placing the central point (the fulcrum) at the joint that was measured. For the purposes of this study, hip flexion and extension were the measurements of interest. To assess the range of motion for the hip, the fulcrum was placed lateral to the greater trochanter of the femur. The stationary arm was aligned with the lateral midline of the pelvis while the movement arm was aligned with the lateral midline of the femur. For the movement arm, the femoral epicondyle was the reference point for alignment.

Hip flexion was measured with the individual lying in a supine position. Hip extension was measured with the individual lying in a prone position. For both assessments, a passive range of motion was examined. This consisted of the primary investigator stretching the individual to the point of mild discomfort. At that point, the measurement was made and the individual was returned gently to a resting position.

Standard Bench

A standard bench, which is approximately 48 inches in height, was used during the modified single leg squat throughout the training period. The bench was placed behind the athlete and they placed the leg not being used as the prime mover for the unilateral squat on the top of the bench for stability purposes. Throughout the training period, the same bench was used so that the training is standardized across all subjects. Each bench included a non-slip surface that prevented the stability foot from slipping off.

Statistics

For this study, statistics that were included are measures of central tendency, the Wilcoxon Signed Rank Test and the Mann Whitney U Test. Measures of central tendency (i.e.

mean, median, mode, standard deviation) helped to describe the population's baseline scores from the pretest, notified differences throughout the testing period, and assessed differences at posttest. These measures can describe each group independently as well as all the participants as a whole. To compare groups, absolute change and percent change for pretest and posttest measures were analyzed. Additionally, to test the significance of changes within group and between groups, the Wilcoxon Signed Rank Test and the Mann Whitney U test were used respectively. The Wilcoxon Signed Rank Test and the Mann Whitney U test are both non parametric measures, which means that they are tests for which the results are only applicable to the tested population. In this case, the sample did not have sufficient size (>30) to make assumptions about the population in general. The Wilcoxon Signed Rank Test was used as an alternative to the repeated measures T-test. This test converted scores on a particular test into ranks, and then compared the scores at Time 1 and Time 2. The Mann-Whitney U Test was used to test for differences between two independent groups on a continuous measure. This test translated the scores to rank across the two groups. The evaluation involved comparing medians between groups to find if any significant differences existed.

CHAPTER IV

RESULTS

Subjects' Characteristics

The study consisted of 21 subjects (10 females and 11 males) that were members of the IUP varsity swim team (age 20.38 ± S.D. 1.3 years). Of the expected subject population of 38, 7 could not participate due to their qualification for the NCAA national meet or their participation in another varsity sport. Of the remaining 31, seven chose not to participate. Twenty-four subjects began the training program and one had to withdraw from the study due to the training being too painful on their knees. The other two subjects did not meet the eighty percent attendance requirement during the training period for inclusion in the final results. Prior to initiation of the training program, each subject had performed a similar resistance-training program for the previous six months during their in season training. All subjects were apparently healthy individuals who passed screening procedures in their initial instructional session. Once each subject completed an informed consent form, they were randomly separated into two groups. One group (n=10, 5 Female & 5 Male) completed a traditional bilateral back squat (BBS) with two leg plyometrics and one group (n=11, 5 Female & 6 Male) completed a modified single leg squat (MSLS) with single leg plyometrics throughout the eight week training period. Each of these individuals completed a five repetition maximum squat, goniometry measures (hip flexion and hip extension), a bilateral jump height test, a unilateral jump height test (left and right legs), and an agility test before (pre) and after (post) the sixteen training sessions.

The following table describes the data obtained in the initial assessment of each group during the pretesting.

Table 1

Initial Information

BBS			MSLS	
Mean	Standard Dev.	Variable	Mean	Standard Dev.
20.30 years	1.5	Age	20.45 years	1.13
151.50 lbs.	76.4	5RM Squat	158.64 lbs.	37.2
9.70°	1.5	Hip Extension	10.95°	2.0
80.40°	18.4	Hip Flexion	82.91°	12.1
16.95 in.	4.1	Bilateral Jump	17.54 in.	3.6
10.65 in.	3.5	Right Leg Jump	10.90 in.	2.8
10.35 in.	3.9	Left Leg Jump	11.09 in.	3.1
11.55 sec.	1.2	T-test	11.69 sec.	1.4

The first hypothesis of this study was that the relative change in muscular strength, assessed by a bilateral 5RM squat, would not be significantly different between unilaterally trained versus bilaterally trained athletes. Descriptive statistics of the 5RM squat are displayed in the following table.

Table 2

5RM Squat Descriptive Statistics

Group		N	Mean	Std. Deviation (S.D.)
BBS	Initial 5RM (lbs)	10	151.50	76.378
	Final 5RM (lbs)	10	186.00	77.057
	% Change 5RM %	10	27.8263	16.62701
MSLS	Initial5RM (lbs)	11	158.64	37.222
	Final5RM (lbs)	11	182.27	38.624
	% Change 5RM %	11	15.6614	7.85243

When comparing absolute values, the two training groups were very similar in terms of their mean initial 5RM squat strength. The BBS group started with an initial value of 151.50lbs. ± S.D. 76.378 while the MSLS group started with an initial value of 158.64lbs. ± S.D. 37.222. The BBS group and MSLS group at posttest ended with a result of 186.00lbs. ± S.D. 77.057 and

182.27lbs. ± S.D. 38.624 respectively. The mean percent change of the groups was 27.83% ± S.D.16.63% for the BBS group and 15.66%± S.D. 7.85% for the MSLS group.

To compare the changes within each group from pretest to posttest, the Wilcoxon Signed Rank Test was used to determine if significant increases in the weight of the 5RM squat were made. The following table describes the Wilcoxon test results.

Table 3

Within Group 5RM Squat Comparison

Group		Initial 5RM – Final 5RM
BBS	Z	-2.816[b]
	Asymp. Sig. (2-tailed)	.005
MSLS	Z	-2.965[b]
	Asymp. Sig. (2-tailed)	.003

a. Wilcoxon Signed Ranks Test
b. Based on negative ranks

Any p value less than .05 was considered a significant interaction for that training group. As is evidenced from the table, both the MSLS training (p=.003) and the BBS training (p=.005) had a significant effect on the results of the 5RM squat at the time of posttest measure versus the pretest measure. Next a comparison was made to test if there was a difference in the impact of a training group on the performance outcome. The following table displays the between group comparison.

Table 4

Between Group 5RM Squat Comparison

	Percent Change 5RM
Mann-Whitney U	26.000
Wilcoxon W	92.000
Z	-2.049
Asymp. Sig. (2-tailed)	.040
Exact Sig. [2*(1-tailed Sig.)]	.043

As is depicted by Table 3, there was a significant difference in the outcome between groups. The BBS group had a significantly higher mean percent change in the 5RM squat (p=.043) than the MSLS group. This means that the muscular strength increased more in the BBS group than it did in the MSLS group. Therefore the first hypothesis was rejected. There was one outlier in the data pool for the BBS group and if the outlier was to be removed from the analysis, the significance of this interaction would be removed.

The second hypothesis was that athletes who train unilaterally would show a significantly greater relative increase in their bilateral and unilateral countermovement jump height when compared to bilaterally trained individuals. The following table illustrates how the absolute values and percent change for jump height compared throughout the study.

Table 5

Jump Height Descriptive Statistics

Group		N	Mean	Std. Deviation (S.D)
BBS	Initial Bilateral Jump (in.)	10	16.9500	4.14628
	Final Bilateral Jump (in.)	10	17.2000	4.51664
	% Change Bilateral Jump %	10	1.4445	7.99307
	Initial Right Leg Jump (in.)	10	10.6500	3.49643
	Final Right Leg Jump (in.)	10	10.2500	3.47411
	% Change Right Leg Jump %	10	-3.6701	9.68023
	Initial Left Leg Jump (in.)	10	10.3500	3.88051
	Final Left Leg Jump (in.)	10	10.8500	4.05552
	% Change Left Leg Jump %	10	6.4625	20.19051
MSLS	Initial Bilateral Jump (in.)	11	17.5455	3.60870
	Final Bilateral Jump (in.)	11	18.0455	3.99659
	% Change Bilateral Jump %	11	2.7508	8.19086
	Initial Right Leg Jump (in.)	11	10.9091	2.80908
	Final Right Leg Jump (in.)	11	11.0455	2.48450
	% Change Right Leg Jump %	11	2.6414	12.25128
	Initial Left Leg Jump (in.)	11	11.0909	3.12104
	Final Left Leg Jump (in.)	11	11.5000	2.74773
	% Change Left Leg Jump %	11	5.0319	13.43673

The jump height performance was similar in percent change and in absolute values when observing the data from each group. Percent change in bilateral jump for the BBS group was 1.44% ± S.D. 7.99% and for the MSLS group was 2.75% ± S.D. 8.19%. For the right leg jump height the percent change was -3.67% ± S.D. 9.68% for the BBS group and 2.64% ± S.D. 12.25% for the MSLS group. Percent change in the left leg jump height for the BBS group was 6.46% ± S.D. 20.19% and for the MSLS group was 5.03% ± 13.44%. The Wilcoxon Signed Rank test compared absolute changes within each group to find if a significant change occurred through the training period. The following table highlights the interactions.

Table 6

Within Group Jump Height Comparison

Group		Final Bilateral - Initial Bilateral	Final Right Leg – Initial Right Leg	Final Left Leg – Initial Left Leg
BBS	Z	$-.688^{b}$	$-.992^{c}$	-1.109^{b}
	Asymp. Sig. (2-tailed)	.491	.321	.268
MSLS	Z	-1.119^{b}	$-.281^{b}$	$-.776^{b}$
	Asymp. Sig. (2-tailed)	.263	.779	.438

b. Based on negative ranks

As is expressed through Table 5, there was not a significant interaction in either group through any of the three jump height measurements. This means that the squat and plyometric training program did not have a significant effect on the jump height (in.) that each participant was able to attain. Neither group had a significant interaction for absolute change when comparing the pretest and posttest results of the jump height. The following table expresses the between group differences in terms of the jump height measurements.

Table 7

Between Group Jump Height Comparison

	% Change Bilateral	% Change Right Leg	% Change Left Leg
Mann-Whitney U	53.000	40.000	49.500
Wilcoxon W	119.000	95.000	115.500
Z	-.141	-1.064	-.389
Asymp. Sig. (2-tailed)	.888	.288	.698
Exact Sig. [2*(1-tailed Sig.)]	.918[b]	.314[b]	.705[b]

b. Not corrected for ties.

As stated earlier, a significance level (p<.05) must be attained to show that a significant interaction occurred between training groups. The mean values for bilateral jump height (p=.918), right leg jump height (p=.314), and left leg jump height (p=. 705) evidence that there was not a significant difference between group. Therefore, hypothesis number two was rejected.

The third hypothesis was that athletes who train unilaterally would show a significantly greater relative decrease in T-test time when compared to bilaterally trained individuals. The following table expresses the absolute results and percent change of the T-test time over the course of the eight-week training period.

Table 8

T-test Descriptive Statistics

Group		N	Mean	Std. Deviation (S.D.)
BBS	Initial T-test (sec.)	10	11.8870	1.14422
	Final T-test (sec.)	10	11.5550	1.23183
	% Change T-test %	10	-2.7918	4.35272
MSLS	Initial T-test (sec.)	11	11.6900	1.37559
	Final T-test (sec.)	11	11.3655	1.19659
	% Change T-test %	11	-2.5834	3.97805

Data from the T-test was recorded in seconds to describe the length of time that it took the individual to complete the agility test. A negative percent change was expected due to a drop in total time to finish the T-test. The BBS training group had an average percent change of -2.79% ± S.D. 4.35% and the MSLS group had an average percent change of -2.58% ± S.D. 3.98%. Both groups had relatively similar pretest and posttest T-test times. The Wilcoxon Signed Rank Test was used to detect the significance of changes within each training group.

Table 9

Within Group T-test Time Comparison

Group		Final T-test - Initial T-test
BBS	Z	-1.836[b]
	Asymp. Sig. (2-tailed)	.066
MSLS	Z	-1.689[b]
	Asymp. Sig. (2-tailed)	.091

c. Based off positive ranks.

When comparing posttest T-test times to pretest T-test times, there was not a significant reduction in time for either group but both groups were approaching significance (BBS=.066, MSLS= .091). There is an indication that the training had an impact in reducing the T-test time in both groups but the change was not significant. The comparison between groups is made in the following table.

Table 10

Between Group T-test Time Comparison

	% Change T-test
Mann-Whitney U	53.000
Wilcoxon W	108.000
Z	-.141
Asymp. Sig. (2-tailed)	.888
Exact Sig. [2*(1-tailed Sig.)]	.918[b]

b. Not corrected for ties.

A comparison between groups showed that there was no significant difference by training group on the T-test time. The p value of .918 indicates that the two types of training did little to differentiate the performance outcome. With these results the third hypothesis was rejected.

The fourth hypothesis was that athletes who train unilaterally would show a significantly greater relative increase in hip joint range of motion as assessed with goniometry when compared to bilaterally trained individuals. The following table expresses the descriptive statistics for the flexibility measure.

Table 11

Goniometry Descriptive Statistics

Group		N	Mean	Std. Deviation
BBS	Initial Extension (°)	10	9.7000	1.45678
	Final Extension (°)	10	11.1500	1.05541
	% Change Ext. %	10	16.3986	11.88413
	Initial Flexion (°)	10	80.4000	18.42975
	Final Flexion (°)	10	86.2000	16.39309
	% Change Flex. %	10	8.2064	7.57083
MSLS	Initial Extension (°)	11	10.9545	2.00567
	Final Extension (°)	11	11.3636	1.97599
	% Change Ext. %	11	4.4973	11.03483
	Initial Flexion (°)	11	82.9091	12.09301
	Final Flexion (°)	11	92.0000	13.34728
	% Change Flex. %	11	11.9762	16.43913

Table 10 depicts the amount of mean percent change per group through goniometry for extension (BBS = 16.40% ± S.D. 11.88%, MSLS 4.50% ± S.D. 11.03%) and for flexion (BBS= 8.21 ± S.D. 7.57%, MSLS= 11.98% ± S.D.16.44%). Additionally, the mean data for the initial (PRE) and final (POST) measurements for both flexion and extension are present in table 4 categorized as the mean column.

The Wilcoxon Signed Rank test was then used to detect any significant within group changes for flexibility as measured by goniometry for hip flexion and hip extension. In the following table, the within group changes are displayed.

Table 12

Within Group Goniometry Comparison

Group		Final Ext. - Initial Ext.	Final Ext. – Initial Ext.
BBS	Z	-2.675[b]	-2.499[b]
	Asymp. Sig. (2-tailed)	.007	.012
MSLS	Z	-1.017[b]	-2.138[b]
	Asymp. Sig. (2-tailed)	.309	.033

b. Based off negative ranks.

Both the BBS group (p=.012) and the MSLS group (p=.033) had a significant increase in their hip flexion measures through goniometry. This means that both training programs had a significant impact on that flexibility measure. For hip extension the BBS group (p=.007) had a significant interaction for hip extension while the MSLS group (p=.309) did not have a significant interaction. The comparison between group effects is displayed in the following table.

Table 13

Between Group Goniometry Comparison

	% Change Extension	% Change Flexion
Mann-Whitney U	25.000	51.000
Wilcoxon W	91.000	117.000
Z	-2.115	-.282
Asymp. Sig. (2-tailed)	.034	.778
Exact Sig. [2*(1-tailed Sig.)]	.036[b]	.809[b]

b. Not corrected for ties.

Through a comparison between groups, it is shown that there was a significant difference in hip extension with the BBS improving more than the MSLS at a p-value of .036. When comparing hip flexion, there was not a significant change between groups (p= .809). With this information, the fourth hypothesis was rejected.

In summary, the four of the original hypotheses were rejected. There was a significant change in maximal strength for the BBS group when compared to the MSLS group (p=.043). A significant change also existed between groups for hip extension (p=.036), with a greater change evidenced by the BBS group. For all other variables, the relative change in those variables was not significant when comparing the two training groups.

CHAPTER V

DISCUSSION

As the field of strength and conditioning continues to grow, the need to evaluate training practices becomes essential so that performance can continue to improve. Whether these new resistance-training techniques challenge the scientific basis of movement or the practicality of use in a program, strength and conditioning professionals are responsible for analysis of their effectiveness. Ultimately, these decisions come down to training at a load and velocity that best corresponds to competitive movement (Rahmani, 2001) or training to maximized the effects of the appropriate energy systems. The squat or a variation of the squat is an exercise that is used in a program in nearly every setting, unless contraindicated. With this knowledge, professionals should question how these squat variations compare to the back squat related to performance outcomes, training adaptations, and eventually how these techniques transition to the competitive setting.

When assessing previous research that compares unilateral lower body resistance training to bilateral lower body resistance training, there have been few studies that directly compare the two training programs over a period of time. Furthermore, there have been even fewer studies of this nature that examine squat training styles on previously resistance-trained athletes. The two most relevant studies have been completed by McCurdy et. al. through the use of the modified single leg squat (MSLS) and the bilateral back squat (BBS). Results of an eight-week training study using a very similar training design to that of the present study on untrained individuals differed greatly when comparing the results to those of this study. In the untrained individuals, the unilateral group performed significantly better over the bilateral group on the unilateral jump height ($p=0.001$) (McCurdy, 2005) while in the trained athletes the unilateral jump height was shown to be very similar between groups. Also, in the untrained individuals, there was no significant difference in relative change between groups at posttest when comparing the 5RM squat to pretest measures. In the current study, there was a significant difference in percent change of 5RM squat with the BBS group having a significantly greater relative change at posttest (p=.043) than at pretest. These differences could be attributed, due to training status difference between studies, the ability to place higher loads on the BBS for the athletes when comparing the loads to the MSLS. The gap between the amounts of absolute weight for the exercises when comparing groups may have been smaller due to the lack of previous resistance training.

In terms goniometry and agility testing, that were measured through this study, there has been no previous research on those assessments relative to unilateral and bilateral training to compare the results. Throughout this study there was a significant difference between pre-post measures for hip extension in the BBS group (p=.036) when compared to the MSLS group. However, there were no significant differences for hip extension or T-test time. One aspect of previous studies that was not assessed through the current study was EMG readings related to the training group. Another study by McCurdy et. al. (2010) detected that the MSLS had a significantly higher activation of the gluteus medius and the hamstrings (p<.05) than the BBS. Although these specific muscles are not the primary muscles involved in force production for the squat movement, they do assist in providing stability and decrease injury risk.

This information can be applied to strength and conditioning programs throughout all levels of sport. Despite the differences found in changes of maximal strength, the MSLS group performed comparably well when compared to the BBS. Although the performance outcomes may have been attenuated in some variables for the MSLS, it should be considered for use as a supplementary exercise for the BBS. The MSLS provides an added stability and balance component that may not be as crucial in the BBS. Some practical information that can be taken from the methodology is the length of time to complete the exercises as well as the relative difficulty for each group. Despite using a similar percentage of an estimated 1RM for both training groups, the time that it took to complete a training session was lengthier for the MSLS for each day. Due to the time sensitive nature of strength and conditioning sessions in general, the use of the MSLS may be less practical for those with limited time. Despite a significantly lower increase in 5RM strength, the MSLS group seemed to be much more fatigued after the training bouts when compared to the BBS group. This could be attributed to the increased amount of time under stress or the high activation of a large muscle group over an extended time.

Some limitations of the methodology may have influenced the results of the current study. These limitations must be taken into account when reading about the results. The small sample size (n=21) makes it difficult to extend the results to other populations. With this sample size, the results can only be relative to the Division II collegiate swimmer rather than to athletes in general. A limitation that may have had an impact on jump height may have been the decision to only use plyometric training as the power component of the program. During the regular season and preseason the athletes in the study had also used Olympic lifting as part of their training so the force production through this training may not have increased as drastically had Olympic movements been utilized. Due to the elevated training status of the individuals who participated in the study, the training modalities may not have provided enough of a stimulus to drastically increase any of the performance variables. If a less conditioned population was used, there may have been greater changes associated when comparing pretesting and posttesting.

Through future research, the areas that should be examined are special populations for this type of training. A multicenter trial involving individuals of similar ability levels following a standardized program comparing the two training styles on a larger and more diverse population would be useful in obtaining a larger effect size for training. The use of multiple centers could combat the issue of the small sample size because it may be difficult to find a large population at one training center. The use of both exercises in conjunction with one another compared to the use of a BBS alone could further emphasize the need for variability in a training program. This type of design would test if the use of both squat training types had a larger effect than the BBS alone. Lastly a formula to calculate a percentage of a BBS that is appropriate for the MSLS exercise could be of great assistance. To create this formula, the researcher would have to test both the BBS and the MSLS so that they could assess the average ratio between the two exercises across all subjects.

In summary, there is room to utilize both training styles into any strength and conditioning program. Despite the significant differences in the 5RM back squat strength variable as well as the goniometry measure, the usability and practicality of the MSLS is quite strong. The degree to which each training style is used can vary for special populations when compared to the general public. Barring any physical limitations, it is logical to utilize both training methods in any strength and conditioning program or any other wellness program that is designed. Whether these exercises are used to complement one another or are used separately is up to the discretion of the strength and conditioning professional.

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Appendix A

Health History

Name ______________________ Date ___________

Address ___________________________________

Home phone ________________ Emergency contact_______________________

E-mail address ______________

Gender: _____

Age _________ Birthdate _____________ Weight ____________ Height ____________

Are you taking any medications? No ____ yes ____

(Please list medications and reasons for usage below)

____

Are you taking any vitamins or dietary supplements? No ____ yes ____

(Please list supplements and reasons for usage below)

Do you now, or have you had in the past:	yes	no
1. History of heart problems, chest pain or stroke?	___	___
2. Increased blood pressure?	___	___
3. Any chronic illness or condition?	___	___
4. Do you ever get dizzy, lose your balance or lose consciousness?	___	___
5. Difficulty with physical exercise?	___	___
6. Advice from physician not to exercise?	___	___
7. Recent surgery (last 12 months)?	___	___
8. Pregnancy (now or within last 3 months)?	___	___
9. History of breathing or lung problems?	___	___
10. Swollen, stiff, or painful joints?	___	___

11. Foot problems? ___ ___

12. Back problems? ___ ___

13. Any significant vision or hearing problems? ___ ___

14. Diabetes or thyroid condition? ___ ___

15. Do you ever drink alcoholic beverages? ___ ___

16. Increased blood cholesterol? ___ ___

17. History of heart problems in immediate family? ___ ___

18. Hernia, or a condition that may be aggravated by lifting weights? ___ ___

19. Do you have asthma? ___ ___

20. Have you had any fractures, sprains, strains? ___ ___

If yes, what type of injury? And the date of occurrence?

Have you been cleared by the athletic trainer for participation in resistance training?

How did the injury occur?

Please explain any yes answers below.

(If necessary use the back of this page)

Appendix B

Informed Consent Form

You are invited to participate in this research study. The current form will address details of the study and will allow you to make a decision regarding your participation. You are able to participate in this study because you are a collegiate athlete and have had previous resistance training experience. If you have any questions feel free to ask.

The aim of this study is to compare two lower body, unilateral versus bilateral, training styles on the development of various aspects of fitness, such as jump height, strength, agility and flexibility. This will take place through a pre-test to gather baseline data. Testing will include a five repetition maximum squat test, a test of jump height (unilateral and bilateral), a T-test for agility and measurement of flexibility with a goniometer, which will measure the angle of hip flexion and extension. Following testing, the training program will span eight weeks and will require approximately sixteen training sessions, and a follow up post-testing to gauge changes in performance. Through that time, individuals will be asked to perform lower body (leg) training with vary amounts of resistance. Unilateral or bilateral squat exercises as well as plyometrics will be utilized in the training sessions. Exercises that will be completed could be a part of any typical training program across the country. Intensity will be moderate-vigorous in nature and may induce muscle soreness after the training bouts. Over the course of the eight weeks, participants can expect to use bodyweight, dumbbells and barbells as part of the training plan. Prior to initiation of the training program, participants will be evaluated for technique to ensure that injury risk remains very low throughout the program.

Your name will not be used or released with the research findings so your performance will be kept confidential. All data collected will be expressed as group data, ensuring that no individual records will be released. Throughout testing, all results will be locked away in a secure location.

Participation in this study is completely voluntary. If at any time throughout the training program you would like to withdraw yourself from the study, you may do so without any negative consequences. If you decide to withdraw, any information collected on your performance will be terminated. The results of the research could be published in a scientific journal, but in this case, as stated previously, your name will not be attached to any of the findings presented.

If you are willing to participate, you will sign the attached form indicating your consent to take part in the study. If you have any questions, you can contact me at RKJP@iup.edu or by phone (724) 859-1319.

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Faculty Advisor:
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Indiana, PA 15705
Mark.Sloniger@iup.edu

VOLUNTARY CONSENT FORM:

By signing this form, I acknowledge that I have read and understand the informed consent form for volunteering for this study. I understand that my identity will be kept confidential and that I am free to withdraw at any time. In addition, I understand that there will be no compensation provided for my participation. My signature indicates that I understand the conditions of this study.

Name (PRINT) ______________________________________

Signature ____

Date ___________

Email ___________

Phone Number ______________________

As the principal investigator, I attest that I have provided all necessary information to ensure that the potential participant is fully informed on their decision to participate in this research study. Additionally, I have been open to and answered any questions that the participant had regarding their safety throughout the program.

Name (PRINT) ____

Signature ____

Date ____________

Appendix C

Repetition Maximum Testing Protocol

1. Warm up with a light resistance that easily allows for 5-10 repetitions
2. Take a one-minute rest period
3. Estimate a warm up load that will allow 3-5 repetitions by adding
    a. 10-20lbs or 5-10% for upper body exercise
    b. 30-40lbs or 10-20% for lower body exercise
4. Take a two-minute rest period
5. Estimate a load that will allow 2-3 repetitions by adding
    a. 10-20lbs or 5-10% for upper body exercise
    b. 30-40lbs or 10-20% for lower body exercise
6. Take a two to four-minute rest period
7. Increase the load
    a. 10-20lbs or 5-10% for upper body exercise
    b. 30-40lbs or 10-20% for lower body exercise
8. Perform a 1-RM
9. If successful, take a two to four minute rest period and repeat step 7, If failed take a two to four-minute rest period and decrease the load by
    a. 5-10lbs or 2.5-5% for upper body exercise
    b. 15-20lbs or 5-10% for lower body exercise
10. Repeat Step 8

Baechle, T. R., & Earle, R. W. (2008). *Essentials of Strength Training and Conditioning (*3rd ed.*)*. Champaign, IL: Human Kinetics.

Appendix D

Pre Test/ Post Test Collection Sheet

Name: _________________

Sit and Reach Test (in.) (*to nearest ½ in.*)

	Trial 1	Trial 2	Trial 3	Average
Pre				
Post				

Bilateral Jump Height (in.) (*to nearest ½ in.*)

	Trial 1	Trial 2	Trial 3
Pre			
Post			

Unilateral Jump Height (in.) (*to nearest ½ in.*)

	Trial 1	Trial 2	Trial 3
Pre			
Post			

T-test (seconds)

	Trial 1	Trial 2
Pre		
Post		

5RM Squat (lbs.)

	Weight
Pre	
Post	

Appendix E

Repetition Maximum Training Chart

Max reps (RM)	1	2	3	4	5	6	7	8	9	10	12	15
%1RM	100	95	93	90	87	85	83	80	77	75	67	65
Load (lbs or kg.)	10	10	9	9	9	9	8	8	8	8	7	7
	20	19	19	18	17	17	17	16	15	15	13	13
	30	29	28	27	26	26	25	24	23	23	20	20
	40	38	37	36	35	34	33	32	31	30	27	26
	50	48	47	45	44	43	42	40	39	38	34	33
	60	57	56	54	52	51	50	48	46	45	40	39
	70	67	65	63	61	60	58	56	54	53	47	46
	80	76	74	72	70	68	66	64	62	60	54	52
	90	86	84	81	78	77	75	72	69	68	60	59
	100	95	93	90	87	85	83	80	77	75	67	65
	110	105	102	99	96	94	91	88	85	83	74	72
	120	114	112	108	104	102	100	96	92	90	80	78
	130	124	121	117	113	111	108	104	100	98	87	85
	140	133	130	126	122	119	116	112	108	105	94	91
	150	143	140	135	131	128	125	120	116	113	101	98
	160	152	149	144	139	136	133	128	123	120	107	104
	170	162	158	153	148	145	141	136	131	128	114	111
	180	171	167	162	157	153	149	144	139	135	121	117
	190	181	177	171	165	162	158	152	146	143	127	124
	200	190	186	180	174	170	166	160	154	150	134	130
	210	200	195	189	183	179	174	168	162	158	141	137
	220	209	205	198	191	187	183	176	169	165	147	143
	230	219	214	207	200	196	191	184	177	173	154	150
	240	228	223	216	209	204	199	192	185	180	161	156
	250	238	233	225	218	213	208	200	193	188	168	163

Baechle, T. R., & Earle, R. W. (2008). *Essentials of Strength Training and Conditioning (*3rd ed.*)*. Champaign, IL: Human Kinetics.

Appendix F

Daily Tracking Sheet

Name: ________________

Initial 1RM: ___________ **Final 1RM: ___________**

Date	**Set 1**	**Set 2**	**Set 3**	**Set 4**	**Set 5**	**Set 6**

Appendix G

Rest Periods

NSCA Recommendations

Training Goal	Rest Period Length
Strength	2-5 minutes
Power: Single-Effort Multiple-Effort	2-5 minutes
Hypertrophy	30 seconds-1.5 minutes
Muscular Endurance	≤ 30 seconds

Current Study Rest Periods

Training Goal	Bilateral Group	Unilateral Group
Strength (5 repetitions)	3 minutes	1.5 minutes between legs
Hypertrophy (8 or 10 repetitions)	1 minute	30 seconds between legs
Muscular Endurance (15 repetitions)	30 seconds	15 seconds between legs

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Appendix H

Training Progression

Session #	Sets x Reps	% of 1RM
1	3x15	50
2	3x8	82
3	3x10	75
4	3x5	87
5	3x15	50
6	3x8	82
7	4x5	87
8	3x15	50
9	4x5	87
10	3x10	75
11	5x5	87
12	4x10	75
13	3x15	50
14	6x5	87
15	3x10	75
16	4x5	87

Appendix I

Load Increases for Training Progression

Description of the athlete*	Body area exercise	Estimated load increase
Smaller, weaker, less trained	Upper Body Lower Body	2.5-5 pounds (1-2 kg) 5-10 pounds (2-4 kg)
Larger, stroner, more trained	Upper Body Lower Body	5-10+ pounds (2-4+ kg) 10-15+ pounds (4-7+ kg)

Baechle, T. R., & Earle, R. W. (2008). *Essentials of Strength Training and Conditioning (*3rd ed.*)*. Champaign, IL: Human Kinetics.