ASSESSING EXPLOSIVE POWER PRODUCTION USING THE BACKWARDS OVERHEAD SHOT THROW AND THE EFFECTS OF MORNING RESISTANCE EXERCISE ON AFTERNOON PERFORMANCE

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ABSTRACT

LAURA LYNN GERRAUGHTY: Assessing explosive power production using the backwards overhead shot throw and the effects of morning resistance exercise on afternoon performance
(Under the direction of Claudio L. Battaglini, Ph.D.)

The purpose of this pilot study was to preliminarily validate the backwards overhead shot throw (BOST) against the vertical jump (VJ) as a test of explosive power. Secondarily, effects of a morning resistance exercise bout on afternoon explosive power performance were examined. Throwers in the sport of athletics (N = 14) performed one control and one experimental trial on separate days. Trial 1 consisted of VJ and BOST testing performed in the afternoon. For Trial 2, participants reported for a short resistance training session in the morning before repeating the VJ and BOST testing that afternoon. BOST scores and VJ peak power were correlated in both trials ($r=0.64$, $p < 0.05$). BOST scores improved in Trial 2 over Trial 1, but VJ power failed to improve. Results suggest that BOST is a valid test of explosive power production, and a morning resistance training session improves BOST performance that same afternoon.

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TABLE OF CONTENTS

CHAPTERS

CHAPTER I

INTRODUCTION

Collectively, the throwing events in the sport of athletics present a unique challenge among explosive power sports. Performance is based almost entirely on physical fitness and technical mastery; strategy plays only a minor role. The incorporation of heavily-weighted implements with specific aerodynamic characteristics places some extraordinary demands on the athlete within those first two domains of training. For example, the 800 g javelin, the lightest of the men's implements, is still more than five times the mass of a baseball (Major League Baseball, 2008; IAAF Rules, 2009). Implements this heavy must be released with a specific alignment and spin to generate efficient flight (Hubbard, 1989). Aside from maintaining the minimal body control required to ensure a legal throw, all other technical and physical training aspects of the events are focused on maximum implement displacement for distance.

The physical demands of the throws are three-fold: 1) acceleration of one part of the body in relationship to another (i.e., change body position) according to the demands of the technique; 2) acceleration of the body and implement together in the direction of the throw, and 3) deceleration of the body while still accelerating the implement in the direction of the throw. Explosive power production is the ability to start and accelerate an implement over a set distance (Newton & Kraemer, 1994). The distance of implement travel is set by factors outside the realm of physical training. In order of importance, venue specifications, throwing technique, and competitor stature dictate the total displacement of the person and the implement in the direction of the throw up to the point of release. From a physical preparedness standpoint, then, what sets athletes apart in these disciplines is the ability to produce force quickly (Newton & Kraemer, 1994).

To assess the training state and physical preparedness for explosive power performance across all of the throwing events in athletics, it is useful to use a general field test of explosive power production. Selection of the appropriate test is key in generating an accurate profile of performance readiness. The vertical jump (VJ) is one such commonly-used test (Church, Wiggins, Moode, & Crist, 2001; Gourgoulis et al., 2003; Jensen & Ebben, 2003; Mayhew et al., 2005; Stockbrugger & Haennel, 2001; Stockbrugger & Haennel, 2003; Young et al., 1998). However, this movement focuses primarily on hip and leg function and includes little trunk or arm contribution to total power production (Mayhew et al., 2005; Stockbrugger & Haennel, 2001; Stockbrugger & Haennel, 2003). In addition, the vertical jump focuses on accelerating body mass only and ignores the element of momentum production and transfer to an implement (Stockbrugger & Haennel, 2001; Stockbrugger & Haennel, 2003).

Another test that has been examined in athletics as an explosive power test is the backwars overhead medicine ball throw, known as the BOMB test (Barrett, 2006; Duncan, Al-Nakeeb, & Nevill, 2005; Gabbett, Georgieff, & Domrow, 2007; Mayhew et al., 2005; Stockbrugger & Haennel, 2001; Stockbrugger & Haennel, 2003) which is believed to be a better indicator of throwing performance than the VJ because of the involvement of an implement, as well as the recruitment of the core and upper extremities to add to power production (Stockbrugger & Haennel, 2001). However, some disagreement exists within what limited literature exists regarding the validity of the

BOMB as a test of explosive power production. Stockbrugger and Haennel (2001) have previously verified the accuracy and validity of BOMB test scores using VJ performance as a benchmark. The same researchers have also examined several factors that contribute to BOMB performance (Stockbrugger & Haennel, 2003). When a similar study conducted by Mayhew et al. (2005) using a different population using different methods for measuring explosive power production, the relationship between BOMB distance and actual power production was not as strong (Mayhew et al., 2005).

The backwards overhead shot throw (BOST) test is commonly used in physical testing batteries for the throws events (Jones, 1998). The BOST test is biomechanically similar backwards overhead medicine ball throw (BOMB) test and is believed to be more useful than the BOMB when testing throws events athletes. The reason for that is because the use of standard competition-weight implements used by the BOST test is as practical as a field test and anecdotally allow the prediction of actual competitive throwing distances from the results (Jones, 1998). However, little research is available on the validity and reliability of the BOST as a test of explosive power.

From the above research on the BOMB throw, the BOST test shows promise as a potentially valuable performance predictor in the throws events. However, it is clear that further research is warranted. In addition to the somewhat equivocal results regarding the validity of the BOMB throw, no studies have examined the validity of the BOST test as an indicator of performance readiness in throws athletes. Also, none of the above studies have assessed the role of factors such as testing technique that may contribute to variation in performance outcomes.

Explosive power production can be improved by long-term training intervention (Lyttle, Wilson, & Ostrowski, 1996; Newton & Kraemer, 1994). In the short term, performance in activities such as jumping and sprinting, which require explosive power production, is enhanced when performed three to twenty minutes after a single bout of resistance exercise (Gourgoulis, Aggeloussis, Kasimatis, Mavromatis, & Garas, 2003; Güllich & Schmidtbleicher, 1997; Sale, 2002; Matthews, Matthews, & Snook, 2004; Young, Jenner, & Griffiths, 1998; Aagaard et al., 2002; Sargent & Dolan, 1987). Anecdotal evidence exists for the ergogenic effects of resistance exercise warm-up on competitive power performance (Matthews et al., 2004).

Given the benefits of a pre-exercise resistance training bout on explosive power performance during a workout, Young and colleagues (1998) suggest further exploring the possibility of performing a weight training workout immediately before a competition to aid performance. One special consideration for competition versus the practice setting is the extended period between the resistance training bout and the actual competitive performance. In the sport of athletics, lengthy check-in and event warm-up procedures, as well as the lack of available weight training facilities at the competition venue, would extend the time between a resistance training bout and the first competitive throw could be several hours. (Matthews et al., 2004).

Many benefits of a pre-performance warm-up are dependent on elevated muscle temperature and therefore can be expected to resolve shortly after the cessation of activity (Biener, Battaglini, Padua, & Hirth, 2007; Bishop, 2003). However, several neural mechanisms for performance enhancement may extend beyond the three- to twenty-minute window examined in most studies. For example, one justification for the prescription of heavy-load resistance exercise immediately prior to explosive power performance in training, a practice called "contrast loading", is the resulting activation of the central nervous system (Young et al., 1998). In addition, dynamic warm-up movements such as running have been shown to increase power production human muscle by decreasing reflex inhibition (Rosenbaum & Hennig, 1995). Warm-up activities such as resistance exercise may reduce competitor anxiety and improve psychological preparedness (Biener et al., 2007; Bishop, 2003; Fry, Stone, Thrush, & Fleck,1995). Additionally, it is expected that physiochemical and neurological causes of fatigue, such as intramuscular lactic acid accumulation and low-frequency motor unit fatigue, should be resolved or attenuated by the end of the twenty-minute window (Robinson et al., 1995; Sargent & Dolan, 1987; Bentley & Lehman, 2005) and therefore can be expected to detract less from performance.

While many studies have looked at the effects of a resistance exercise warm-up on immediately subsequent (i.e., up to twenty minutes post-exercise) explosive power performance, few studies have examined the decay in performance improvement over several hours after the weight training session (deVillarreal, González-Badillo, & Izquierdo, 2007; Woolstenhulme, Bailey, & Allsen, 2004), and to the knowledge of these investigators, none have looked at this phenomenon in athletics participants in the throws events.

STATEMENT OF PURPOSE

The primary purpose of this study is to assess the validity of the BOST against the more commonly-used VJ as a measure of explosive power production. The secondary goal of this investigation is to determine if performing a morning total-body resistance exercise workout affects backwards overhead shot throw (BOST) and vertical jump (VJ) performance in an afternoon session four to six hours later.

HYPOTHESES

- H1: BOST performances and VJ peak power outputs will be significantly correlated when not preceded by a morning resistance training workout four to six hours earlier (Trial 1 – Control Condition).

- H2: BOST performances and VJ peak power outputs will be significantly correlated when preceded by a morning resistance training workout four to six hours earlier (Trial 2 – Experimental Condition).

- H3: Mean VJ peak power output will improve after a morning resistance training workout four to six hours later, as compared to the control condition of no morning workout.

- H4: Mean peak performance in the BOST will improve after a morning resistance training workout four to six hours later, as compared to the control condition of no morning workout.

LIMITATIONS

- Dietary and sleep patterns will be evaluated qualitatively by recall but are not actually measured or controlled for here (Brooks, Fahey, &. Baldwin, 2005).

- One-repetition maximum lifting capacity in the back squat and power clean lifts will be estimated from a submaximal test (Brzycki, 1993; Franklin, Whaley, Howley, & Balady, 2000).

- Loads necessary and sufficient to produce maximal motor unit recruitment and power production in the power clean and back squat exercises are estimated and not directly measured (Gourgoulis et al., 2003; Tan, 1999; Newton & Kraemer, 1994).

- The current training state of the participants is not controlled for here.

DELIMITATIONS

- All participants will be experienced collegiate and post-collegiate athletes in the throwing events in the sport of athletics.

- The warm-up protocol will be standardized for the familiarization session, the resistance training bout, and both trials.

- Hydration status will be controlled for using both urine specific gravity testing and body mass measurement before each trial as well as the resistance training bout.

- Resistance exercise bout and trial start times will be standardized within and among participants to minimize the effects of diurnal changes in hormonal and neurological milieu on testing results.

- This investigation seeks to determine if a performance effect of resistance training exists. Direct measurement of the potential causes of any performance effect, such as changes in hormonal profile or peripheral or central nervous system activity, are points for future study.

DEFINITION OF TERMS

- Take-off: In a VJ, the point at which the feet leave the ground.
- Countermovement: A movement which causes the muscles to be stretched before contraction to increase muscle force production. In a VJ, a dynamic hip and knee bend immediately prior to extension and subsequent take-off.
- Arm Involvement: In a VJ, the upward swing of the arms from the shoulder prior to take-off.
- VJ Peak Power Output: The maximum power, in watts, produced at any between the initiation of the countermovement and the take-off.
- VJ Average Power Output: Calculated as the area under the force-time curve generated between the initiation of countermovement and take-off divided by the time elapsed between initiation of countermovement and take-off, expressed in watts.
- VJ Height: Calculated as the difference between the maximum height touched with the upward-extended hand during a VJ and the maximum height touched by that same upward-extended hand during a standing vertical reach.
- Explosive Power Production: Mechanical work performed through force development within the muscle immediately following the initiation of contraction (Aagaard et al., 2002; Newton and Kraemer, 1994).
- Repetitions Maximum ("RM"): In resistance training, the maximum external resistance that can be moved successfully for a set number of repetitions of a resistance exercise (Tan, 1999).

- External Resistance: In resistance training, an object placed on or attached to the body to resist movement at a joint.
- Heavy Load: In resistance training, an external resistance of >80% of 1 RM (Tan, 1999; Newton & Kraemer, 1994).
- Light Load: In resistance training, an external resistance of 30-60% of 1 RM, usually performed at sport-specific speed (Tan, 1999; Newton and Kraemer, 1994).
- Plyometrics: A training method intended to enhance explosive power production through neural disinhibition at the Golgi tendon organ. A countermovement is performed before muscle contraction to exert a stretch with greater force and speed than what is normally experienced in training and competition, resulting in greater force production (Newton and Kraemer, 1994).

ASSUMPTIONS

- It is assumed that participants have not used performance-enhancing pharmaceuticals or consumed substances such as alcohol or illegal drugs that could affect the results prior to or while enrolled in the study.

SIGNIFICANCE

Since the throwing events in athletics rely on power production from the core and upper extremity musculature as well as the lower extremities, it is useful to assess the validity of the BOST as a potential field test of total-body explosive power production. Additionally, given the exceptional level of dependence of the throwing events on internal factors such as physical conditioning and preparedness, versus external influences such as strategy, the potential for an acute bout of resistance exercise to enhance competitive throws performance merits future investigation. Research has demonstrated the beneficial effects of a resistance exercise warm-up on subsequent athletic performance within a three- to twenty-minute window following the resistance exercise. However, further investigation is needed to determine if the effect remains four or more hours after the weight training session – a period of time that makes the use of a resistance exercise warm-up more feasible in a throws competition situation. The results of this investigation will help to determine ideal training practices for athletes and coaches involved in throwing events in the sport of athletics. Currently, the NCAA Division I rules do not permit required strength and conditioning sessions on the same day as a competition, although these athletes may perform a pre-competition workout on their own. If a resistance exercise warm-up is shown to be useful by this and future studies, these results may have a bearing on NCAA rules and guidelines.

CHAPTER II

REVIEW OF LITERATURE

This literature review was organized into four sections. The first section presents the review of testing procedures for the assessment of total-body power production in throwing athletes. This is followed by a review of studies that examined the impact of resistance training on improving explosive power performance in humans, presented in the second section. The third section reviews the immediate impact of an acute bout of resistance exercise on explosive power production. Lastly, the fourth section reviews the lasting effects of an acute bout of resistance exercise on the same parameters.

MEASURING EXPLOSIVE POWER

The VJ has been previously validated as a field test of explosive power production (Harman, Rosenstein, Frykman, Rosenstein, & Kraemer, 1990; Johnson & Bahamonde, 1996). In aN investigation involving 18 physically active males aged 28.5 ± 6.9 years, Harman and colleagues (1990) tested vertical jumping performance under four conditions involving some combination of arm involvement (arms or "A" versus no arms or "NA") and countermovement (countermovement or "C" versus no countermovement or "NC"). Three maximal attempts were taken for the four combinations of conditions. Force plate data was used to calculate total body center of mass (TBCM) displacement, or the difference between the height of the participant's center of mass while standing and at the highest point in the jump (Harman et al., 1990). The investigators report high test-retest reliability across all four conditions with regards to several variables. VJ peak power output – the highest power output measured on the force plate – was highly correlated with positive TBCM displacement after takeoff ($r = 0.91$, $p < 0.01$). TBCM displacement and body mass together explained 92% of the variation in VJ peak power output. From these results, it was concluded that the countermovement VJ with arm involvement, the combination of arm and leg movements selected for the present study based on its close resemblance to the BOST, is both a reliable measure of jumping ability and a valid predictor of VJ peak power output (Harman et al., 1990).

Johnson and Bahamonde (1996) independently validated the VJ as a measure of both peak and average power output using a larger sample of a population more similar to the one proposed for this investigation. One hundred eighteen college athletes (69 men and 49 women) in the sports of baseball, softball, basketball, football, tennis, athletics, and volleyball were enrolled in the study. Each participant executed three practice and three maximal effort VJ attempts off of a Kistler force platform. VJ height was measured using a Vertec vertical jump trainer (Johnson & Bahamonde, 1996). Prediction equations were developed from force plate data, VJ height, and anthropometric measurements using stepwise multiple regression analysis. The following regression equation was developed for VJ peak power output, where P = power (in watts), VJ = vertical jump (in centimeters), m = mass (in kilograms), and h = body height (in cm):

$$P_{peak} = 78.5\ VJ + 60.6\ m - 15.3\ h - 1308\ (R^2 = 0.91,\ SEE = 462\ W)$$

The above variables were selected on the basis of ease of measurement in the field as well as predictive value. It was concluded that the VJ is a valid predictor of both peak and average power output. The best of three VJ trials was recorded for analysis, so no comparison can be drawn on the test-retest reliability between this and the previous study. In this case, VJ height was measured, an easier field calculation than the TBCM displacement measurements reported in the Harman investigation (1990). (Johnson & Bahamonde, 1996).

The backwards overhead shot throw (BOST) is a commonly-used test of total body explosive power production for the throws events (Jones, 1998). It is unclear whether the use of competition-weighted implements adds to the throws-specific predictive value of the test, but more importantly, the incorporation of readily-available equipment makes the test superior on the basis of its practicality in the field setting. However, little research exists on the validity of this test. For this reason, it is useful to examine research using the biomechanically similar backwards overhead medicine ball (BOMB) throw, which has been previously validated.

Stockbrugger and Haennel (2001) have previously studied the accuracy and validity of the BOMB test with a three-kilogram medicine ball, using VJ power output and VJ height as benchmarks. Twenty competitive outdoor sand volleyball players (ten males and ten females) were recruited. Following a same-day familiarization session, participants were tested in the VJ and BOMB throws in that order (three attempts in each). At least five but not more than twenty days later, the participant returned to re-test body mass, VJ, and the BOMB throw. VJ power production was calculated for both testing sessions using the Lewis formula (Stockbrugger & Haennel, 2001). It was not specified whether the calculated VJ power production was a peak power or average power value. Intraclass correlations and Pearson correlations for test/re-test values on VJ, BOMB throw, and VJ power output showed that all three tests demonstrated very strong test/re-test reliability. It was determined that body mass explained the largest amount of variance in VJ power output at 89% (SEE ± 10.855 kg • s^{-1}). Body mass accounted for 63.1% of the variance in BOMB throw as well (SEE ± 2.068 m). The investigators concluded that BOMB throw distance was a better predictor of VJ power production than of VJ height because of the large contribution of body mass to the total variation in both VJ power output and BOMB distances (Stockbrugger & Haennel, 2001). It remains to be seen whether this relationship will hold up when heavier weights (4k g and 7.26 kg) are used and how standardization of implement weights by gender will affect the relationship between VJ peak power output and and BOST performance.

The same researchers later examined whether performance in the BOMB test in power athletes was specific to sport demands. Twenty male "jump" (volleyball players) and "nonjump" (wrestlers) athletes were recruited. The jump athletes were aged 18.9 ± 1.4 and 83.2 ± 8.9 kg in weight. The nonjump athletes were 20.0 ± 2.9 years in age and weighed 84.8 ± 25.3 kg. Each was assessed for vertical jump, BOMB throw, chest medicine ball throw, 1 RM bench press, and 1 RM leg press, on two separate occasions. VJ power output and leg press/bench press totals were also calculated (Stockbrugger & Haennel, 2003). The relationship between BOMB throw and VJ power output in jump athletes was confirmed in this study. The two groups differed on which absolute performance parameters were correlated with BOMB results. However, when strength and power parameters were expressed relative to body mass, the results for both jump and nonjump athletes exhibited significant correlations between BOMB throw and VJ height as well as BOMB throw and chest medicine ball throw (Stockbrugger & Haennel, 2003). Based on these results, it was confirmed that BOMB throw results are a good indicator of lower body power production, as assessed by VJ power production. In addition, the strong correlation with upper body power production (chest medicine ball throw relative to body mass) validates the BOMB throw as a total-body explosive power measure. That validity was established in two very different groups of athletes suggests a strong chance for validity in other intermediate populations.

In the above two studies by Stockbrugger and Haennel (2001, 2003), the Lewis equation was used to calculate VJ power output. There is some disagreement as to the validity of the Lewis equation as a calculation of power index (Mayhew et al., 2005; Johnson & Bahamonde, 1996). For this reason, the research team led by Jerry Mayhew (2005) again sought to validate the BOMB throw as a field test of VJ power production (both peak and average power output, in this case) this time measuring the latter directly using a force plate. Forty trained NCAA Division II football players performed two maximal VJ trials from the force plate to measure power output directly, at the same time using a Vertec Vertical Jump Trainer set up over the platform for VJ height measurement. This was followed by three attempts in the BOMB throw, this time using a 7 kg medicine ball, a weight more similar to that designated for the male participants in the present proposed study. When BOMB performance was correlated to VJ peak and average power outputs calculated from force plate measurements, the relationship was significant but moderate ($r_{peak} = 0.59$, SEE ± 794 W). Whereas the relationship between power output and body mass was strong in previous studies (Harman et al., 1990; Johnson & Bahamonde; 1996), coefficients of variation between body mass and VJ peak power output here were accordingly low ($R^2 = 0.13$). To facilitate comparison between this investigation and the 2001 study by Stockbrugger and Haennel, Mayhew and colleagues (2005) calculated VJ power output from the Lewis equation and correlated it with the BOMB throw, the result of which was a significant ($p < 0.01$) correlation of 0.54. The correlation of BOMB distance to VJ power output was similar among force plate VJ peak power output and VJ power output calculated by both the Lewis and Harman equations ($r = 0.59$, 0.54, and 0.56, respectively; Harman et al., 1990). Taken together with the lack of correspondence between the BOMB to VJ power output correlation obtained by Mayhew (2005) and that in the Stockbrugger and Haennel (2001) study ($r = 0.906$ for the latter study), this evidence weakens the assertion that the Lewis formula is not a valid measure of VJ power output (Mayhew et al., 2005; Stockbrugger & Haennel, 2003). Mayhew and colleagues (2005) proposed that the difference in findings were due to the mixed-sex sample used in the Stockbrugger and Haennel (2001) investigation, as a range of body compositions inherent in gender differences would reduce the effects of body mass on power production. Also, Stockbrugger and Haennel (2001) permitted participants to take practice throws before measuring, but this was not the case in the Mayhew study (2005). Mayhew and colleagues (2005) acknowledged that a learning effect may have caused greater variation in BOMB throw distances and therefore a lower correlation between BOMB results and VJ power production.

In addition, BOMB technique was not assessed in any of these studies as a factor that may contribute to variation in BOMB performances. Stockbrugger and Haennel (2001) specify that the arms be kept straight during the throw and that a jump with full plantar flexion be performed at the end of the movement to produce a movement similar to a VJ. Mayhew and colleagues (2005) state simply that the BOMB throws was performed using the methods used by Stockbrugger and Haennel (2001). However, the photo sequence in the Mayhew (2005) paper depicts a bent-armed throw without a jump at the end, a movement more similar to an Olympic lift than a countermovement jump. Together with the learning effect described in the BOMB results, this suggests that BOMB throw form was not standardized (Stockbrugger & Haennel, 2001;). This suggests that if the biomechanically-similar BOST is to be validated against VJ power output, BOST technique must be accounted for.

RESISTANCE TRAINING AND EXPLOSIVE POWER

Resistance training produces several physiological changes that, when used on a consistent basis, can lead to adaptations beneficial to explosive power production (Kraemer et al., 1990; McMillan et al., 1993). Long-term (more than eight weeks) training adaptations include changes in tissue architecture such as muscle hypertrophy, increased pennation angle of the muscle fibers to the line of force production, and myosin heavy-chain (MHC) isoform conversion (Brooks et al., 2005; Aagaard et al., 2002; Behm & Butterwick, 1995). Thomas and colleagues (1983) performed a multiple regression analysis of twenty-seven physiological and psychological factors presumed to affect the success of power athletes in the sport of athletics (sprinters and jumpers, in this case). Twenty male collegiate athletes were evaluated. The multiple regression analysis revealed that body composition, body weight, and two measures of leg muscle balance – all indices that can be modified with resistance training – combined with the athletes' year in school to explain over 80% of the variation in athletic performance (Thomas, Zebas, Bahrke, Araujo, & Etheridge, 1983).

In order to produce the desired adaptations, exercises within a single bout of resistance training are prescribed according to intensity (prescribed as either the maximum load that can be lifted for a set number of repetitions or as a percentage of one-repetition maximum), volume (product of number of sets and repetitions per set), loading form (concentric, eccentric, or isometric), speed of contraction, and rest period between sets (Tan, 1999). In a five-week training study of 33 weight-trained men aged 20.4 ± 3.5 years, Robinson and colleagues (1995) employed a program of three to five sets of ten repetitions at 10 RM to produce improvements in 1 RM for the back squat exercise. The investigators also found that a longer rest interval of three minutes produced greater longitudinal gains in 1 RM squat than groups doing the same program with either thirty seconds or ninety seconds of rest between sets (Robinson et al., 1995). Benedict Tan (1999) summarized findings in a review four years later, concluding that the workout scheme of heavy loading (70 to 120%) across all loading forms for multiple sets (three or more) of one to six repetitions with three to five minutes of rest between sets is most effective at producing maximal strength gains.

Rhea and colleagues (2002) have since reinforced Tan's assertion of the need for multiple sets of an exercise to produce maximum strength gains. In a twelve-week training study employing sixteen young men aged 21 ± 2.0 years, it was determined that three sets of the bench press and leg press exercises performed between 4 RM and 8 RM three times per week was found to be superior to one set of each exercise at the same intensity for eliciting gains in maximal strength (Rhea, Alvar, Ball, & Burkett, 2002). While Tan advocates sets in the one- to six-repetition range, it appears from the Robinson (1995) and Rhea (2002) studies that sets of as high as eight to ten repetitions can still produce maximum strength gains, provided they are performed at maximum intensity.

While muscle hypertrophy and body morphology are key indicators of the ability to produce force, this is only half of the equation. Explosive power has two components: 1) total force production and 2) the rate at which the force is produced (Newton & Kraemer, 1994; Lyttle et al., 1996; Tan, 1999; Gourgoulis et al., 2003; Ebben 2002; Aagaard et al. 2002). While training with heavy loads (> 80% of 1 RM) to improve total force production has been shown to improve total power production, training with light loads (< 60% of 1 RM) at sport-specific speeds is generally done concurrently for greater performance improvements (Tan, 1999; Lyttle et al., 1996; Aagaard et al., 2002; Lyttle et al., 1996; Newton & Kraemer, 1994).

Changes induced by maximum speed training or short-term (about four weeks) maximum strength training are mostly neurological in nature (Brooks, Fahey, & Baldwin & 2005). The adaptations are reflected in amplified total EMG activity: augmented rate coding and increased incidence of interpolated twitches in low-frequency motor units; increased recruitment and longer duty cycle for high-threshold motor units; reduced inhibition by peripheral mechanoreceptors and subsequent reflex potentiation; and intramuscular (motor unit) and intermuscular (agonist/antagonist/synergist) synchronization (Behm & Butterwick, 1995; Aagaard et al., 2002; Brooks et al., 2005; Bentley & Lehman, 2005). Increased firing frequency and higher incidence of doublets in low-threshold motor units, as well as reduced reflex inhibition and improved inter- and intramuscular coordination increase the rate of force production (Behm & Butterwick, 1995; Aagaard et al., 2002; Bentley & Lehman, 2005). Increased and more sustained recruitment of higher-threshold motor units acts to increase total force production (Brooks et al., 2005).

Training methods previously used to develop the velocity aspect of explosive power production have included multiple (two to six) sets of eight to ten repetitions for each exercise within a workout (Lyttle et al., 1996). Intensities employed to improve the capacity for rapid force development include resistances of 30 to 60% of 1 RM, with resistances in the 30 to 40% range generally producing optimal power production (Newton & Kraemer, 1994; deVillarreal et al., 2007). In this type of training, it is not the actual load but the intent to move the resistance with maximum velocity that overloads the muscle and prompts a training adaptation (Behm & Butterwick, 1995; Newton & Kraemer, 1994).

Often, maximum strength and maximum speed schemes are combined in the same workout. For example, Häkkinen and coworkers (1988) recruited eight well-trained Finnish weightlifters (aged 23 ± 3 years) with the intent of characterizing the hormonal response to two consecutive intensive weight training sessions four hours apart on the same day. The second session included both Olympic movements and the back squat exercise. Each exercise was performed in multiple sets of one to six repetitions, with resistances ranging from 70 to 110% of 1 RM. The rest intervals were two to three minutes between sets and three to five minutes between exercises (Häkkinen et al., 1988). The nature of the Olympic-style lifts necessitates maximum velocity for successful completion of the lift; therefore, they are usually employed for improving the rate of force production. On the other hand, the back squat exercise, when performed at a high percentage of 1 RM, may be completed successfully independently of barbell speed. Therefore, this lift, when performed at the intensities described in the above study, lends itself mostly to maximum strength gains.

ACUTE RESISTANCE TRAINING AND POWER

Previous investigations have shown short-term enhancement of explosive power performance with prior resistance exercise (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002); Bentley & Lehman, 2005; Fry et al., 1995; Gourgoulis et al., 2003; Güllich & Schmidtbleicher, 1997; Jensen & Ebben, 2003; Lyttle et al., 1996; Matthews et al., 2004; Sargeant & Dolan, 1987 ; Young et al., 1998). Proposed mechanisms for acute (immediate post-exercise) improvement in explosive power performance mirror neurological adaptations to chronic training. These include increased probability of low-threshold motor unit recruitment, called postactivation potentiation (PAP). PAP is thought to be achieved through an accumulation of calcium ions in the pre- and post-synaptic cells, as well as an increase in calcium sensitivity in Type II muscle fibers by phosphorylation of myosin heavy chains (Sale, 2002; Güllich & Schmidtbleicher, 1997). Other proposed mechanisms include improved motor unit synchronization, improved intermuscular synchronization, reduced central and peripheral nervous system inhibition, and increased arousal (Güllich & Schmidtbleicher, 1997; Matthews et al., 2004).

The concept of complex training, also called contrast loading, is predicated on the benefits of acute resistance exercise on explosive power performance. (Ebben, Jensen,& Blackard, 2000; Newton & Kraemer, 1994 ; Ebben, 2002 ; Matthews et al., 2004). Complex training entails alternating sets of heavy-load resistance exercises with plyometric exercises of similar movement patterns within the same workout (Ebben, 2002). It is thought that heavy-load resistance exercise improves the training stimulus of the subsequent explosive power production in plyometric movements (Jensen & Ebben, 2003).

Some studies have looked at the effects of resistance training with maximal external resistance on subsequent total force production and explosive power performance. Matthews and colleagues (2004) tested twenty male professional rugby players (23 ± 3.5 years of age) in two 20-meter sprints with and without a 5 RM set of back squats during the ten-minute rest period between sprints. Performing the back squats between sprints produced a statistically ($p < 0.0001$) and practically (0.098 s) improved 20-meter sprint time between trials, while rest between trials had no effect on sprint time (Matthews et al., 2004).

The research team of Young, Jenner, and Griffiths (1998) tested ten men between the ages of 18 and 31 in a loaded countermovement jump using a repeated-measures study design. The loaded countermovement jump was performed on a Smith machine (Melbourne Gym Equipment) with the 19 kg bar resting across the shoulders. The participants squatted down to a self-selected height and immediately jumped for height. Participants performed three sets of loaded countermovement jumps, resting between sets one and two and then performing a 5 RM set of half-squats between the second and third sets of jumps. Loaded countermovement jump showed no improvement between sets one and two but increased by 2.8% ($p < 0.05$) from set two to three. It was concluded that resistance exercise such as a 5 RM set of back squats improves subsequent explosive power performance (i.e., in the loaded countermovement jump). (Young, Jenner, and Griffiths, 1998).

Güllich and Schmidtbleicher (1997) indirectly demonstrated the effects of PAP on athletic performance by recording power production changes induced by maximum voluntary isometric contractions (MVC's). For the MVC's, subjects were situated supine on a gymnastics mat, with the leg resting on a 22 cm box and the ankle held in 90° of dorsiflexion such that plantar aspect of the foot against a force plate. Participants were instructed to plantaflex as forcefully as they were able against the force plate. No movement was produced at the ankle joint. Ten trained power athletes and seven untrained physical education students were recruited for the study. The focus of the study was the H-reflex arc, which is normally activated via Group 1a afferent stimulation and amplifies the initial force output from muscle activation (Hodgson, Docherty, & Robbins, 2005). Since the H-wave amplitude changes according to the number of muscle fibers recruited during the initial muscle contraction, the H-wave is a useful indicator of motor unit recruitment. H-reflex response was recorded before, during, and after five MVC's of the lateral triceps surae muscle. H-wave amplitude was initially depressed during MVC's (probably due to muscle fatigue) but then rebounded at four minutes post-MVC to remain significantly elevated ($p < 0.05$) through the end of the experiment at 13 minutes. It was concluded from the elevated H-reflex arc that more motor units were activated during the electrically-induced contractions following the MVC's than were activated pre-MVC (Güllich & Schmidtbleicher, 1997).

Other investigators have shown no improvement in force production or explosive power performance following heavy-load resistance exercise. Jensen and Ebben (2003) recruited 21 NCAA Division I athletes in the sports of volleyball, wrestling, and the field events of athletics for a study on the optimal rest period for contrast loading. Participants performed six sets of single countermovement VJ repetitions, one before and five after a 5 RM set of squats. The final five countermovement VJ repetitions were performed ten seconds, one minute, two minutes, three minutes, and four minutes after squatting, respectively. Other than the ten-seconds-post jump height, which was significantly lower than the other jumps for both men and women ($p \leq 0.05$), there was no significant difference pre- to post-squat in mean countermovement VJ height or peak ground reaction force (a factor in determining VJ peak power output), regardless of training experience. The investigators concluded that within a workout, there is neither a benefit nor a drawback to performing plyometrics in alternation with heavy-load resistance training in the same workout. It is possible that the repeated-measures study design affected the results. For example, on the countermovement VJ measurements taken four minutes post-squat, participants had already performed four single maximum-effort countermovement VJ attempts during the post-squat rest period. This may have led to a slower rate of recovery and therefore no performance improvement. In addition, Güllich and Schmidtbleicher (1997) didn't detect a performance improvement beyond pre-test measurements until four minutes post-MVC. Had Jensen and Ebben (2003) continued to test beyond four minutes of recovery time, it is possible that an improvement in countermovement VJ performance may have been detected.

Other studies have incorporated the use of resistance exercise with light external resistance moved for maximum power production to examine the effects on subsequent explosive power performance. Gourgoulis and coworkers (2003) examined the change in VJ performance pre- to post-resistance exercise using multiple submaximal sets of the back squat between two sets of countermovement VJ trials. Twenty physically active men ages 21.8 ± 1.1 years performed two vertical jump trials, five sets of two back squat repetitions of increasing intensities ranging from 20% to 90% of 1 RM, and then two more countermovement VJ trials immediately following the squats. All squat repetitions were executed at maximum velocity. A statistically significant ($p < 0.05$) improvement of 2.39% in countermovement VJ height was observed pre- to post-test (Gourgoulis et al., 2003).

It is interesting to note that in three investigations, a greater performance improvement was seen in the more highly-trained participants. In the Gourgoulis group study (2003), when the participants were split by back squat maximal strength, the improvement in VJ performance increased from 2.39% to 4.01% over pre-test values for the participants with higher maximal strength values. Young and colleagues (1998) noted that the single participant with the heaviest 5 RM back squat also showed the greatest improvement in loaded countermovement jump following the back squat. When Güllich and Schmidtbleicher (1997) separated out the athletes from the physical education students in their statistical analysis, H-reflex amplitude not only remained elevated post-MVC but appeared to continue to rise through the completion of the study, whereas the mean value for the untrained group returned to baseline within ten minutes of the last MVC.

As previously stated, explosive power has two components, total force production and the rate at which the force is produced (Newton & Kraemer, 1994; Lyttle et al., 1996; Tan, 1999; Gourgoulis et al., 2003; Ebben 2002; Aagaard et al. 2002). Studies have reported that resistance exercise at submaximal intensity fails to improve total force production. Güllich and Schmidtbleicher (1997) also noted that a submaximal (i.e., three repetitions at 90% of 1 RM) resistance training warm-up failed to induce improvements in force production or explosive power performance. Similarly, Gourgoulis and colleagues (2003) recorded a non-significant change in force production during a countermovement jump during their investigation. However, they did observe an increase in countermovement jump height (explosive power performance) with a submaximal warm-up (Gourgoulis et al., 2003). The lack of improvement in total force production is expected. If calcium ion availability is increased in pre- and post-synaptic cells through PAP, it would only affect the activation of low-threshold motor units, since calcium ion saturation would still occur at the high stimulation frequencies associated with high-threshold motor units. Therefore, the rate of force production within the muscle, but not the maximum force produced, would be affected (Sale, 2002). When performing a bodyweight explosive power activity against gravity, such as the VJ, improved rate of force production would enhance VJ performance, even if total force applied is unchanged. It is possible that the submaximal percentage of 1 RM used in the Gourgoulis study (2003) still provided a maximal stimulus because the participants in the latter investigation were encouraged to move the submaximal resistance with maximum velocity (Lyttle et al., 1996; Gourgoulis et al., 2003). It is not noted whether this was a requirement of the participants in the in the Güllich and Schmidtbleicher study (1997). This would explain why Gourgoulis and colleagues (2003) observed a significant increase in VJ height while Güllich and Schmidtbleicher (1997) did not.

DURATION OF THE EFFECTS OF ACUTE TRAINING

Previous studies have examined the effects of a recovery window somewhere between three and twenty minutes post-exercise (Sargeant A.J. and P. Dolan, 1987;

Jensen & Ebben, 2003; Ebben et al., 2000; Gourgoulis et al., 2003; Güllich & Schmidtbleicher, 1997; Matthews et al., 2004; Young et al., 1998). However, evidence in these and other investigations suggests that performance augmentation from a single resistance exercise bout may extend well beyond this short window. For example, the above-detailed study by Güllich and Schmidtbleicher (1997) showed steadily-increasing elevations in H-reflex arc intensity in the athletic subgroup through thirteen minutes post-MVC, with no indication of a downturn in the trend at that point (Güllich & Schmidtbleicher 1997). This suggests that the increased motor unit recruitment indicated by the elevated H-reflex arc would remain well beyond the thirteen minute window recorded.

Low-frequency fatigue (LFF) reduces the release of calcium ions from the sarcoplasmic reticulum in response to repeat low-frequency stimulation of less than 100 Hz that occurs during low- to moderate-intensity exercise, physical labor, or activities of daily living (Bentley & Lehman, 2005; Hodgson et al., 2005). Intermittent failure of excitation-contraction coupling in low-threshold fibers affects rate of force production. While LFF may last hours or even until the following morning (Hodgson et al., 2005), its effects may be reduced with a greater recovery period. Additionally, it is expected that other physiochemical causes of fatigue, such as intramuscular lactic acid accumulation, should be greatly reduced if not resolved beyond twenty minutes post-exercise (Robinson et al., 1995; Sargent & Dolan, 1987). Therefore, reduced fatigue in comparison to neuromuscular potentiation should produce a net improvement in explosive power production and athletic performance (Biener et al., 2007; Bishop, 2003).

In addition to the neuromuscular benefits of a resistance exercise warm-up, a morning exercise session may have positive psychological effects on same-day competitive performance. Fry and coworkers (1995) recruited nineteen male junior-aged Olympic lifters in a crossover study design examining the psychological effects of a morning workout session on afternoon simulated competitive lifting performance. Participants tested on two separate days, with the afternoon competition preceded either by rest or a morning training session five hours prior. Six of the nineteen participants improved in vertical jump performance as well as competition-rules clean and jerk and snatch lifts in the afternoon. Of the "responders" that improved with a preceding workout, all reported a higher level of anxiety at all times on an abridged Profile of Mood States questionnaire throughout testing, with no differences between testing conditions. It was concluded that the morning workout helped lessen the detrimental physical effects of this anxiety so that the athletes were able to perform well competitively despite it (Fry et al., 1995).

In an innovative study investigating both recovery period and type of warm-up, deVillarreal and colleagues (2007) found performance in the countermovement VJ remained elevated pre- to six hours post-exercise when a maximal-effort warm-up was performed. Twelve males aged 21 to 26, each with two to four years of resistance training experience and six years of volleyball experience, were recruited to participate. In a balanced, randomized study design, participants performed one of seven warm-up protocols over the course of four weeks: 1) 3 x 5 repetitions of the loaded countermovement jump (performed as described above), one minute of rest between sets; 2) 2 x 4 repetitions of the back squat at 80% of 1 RM followed by 2 x 3 repetitions of the back squat at 85% of 1 RM, one minute of rest between sets; 3) 2 x 4 repetitions of the back squat at 80% of 1 RM in the back squat followed by 2 x 2 repetitions of the back squat at 90% of 1 RM, one minute of rest between sets; 4) 3 x 5 repetitions of a plyometric exercise with no external resistance, one minute rest between sets; 5) a specific warm-up for a volleyball match; 6) 3 x 5 repetitions at 30% of 1 RM in the back squat, one minute rest between sets; and 7) no workout (deVillarreal et al., 2007). Height achieved in the VJ was greater after warm up protocols incorporating an external load or a volleyball-specific warm-up incorporating maximal-effort jumping; however, no improvement was seen six hours out (deVillarreal et al., 2007). It is of note that, of all warm-up protocols consisting of exercises performed against an external resistance, two protocols with submaximal loads performed with maximum effort did not produce an increase in measured performance parameters in the six hours post-exercise measurement. It was concluded by the investigators that near-maximal loading (> 80% of 1 RM) or movement-specific exercises (i.e., loaded countermovement jump for the VJ tests) tended to have the longest-lasting effects. The results obtained by deVillarreal et al. (2007) were consistent with the findings of Fry and colleagues (1995). The morning workout used in the Fry et al. (1995) study – a total of eight sets of three repetitions in the snatch pull and clean pull at 85% of 1 RM of the snatch and clean, respectively – may not have been of sufficient intensity to produce a performance effect five hours post-exercise in the majority of the participants.

In addition, apparently similar loaded and plyometric movements have been shown to vary considerably upon further biomechanical analysis. One study involving seven male NCAA Division I intercollegiate athletes compared the hang snatch to the unloaded vertical jump. Significant kinetic but not kinematic similarities were found between the two tests (Canavan, Garrett, & Armstrong, 1996). Canavan, Garrett, and Armstrong (1996) concluded that biomechanical differences such as those cited above could explain why a back squat warm-up performed at a high velocity would fail to have a lasting effect on loaded countermovement jump performance, a plyometric movement that looks similar in part to the back squat.

Using female basketball players, Woolstenhulme, Bailey, and Allsen (2004) reported no change in VJ height six hours after a resistance training workout. The resistance training workout included three to six sets each of seven different exercises performed at between 5 RM and 12 RM (Woolstenhulme et al., 2004). Training history may have been a factor, considering the athletes had only been resistance trained for four weeks prior to the investigation. The lack of a performance improvement in any of the testing parameters six hours out from the resistance workout is in agreement with the findings of the aforementioned studies by Güllich and Schmidtbleicher (1997), Young et al. (1998), and Gourgoulis et al.(2003). Güllich and Schmidtbleicher (1997) saw the H-reflex arc elevation detected in the triceps surae muscle following maximum voluntary contraction resolve within ten minutes of the maximum voluntary contractions in the physical education student group, while the H-reflex arc amplitude remained elevated in the national-class speed-strength athletes measured. Young and colleagues (1998) measured loaded countermovement jump height with and without a preceding set of 5 RM set of back squats and reported that the participant with the highest 5 RM also demonstrated the greatest increase in loaded countermovement jump height between trials. Gourgoulis and colleagues (2003) compared VJ height prior to and following a warm-up of back squats and reported that subjects with greater maximal strength (i.e., higher 1 RM in the back squat) showed a greater improvement between trials than subjects with lower maximal strength.

SUMMARY

The vertical jump, a commonly-used field test of lower body explosive power, has been previously validated. The BOST commonly used is a throws-specific test of total-body explosive power production that has not been validated as thoroughly. Because of the dearth of information on the BOST, it is useful to examine the literature on the biomechanically similar BOMB test. Investigators have assessed the BOMB as a measure of total-body explosive power production, but there is some disagreement as to the validity of the test. No previous study has assessed BOMB form as a contributing factor to BOMB test validity. Based on related research from the BOMB test, the BOST should be promising as a field test of total body power production, but research is needed to determine its validity.

The capacity for explosive power production may be trained using a combination of light resistance training performed at maximal speeds and heavy resistance training. Explosive power may also be improved by a single bout of resistance exercise immediately prior to the athletic performance. The types of workout schemes used to produce this effect are similar to those used in training for a chronic adaptation. The acute neuromuscular adaptations to resistance exercise mirror those attained through chronic resistance training.

Little research has been done on the long-lasting acute affects of resistance exercise, the results of which suggest potential for a long-term elevation in performance.

The mechanisms that produce a short-term performance improvement may last longer than the three- to twenty-minute window most studied. In addition, the effects of fatigue from the resistance exercise may be attenuated with a longer rest interval. Further research is required to assess whether an acute resistance exercise bout affects explosive power performance several hours later.

Therefore, the primary purpose of this study is to assess the validity of the BOST against the more commonly-used VJ as a measure of explosive power production in experienced collegiate and post-collegiate athletes in the throwing events in the sport of athletics. The secondary goal of this investigation is to determine if performing a morning total-body resistance exercise workout affects BOST and VJ performance four to six hours later.

CHAPTER III

METHODS

SUBJECTS

Fourteen collegiate and post-collegiate athletes in the throwing events in the sport of athletics, aged 18 to 28, gave written informed consent for participation in the study. Participants were required to have had at least one year of experience in one or more of the shot put, discus, hammer, javelin, or weight throw events in athletics. All must have had at least one year of weight training experience that includes the power clean and back squat lifts. For both criteria, the experience must have been current within two years of study enrollment. "One year" was defined as one or more of the following:

- One calendar year on the active roster in a college varsity intercollegiate program;
- A total of three full regular seasons of high school or summer club team active participation, and/ or
- A total of at least six open competitions over the course of no fewer than five and no more than twelve consecutive months.

All participants were healthy and free of any orthopedic injury that would have precluded successful completion of study requirements. The procedures used in this investigation were approved by the Biomedical Institutional Review Board for Human Subjects Research at the University of North Carolina at Chapel Hill (Study # 09-0491).

EXPERIMENTAL DESIGN

This study was performed using a counterbalanced design with respect to the performance test order within the trials, where subjects served as their own controls. Seven participants performed the VJ before the BOST in the testing sessions, while the other seven performed these tests in the reverse order. Participants were matched by non-random assignment with the intent of balancing the groups with respect to gender, height, body mass, and predicted 1 RM in the back squat and power clean exercises.

Following a familiarization session on a separate day, Trial 1 (Control condition) consisted of a resting in the morning and then testing in the VJ and BOST in the afternoon four to six hours later. Trial 2 (Experimental condition) included a resistance training bout in the morning and VJ and BOST testing in the afternoon. Familiarization and both trials were performed in sequence within one week to control for the effects of change in training state on testing results, with sessions rescheduled on the basis of hydration status, excessive muscle soreness, or scheduling conflicts. Session start times were standardized within a two-hour window to minimize the effects of diurnal hormonal changes on the testing performances (Biener et al., 2007; Brooks et al., 2005). A graphic representation of the study design is shown in Figure 1 below.

FIGURE 1: STUDY DESIGN. Familiarization and both trials were completed within one week.

	FAMILIARIZATION	TRIAL 1: CONTROL CONDITION	TRIAL 2: EXPERIMENTAL CONDITION
MORNING		Rest (No resistance exercise administered)	Questionnaire & USG Warm-up Back squat Power clean
AFTERNOON	Informed Consent Par-Q Demographics & Anthropometrics Warm-up BOST & VJ Power clean 4 RM testing	Questionnaire & USG Warm-up BOST and VJ testing	Questionnaire & USG Warm-up BOST and VJ testing

DATA COLLECTION AND INSTRUMENTATION

Forms: Informed consent was obtained using the University of North Carolina-Chapel Hill Consent to Participate in a Research Study for Adult Participants, Social Behavioral Form (Appendix A). Physical preparedness for study participation was assessed using the Participation Questionnaire (PAR-Q; Heyward, 2002). Baseline anthropometrics, demographics and eating and sleeping patterns were recorded using the Familiarization Session Questionnaire (Appendix B). Pre-session body mass, urine specific gravity, eating and sleeping patterns, and physical activity preparedness were assessed using the Pre-Session Questionnaire (Appendix C). BOST technique was assessed using the rubric in Appendix D.

Anthropometrics and Urine Specific Gravity Measurements: Participant height was measured using a Perspective Enterprises Portable Infant/Adult stadiometer (Portage, Michigan, USA). Body mass was measured using a medical scale (Model No. BP15-400T, Type 15; Chatillon, Largo, Florida, USA). Reach was assessed with a 15-meter closed-reel fiberglass tape measure (Economy model, M-F Athletic, Cranston, Rhode Island, USA). Urine specific gravity was assessed using a refractometer (TS Meter, American Optical Corp., Keene, NH, USA).

Resistance Exercise and Performance Testing: The back squat and power clean exercises were performed on a wooden platform using a 20 kg Olympic lifting bar with steel and rubberized Olympic lifting plates (Eleiko Sport AB, Halmstad, Sweden). Vertical jump was measured using a Vertec jump measuring device (Gill Athletics, Champaign, IL, USA). The backwards overhead shot throw was performed using a 4 kg and 7.26 kg polyvinyl soft-shelled shot (Hadar Athletic, Humboldt, Iowa, USA). The throws were measured using a 50-meter open-reel steel measuring tape (M-F Athletic, Cranston, Rhode Island, USA). Rest and warm-up activity intervals were timed using a handheld stopwatch (AccuSplit AX602, Livermore, California, USA).

FAMILIARIZATION SESSION AND TRIALS 1 AND 2

Familiarization Session

The first portion of the familiarization session was performed in the lab, where informed consent administration, pre-enrollment screening for inclusion or exclusion, and recording of demographics and anthropometrics were performed. Participants next moved to an indoor field house facility, where they were introduced to the warm-up protocol first and then the BOST and VJ tests. The session concluded in a weight room facility where 4 RM testing for the power clean and back squat were performed.

Questionnaires, Anthropometrics and Baseline Data: During this session, the Principal Investigator (PI) informed the participants of the anticipated risks and benefits of the study and asked for signed informed consent. The PI then asked participants to fill out a Physical Activity Readiness Questionnaire. Responses to the PAR-Q were evaluated by the PI or the Faculty Advisor to determine the participant's physical readiness for study participation. Participants were also asked about any history of illness or orthopedic injury that may affect their ability to complete the demands of the study.

The PI then proceeded with anthropometric measurements and the Familiarization Session Questionnaire. Subject height was recorded to the nearest 0.1 cm using a stadiometer. Body mass was measured to the nearest 0.1 kg and recorded, along with information on gender and age. Standing vertical reach was determined for later VJ performance calculation. For this assessment, participants stood with their backs to a wall and their dominant arm extended overhead. Reach was read from the tip of the middle finger on the raised hand off of a fiberglass tape measure secured to the wall.

Warm-up Protocol: Following a demonstration of each warm-up skill, participants were asked to complete each in the dynamic warm-up protocol detailed in Biener, et al. (2007), with time spent on each to correct form and answer participant questions. This warm-up was typical in length and intensity of that used by experienced throwers such as those recruited for this study. The warm-up consisted of 20 different movements, each over a straight 20-yard distance. The first 10 yards consisted of stretching poses or movements interspersed with jogging steps. The second 10 yards was covered with a run at some percentage of the participant's fastest sprint, as perceived by the participant. At the end of 20 yards, the participant was instructed jog back to the starting point. The series of dynamic movements and the subsequent running speed was performed in this order:

1) *Ankle Skip:* Skipping with emphasis on using the plantar flexors to propel the body off the ground. Participants jogged the second ten yards.
2) *Forward Run:* Participants jogged the full twenty yards.
3) *Backward Run:* Participants ran backwards for the first ten yards and jogged the second ten yards.
4) *Russian Walk/Quad Pull:* Intended to stretch the hamstrings and hip flexor muscle groups. While standing in single-support, the hip was flexed and the knee was picked up to the chest. The leg was then extended forward. The hip was then extended, causing the leg to sweep down to the ground. The knee was then flexed and the foot is grasped with the ipsilateral hand. The gluteal muscles were then contracted to open the hip angle while the hand pulled the knee into further flexion. Participants covered the second ten yards at perceived 50% of their maximum sprint.
5) *Knee Hug/Side Lunge:* Performed facing sideways to the direction of movement. The movement was initiated in single-support with the hip flexed and the knee hugged to the chest. The knee was then released and a step was taken laterally in the direction of movement, flexing the knee of the leading leg and both hips. The support leg remained in extension. The first pose was designed to stretch the gluteal and hamstrings muscle groups on the non-support leg. The second pose was designed to stretch the hip adductors of the extended support leg. The first

ten yards was performed facing one direction and the second facing the other direction.

6) *Balanced Gluteal Stretch:* Intended to stretch the gluteal muscles and other hip external rotators. Performed in single-support. The knee of the free leg was flexed, the lateral side of the leg laid across the supporting quadriceps muscles, and the hip abducted and externally rotated. (Viewed from the front, the legs formed a figure "4".) The hips and supporting knee were then flexed to a seated position. Participants covered the second ten yards at a perceived 50% of their maximal sprint.

7) *Marching Drill:* Intended to stretch the hamstrings muscle group. Performed in single-support. With the arms abducted to 90° for balance, the free leg was swung into hip flexion and adduction such that the foot touches the elevated contralateral hand. Participants covered the second ten yards at a perceived 50% of their maximal sprint.

8) *Reverse Marching Drill:* Intended to stretch the hamstrings muscles. Performed in single-support. With the free leg extended posteriorly, the hips and trunk were flexed forward and the arms were extended down toward the ground. Participants covered the second ten yards at a perceived 50% of their maximal sprint.

9) *Open Hip:* Intended to loosen the hip joint. Performed standing in single-support. The free leg was flexed at the knee and hip to produce a 90° angle at both joints. With both joints held in flexion, the hip was abducted to 90°. Participants covered the second ten yards at a perceived 50% of their maximal sprint.

10) *Close Hip:* Performed as with the Open Hip drill, only starting with the hip in abduction and then adducting to neutral. Participants covered the second ten yards at a perceived 50% of their maximal sprint.

11) *Side Shuffle:* A lateral galloping movement performed with the hips and knees flexed and the head and chest held vertically. The first ten yards were covered facing one direction and the second ten yards the other direction.

12) *Carioca with High Knee Step-Over:* A lateral running movement where the trailing leg crosseed to step ahead of the leading leg, first anteriorly then posteriorly. When the trailing leg crosses anteriorly to the leading leg, this movement was done with exaggerated hip and knee flexion. The first ten yards were covered facing one direction and the second ten yards the other direction.

13) *Walking Lunge with Rotation:* Intended to stretch the hip flexor muscles. Performed by stepping forward, flexing the leading knee and hip. The back leg was held in extension. The head and shoulders were then rotated in the direction of the lead leg. The stretch was intended to be felt in the hip flexors of the extended leg. Participants covered the second ten yards at a perceived 75% of their maximal sprint.

14) *Butt Kickers:* Forward running with slowed forward progression. Emphasis on knee flexion and hip extension such that the heels were driven towards the gluteal muscles in quick succession. Participants covered the second ten yards at a perceived 75% of their maximal sprint.

15) *High Knees:* Forward running with slowed forward progression. Emphasis on quick hip and knee flexion to 90° in quick succession. Participants covered the second ten yards at a perceived 75% of their maximal sprint.

16) *Prancing:* A forward run with knees held in extension, using the plantarflexors, hamstrings, and gluteal muscle groups to produce movement. Participants covered the second ten yards at a perceived 90% of their maximal sprint.

17) *Power Skip:* Skipping with an emphasis on height. Participants covered the second ten yards at a perceived 90% of their maximal sprint.

18) *Run with 360° Rotation*: Began with a run forward for 10 yards at a perceived 75% of maximum sprint. Participants then stopped and turned in place for one full 360° rotation. Participants covered the second ten yards at a perceived 90% of their maximal sprint.

19) *Run with 360° Rotation:* Performed as above, this time rotating the other direction on the 360° turn.

20) *Acceleration to Sprint:* Forward running, starting at a jogging pace and working up to a full sprint within the first ten yards. Full speed was maintained through the second ten yards.

Vertical Jump: To perform the VJ test, participants started by standing under the apparatus with feet at a self-selected width. They then squatted down without moving their feet and moved immediately to execute a countermovement VJ for maximal height. Participants were encouraged to use an arm swing and a countermovement dip with the legs prior to the jump to maximize jump height. The goal of the exercise was to displace the highest possible plastic crossbar height marker with a raised dominant hand during the jump. See Appendix F for a diagram of VJ testing technique.

Backwards Overhead Shot Throw: To perform the BOST for distance, participants began by standing with their heels on a line. Participants held the shot with two hands at arms' length, squatted down with the shot held between the knees, and then explosively extended the hips, knees, and ankles with maximum effort, releasing the shot upward and backward overhead with arms straight. The goal of the exercise was to throw the shot as far as possible. See Appendix E for a diagram of the BOST technique. Consistent with regulation implement weight assignments (IAAF Competition Rules, 2009) and previously used physical performance testing practices (Jones, 1998; Mayhew et al., 2005), women tested using a four-kilogram shot, and men tested using a 7.26 kg shot.

Weight Lifting: Following the two skills tests, the PI and members of the research team guided participants through a four-repetitions maximum (4 RM) test in the power clean exercise to determine the maximum weight that can be used in the completion of four repetitions of the power clean exercise with proper form (Franklin et al., 2000). Submaximal 4 RM testing was used in this case instead of maximal testing in order to reduce the risk of injury associated with lifting maximal loads (Heyward, 2002; Brzycki, 1993).

The power clean exercise can be described in terms of initial pull, second pull, and catch phases. The starting position was with the feet parallel and shoulder-width apart. The hips and knees were then flexed so that the lifter was able to bend down with a flat back to grasp the bar. With the shoulders directly over the bar, the hand grip was slightly wider than shoulder-width apart, just outside the legs.

The first pull was initiated by standing up, extending the hips, knees, and ankles explosively while keeping the shoulders directly over the bar. The hips were translated anteriorly so that the anterior thighs came into contact with the barbell at the end of this movement. The barbell was further accelerated in the second pull by shrugging the shoulders and then bending the elbows to pull upwards on the bar with the arms. In the catch phase, the hips and knees were flexed quickly to create a dropping motion, allowing the body to move under the bar. The barbell was caught across the clavicles and anterior deltoid muscles of the shoulders and supported with the hands. The barbell was returned to the ground at the completion of the lift by standing up, lowering the barbell to hip height with the arms, then releasing the grip and allowing the barbell to fall to the floor. The rubberized weight plates and platform lifting surface allowed the bar to hit the ground with minimal bouncing or damage to the equipment.

Testing was completed according to American College of Sports Medicine protocol (Franklin et al., 2000), with one exception – 1 RM values were not predicted from anything higher than a 6 RM. This was done to ensure that the lift was performed as explosively as possible and to reduce the risk of injury from fatigue on such a technique-intensive lift. The first set was performed using an estimated 50 to 70% of the participant's perceived 4 RM. The second set was performed at an estimated 80 to 90% of 4 RM. The third set was performed at 100% of estimated 4 RM, based on training history and the performance in the first two sets.

The participant did as many repetitions as possible on the third set, up to six. If the participant performed between one and six successful repetitions, the weight and number of repetitions from the third set was used in the 1 RM calculation. If the participant was able to perform six successful repetitions with submaximal effort, then the weight was then increased and a fourth set was performed. Five minutes of rest was given between sets.

The same protocol was used for a 4 RM test in the back squat exercise, with the exception that a 1 RM maximum was predicted from the heaviest weight performed for ten repetitions or fewer. The back squat was performed with the weighted barbell resting across the upper back over shoulder blades and upper portion of the trapezius muscle and supported with the hands. The knees and hips were flexed until the anterior aspect of the thighs was parallel with the ground. The lift was completed by extending the knees and hips to return to the starting position.

The results of this testing was used to determine the workout weight used for each exercise during the resistance training bout. First, 1 RM was predicted using the equation reported in Brzycki M. (1993): Predicted 1 RM = Weight Lifted · $[1.0278 - (0.0278 \cdot \text{Number of Repetitions Performed})]^{-1}$. The calculated 1 RM value obtained for the back squat exercise was multiplied by 85% and the 1 RM for the power clean by 35% to obtain workout values for the experimental condition resistance training session (Gourgoulis et al., 2003). Before being released for the day, participants were asked to refrain from alcohol consumption and any training activities more intense than activities of daily living, as well as to maintain normal eating and sleeping habits for the remainder of the study.

Trial 1: Control Condition

For this trial, participants reported between 1:00 pm and 3:00 pm. Prior to any activity, participants were given a brief questionnaire orally regarding timing of last meal, sleeping patterns, and qualitative level of fatigue and muscle soreness. To ensure proper hydration status, participants then provided a small urine sample that was analyzed by refractometry for specific gravity. As a backup measure, body mass was also taken and compared with the familiarization session measurement. Dehydration or excessive muscle soreness were cause for rescheduling the session to the following day. All performed the warm-up protocol practiced during the familiarization session. Half of the participants tested the BOST first, whereas the other half tested the VJ first, according to their assigned testing order.

Participants were given three practice and three measured attempts at the BOST test (Duncan et al., 2005). The throw was measured to the nearest centimeter as the distance between the closest point of contact of the implement with the ground and the starting line using a steel tape measure. A rest interval of three to five minutes was given between attempts. The PI, a USA Athletics Level 1 certified instructor, rated the technique of each participant for the three measured throws in total on a 5-point scale, with “1” representing “poor” technique, “2” = “fair”, “3” = “average”, “4” = “good”, and “5” = excellent”. All throws rated at a “3” or better, or the best attempt should no throw meet the requirements for a rating of “average”, were recorded.

For VJ testing, participants completed all attempts in a row, with a one-minute rest interval between attempts, consistent with the protocol used in the investigation by Stockbrugger and Haennel (2003). Each continued to jump for height until no plastic crossbar markers were touched or moved on two consecutive attempts. VJ was measured as the participant's reach subtracted from the height of the plastic crossbar they were able to touch. VJ peak power output was then calculated using the regression equation developed by Johnson and Bahamonde (1996): $P_{peak} = 78.5\ VJ + 60.6\ m - 15.3\ h - 1308$ ($R^2 = 0.91$, SEE = 462W). "P_{peak}" is peak power (in W), "VJ" is maximum vertical jump height attained (in cm), "m" is body mass (in kg), and "h" is participant height (in cm).

Trial 2: Experimental Condition

Morning Session. Participants reported between the hours of 8:00 am and 10:00 am. After the same questionnaire as used before the first testing session, as well as body mass and urine specific gravity measurements, all performed the warm-up introduced in the familiarization session. Participants then completed a two-part weight lifting workout typical of that used in training for explosive power sports, consisting of four sets of the power clean at a light (35% of 1 RM) resistance, one submaximal (50% of 1 RM) set of six repetitions of the back squat as a warm-up, and one set of the back squat exercise at a heavy (85% of 1 RM) resistance and (Gourgoulis et al., 2003; Tan, 1999; Lyttle et al., 1996). Participants were limited to four repetitions per set in the more technically-challenging power clean exercise to ensure maximal effort and barbell speed on each repetition (Lyttle et al., 1996; Tan, 1999; Gourgoulis et al., 2003). Participants were encouraged verbally to move the barbell at the fastest possible speed in both exercises (Behm, 1995; Tan, 1999). At least three but no more than five minutes of rest were taken between each set, and five minutes of rest was given between exercises (Tan, 1999; Robinson et al., 1995; Gourgoulis et al., 2003; Häkkinen et al., 1988; Young et al., 1998).

The second set of the back squat exercise was performed to fatigue, defined as either failure to complete the lift on any single repetition or two successive repetitions with improper form (Tan, 1999), as judged by the PI. Before being released at the end of the session, participants were asked to refrain from exercising until the next testing session, as well as to maintain normal eating habits and to refrain from sleeping or working out.

Afternoon Session. Participants reported four to six hours after the completion of the first session. This period of time was selected because it most closely resembled the time periods used in previous research (deVillarreal, González-Badillo, and Izquierdo, 2007; Woolstenhulme, Bailey, and Allsen, 2004). This is also a feasible amount of time to allow for transit, clerking, practice throwing, and other pre-competition procedures between the resistance training session and the first competitive throw, should a resistance exercise warm-up actually be used on the day of a competition. After the questionnaire, urine specific gravity and body mass measurements, and warm-up procedures, participants will repeat the BOST and VJ tests in the same order as in Trial 1.

STATISTICAL ANALYSES

All data was reduced and analyzed using SPSS Version 16.0 for Microsoft Windows (SPSS, Inc., Chicago, IL). Independent-samples t-tests were used to compare mean age, height, body mass, reach, predicted 1 RM values for the back squat and power clean, and BOST and VJ between the seven participants that performed the BOST first in both trials and the remaining seven that performed the VJ first to examine the potential for an effect of performance test order within each trial. Significance in all cases was determined with a probability value of $p \leq 0.05$.

- H1: Highest recorded BOST distances and VJ peak power scores from Trial 1 (Control condition) were compared using a Pearson correlation.
- H2: Highest recorded BOST distances and VJ peak power scores from Trial 2 (Experimental condition) were compared using a Pearson correlation.
- H3: A paired-samples t-test was used to compare group mean VJ peak power between the test and control conditions. The independent variable was testing condition (morning weight training session or morning rest). The dependent variable was VJ peak power.
- H4: A paired-samples t-test was used to compare mean BOST performance between the test and control conditions. The independent variable will be testing condition (morning weight training session or morning rest). The dependent variable was farthest recorded BOST distance.

CHAPTER IV

RESULTS

The primary purpose of this study was to validate the BOST as a test of explosive power performance against the more commonly used VJ. The secondary purpose was to investigate the effects of an acute bout of resistance exercise in the morning on afternoon vertical jump (VJ) peak power output and backwards overhead shot throw (BOST) performance.

PARTICIPANTS

Participant anthropometric characteristics and performance statistics are reported in Table 1 below:

TABLE 1. Participant Anthropometric Characteristics and Performance Statistics

	Total (N = 14) Mean	± SD
Height (cm)	178.8	11
Body Mass (kg)[+]	95.1	26.9
Age (yr)	20.7	2.5
Reach (cm)*	231	14
Power Clean 1 RM (kg)**	99.9	33.5
Back Squat 1 RM (kg)**	148.5	54.7

[+]Body mass is reported from familiarization session measurements.

Independent-samples t-tests were performed to compare means for height, body mass, age, reach, power clean predicted 1 RM and back squat predicted 1 RM between groups with respect to performance test order within trials. No significant difference was found between groups for height ($p = 0.354$), reach ($p = 0.228$), body mass ($p = 0.167$), age ($p = 0.154$), reach ($p = 0.228$), power clean 1 RM ($p = 0.643$), or back squat predicted 1 RM ($p = 0.928$).

HYPOTHESES 1 AND 2

Hypotheses 1 and 2, BOST performances and VJ peak power scores will be significantly correlated for Trials 1 and 2, respectively, were analyzed using a Pearson correlation. Highest recorded BOST distance and VJ peak power, calculated from highest attained VJ and body mass for each participant during each trial were used in the analysis. A significant correlation of $R = 0.646$ ($R^2 = 0.417$) was found between BOST distance and VJ peak power for Trial 1 ($N = 14$, $p = 0.012$). A significant correlation of $R = 0.656$ ($R^2 = 0.430$) was found between BOST distance and VJ peak power for Trial 2 ($N = 14$, $p = 0.011$).

HYPOTHESIS 3

Hypothesis 3, mean VJ peak power will improve after a morning resistance training workout, as compared to the control condition of no morning workout, was analyzed using a paired-samples t-test. VJ peak power was calculated from maximum VJ height attained in each trial and the body mass measured before each trial. Mean VJ peak power was 6901 ± 1531 W for Trial 1 and 6943 ± 1490 W for Trial 2. No statistically significant difference was detected for VJ peak power between trials ($N = 14$, $t = -0.71$, $p = 0.488$).

HYPOTHESIS 4

Hypothesis 4, mean peak performance in the BOST will improve after a morning resistance training workout, as compared to the control condition of no morning workout, was also assessed using a paired-samples t-test. BOST distance was reported as the maximum recorded distance for each trial. Group mean BOST distances were 11.46 ± 1.28 m for Trial 1 and 11.76 ± 1.37m for Trial 2. A statistically significant difference was found between trial means for BOST distance (N = 14, t = -3.2, p = 0.006).

In summary, VJ peak power and BOST distance were found to be correlated between each trial. VJ peak power was found to explain 42 to 42% of the variation in BOST distances. VJ peak power output failed to improve between trial 1 (control condition of no morning workout) and the experimental condition of a morning lift before afternoon testing. By contrast, BOST distance showed significant difference between trials with improvement in throwing distance observed in trial 2 (experiment condition of a morning lift workout).

CHAPTER V

DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

DISCUSSION

Explosive power production is key in the throwing events of the sport of athletics. Much attention is given to the development, refinement, and measurement of this capacity on the part of athletes and coaches. The BOST test and VJ peak power production were selected for testing parameters in this study with the primary purpose of examining the correlation between throwing distance in the sport-specific BOST test and performance in the more generally used measure of VJ peak power output. A secondary purpose of this investigation was to examine changes in group mean explosive power performance when assessed four to six hours after a resistance exercise bout, as compared to the control condition of no morning workout. The intent of the study was to aid in the selection of appropriate testing parameters in assessing explosive power performance readiness in throws athletes in the sport of athletics, as well as to provide coaches and athletes with information regarding the usefulness of a resistance exercise warm-up to improve competitive throws performance.

Hypotheses 1 and 2

Hypotheses 1 and 2 stated that VJ peak power production and BOST distance would be significantly correlated in Trials 1 (Control Condition) and 2 (Experimental Condition), respectively. Pearson correlation analyses for both hypotheses showed significant results at $p = 0.012$ and 0.011 for Trials 1 and 2. Consistent with previous research showing only a weak relationship between VJ height and BOST distance (Stockbrugger & Haennel, 2001; Mayhew et al, 1990), VJ peak power production, and not VJ height, was used in the analysis. The purpose of this analysis was to validate the BOST as a measure of power production against the previously validated construct of the VJ (Johnson & Bahamonde, 1996; Harman et al., 1990). Although the evidence is indirect, the significant correlation of BOST distance with VJ peak power output lends preliminary support to the BOST as a valid test of explosive power performance.

VJ power production and BOST distance were analyzed separately for Trials 1 and 2 to allow for the possibility of the performance test results varying differently in response to the control versus the experimental conditions. This is consistent with the separate treatment of BOST and VJ peak power output responses for Trials 1 and 2 in Hypotheses 3 and 4 below. The finding that BOST distance and VJ peak power measurements from Trial 2 still correlate significantly may at first seem to suggest that BOST results are not sensitive to the condition of a morning resistance training session prior to testing.

However, a significant mean difference between control and experimental conditions in BOST distance but not in VJ peak power output begs further analysis to determine whether VJ peak power output and BOST measure the same capacity. A simple regression of VJ peak power output on BOST distance revealed that VJ peak power production explained about 42 to 43% of the variation in BOST scores. This finding both further supports the validity to the BOST as a measure of preparedness for explosive power performance, but it also means that 58% of the variability in BOST scores can be explained by other factors.

Some of the variation in the BOST marks not explained by VJ peak power may be from participants relying on strengths and technical strategies in one test that are either not useful or directly detrimental to performance in the other assessment. A study by Stockbrugger and Haennel (2003) compared twenty male jump (volleyball) and twenty male nonjump (wrestling) athletes with regards to various upper and lower body strength and explosive power field test correlates with BOMB throw performance. It was found that the two groups varied with respect to which field tests were more highly correlated with BOMB performance. The authors suggested that athletes use different strategies to execute the BOMB throw based on their strengths, as determined by their training state and individual differences (Stockbrugger & Haennel, 2003). The same may be true for throwers testing in the the biomechanically-similar BOST. There is considerable difference among throws events athletes with respect to training practices, which results in each athlete having a unique set of strengths. Within the sample used in this study, the athletes were also in various stages of their training cycles ranging from detraining and rest to peak competitive shape, which would also have an effect on their physical and mental approach to testing. For example, an athlete in peak shape is accustomed to competing but might not be at his peak strength during that training period. By contrast, an athlete in the pre-competitive or early competitive phase of training might not be as well-practiced in a competitive setting but may be training harder and be physically stronger at that point.

In the weight room, athletes rely on different strengths to execute the same lifting movements and therefore activate the musculature in slightly different ways. The potentiating effects of a morning resistance workout on afternoon throwing and jumping performance would only occur in those muscles activated maximally (Güllich & Schmidtbleicher, 1997; Gourgoulis et al., 2003; Lyttle et al., 1996; Sale, 2002). For example, in the back squat, distribution of body mass back over the heels and placement of the barbell lower across the upper back would emphasize activation of the lower back and other trunk musculature. If the barbell is placed higher, across the back of the shoulders, and the weight is distributed over the mid-foot, greater emphasis is placed on the recruitment of hip and leg musculature. Using this example, a back squat emphasizing the lower back and trunk may better prepare the athlete for the BOST, while back squat form that better recruits the hip and leg musculature may favor VJ peak power production.

From this, it is concluded that the BOST should be assessed in addition to, if not instead of, VJ peak power output as a separate index of explosive power production. The involvement of the entire body instead of just the hips and legs, as well as the transfer of force to an implement, distinguish the BOST from the VJ and make it more suited to explosive power assessment in the throws events (Stockbrugger & Haennel, 2001; Stockbrugger & Haennel, 2003; Mayhew et al, 1990).

Hypothesis 3

Hypothesis 3 stated that VJ peak power would improve when performed four to six hours after a morning resistance training workout, as compared to the control condition of no morning workout. In the current study, VJ peak power production failed to improve significantly over the control condition when the trial was preceded by a morning resistance exercise bout. Similarly, Gourgoulis and colleagues (2003) also noted no significant increase in VJ peak power following a resistance exercise warm-up.

In the Gourgoulis (2003) study, VJ trials were performed before and immediately following a warm-up of five sets of two repetitions of submaximal back squats with external resistances ranging from light loads ($< 60\%$ of 1 RM) to heavy loads ($> 80\%$ 1 RM). All repetitions were performed at maximum velocity. Similarly, the resistance exercise warm-up used in the present study consisted of exercises at both light (35% of 1 RM) and heavy (85% of 1RM) external resistance loads, both performed at maximum velocity. The workout protocol in this study employed a similar number of sets – six total – but two different exercises were used instead of one. Participants Gourgoulis (2003) study were allowed to rest only 5 minutes following the back squat sets, but VJ peak power output still failed to improve after the participants were permitted four to six hours of recovery after the resistance exercise warm-up. Taken together, this evidence suggests that VJ peak power output is not significantly affected by a submaximal resistance exercise warm-up consisting of multiple (five or six) sets performed at maximal velocity with both heavy and light loads, regardless of the type of exercise performed or the rest interval between the resistance exercise and testing.

Whereas VJ peak power output is unaffected by recovery time after the resistance exercise bout, VJ height appears to be affected by the time between resistance exercise and VJ testing. VJ height failed to increase significantly between trials in this study ($p = 0.342$). However, the Gourgoulis and coworkers (2003) study saw a significant increase of 2.39% in VJ height attained ($p > 0.05$). Similarly, in a study by deVillarreal and colleagues (2007), statistically significant increases of 4.59 to 5.01% in countermovement VJ height were seen five minutes post-resistance-exercise ($p < 0.05$). Participants – twelve trained male volleyball players aged 21 to 26 years, in this case –

were tested in the VJ after both a five-minute and a six-hour rest interval on two occasions following two separate heavy (≥ 80% of 1 RM) back squat workouts. Jump heights remained elevated at six hours post-training, but not significantly so (deVillarreal, González-Badillo, & Izquierdo, 2007). The significant improvement in VJ height immediately following resistance exercise reported by deVillarreal and colleagues (2007) and Gourgoulis et al. (2003) may have been due to the short recovery period following the resistance exercise bout. The return of mean VJ height to baseline four to six hours post-exercise seen in the present study as well as in deVillarreal and colleagues (2007) is indicative that a mechanism, such as muscle temperature elevation, is active early on but that is no longer be present several hours later (Biener et al., 2007; Bishop, 2003).

Another factor that could contribute to the failure of VJ peak power output to significantly improve following resistance exercise, regardless of the elapsed time between the resistance exercise and VJ measurement, is the difference in training level of the participants. The athletes used in this study were mostly NCAA Division I athletes, many of whom have competed at the Regional or National level in this league. Gourgoulis and colleagues (2003) described their population only as physically active males. The mean vertical jump heights obtained in this investigation were nearly double those obtained in the Gourgoulis study (66 ± 15 cm versus 33.7 ± 5.1 cm or 34.5 ± 5.6 cm). Mean countermovement jump heights obtained in the deVillarreal (2007) study were not directly reported, although they ranged from greater than 40 cm to just under 55 cm throughout the study (deVillarreal et al. 2007).

Given the competitive level of the athletes in this study, combined with their mean VJ height as compared to athletes of a similar demographic in other studies, it can be said that the athletes in the present investigation were skilled and exhibited high-level performance in VJ testing. High-level throws athletes such as these often perform maximum effort jumping in training in the form of plyometrics. They may have a set technical approach to the skill, regardless of physical preparedness. Even if the participants were more prepared to perform well following the morning resistance exercise bout prior to Trial 2, they may not have utilized this adaptation effectively for improved performance in the experimental condition trial. This conjecture is supported by the observation that several of the participants continued to improve their VJ performance on a second attempt at a height (i.e., following an attempt where no improvement was made) if verbal feedback regarding takeoff or mechanics in the air was given. In other words, it took a verbal cue to encourage them to change technical strategies and better utilize their physical capacity for explosive power production at that time.

It is also possible that, at the comparatively high level of performance in the VJ demonstrated by the participants in the present investigation, it would be difficult to detect a significant increase in VJ height in the small sample used here. Though most participants failed to improve in the second trial, all came within 1.5% of their Trial 1 height, and qualitatively most achieved their maximum height in fewer attempts than in Trial 1. In other words, while no improvement was seen in VJ height or VJ peak power output, there was a qualitative improvement in time to peak performance. This is important to mention, as in the throwing events, athletes have a limited number of warm-up repetitions followed by a small number of attempts (three, in most cases) to post their best mark. Therefore, the ability to optimize power production early on in a series of performances is key.

Hypothesis 4

Hypothesis 4 stated that mean peak performance in the BOST would improve after a morning resistance training workout four to six hours beforehand, as compared to the control condition of no morning workout. The results of the current study show a statistically significant improvement in BOST distance in Trial 2 (Experimental Condition) over Trial 1 (Control Condition) ($p = 0.006$). While the above studies have examined the effects of a resistance training warm-up on VJ performance, there is little research on the effects of resistance exercise on subsequent BOST or BOMB performance, so no comparisons may be drawn. However, given the assumption that the use of competition-weight implements in the BOST allows parallels to be drawn between BOST distance and shot put performance, for example, a mean difference between trials of 30 cm – nearly a third of a meter – is a large difference by practical standards, considering that at high levels of competition this event is often won by a couple of centimeters.

One possible explanation for the increase in mean BOST distance in the absence of improvement in VJ peak power is the potential kinematic differences between the two movements that are at least partially kinetically similar. No research exists for the biomechanical comparison of the VJ and the BOST, but an analysis of the squatting vertical jump versus the hang snatch Olympic-style lift – a movement that is similar to the BOST in kinetics and in the requirement of moving an external resistance – performed by Canavan and colleagues (1996) – showed significant kinematic differences between these two kinetically similar movements. Resistance exercise may produce neurological effects beneficial specifically to the kinematics of the BOST but not to the VJ – for example, by better preparing the upper body musculature for throwing.

Additionallly, the BOST test is a more technical movement by nature of the trunk and upper extremity involvement as well as the use of an implement, and therefore presents more opportunity for changes in recruitment patterns between trials than a VJ. Qualitatively, the BOST and similar movements was not present as extensively in the participants' training as was jumping for height. Among those that did perform the BOST on a regular basis, variations existed among participants in the techniques used. However, if BOST strategies differed between trials for individual participants, the changes would have been at a level not readily apparent to the observer (i.e., minor differences in muscle recruitment strategies) and not at the gross technical level (Stockbrugger & Haennel, 2003). Just as with the VJ, participants were permitted to practice the BOST during the familiarization session to reduce the effects of practice on performance across trials (Duncan et al., 2005). Technique scores suggest that a learning effect did not occur across trials. The median BOST technique ratings were 4.5 for both trials, with a range of 3.0 to 5.0 on Trial 1 and 3.5 to 5.0 on Trial 2, so major improvements in technique between trials would not have accounted for the large improvement in BOST scores. It would be helpful, then, to record actual muscle activity and force production to assess the role of muscle recruitment strategies in BOST performance.

In a study of adolescent (15- and 16-year-old) rugby players, Duncan and colleagues (2005) determined that BOMB throw marks tended to stabilize to an error of

10 cm between trials at between five and six throws. With this in mind, in addition to the familiarization session, participants in this study were given three practice and three marked attempts per trial in the BOST to maximize test-retest reliability while minimizing fatigue. The three marked attempts were presented as intended to simulate a three-throw competition. While few, if any, appeared to out-throw their marked performances during the three warm-up attempts, several of the participants stated that they felt they could have thrown farther if given more attempts. One noted that he was "accustomed to making finals" in a throwing competition and having three more attempts to improve his standing. The findings of the present study suggest that further research is warranted to explore whether the mean difference in BOST scores would have increased if participants were allowed more attempts.

CONCLUSION

In summary, hypothesis 1, BOST performances and VJ peak power outputs will be significantly correlated when not preceded by a morning resistance training workout four to six hours earlier (Trial 1 – Control Condition), was accepted. Similarly, hypothesis 2, BOST performances and VJ peak power outputs will be significantly correlated when preceded by a morning resistance training workout four to six hours later (Trial 2 – Experimental Condition), was accepted. Hypothesis 3, mean VJ peak power output will improve after a morning resistance training workout four to six hours later, as compared to the control condition of no morning workout, was rejected. Hypothesis 4, mean peak performance in the BOST will improve after a morning resistance training workout four to six hours later, as compared to the control condition of no morning workout, was accepted. The significant correlation between BOST performance and VJ peak power production suggests that the BOST is a valid test of readiness for explosive power performance. A significant difference in mean performance between trials was found for the BOST test but not for VJ peak power. However, the large variance in BOST scores not explained by VJ peak power indicates that the BOST assesses a slightly different aptitude than VJ peak power output.

Overall, these preliminary findings indicate that a morning resistance exercise bout consisting of both heavy and light resistances performed at maximal intensity may help afternoon competitive throwing performance on the same day. However, these findings may be specific to high-level collegiate and post-collegiate throws athletes in the sport of athletics. More research is needed to determine whether these findings may be generalized to other populations, as well as to address the possible limitations of the present study so as to confirm or refute its results.

RECOMMENDATIONS FOR FUTURE RESEARCH

The purpose of this study was to determine whether a morning resistance exercise bout affected afternoon throwing and jumping performance. To further validate the BOST as a measure of explosive power production, future research should seek to lend both content and criterion validity to the construct evidence provided here. Direct measurement of nerve conduction, muscle EMG activity, joint kinematics, and force production to assess the role of muscle recruitment strategies on BOST and VJ peak power performance is a topic for future research. To further validate the BOST as a predictor of throwing performance, it would be useful to compare BOST scores with actual competitive outcomes to determine correlation as well as to verify any direct predictive mathematical relationship between BOST distances and competitive throwing distances.

Also with regards to study design, a mixed resistance exercise protocol of heavy and light loads was employed here. The improvement in BOST scores between trials in this study suggests that the protocol employed was sufficient to produce performance improvements. However, heavy resistance exercise, especially on the morning of a competition, carries with it the risk of injury or excessive fatigue. More research is warranted to examine the efficacy of different resistance exercise protocols to see what type, volume, and intensity of exercise is minimally necessary to produce an effect.

This study looked only at peak performance in the BOST and VJ and did not account for time to peak. Success in competitive throwing rests on the ability to produce the best performance in just three throws, with the competitive advantage given to the athlete that can have a high-level performance early on and apply psychological pressure on their opponents. Therefore, in future, it may also be useful to look at the number of repetitions in the BOST and VJ taken to achieve peak performance.

The current study is limited by the small participant pool and the lack of control for an order effect of control condition and experimental condition trials. It would be useful to repeat this study with a larger number of subjects and a counterbalanced design in which participants are randomly assigned according to performance assessment order (VJ and BOST) as well as trial (control vs. experimental) order. An effort should also be made to better standardize for the training state of the participating athletes.

Other confounders that deserve consideration include psychological preparedness for activity. On more than one occasion during this study, participants commented during Trial 2 that they felt "pumped" and ready for activity. By contrast, some participants professed to feel sluggish and accordingly failed to improve on some or both testing parameters. Further attention should be given to the action of same-day resistance exercise on mood and arousal in competitive throwers. The effect of coaching on VJ and BOST performance is also a topic for future investigation.

APPENDIX A

University of North Carolina-Chapel Hill
Consent to Participate in a Research Study
Adult Participants
Social Behavioral Form

IRB Study #____________________
Consent Form Version Date: _28 April 2009_____

Title of Study: Effects of a morning resistance training session on afternoon performance in vertical jump and overhead shot throw tasks

Principal Investigator: Laura Gerraughty, BA
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Faculty Advisor: Claudio Battaglini, PhD
Funding Source and/or Sponsor: not funded

Study Contact telephone number: (603) 801-9472
Study Contact email: throwing_study@unc.edu

What are some general things you should know about research studies?
You are being asked to take part in a research study. To join the study is voluntary.
You may refuse to join, or you may withdraw your consent to be in the study, for any reason, without penalty.

Research studies are designed to obtain new knowledge. This new information may help people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study.
You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?
The purpose of this research study is to learn about the effects of a morning strength and conditioning session on afternoon jumping and throwing performance.

You are being asked to be in the study because of your experience in the throwing events in athletics.

Are there any reasons you should not be in this study?
You should not be in this study if you have any orthopedic injuries or other health issues that

would prevent you from completing study requirements.

<u>How many people will take part in this study?</u>
If you decide to participate, you will be one of approximately sixteen people in this research study.

<u>How long will your part in this study last?</u>
Your involvement will last four days. The study will include one familiarization session of two hours, two workout sessions of one hour and two hours respectively, and three testing sessions of forty-five minutes each. There is no follow-up procedure after the completion of this study.

<u>What will happen if you take part in the study?</u>
GENERAL PROCEDURES

You will be asked to perform a familiarization session on day one, one testing session on day two, and two testing sessions on day three of the protocol.

DAY 1: FAMILIARIZATION SESSION

Questionnaires, Anthropometrics and Baseline Data: Following the receipt of your informed consent, the Principle Investigator will ask you to fill out a Physical Activity Readiness Questionnaire (PAR-Q). Responses to the PAR-Q will be evaluated by the Principle Investigator and the Faculty Advisor to determine your physical readiness for study participation. Your height and body mass will be measured and recorded, along with information on gender and age. You will be asked to stand with your back to a wall and your dominant arm extended overhead to measure how high you are able to reach.

Warm-up Protocol: You will be asked to complete a warm-up. After five minutes of jogging, you will perform 20 different movements, each over a straight 20-yard distance. The first 10 yards will consist of stretching poses or movements interspersed with jogging steps. The second 10 yards will be covered with a run at some percentage of your fastest sprint. At the end of 20 yards, you will be asked to run around the cone marker and jog back to the starting point. The series of dynamic movements will be (in order):

21) *Ankle Skip:* Skipping emphasizing using the ankles to propel the body off the ground.
22) *Walking Gastrocnemius*: A standing pose to stretch the calves. Performed by stepping forward, bending the lead knee and hip. The back leg is held straight, with the back heel kept flat on the ground. The stretch will be felt in the back calf.
23) *Forward Run*
24) *Backward Run*
25) *Russian Walk/Quad Pull:* Intended to stretch the muscles in the back of the leg and on the front of the hip and thigh. While balancing on one leg, first pick the other knee up to the chest, then extend the leg out straight forward. Sweep the straight leg down to the ground, then bend the knee and grab the foot with the same-side hand. Squeeze the buttocks to open the hip while pulling the heel to the buttocks with the hand.
26) *Knee Hug/Side Lunge:* Facing sideways to the direction of movement, stand on one leg and hug the other knee to the chest. Release the leg, step out onto it in the direction of movement, and bend that knee and hip, keeping the other knee straight. The first pose is designed to stretch the buttocks and back of the thigh on the non-support leg. The second pose is designed to stretch the inside of the thigh on the straightened leg.
27) *Balanced Gluteal Stretch:* Intended to stretch the buttocks. Performed standing on one leg. The other leg is bent, the outside of the ankle is laid across the top of the supporting

thigh, and the bent knee is turned to the side. (Viewed from the front, the legs form a "4".) The hips and supporting knee are then bent to a seated position.

28) *Marching Drill:* Intended to stretch the back of the leg. Performed standing on one leg. With the arms held out to the sides for balance, swing the straightened free leg up to touch the foot to the opposite hand.
29) *Reverse Marching Drill:* Performed standing on one leg. Extend the free leg directly backwards, bend at the waist, and reach for the ground.
30) *Open Hip:* Intended to loosen the hip joint. Performed standing on one leg. Bend the free leg at the knee and hip, picking the knee up to the front. Holding the knee up, rotate the hip to pull the knee out to the side.
31) *Close Hip:* Performed as with the Open Hip drill, only starting with the knee to the side and rotating it to the front.
32) *Side Shuffle:* A gallop performed facing sideways to the direction of movement. Performed with the hips and knees bent and the head and chest up (near vertical).
33) *Carioca with High Knee Step-Over:* A sideways running movement where the trailing leg crosses to step ahead of the leading leg, first in front then behind. When the trailing leg crosses in front of the leading leg, this movement is done with an exaggerated knee lift to the chest.
34) *Walking Lunge with Rotation:* Intended to stretch the front of the hip and thigh. Performed by stepping forward, bending the leading knee and hip. The back leg is held straight. The head and shoulders are then turned sideways in the direction of the lead leg. The stretch should be felt in the back leg and hip.
35) *Butt Kickers:* Forward running with slowed forward progression. Emphasis on driving the heels to the buttocks in quick succession.
36) *High Knees:* Forward running with slowed forward progression. Emphasis on driving the knees to the chest in quick succession, bringing the tops of the thighs up to parallel.
37) *Prancing:* A forward run with legs held straight.
38) *Power Skip:* Skipping with an emphasis on height.
39) *Run with 360° Rotation*: Run forward for 10 yards, then stop and turn in place.
40) *Acceleration to Sprint:* Forward running, starting at a jogging pace and working up to a full sprint.

The Principle Investigator will demonstrate each movement first and then ask you to perform it. Time will be spent on each to correct form and answer any questions you may have.

Backwards Overhead Shot Throw: Following the warm-up, you will be given the opportunity to practice the backwards overhead shot throw until you are comfortable with the movement. You will start by standing with your heels on a line. You will hold the shot with two hands at arms' length, squat down with the shot held between the knees, and then jump upwards with maximum effort, releasing the shot upward and backward overhead with arms straight. The goal of the exercise is to throw the shot as far as possible. Women will test using a four kilogram shot, and men will test using a 7.26-kilogram shot.

Vertical Jump: Vertical jump will be performed using a Vertec jump measuring device, consisting of a pole with movable plastic height markers at the top. To perform the vertical jump, you will start standing under the apparatus with feet at a comfortable width. You will then squat down without moving your feet and move immediately to jump as high as possible. The goal of the exercise is to move the highest possible plastic crossbar height marker with your hand during the jump.

Weight Lifting: After the shot throw, the Principle Investigator and members of the research team will guide you through a test to determine the maximum weight that you are able to use for four repetitions of the power clean exercise. The same will be done for the back squat exercise. The results will be used to calculate the weight you will use in the weight training testing session.

Before being released for the day, you will be asked to refrain from alcohol consumption and to maintain normal eating and sleeping habits for the remainder of the study.

DAY 2: CONTROL CONDITION

On the second day, you will be asked to report between 1:00pm and 3:00pm. Prior to any activity, you will be asked about your eating and sleeping patterns as well as how tired you feel. You will also be weighed and asked to provide a small urine sample to see if you are properly hydrated to ensure your safety and your ability to perform to the best of your ability. The sample will be collected in a sterile plastic container for the analysis of hydration that will be performed by specific gravity method using an optical densitometer. Two drops of urine will be placed on the densitometer plate reader. The densitometer is then held up to a light and a reading is taken by viewing the sample from the densitometer eye piece. If it is determined that you are not properly hydrated, the testing session will be re-scheduled to the following day. You will then perform the warm-up protocol practiced during the familiarization session.

You will test the vertical jump and backwards overhead shot throw in either order. You will be given three practice and three measured attempts at the backwards overhead shot throw test. You will test in a pre-determined order to simulate a athletics throws competition. For the vertical jump, you will complete all attempts in a row, with a one-minute rest interval between attempts. You will continue to jump for height until no plastic crossbar markers are touched or moved on two consecutive attempts.

DAY 3: EXPERIMENTAL CONDITION

Morning Session. On the third day, you will be asked to report for a start time sometime between the hours of 8:00am and 10:00am. After the same questionnaire as used before the first testing session, You will also be weighed and asked to provide a small urine sample to see if you are properly hydrated to ensure your safety and your ability to perform to the best of your ability. If you are not properly hydrated, the testing session will be re-scheduled to the following day. You will then perform the warm-up as introduced in the familiarization session. You will then be asked to perform three sets of the back squat exercise using a weight calculated from the heaviest weight you were able to lift in this exercise during the familiarization session. You will be allowed at least three but no more than five minutes of rest between each set. Following a five-minute rest, you will then perform four sets of four repetitions in the power clean. Again, you will be allowed at least three but no more than five minutes for recovery between sets. You are asked not to exercise again until the next testing session.

Afternoon Session. You will be asked to report one last time between 1:00pm and 3:00pm on that same afternoon. After the questionnaire, body weight measurement, specific gravity analysis, and warm-up procedures, participants will repeat the backwards overhead shot throw and vertical leap tests in the same order as on the previous day. If you are not properly hydrated at the start of the afternoon session, testing will be cancelled for the day and both the morning and afternoon sessions will be performed again on the following day.

What are the possible benefits from being in this study?

Research is designed to benefit society by gaining new knowledge. You may not benefit personally from being in this research study.

What are the possible risks or discomforts involved from being in this study?

There is no anticipated risk of psychological harm, economic loss, or legal jeopardy associated with this study. As with any participation physical activity requiring powerful movements, such as jumping, throwing, or lifting weights, there is some risk of orthopedic injury.

However, exclusion criteria as well as during-study monitoring by the research team are designed to ensure that only those physically prepared for the demands of the study are enrolled and continue to participate. Injury is unlikely due to your prior experience, as the procedures in this investigation are no more rigorous than what you've experienced during normal throws training and competition. There may be uncommon or previously unknown risks. Should you experience any problems during the study, you should report them to the researcher.

How will your privacy be protected?

Upon enrollment in the study, you will be assigned an identification number. All written information collected associated with this identification number will be stored in a locked file cabinet located in Dr. Claudio Battaglini's office at the University of North Carolina at Chapel Hill, Fetzer Gymnasium, room 026A. Only the above-listed research team will have access to this information. Electronic files will be stored on an external USB drive owned by the principal investigator and will be password-protected. You will not be identified in any report or publication about this study. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies for purposes such as quality control or safety.

What will happen if you are injured by this research?

Should you sustain an injury during the study, immediate care will be given on-site, and you will be referred for additional care to the appropriate providers on campus, such as Campus Health Services or the UNC Hospitals Emergency Room, if necessary. All research involves a chance that something bad might happen to you. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. However, by signing this form, you do not give up any of your legal rights.

Will you receive anything for being in this study?

You will not receive anything for taking part in this study.

Will it cost you anything to be in this study?

There will be no costs for being in the study.

What if you are a UNC student?

You may choose not to be in the study or to stop being in the study before it is over at any time. This will not affect your class standing or grades at UNC-Chapel Hill. You will not be offered or receive any special consideration if you take part in this research.

What if you are a UNC employee?

Taking part in this research is not a part of your University duties, and refusing will not affect your job. You will not be offered or receive any special job-related consideration if you take part in this research.

<u>What if you have questions about this study?</u>
You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or concerns, you should contact the researchers listed on the first page of this form.

<u>What if you have questions about your rights as a research participant?</u>
All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject you may contact, anonymously if you wish, the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

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Title of Study: Effects of a morning resistance training session on afternoon performance in vertical jump and overhead shot throw tasks

Principal Investigator: Laura Gerraughty, BA

<u>Participant's Agreement:</u>

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

____ __________________
Signature of Research Participant Date

____
Printed Name of Research Participant

____ __________________
Signature of Research Team Member Obtaining Consent Date

____
Printed Name of Research Team Member Obtaining Consent

APPENDIX B

FAMILIARIZATION SESSION QUESTIONNAIRE

PARTICIPANT ID_____________________________

DEMOGRAPHICS & ANTHROPOMETRICS

Gender: M / F Age:

____________years

Height: ______________ cm Body Mass: ____________

kg

Reach: ______________ cm

Track & Field Event(s): _______________________

____

____

EATING & SLEEPING PATTERNS

Normal Bed Time: _______AM / PM Normal # Hours of Sleep:

____

Normal # Meals per Day: ________________

APPENDIX C

PRE-SESSION QUESTIONNAIRE

PARTICIPANT ID__________________

DAY #: ______________________ SESSION: AM / PM

EATING & SLEEPING PATTERNS

Bedtime: __________ AM / PM # Hours of Sleep: _______________

Time of Last Meal: _________ _AM / PM # Meals Today: _______________

PHYSICAL ACTIVITY PREPAREDNESS

Perceived Fatigue: (none) 0 1 2 3 4 5 (want to go to sleep)

Muscle Soreness: (none) 0 1 2 3 4 5 (unbearable)

- -

DAY #: ______________________ SESSION: AM / PM

EATING & SLEEPING PATTERNS

Bedtime: __________ AM / PM # Hours of Sleep: _______________

Time of Last Meal: __________ AM / PM # Meals Today: _______________

PHYSICAL ACTIVITY PREPAREDNESS

Perceived Fatigue: (none) 0 1 2 3 4 5 (want to go to sleep)

Muscle Soreness: (none) 0 1 2 3 4 5 (unbearable)

APPENDIX D

BOST TECHNIQUE RATING RUBRIC

PARTICIPANT ID________________________

CONTROL CONDITION

(worst technique)	1	2	3	4	5	(best technique)

EXPERIMENTAL CONDITION

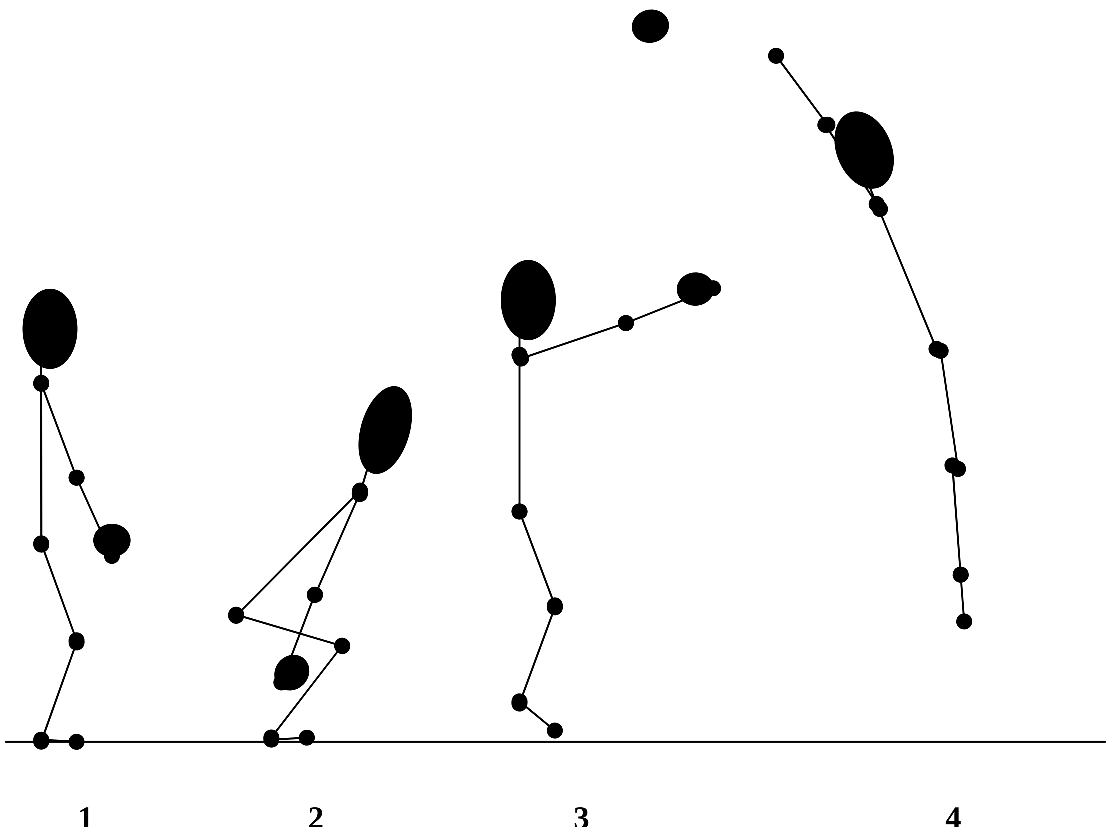
(worst technique)	1	2	3	4	5	(best technique)

RATING RUBRIC

Best technique	5	- Arms remain straight throughout throw - Ankles, knees, and hips all extend at the same time - Ankles, knees, and hips extend at the point of release - Shot is released cleanly
	4	- Arms remain straight throughout throw - At least two of three joints (ankle, knee, and hips) extend at the same time - At least two of the three joints (ankle, knee, and hips) extend at point of release - Shot is released cleanly
	3	- Arms bend slightly during throw but extend by release - At least two of three joints (ankle, knee, and hip) extend at the same time - At least two of the three joints (ankle, knee, and hip) extend but either before or after point of release - Shot slips in participant's hands or goes directly downward on one or two attempts
	2	- Arms bend slightly during throw but extend by release - Only one of three joints (ankle, knee, and hip) extend - Only one of three joints (ankle, knee, and hip) extends at point of release - Shot slips in participant's hands or goes directly downwards on one or two attempts
Worst technique	1	- Arms bend during throw and do not extend - None of three joints (ankle, knee, or hip) extend - Participant is unable to balance well enough to avoid stepping backwards over the marking line - Shot slips in participant's hands or goes directly downwards on three or more attempts

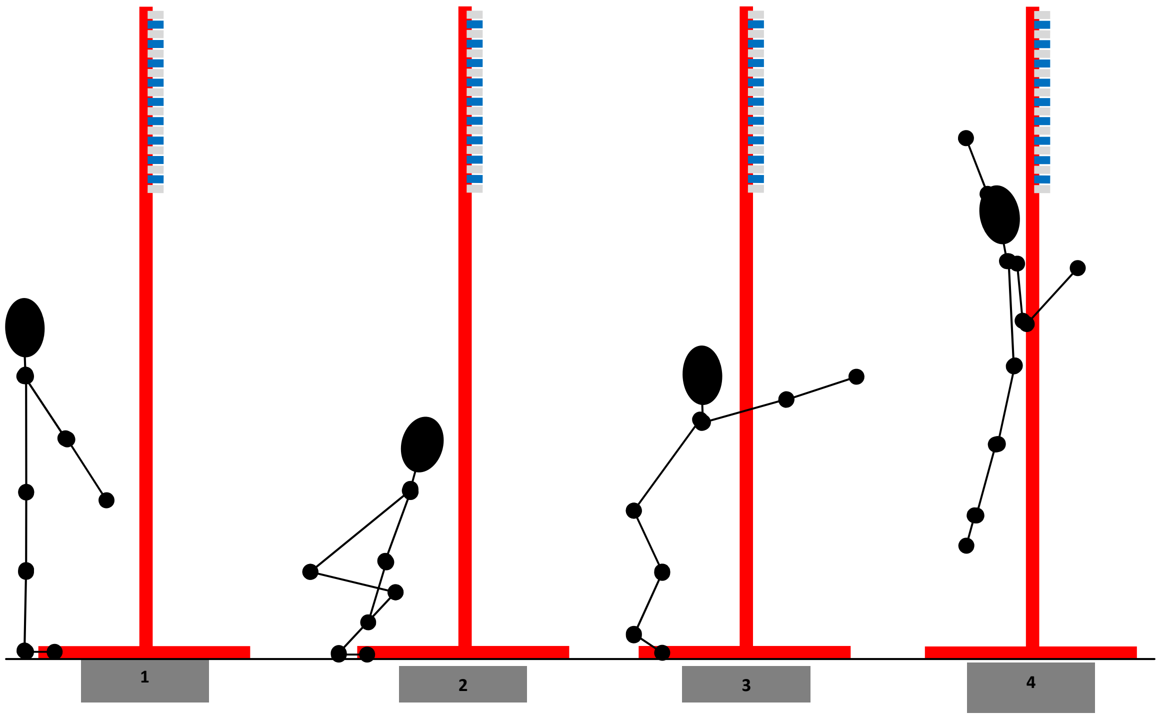
APPENDIX E

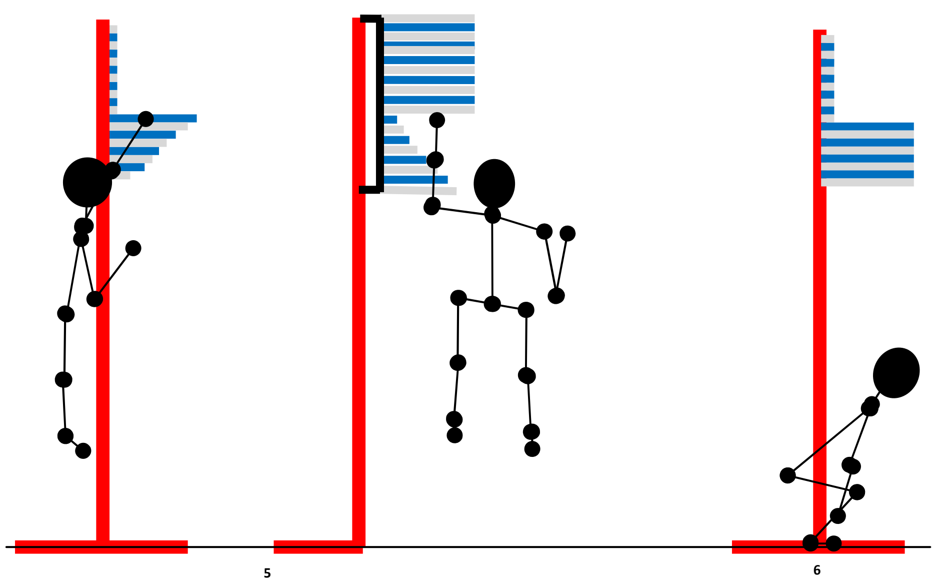
BACKWARDS OVERHEAD SHOT THROW TECHNIQUE



APPENDIX F

VERTICAL JUMP TESTING TECHNIQUE





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