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# Relationships Among Field Tests Of Lower Body Power In Collegiate Football Players

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# Relationships Among Field Tests of Lower Body Power in Collegiate Football Players

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BY

Gregory J. Young

**THESIS**

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# ABSTRACT

Measuring and assessing lower body power is vitally important to strength and conditioning coaches since nearly every sport in some way depends on the athlete's ability to use his lower body explosively. Strength and conditioning coaches are responsible for ensuring that training programs meet these goals, and to do so, they must have a way to assess lower body power. Field tests are most commonly used, yet some are more practical to administer than others, especially if a large number of athletes is to be tested. For example, the standing long jump is easy to administer, time efficient, and requires little space or equipment, yet it is not as commonly used as some other power assessments. Therefore, this study's primary purpose was to validate the standing long jump as a power test in collegiate football players. A secondary purpose was to determine the strength of relationships among lower body power variables in collegiate football players.

Fifty-four members of the Eastern Illinois University NCAA Division I-AA varsity football team served as subjects for this study. Data was gathered from the March 2004 testing of the football team by the strength and conditioning staff. Relationships among the vertical jump, standing long jump, 1-RM power clean, 1-RM back squat, speed in the 40-yard sprint, vertical jump power, 1-RM power clean relative to body weight, 1-RM back squat relative to body weight, and body weight were analyzed using Pearson's correlation coefficient.

Results of this study showed a high correlation ($r = .821$) between vertical jump and standing long jump. Vertical jump and standing long jump both correlated highly (r

= .789 and r = .774, respectively) with speed in the 40-yard sprint as well. Vertical jump, standing long jump, and speed in the 40-yard sprint all also had moderate to high correlations with relative values of the 1-RM power clean and 1-RM back squat and inverse relationships with body weight.

In addition, 1-RM power clean had a high correlation (r = .726) with 1-RM back squat. The 1-RM power clean and 1-RM back squat both had moderate correlations (r = .660 and r = .620, respectively) with vertical jump power. These three assessments were also associated with body weight and had weak relationships with vertical jump, standing long jump, speed in the 40-yard sprint, and relative 1-RM values of the power clean and back squat.

From the results of this study, one can conclude that the standing long jump is a valid field test of lower body power since it correlated highly with the already-accepted vertical jump test. The 1-RM power clean seems to reflect the strength component of power since it correlated well with the 1-RM back squat and poorly with speed in the 40-yard sprint. Vertical jump and standing long jump seem to measure the speed component of power since both jumps had strong relationships with speed in the 40-yard sprint and weak relationships with both the 1-RM power clean and 1-RM back squat. Lastly, body weight ought to be considered in assessing power because doing so improved the relationships between the jumping assessments and the 1-RM power clean and 1-RM back squat; this will allow different sized athletes to be compared. Understanding this information will give strength and conditioning coaches a broader view of their athletes' power and allow them to better evaluate and train athletes.

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# CHAPTER 1

# INTRODUCTION

Measuring and assessing lower body power is critically important to members of the strength and conditioning profession as nearly every sport at nearly every level hinges in some way on an athlete's ability to use his lower body in a powerful manner. For example, Costill, Hoffman, Kehoe, Miller, and Myers (1968) and Sawyer, Ostarello, Suess, and Dempsey (2002) found that starters on college football teams were significantly more powerful than nonstarters. It is the strength and conditioning coach's responsibility to ensure that training programs meet these needs, and to do so, he or she must have a way of measuring lower body power to recognize athletes' improvements and to evaluate the effectiveness of training. Coaches can choose from several testing options, but field tests are preferred because they are often more time efficient and more specific to movement patterns used in competition.

Despite having options in choosing lower body power tests, not all field tests are as time-efficient or competition-related as others. For example, the vertical jump test has been recognized as a measure of lower body power (Klavora, 2000), yet it may not always be the best tool to use. Measuring each athlete's reach height, measuring each athlete's maximum jump height, and then calculating the difference between the two to obtain a vertical jump score can be a time-consuming process, especially if many athletes are to be tested. Also, since different procedures for determining vertical jump height exist, testers must be trained on specific instrumentation and technique to obtain reliable scores from this type of test. Lastly, several sports require lower body force to be created horizontally, yet the vertical jump test does not measure the power created in that horizontal manner.

The one-repetition max (1-RM) of explosive lower body exercises have also been used to assess lower body power. For example, the power clean has been shown to reflect lower body power (Baechle and Earle, 2000), yet using this assessment may not be the most efficient method. Testing untrained or detrained athletes in this manner may not be safe, as the intensity of the lift might be too great for these athletes to handle safely. This type of measurement can also be quite time-consuming because the athletes make several attempts at increasing weights until a true 1-RM is determined. In addition, supervisors of this type of testing need to be well trained in 1-RM testing and in the technique of the lift to help ensure the safety of the athletes.

Another option might be to determine the 1-RM of an exercise measuring lower body muscular strength. Since power is the product of force and distance divided by time (Mayhew, Piper, Schwegler, and Ball, 1989), an athlete's maximum lower body strength—the maximum amount of force he can voluntarily exert—plays a role in how powerful or explosive he can be in competition. Strength and conditioning coaches therefore often use the 1-RM back squat as a measure of lower body strength (Ebben, 1998). While the 1-RM back squat test does measure the maximum amount of force an athlete's lower body can exert, it too has the same shortcomings that the 1-RM power clean has regarding safety, time-efficiency, and supervision needs.

The definition Mayhew et al. (1989) offered for power can also be expressed as the product of force and speed. Thus, an athlete's speed of muscular contraction plays a role in power production, and speed is most often tested in football players using a 40-

yard sprint test (Ebben, 1998). While this sprint test does measure maximum running speed and the speed at which the lower body's musculature is able to contract, it requires a lot of open space and can be quite time-consuming to test a large group of athletes. Coaches timing this test must also be experienced enough to record accurate times; in such a short sprint, even a one-tenth of a second inaccuracy makes a big difference.

The standing long jump has also been used both as an exercise to improve lower body explosiveness and as a test of lower body power. This test has not, however, been used as frequently or as universally as some other assessments. The standing long jump is simple to administer, especially when compared to other measurements. It is much faster to use than the vertical jump test because you do not need to measure the athlete's maximum reach height or perform any calculations to obtain a score. It is also much faster to administer than a 1-RM test since you do not need to allow time for several trials of increasing intensity. In addition, the standing long jump test requires very little space or special equipment. The vertical jump test requires instrumentation to measure maximum reach and vertical jump height, as well as high ceilings or cooperative weather in order to achieve high jumps. Testing an athlete's 1-repetition max requires proper free weight lifting equipment, and timing an athlete in a 40-yard sprint requires a large amount of open space. Testing the standing long jump, however, requires only a tape measure and the space of a narrow hallway. Very little training is needed for testers to assess lower body power this way; they must simply be able to mark where the jumper's heel lands and read a tape measure. Lastly, the standing long jump measures the horizontal displacement of the athlete, a key component to many athletic activities.

It is clear that field tests do not measure all three factors—force, distance, and time—in the definition of power. To truly measure power, all three variables must be determined, and high-tech laboratory equipment is typically required to do so accurately. However, these field tests do assess the speed-strength interaction and are therefore considered power tests outside of the laboratory setting (Baechle and Earle, 2000).

## Purpose of the Study

The primary purpose of this study was to determine whether the standing long jump is a valid field measure of athletes' lower body power. A secondary purpose was to determine the strength of relationships among lower body power variables in collegiate football players.

## Hypothesis

The primary hypothesis of this study was that the standing long jump would correlate well with other established measures of power and therefore be a valid test. A secondary hypothesis was that there would be significant correlations among variables of lower body power, and these correlations would improve when body weight was considered. This was expected because the assessments are similar—they all require lower body explosiveness and extension at the hip, knee, and ankle joints—and considering body weight would eliminate advantages or disadvantages of different-sized athletes. The expected significant correlations among these measures would indicate the standing long jump test might be an effective field measure of lower body power, as other assessments used in the study have already been shown to be acceptable measures.

## Scope of the Study

This study took place in a collegiate strength and conditioning setting. All subjects used were male Eastern Illinois University NCAA Division I-AA college football players who had completed at least one season of training.

In addition, all tests administered for this study were field tests. No measurements were taken in a laboratory setting to allow this study's results to be more representative of what one might expect to observe in the field.

## Limitations of the Study

The small number of participants used in this study and the fact that subjects were not randomly selected might be limitations. Results obtained from this investigation might be more meaningful or generalizable if a larger number of athletes were studied and if participants were selected randomly.

Also, while the coaches made sure to motivate and encourage all subjects in the same manner, there is no guarantee that all subjects put forth a maximum effort in the testing situations. While this scenario is common in studies using human subjects, it is nonetheless a potential limitation.

## Significance of the Study

Several researchers have investigated the relationships among variables of lower body power field tests. However, few have included speed, strength, and power assessments like this study did. Therefore, this study was unique in that it studied relationships among variables from speed, strength, and power assessments commonly used in the field.

## Definitions of Terms

1-RM: The maximum amount of weight that can be lifted for one repetition using proper exercise technique.

40-yard sprint: A test of running speed in which the athlete sprints a distance of 40 yards and is timed to allow speed calculation.

Back squat: A free-weight exercise in which the athlete places a barbell across his shoulders on the upper back. From a standing start position, the athlete squats down until his thighs are parallel to the floor and then extends the hips and knees to return to the start position.

Lower body power: The ability of the lower body musculature to exert high force while contracting at a high speed.

Maximum lower body strength: The maximum amount of force an athlete's lower body musculature can voluntarily exert.

Power: Power = force x distance / time = force x speed.

Power clean: A free-weight exercise in which a barbell is lifted explosively from the floor to the fronts of the shoulders.

Speed: The rapidity of movement. Speed = distance / time.

Standing long jump test: A field test of lower body power in which the athlete stands with his toes behind the starting line and jumps horizontally as far as possible. The jump distance is measured from the starting line to the heels of the athlete at the landing point to give a score of horizontal displacement.

Vertical jump test: A field test of lower body power in which the athlete's maximum reach height is subtracted from his maximum vertical jump height to give a score of vertical displacement.

# CHAPTER 2

# REVIEW OF RELATED LITERATURE

Since lower body power is so crucial in athletics, developing ways of assessing it is a necessity among strength and conditioning coaches. Although several methods of measuring it exist, some are more favorable than others. Due to the ease of administering the standing long jump test, this study's primary purpose was to show the standing long jump as a valid field assessment of lower body power. The secondary purpose was to determine the existence and strength of relationships between field test measures of lower body power. This information might be useful to strength and conditioning coaches who want to measure lower body power or to help improve training protocols.

Because this study looked at relationships between lower body power assessments, this literature review will evaluate studies investigating various measures of speed, strength, and power. It will review studies regarding vertical jump, standing long jump, Olympic-style weightlifting, other types of resistance training assessments, and sprint running as power assessment variables.

## Jumping Tests

### Correlational Studies

Seiler et al. (1990) investigated the relationships among power tests in a study involving forty-one male collegiate football players from the University of Arkansas. Researchers randomly selected subjects from the team and placed them into three categories based on the position each subject played. The three groups they designated were backs (including running backs, defensive backs, quarterbacks, and wide receivers), linebackers (including linebackers, tight ends, and fullbacks), and linemen (including both offensive and defensive linemen). Researchers tested the subjects over consecutive days on the vertical jump, the standing long jump, and the 40-yard sprint. To test for the vertical jump, the subject stood against the wall with his arm raised as high as possible. His middle finger was chalked, and a baseline mark was obtained. Then, the subject jumped vertically and marked a blackboard with his chalked finger to obtain a vertical jump height. The difference between the highest mark and the baseline mark was measured to the nearest half-inch and recorded as the vertical jump height. Standing long jump was measured by starting the subject behind the starting line and having him jump as far as possible horizontally, measuring the distance to the nearest half-inch. Researchers timed the 40-yard sprint electronically, and the times were then converted to units of speed for analysis. Results of this study showed a high correlation ($r = .82$) between the vertical jump and the standing long jump. Speed in the 40-yard sprint was also highly correlated with both the vertical jump and the standing long jump ($r = .77$ and $r = .89$ respectively). However, the jumping tests had a strong inverse relationship with body weight, leading the authors to conclude that linemen—who typically have larger body masses than other members of a football team—might necessitate a different evaluation since their increased weights put them at a disadvantage. This study also concluded that no one power test appears to be specific enough to assess the power needs of college football and that coaches ought to use multiple tests to get a comprehensive evaluation of their athletes.

Costill, Miller, Myers, Kehoe, and Hoffman (1967) also studied the relationships among lower body power variables. These authors used seventy-six male college athletes—sixty-five of whom were football players—to determine the relationships. Subjects were tested on consecutive days on the vertical jump, the standing long jump, the 40-yard sprint, and the 1-RM back squat exercise. The vertical jump and the standing long jump were measured to the nearest half-inch in a manner similar to the previously mentioned study. The 40-yard sprint was timed the nearest tenth of a second using a handheld stopwatch, and three separate timers timed each trial. For the 1-RM back squat testing, subjects were required to squat down until their knees were bent to 90° with a loaded barbell across their upper back and shoulders and return to the starting standing position. Each subject's 1-RM was defined as the maximum amount of weight he could lift for one repetition. Results of this investigation showed a strong relationship (r = .672) between the vertical jump and the standing long jump. Similar correlations were seen between the 40-yard sprint and both the vertical jump and the standing long jump. On the other hand, both the vertical jump and the standing long jump had low inverse correlations to the 1-RM back squat (r = -.350 and -.271 respectively). In addition, both jumping tests had moderate inverse correlations with body weight, showing that larger athletes did not perform as well as smaller athletes did.

In a similar study, Beckenholdt and Mayhew (1983) studied the relationships between vertical jump, standing long jump, and the 40-yard sprint in male collegiate athletes. Fifty subjects participated in the study and represented football, soccer, baseball, basketball, and wrestling teams. All testing was completed in one afternoon session, and testing order was randomized except for the 40-yard sprint because of the potential fatigue it might introduce. To assess the vertical jump, a cloth tape and roller device was attached to a belt secured around each subject's waist. The loop of the tape ran between the legs, and when the subject jumped vertically, the tape was pulled tight through the roller. The jump height was read from the tape and recorded to the nearest tenth of a centimeter. The standing long jump was assessed similarly to other studies, and the 40-yard sprint was timed electronically. Results of this study showed strong relationships between vertical jump, standing long jump, and the 40-yard sprint. Vertical jump and standing long jump had a high correlation (r = .79). Both the vertical jump and the standing long jump had high inverse correlations (r = -.76 and r = -.70, respectively) with time in the 40-yard sprint. These inverse relationships represent smaller times and thus higher speeds associated with good jumping scores. This study therefore concluded that vertical jump and standing long jump correlated highly and that both of these jumps had strong relationships with sprinting speed.

In contrast to the previous studies using only male athletes as subjects, Mayhew, Bemben, Rohrs, and Bemben (1994) studied the relationships of power tests in female college athletes. This group of sixty-four subjects was made up of members of the varsity volleyball, basketball, soccer, tennis, and softball teams at an NCAA Division II university. Testing order was randomized, and scores from the vertical jump, standing long jump, and 40-yard sprint tests were measured similarly to previous studies. Results of this study showed a moderate correlation (r = .57) between vertical jump and standing long jump, which was somewhat lower than what was observed male athletes (Seiler et al., 1990; Costill et al., 1967; Beckenholdt and Mayhew, 1983). Relationships between the two jumping tests and the 40-yard sprint were also moderate. Lastly, the authors found low correlations between body weight and vertical jump, standing long jump, and 40-yard sprint. They concluded that one single test could not effectively identify an athlete's power, that athletes with larger body weights should be evaluated using different tests than athletes with smaller body weights, and that an athlete's body size should be considered in the evaluation of lower body power.

While their results cannot be as easily generalized to athletes, Mayhew and Salm (1990) used non-athletes as subjects to determine differences in power tests. These authors tested 82 untrained male and 99 untrained female college students over a four-week period in which the subjects were not allowed to practice or train for the tests. Measurements of the vertical jump and standing long jump were obtained similarly to the methods described in previous studies. Timers of the 40-yard sprint used handheld stopwatches and started their clock on the subject's first movement. Results of this study found that males scored significantly higher in measures of power, and this difference was only slightly decreased when body weight was taken into account. This investigation also found a correlation coefficient of $r = .63$ between vertical jump and standing long jump in male subjects and a correlation coefficient of $r = .67$ between the two jumps in female subjects. Similar relationships were seen when the vertical jump and the standing long jump were correlated with the time of the 40-yard sprint for both genders. The correlation coefficient between the vertical jump and 40-yard sprint time was $r = -.63$ in male subjects and $r = -.69$ in female subjects. The standing long jump to 40-yard sprint time correlations were $r = -.62$ in males and $r = -.74$ in females. The inverse relationships shown reflected a smaller time and thus a higher speed corresponding to better jump scores; jumping ability and running speed therefore had a strong positive relationship.

Lastly, this study found that body weight had a poor and inverse relationship with jumping and sprinting ability.

Manning, Dooly-Manning, and Perrin also used non-athletes as subjects in their 1988 study. In an attempt to identify good power tests and correlations between various assessments, the authors studied thirty-one college-aged males who were physically active but did not compete in intercollegiate athletics. Subjects were randomly assigned an order to test in the vertical jump, standing long jump, and 40-yard sprint, and testing took two days to complete. Methods used to measure vertical jump and standing long jump were similar to what other authors used, and the 40-yard sprint was timed by a handheld stopwatch. Scores of the vertical jump were converted to watts using the Lewis formula prior to analysis. Results of this investigation revealed that the standing long jump had a moderate inverse correlation with time in the 40-yard sprint (r = -.62), meaning that standing long jump and sprint speed were positively related. The standing long jump and vertical jump power—which considers the subject's body weight and vertical jump height (Harman, Rosenstein, Frykman, Rosenstein, and Kraemer, 1991)—had a weaker relationship (r = .40), while the 40-yard sprint and vertical jump power had a poor correlation (r = .06). These researchers concluded that a single best power test does not exist and that coaches ought to consider many variables relating to the sport and the athlete when assessing power.

In a similar study, Considine and Sullivan (1973) examined the relationships of lower body power in 38 male undergraduate students at Indiana University. Although the subjects were physically active, they too were not competing in intercollegiate athletics. Using methods similar to other authors, these researchers found that the vertical jump and the standing long jump had a moderate (r = .56) correlation. Interestingly, this relationship was quite similar to what Mayhew et al. (1994) found in studying female college athletes. In addition, this investigation discovered that the vertical jump and standing long jump had low correlations with measures of maximal hip and knee strength.

Several investigators have also studied relationships between various jumping tests and laboratory-based maximum force or power assessments. For example, Liebermann and Katz (2003) found that vertical jump power measured on a force platform was highly correlated to leg strength assessed by a 1-RM leg press in 106 physically active subjects. Also, Thomas, Fiatarone, and Fielding (1996) showed a strong relationship between vertical jump height and leg press power measured on a computer-interfaced leg press apparatus.

Ugarkovic, Matavulj, Kukolj, and Jaric (2002) studied thirty-three male basketball players from a premier national junior league and found that vertical jump had a low (r = .38) correlation with maximum isometric hip extension force and a modest (r = .52) correlation with maximum isometric knee extension force. Peak knee extension torque tested isokinetically had a similar correlation (r = .496) with vertical jump according to Dauty, Bryand, and Potiron-Josse (2002). Young and Wilson (1999), Ashley and Weiss (1994), and Weiss, Relyea, Ashley, and Propst (1997) also all found that vertical jump scores had moderate relationships with isokinetic squatting exercises involving hip and knee extension at different velocities. Thus, the magnitudes of relationships between vertical jump and maximum strength in laboratory settings differ based on the type of muscle contraction and joint movement being assessed.

Vertical Jump as a Power Assessment

Harman et al. (1991) performed a study to determine a method of estimating the peak and average power generated by an individual using vertical jump height and body weight. They felt that obtaining a value beyond simply the height jumped would provide more useful information to the evaluator. For example, if two individuals with different body weights jump vertically the same distance, they do not create the same amount of power to manipulate their center of mass. The heavier athlete would actually display more power output than the lighter athlete, and this may be critical in certain sporting activities. The authors evaluated the results from a vertical jump test using the chalked-fingers method described earlier and the results from force platform jumps to develop regression equations so that power production could be assessed using vertical jump height and body weight. The authors developed the following Lewis equations:

Peak power (W) = 61.9 x jump height (cm) + body mass (kg) + 1,822

Average power (W) = 21.2 x jump height (cm) + 23.0 x body mass (kg) – 1,393

The authors concluded that their equations would offer good estimates of power produced by vertical jumps, but they cautioned that inconsistent testing methods of the vertical jump would make the regression equations less reliable.

In a similar study, Keir, Jamnik, and Gledhill (2003) used a much larger sample size to develop their own regression equation to estimate peak power output from vertical jump height and body mass. Their methods and rationale for doing research were similar to those of Harman et al. (1991). The resulting Sayers equation estimates peak power produced in the vertical jump test and is as follows:

Peak power (W) = 60.7 x jump height (cm) + 45.3 x body mass (kg) – 2,055

The authors of this study reported that using the Sayers equation to determine peak power was far more accurate than using the Lewis equation when verified using force platform laboratory equipment. They reported that the Lewis equation underestimated peak power output by 73%, but the Sayers equation peak power estimation was within 2% of the power output value as determined by a force platform in both male and female subjects.

Conclusion

Several studies have investigated the relationships between the vertical jump, standing long jump, and other performance variables associated with lower body power. In studies using both athletes and non-athletes as subjects, the literature seems to point out that vertical jump is strongly related to standing long jump. This may be due to these jumps' similar movement patterns. Next, both the vertical jump and standing long jump have shown strong relationships with sprinting speed. On the other hand, vertical jump and standing long jump seem to have weaker relationships with measures of maximum leg strength. These two jumps also showed inverse relationships with body weight in the reviewed studies. Having a large body weight seems to inhibit an athlete's jumping ability, but researchers have made progress in developing formulas to determine power output using vertical jump height and body weight.

## Weight Training Strength and Power Assessments

Correlational Studies

Stone, Byrd, Tew, and Wood (1980) studied the relationships between field measures of lower body power and Olympic weightlifting. Using thirteen males enrolled in a weight-training course at Louisiana State University, the authors determined the relationships between the vertical jump and the 1-RM power clean and between the vertical jump and the 1-RM power snatch. Results of this study showed a correlation coefficient of r = .60 between the vertical jump and 1-RM power clean and a correlation coefficient of r = .46 between the vertical jump and the 1-RM power snatch. These relationships were not impressive, but the correlations increased to r = .80 and r = .75 respectively when the vertical jump scores were converted to vertical jump power using the Lewis equation. The authors concluded that the vertical jump alone might be a good predictor of weightlifting success within a weight class; in a weight class, all of the body weights of the lifters would be similar, and vertical jump would therefore have a stronger relationship with the Olympic lifts. The authors also concluded that vertical jump power should be used instead of vertical jump height to predict weightlifting performance so that the lifter's body weight is considered.

Next, Baker and Nance (1999) studied the relationships between the hang clean, back squat, and running ability. These authors used twenty male professional league rugby players as subjects and tested them on 40-meter sprint time, the back squat, and the hang clean. After their usual rugby warm-up routine, the subjects ran two trials of the 40-meter sprint test. The sprints were timed electronically, and the better of each subject's times was used in analysis. Due to the stage of the subjects' athletic program, these authors chose to obtain 3-repetition maximum (3-RM) scores on the back squat and hang clean exercises instead of the 1-RM measurement many investigators choose. For these exercises, subjects progressed from the warm-up sets to near maximal loads until a 3-RM was found for each exercise. For the back squat, subjects were required to squat down until his thighs were parallel to the floor as determined by the strength and conditioning coach, and the hang clean exercise was performed with the loaded barbell starting at knee height. Results of this investigation showed poor relationships between both the 3-RM back squat and 3-RM hang clean and 40-meter sprint time. However, these correlations greatly improved when 3-RM back squat and 3-RM hang clean scores relative to each subject's body weight were considered. Relative 3-RM back squat had a moderate inverse correlation ($r = -.66$) with 40-meter sprint time, and relative 3-RM hang clean had a slightly higher inverse correlation ($r = -.72$) with 40-meter sprint time. These negative correlation coefficients indicate that higher relative weight training test scores were associated with lower sprint times and thus faster running speeds.

In a study to examine relationships between maximum strength, maximum power and 1-RM power snatch, Stone et al. (2003) used eleven (five male and six female) collegiate throwers from a varsity track and field team. Maximum strength was determined using an isometric midthigh snatch pull, and peak power was determined using a midthigh snatch pull analyzed by an infrared-ultrasonic tracing device. Results of this study showed that the power snatch, peak power from the midthigh pull, and maximum strength from an isometric midthigh pull are all strongly related to one another. Therefore, this study seems to show that maximum strength significantly contributes to the power and explosiveness needed in power snatch and midthigh snatch pull performance.

In another study investigating Olympic-style weightlifting, strength, and power, Hedrick and Anderson (1996) examined the relationships among vertical jump, 1-RM clean, and 1-RM back squat. In this team case study, the authors analyzed data from forty-five NCAA Division I football players who had tested as part of their team's normal football and strength and conditioning evaluation multiple times throughout their college careers. The vertical jump was assessed using a Vertec device, and the athletes could choose to perform either a power clean from the floor or a hang clean from the knees to establish a 1-RM clean value. To test for the 1-RM back squat, each subject was required to squat with a loaded barbell across his shoulders and upper back until the thighs were parallel with the floor; the 1-RM was defined as the maximum amount of weight that could be lifted successfully for one repetition. After analyzing the data, these authors concluded that increases in 1-RM clean and 1-RM back squat were associated with increases in vertical jump height. While one should note that this team case study was not carried out as strictly as most other research projects, the apparent relationships between the vertical jump, 1-RM clean, and 1-RM back squat cannot be ignored.

Koch et al. (2003) also used the 1-RM back squat in their study to determine the relationship between strength and jumping ability. The study used thirty-two college students as subjects (sixteen males and sixteen females). Twenty-one of the subjects (eight males and thirteen females) were enrolled in a weight training class, and the remaining eleven subjects (eight males and three females) were members of a NCAA Division I track and field team. All subjects were familiar with the back squat exercise and underwent testing to determine their 1-RM values. One week later, subjects were tested on the standing long jump using methods similar to previous studies. Results of this study showed a high correlation ($r = .805$) between the 1-RM back squat and the standing long jump, which seems to be a much stronger relationship than what other authors have shown between weight training strength and power assessments and jumping tests. These authors concluded that maximum strength as measured by the back squat plays an important role in developing power and explosiveness used in jumping.

Body weight also seems to be a factor in one's ability to perform the Olympic-style lifts and the back squat. For example, Pilis et al. (1997) reported that body weight was significantly related to performance of both the snatch and the clean-and-jerk exercises. Miller, White, Kinley, Congleton, and Clark (2002) also reported that—among their 261 subjects who had played college football at Texas A & M University between 1993 and 1998—increases in body weight were associated with increases in 1-RM power clean scores and that larger athletes were able to lift more weight than lighter athletes. Mayhew, McCormick, Levy, and Evans (1987) also discovered that body weight was related to 1-RM power clean and 1-RM back squat. Lastly, Costill et al. (1967) found that body weight and 1-RM back squat had a high correlation ($r = .783$) in their study of seventy-six male athletes. Research has therefore shown that body weight and the ability to perform Olympic-style weightlifting exercises or the back squat have strong relationships.

Similarities Between Olympic Weightlifting and Vertical Jump

In their 1996 research, Canavan, Garrett, and Armstrong studied the kinematic relationships between the vertical jump and the Olympic-style hang snatch exercise. They used seven male NCAA Division I athletes from the football and track and field teams who had at least one year of training experience and were injury-free at the time of testing. The athletes were analyzed on a force plate and videotaped with specific areas of the body digitized (top of the head, C-7 spinous process, top of the shoulders bilaterally, elbows, wrists, ends of hands, L-5 lumbar vertebrae, hips bilaterally, knees, ankles, and end of the feet). The athletes then performed the vertical jump and the hang snatch exercise. Each subject's highest power vertical jump and hang snatch exercise were used for analysis. The movement, speed, and force produced at the specific joints throughout the vertical jump and the hang snatch lift were then compared. Results of this study reveal significant relationships in kinematic comparisons between the vertical jump and the hang snatch exercise, leading the authors to conclude that the vertical jump and Olympic-style weightlifting were similar in movement. While the vertical jump might be a quick assessment of Olympic weightlifting success, the authors also stressed the importance of precise technique in performing these lifts to increase the rate of force development.

In another study, Garhammer (1993) also described the similarity of the vertical jump and the explosive Olympic-style weightlifting exercises. He too concluded that, due to the biomechanical similarities, the vertical jump might be a good choice in trying to predict Olympic weightlifting performance. In addition, Garhammer and Gregor (1992) described the similarity between the vertical jump and the Olympic-style power snatch exercise. These authors noted the similar propulsive force patterns and lower extremity movements in both the vertical jump and the power snatch as evidence of their similarity.

Conclusion

While the literature has shown that 1-RM scores of weight training strength and power assessments do not correlate well with vertical jump heights, considering body weight improves these relationships drastically. Converting vertical jump height to a vertical jump power score that considers body weight seems to improve correlation coefficients, and relative values of weight training exercises have been shown to be strongly associated with sprinting speed. In addition, maximum strength seems to be associated with an athlete's power output capabilities. Body weight also seems to be related to the amount of weight an athlete can lift; athletes with larger body weights have been shown to have higher 1-RM values. Lastly, Olympic-style weightlifting exercises and vertical jumping have been shown to have similar propulsive forces and lower extremity movements.

## Sprint Running

Correlational Studies

To determine how effective various measures might be in predicting 40-yard sprint performance in college football players, Swindler (1999) used forty-three members of an NCAA Division II varsity football team as subjects. The author tested the subjects on a number of athletic performance measures including vertical jump, 1-RM back squat, and body weight to investigate their relationships with the 40-yard sprint. To measure 40-yard sprint time, subjects were timed using handheld stopwatches, and each subject ran two testing trials. Vertical jump was measured similarly to previously described studies. In obtaining a 1-RM back squat score, subjects were allowed three trials and had the option of wearing weightlifting belts, knee wraps, or other supportive garments while they tested. Results of this study revealed that both vertical jump and body weight had strong relationships with the 40-yard sprint. The vertical jump correlated with the 40-yard sprint time with a correlation coefficient of $r = -.76$, meaning that high vertical jump scores were associated with lower sprint times and therefore greater sprinting speeds.

The body weight to 40-yard sprint time correlation (r = .78) indicates that larger athletes take more time to run the sprint, and thus run at slower speeds than the smaller-sized athletes. Lastly, this study's results show that 40-yard sprint time and 1-RM back squat had a low (r = .18) correlation. This author concluded vertical jump and body size had an influence on 40-yard sprint performance, but leg strength, assessed by the 1-RM back squat, did not seem to have an effect.

Young, McLean, and Ardagna (1995) found results similar to those of Swindler's 1999 study. They used twenty (eleven male and nine female) elite level junior track and field athletes as subjects and likewise discovered a high inverse correlation (r = -.77) between time in the 50-meter sprint and vertical jump height. This study too shows that sprinting speed and vertical jump are strongly related.

Davis, Barnette, Kiger, Mirasola, and Young (2004) also studied relationships between running performance and other athletic variables in an effort to identify predictors of 40-yard sprint success in college football players. The authors collected data from forty-six NCAA Division I football players to investigate these relationships, and subjects were tested in a 40-yard sprint, the hang clean exercise, and body weight. The 40-yard sprint was timed using handheld stopwatches on an indoor, artificial turf surface. All subjects started the sprint in a three-point football stance, and timers started the clock on the athlete's first movement. Researchers also tested the subjects on the hang clean exercise. The 1-RM hang clean score was calculated from a four to six repetition submaximal intensity test, and each subject started with the loaded barbell at knee level. Results showed that both 1-RM hang clean and body weight had strong relationships with the 40-yard sprint. These authors concluded that stronger (those who performed better in the 1-RM hang clean) and lighter football players ran better in the 40-yard sprint than those athletes who were weaker and heavier. Similarly, Costill et al. (1967), Mayhew et al. (1989), and Seiler et al. (1990) found that large body weights were associated with slower sprinting speed in athletes.

In their 1996 research, Nesser, Latin, Berg, and Prentice examined relationships between performance variables to determine which ones might account for variation in 40-meter sprint performance. They used twenty male college athletes from a variety of sports and tested them on a 40-meter sprint, vertical jump, and isokinetic strength of hip and knee musculature. The 40-meter sprint was timed electronically, and each subject got three trials with four minutes of rest between runs. Vertical jump was obtained using a Vertec device, and isokinetic strength was measured for hip extension, hip flexion, knee extension, and knee flexion at different speeds. Results of this study showed that time in the 40-meter sprint had a moderate inverse ($r = -.464$) correlation with vertical jump, meaning that vertical jump was modestly associated with sprinting speed. Similar relationships were seen between the 40-meter sprint time and the isokinetic strength measures of the hip and knee at higher velocities. The authors therefore concluded that vertical jump and high-velocity isokinetic strength of the hip and knee may be associated with sprinting ability. In a similar study, Kukolj, Ropret, Ugarkovic, and Jaric (1999) found the correlation between 30-meter sprint velocity and vertical jump to be moderate ($r = .48$) and the relationships between 30-meter sprint velocity and maximum isometric strengths of the hip and knee to be poor.

Additional studies have examined the relationships between sprint performance and other measurements of lower body strength as well. For example, Blazevich and

Jenkins (1998) and Guskiewicz, Lephart, and Burkholder (1993) both investigated the relationships between sprint performance—20 meters and 40 yards, respectively—and isokinetic hip extension and hip flexion strength. Results of these studies reveal a strong relationship between sprint speed and hip extension and flexion strength. Conversely, Thomas, Fiatarone, and Fielding (1996) found that 40-yard sprinting performance had a weak relationship with 1-RM leg press strength.

Conclusion

According to the literature, sprinting speed has been shown to be closely related to height of the vertical jump. This similarity may be due to both movements requiring manipulation of the athlete's body weight and extension of the hips, knees, and ankles. While some researchers have reported a good relationship between running speed and strength, others have shown a low relationship between sprinting speed and maximum force production. This seemingly conflicting evidence might be due to differences in testing procedures among different investigators. Lastly, body weight has been shown to have a strong inverse relationship with running speed, pointing out that larger athletes typically sprint slower than smaller athletes do.

## Conclusion

Several studies have investigated the relationships between various measures of lower body movement and athleticism. Researchers have looked at jumping tests, weight training strength and power assessments, and running assessments in their quest to observe these relationships. The literature seems to show that the vertical jump and the standing long jump are strongly related to one another; correlations as high as $r = .82$

have been reported (Seiler et al., 1990). These two jumping tests have also been correlated highly with sprinting speed in both athletes and non-athletes.

In addition, vertical jump, standing long jump, and sprinting speed seem to have strong inverse relationships with body weight. Athletes with large body weights have shown a decreased ability to perform well in jumping and sprinting assessments. However, body weight has been associated with high levels of strength and power in several studies; athletes with larger body sizes typically perform better than smaller-sized athletes in measures of maximal force production and power output. Lastly, jumping and sprinting ability seems to have a poor relationship with maximum strength, but maximum strength relative to body weight has shown stronger relationships with jumping and running speed assessments than absolute scores have. Thus, investigations of lower body power and movement have shown distinct relationships with one another, and the athletic community can use this information to develop a broader evaluation of power in athletes.

# CHAPTER 3

# METHODS

This study analyzed the relationships among lower body power test variables to determine whether standing long jump is a valid field measure of an athlete's power and to determine to what extent these speed-strength assessments were related. Strong correlations among test scores were expected, and factoring body weight into the scores was expected to strengthen the relationships. Finding valid and reliable field tests for lower body power is critical to the strength and conditioning coach, as it is required in nearly all athletic activities.

## Subjects

The subjects consisted of fifty-four NCAA Division I-AA varsity football players at Eastern Illinois University. All subjects had completed at least one season of college football and strength training.

## Research Design

Data was gathered from the March 2004 testing of the Eastern Illinois University football team. The subjects' scores for the vertical jump, standing long jump, 1-RM power clean, 1-RM back squat, 40-yard sprint speed, and body weight were recorded at the time of testing. Testing was overseen by three coaches certified by the National Strength and Conditioning Association (NSCA) as Certified Strength and Conditioning

Specialists (CSCS) and took place over a four-day period. The testing schedule was as follows:

Monday: 1-RM power clean

Tuesday: vertical jump, standing long jump, 40-yard sprint

Wednesday: off

Thursday: 1-RM back squat, body weight

Peak vertical jump power was estimated by factoring body weight and vertical jump height into the Sayers regression equation, which has been shown to be more accurate than previously popular prediction equations (Keir et al., 2003). The Sayers equation is as follows:

Peak power (W) = 60.7 x jump height (cm) + 45.3 x body mass (kg) – 2,055

Body weight was also factored into the 1-RM power clean and 1-RM back squat to allow different sized subjects to be compared. Data from this testing was used to determine correlations between the lower body power tests. All subjects were healthy at the time of testing.

## Testing Procedure

### Warm-up

Prior to testing, the subjects engaged in warm-up activity consisting of light aerobic exercise, a 400-meter jog, followed by increasing levels of anaerobic or dynamic activity. Following the light aerobic activity, all subjects performed a series of shuffles, dynamic flexibility exercises, form running drills, low intensity plyometrics, and static stretching. The warm-up period took approximately fifteen minutes and was directed by the strength and conditioning staff.

Vertical Jump

To measure the vertical jump, a Vertec brand vertical jump instrument was moved to the Eastern Illinois University Lantz Fieldhouse. Testing took place on a flat indoor surface. To determine vertical jump height, each subject stood underneath the Vertec device and reached as high as possible with his dominant hand. The measuring device moves vertically on a pole, and it was set at the height of the tip of the subject's longest finger. Without taking any preliminary steps or hops—bending at the hips and knees and swinging the arms was allowed— each subject jumped vertically as high as possible and reached for plastic flags suspended overhead by the Vertec instrument. The subject tapped the movable flags, each one representing one-half inch. The coach counted the number of flags touched to determine the vertical jump and recorded the score to the nearest half-inch. The Vertec tool, by its design, subtracts the subject's reach height from his vertical jump height to give a score of vertical displacement. The tester was trained on the use of the Vertec device and was competent in its use to administer this test. The vertical jump scores were recorded in inches and later converted to centimeters for statistical analysis.

Standing Long Jump

To measure the standing long jump, a tape measure was secured to the floor of the Eastern Illinois University Lantz Fieldhouse. Each subject stood with his toes behind the marked-off starting line and jumped horizontally as far as possible. No steps or hops of any kind were allowed, but the subjects were allowed to bend at the hips and knees and swing their arms to gain momentum for the jump. The subjects were instructed to land with both feet flat on the floor and hold the landing so that the coach could mark the distance. The distance of the jump was measured from the starting line to the back of each subject's heel to the nearest quarter-inch. Each subject got three trials, and the best of those trials was recorded in inches as the standing long jump score. The scores were later converted to centimeters for statistical analysis.

Power Clean

Prior to performing the 1-RM power clean, subjects performed warm-up sets of the exercise at increasing intensities until they got to their maximum weight done for one repetition with proper technique as determined by the strength and conditioning staff. These warm-up sets of the power clean followed a more general warm-up described earlier. Testing took place in the Eastern Illinois University varsity weightroom in O'Brien Stadium, and this protocol was consistent with the NSCA's guidelines for 1-RM testing (Baechle and Earle, 2000). The subjects used free weights and barbells made by the Uesaka Company and were required to explosively lift the weight from the floor to the fronts of the shoulders using sound power clean technique. Subjects were allowed to wear a weightlifting belt to support the lower back if they desired, but no other wraps or support garments were allowed. Strength and conditioning coaches trained in the performance of this exercise monitored testing. Each subject's 1-RM was defined as the maximum amount of weight he was able to successfully lift for one rep and was recorded in kilograms.

Back Squat

To measure the 1-RM back squat, the subjects again completed the general warm-up described earlier followed by sets of the back squat exercise at increasing intensities in the Eastern Illinois University varsity weightroom in O'Brien Stadium. As with the power clean test, subjects continued to increase intensity until they got to the maximum weight they could successfully lift for one repetition with proper technique as determined by the strength and conditioning staff. This testing protocol was consistent with the NSCA's guidelines for 1-RM testing (Baechle and Earle, 2000). Using free weights and barbells made by the Standard Barbell Company, the subjects were required to squat with the loaded barbell across their shoulders and upper back using proper back squat technique until the thighs were parallel to the floor as judged by a member of the strength and conditioning staff. Again, subjects could choose to wear a weightlifting belt, but no other wraps or supportive garments were allowed. The strength and conditioning coaches monitoring this testing were trained in the performance of this exercise. Each subject's 1-RM was defined as the maximum amount of weight he was able to successfully lift for one repetition and was recorded in pounds. These scores were later converted to kilograms for statistical analysis.

40-yard Sprint

The 40-yard sprint testing took place on the indoor track of the Eastern Illinois University Lantz Fieldhouse. Each subject took part in the general warm-up prescribed by the strength and conditioning staff. The subjects then ran three 40-yard practice attempts at increasing intensities. Two lanes of the track were used for testing, and two subjects ran simultaneously in different lanes. Following completion of all warm-up activities, each subject ran two testing trials, one in each testing lane. Six members of the Eastern Illinois University football coaching staff timed the runners using Robic Model SC-505 stopwatches. Three coaches timed the runner in one lane, while the other three coaches timed the runner in the second lane. Coaches stood at the finish line and started the clock on the subject's first starting movement; they stopped the clock when the subject crossed the finish line. This method of testing is common in football evaluation (Ebben, 1998). Since each subject ran once in each lane, there were six 40-yard sprint scores—one from each coach—for each athlete. These six times were averaged to get the average 40-yard sprint time, and this average time was then converted to meters per second unit of speed for statistical analysis.

<u>Body Weight</u>

Each subject's body weight was recorded in the Eastern Illinois University varsity weightroom in O'Brien Stadium at the time of testing using a digital scale made by Befour, Inc. A member of the strength and conditioning coaching staff recorded the weight of each subject wearing only a T-shirt and athletic shorts. Subjects were not allowed to wear shoes or heavy sweatshirts and sweatpants at the time of body weight measurement. Body weights of the subjects were recorded in pounds and later converted to kilograms for statistical analysis.

## Statistical Analysis

Pearson's correlation coefficient was used to determine the relationships among the lower body power field test variables. Scores of the vertical jump, standing long jump, vertical jump peak power as determined by the Sayers equation, 1-RM power clean, 1-RM back squat, speed in the 40-yard sprint, 1-RM power clean relative to body weight, 1-RM back squat relative to body weight, and body weight were included in the analysis.

# CHAPTER 4

# RESULTS AND DISCUSSION

To validate using the standing long jump as a field test of power and to determine if relationships existed among lower body power variables in college football players, this study collected data from the March 2004 testing of the Eastern Illinois University NCAA Division I-AA football team. Measurements of vertical jump, standing long jump, 1-RM power clean, 1-RM back squat, speed in the 40-yard sprint, vertical jump power, 1-RM power clean relative to body weight, 1-RM back squat relative to body weight, and body weight from fifty-four subjects were analyzed using Pearson's correlation coefficient to determine the existence and strength of these relationships. Since lower body power is crucial in competition, strength and conditioning coaches need to establish valid and reliable tests to assess this explosiveness.

## Results

Table 1 displays the means, standard deviations, and ranges of scores of the lower body power variables assessed in this investigation. The values obtained in this study were similar to the values Fry and Kraemer (1991) reported for college football players.

Table 2 reveals a high correlation between vertical jump and standing long jump, and these two jumps also had a strong correlation with the speed in the 40-yard sprint. In addition to correlating highly with the two jumps, the speed in the 40-yard sprint was highly correlated with both the 1-RM power clean per kilogram body weight and the 1-RM back squat per kilogram body weight. Speed also had a high inverse correlation with

**Table 1**. Means, standard deviations, and score ranges for power tests and physical characteristics (n=54).

| Variable | Mean | SD | Range |
|---|---|---|---|
| Vertical jump (cm) | 70.5 | ± 9.0 | 50.8 – 88.9 |
| Standing long jump (cm) | 263.8 | ± 22.4 | 213.3 – 325.1 |
| 1-RM Power clean (kg) | 114.0 | ± 15.8 | 80.0 – 145.0 |
| 1-RM Back Squat (kg) | 175.0 | ± 28.0 | 111.3 – 238.6 |
| Speed (m/s) | 7.4 | ± 0.4 | 6.1 – 8.1 |
| Vertical jump power (W) | 6689.6 | ± 750.0 | 4924.5 – 8550.7 |
| 1-RM Power clean per kg body weight | 1.1 | ± 0.1 | 0.7 – 1.6 |
| 1-RM Back squat per kg body weight | 1.8 | ± 0.3 | 1.1 – 2.2 |
| Body weight (kg) | 98.5 | ± 19.9 | 72.2 – 142.2 |

**Table 2**. Pearson's correlation coefficients (r) for relationships among lower body power assessment variables.

| Variable | Correlation coefficients | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **VJ** | **SLJ** | **PC** | **BS** | **SP** | **VJP** | **RPC** | **RBS** | **WT** |
| 1. Vertical jump (cm) [**VJ**] | | .821 | .020 | .029 | .789 | .056 | .634 | .620 | -.560 |
| 2. Standing long jump (cm) [**SLJ**] | .821 | | -.015 | -.033 | .774 | -.132 | .661 | .615 | -.608 |
| 3. 1-RM Power clean (kg) [**PC**] | .020 | -.015 | | .726 | -.079 | .660 | .198 | .054 | .535 |
| 4. 1-RM Back Squat (kg) [**BS**] | .029 | -.033 | .726 | | -.086 | .620 | .007 | .341 | .497 |
| 5. Speed (m/s) [**SP**] | .789 | .774 | -.079 | -.086 | | -.311 | .764 | .700 | -.737 |
| 6. Vertical jump power (W) [**VJP**] | .056 | -.132 | .660 | .620 | -.311 | | -.392 | -.306 | .796 |
| 7. 1-RM Power clean per kg body weight [**RPC**] | .634 | .661 | .198 | .007 | .764 | -.392 | | .778 | -.711 |
| 8. 1-RM Back squat per kg body weight [**RBS**] | .620 | .615 | .054 | .341 | .700 | -.306 | .778 | | -.630 |
| 9. Body weight (kg) [**WT**] | -.560 | -.608 | .535 | .497 | -.737 | .796 | -.711 | -.630 | |

body weight. The power clean and back squat exercises correlated well with one another when the absolute and relative values were compared as well.

The vertical jump showed a moderate correlation with the relative 1-RM power clean and 1-RM back squat values and a moderate inverse correlation with body weight. The standing long jump had similar correlations to these variables. Vertical jump power measured in watts also demonstrated moderate relationships with the absolute 1-RM power clean and the 1-RM back squat measures, and these correlations were low when vertical jump power was compared to the relative 1-RM power clean and back squat scores.

Interestingly, the vertical jump and the standing long jump had nearly no relationship to the 1-RM power clean, the 1-RM back squat, or the vertical jump power. Body weight, however, did have a moderate correlation with 1-RM power clean and 1-RM back squat. Also, the speed in the 40-yard sprint had very low correlations with both the 1-RM power clean and the 1-RM back squat.

## Discussion

This study attempted to validate the standing long jump as a power assessment and to show the relationships among lower body power field test variables. The results of this study, which may be valuable to strength and conditioning coaches in measuring lower body explosiveness, show that vertical jump, standing long jump, speed in the 40-yard sprint, 1-RM power clean per kilogram body weight, and 1-RM squat per kilogram body weight all had strong correlations with one another. The 1-RM power clean and the 1-RM back squat also had a high correlation with one another in both absolute and relative measures. On the other hand, vertical jump, standing long jump, and speed in the 40-yard sprint had weak relationships with the absolute 1-RM power clean and 1-RM back squat values. This information seems to point out that vertical jump and standing long jump are more closely related to speed of muscular contraction than strength of contraction, and that body weight should be considered when using the power clean or back squat exercises to assess lower body power.

Vertical jump and standing long jump were highly (r = .821) correlated. This value was similar to the correlation Seiler et al. (1990) and Beckenholdt and Mayhew (1983) reported, and the strong relationship between these two tests may have been due to the similarity between the two jumps. Both the vertical jump and the standing long jump involve explosive contraction of the lower body musculature to propel the body. In addition to similar explosiveness, both jumps require similar movements at the same joints; each necessitates extension at the hip, knee, and ankle. Lastly, the vertical jump and the standing long jump both propel the same resistance through the air. In each jump, the athlete must move his body weight in a powerful manner against gravity. Therefore, potentially because of the similarity between the vertical jump and the standing long jump, the two lower body power assessments had a high correlation.

Vertical jump was not correlated with the 1-RM power clean and the 1-RM back squat (r = .020 and r = .029 respectively). Similarly, Stone et al. (1980) reported the relationship between vertical jump and absolute Olympic weightlifting performance was not strong, and Costill et al. (1967) showed a low correlation between vertical jump and back squat. These poor relationships may have been due to the large variability within the body weights of the subjects. Since football players can have quite different body types (Fry and Kraemer, 1991)—a defensive back or a wide receiver would have a much smaller body weight than a defensive or offensive lineman, for example—this difference between subjects could have led to the weak correlation between vertical jump and these weight training measures. A large football player would be able to perform well on the 1-RM power clean test or the 1-RM back squat test, but that same large athlete may not jump well because of his size. Being able to move a larger body mass is crucial in the vertical jump assessment, but it is eliminated in both the 1-RM power clean and the 1-RM back squat. Having subjects perform poorly on the vertical jump test because of their body weight and well on the 1-RM power clean and 1-RM back squat tests would therefore potentially alter the correlation between these assessments.

While vertical jump correlated poorly with the 1-RM power clean and the 1-RM back squat, it did have a high ($r = .789$) correlation to the speed in the 40-yard sprint. The high correlation reported here was similar to the relationships between vertical jump and sprinting performance that Seiler et al. (1990), Costill et al. (1967), Swindler (1999), and Young et al. (1995) reported. This strong relationship might be due to some similarities between the two assessments. First, both the vertical jump and the 40-yard sprint require explosive contraction of the lower body musculature. Next, both measures involve rapid extension of the hip, knee, and ankle joints. Third, the vertical jump and the 40-yard sprint require the athletes to move the same resistance; in both measures, the subject must powerfully manipulate his own body weight. Therefore—since vertical jump has a strong relationship with speed in the 40-yard sprint and a weak relationship with both the 1-RM power clean and 1-RM back squat—one can conclude that vertical jump is more related to speed of muscle contraction than strength of contraction in producing lower body power.

Even though vertical jump had a low correlation to the absolute 1-RM power clean value, this correlation improved greatly when body weight was considered. Vertical jump and 1-RM power clean per kilogram body weight had a moderate ($r = .634$) correlation, and this was much larger than the correlation seen when the absolute 1-RM power clean value was used. As explained in previous paragraphs, the vertical jump depends on the subject's body weight, and the 1-RM power clean score does not. However, when the 1-RM power clean score is divided by the subject's body weight, it too then depends on the body weight of the individual. This therefore strengthens the relationship between the two measurements. The vertical jump and the 1-RM power clean per kilogram body weight both depend on the subject's body weight and both involve explosively extending the hips, knees, and ankles in a vertical trajectory, so it is logical to expect this type of relationship between the two.

Like it did for the 1-RM power clean, accounting for body weight increased the correlation between the vertical jump and back squat. Table 2 shows that the vertical jump and 1-RM back squat per kilogram body weight also had a moderate ($r = .620$) correlation. The vertical jump and the absolute 1-RM back squat had a poor relationship potentially because large subjects had difficulty moving their larger body masses to jump well, yet this extra size did not affect their ability to perform well in the back squat. Considering body weight corrected for size differences. Both the vertical jump and the 1-RM back squat per kilogram body weight depend on body weight and both involve extension at the hip, knee, and ankle joints. Considering body weight thus improved the correlation between vertical jump and 1-RM back squat.

While factoring body weight into the 1-RM power clean and back squat assessments improved their correlations with vertical jump, body weight and vertical jump had a moderate inverse (r = -.560) correlation with one another. Likewise, Mayhew et al. (1994) found a similar relationship using female athletes as subjects. Performing the vertical jump test involves explosively moving one's body mass, and larger athletes would be at a disadvantage since they would have a larger mass to manipulate. It is therefore logical to conclude that subjects with large body sizes would do poorly in the vertical jump test, potentially leading to the inverse relationship seen between vertical jump and body weight.

There was also a poor relationship between standing long jump and the 1-RM power clean and 1-RM back squat. The weak correlations (r = -.015 and r = -.033 respectively) may be explained using the same reasoning used to explain why the vertical jump correlated so poorly to these weight training strength and power assessments. Football players typically have a large amount of variability in their body sizes (Fry and Kraemer, 1991), and the subjects in this study were no different. In performing the standing long jump test, being able to explosively move one's own body weight is crucial, and larger athletes are at a disadvantage. However, the large body sizes of these athletes do not affect their ability to perform well on the 1-RM power clean or 1-RM back squat measurement. Therefore, having subjects that perform poorly on the standing long jump test because of their size and well on the 1-RM power clean and 1-RM back squat would reduce the strength of the relationships found in this study. In their 1967 research, Costill et al. found a slightly stronger relationship between the standing long jump and 1-RM back squat (r = -.271) than what was discovered in the present study, and conversely, Koch et al. (2003) reported a correlation coefficient of r = .805 between standing long jump and 1-RM back squat using both trained and untrained subjects.

Although the standing long jump correlated poorly with both the 1-RM power clean and the 1-RM back squat, it did—like the vertical jump—have a high (r = .774) correlation with the speed in the 40-yard sprint. Seiler et al. (1990), Costill et al. (1967), Mayhew and Salm (1990), and Beckenholdt and Mayhew (1983) found similar relationships between standing long jump and sprinting ability. This strong relationship may have potentially been due to similarities between the two assessments. First, both the standing long jump and the 40-yard sprint involve rapid and explosive extension of the hip, knee, and ankle joints to propel the body horizontally. Also, both measures require the athlete to manipulate the same resistance; in both tests, the subject must guide his own body weight. Since standing long jump had a poor relationship with both the 1-RM power clean and 1-RM back squat and had a high correlation with speed in the 40-yard sprint, one may therefore conclude that standing long jump is more closely related to speed of muscular contraction than strength of muscular contraction in producing lower body power.

Like the vertical jump, the correlation between standing long jump and 1-RM power clean improved greatly when the subject's body weight was considered. Standing long jump and 1-RM power clean per kilogram body weight had a moderate (r = .661) correlation, and this was a much stronger relationship than when the absolute 1-RM power clean value was used. This improvement may have been due to the fact that dividing the 1-RM power clean score by body weight makes it dependent on body weight like the standing long jump is. Therefore, if standing long jump and 1-RM power clean per kilogram body weight both depend on body weight and both involve explosively extending the hip, knee, and ankle joints, it is logical that these two measures would have a stronger relationship.

Like it did for 1-RM power clean, considering body weight in the 1-RM back squat improved its relationship with standing long jump. The standing long jump and 1-RM back squat per kilogram body weight had a moderate ($r = .615$) correlation. Standing long jump and the absolute 1-RM back squat had a poor relationship potentially because large athletes were not able to jump well, but these same subjects with large body weights could still perform well on the 1-RM back squat assessment. Having a large body mass is a disadvantage in the standing long jump test because jumping involves manipulating one's body explosively, yet the back squat does not penalize subjects for having large masses. Considering body weight in the 1-RM back squat score eliminates this problem. Both standing long jump and relative 1-RM back squat depend on body weight and both require extension of the hip, knee, and ankle joints. Taking body weight into consideration therefore improves the correlation between the standing long jump and the 1-RM back squat.

Similar to the relationship between vertical jump and body weight, standing long jump had a moderate inverse ($r = -.608$) correlation with body weight. This relationship may potentially have been due to similar reasoning as with the vertical jump. Athletes with larger body sizes are at a disadvantage in the explosive standing long jump test and would score poorly. One can therefore conclude that a high body weight negatively affects jumping ability.

The 1-RM power clean and 1-RM back squat had a high ($r = .726$) correlation; Stone et al. (2003) also reported Olympic-style weightlifting performance and maximum strength were strongly related. This could potentially be attributed to similar extension of the hip, knee, and ankle joints. On the other hand, 1-RM power clean has a very low ($r = -.079$) correlation to speed in the 40-yard sprint, similar to the relationship Baker and Nance (1999) reported using a 3-RM hang clean and a 40-meter sprint. This might be due to the large variability in the body sizes of football players. Subjects with large body weights would be at a disadvantage in a running sprint test, but these same athletes would be able to perform well in the 1-RM power clean test. Having subjects test poorly in the speed test due to their large body masses and test well in the power clean test would show a poor relationship. Since 1-RM power clean has a high correlation to 1-RM back squat, an assessment that has been shown to be a measure of strength (Baechle and Earle, 2000), and a very low correlation to speed in the 40-yard sprint, one can conclude that 1-RM power clean assesses mostly the strength component of power and very little of the speed component of power.

Similarly, the 1-RM back squat and speed in the 40-yard sprint had a very low inverse ($r = -.086$) correlation. Likewise, Swindler (1999) and Baker and Nance (1999) reported these two variables had similar relationships. This poor relationship is again likely to be due to large subjects being at a disadvantage in a running test, but that disadvantage is eliminated in the 1-RM back squat measure. Therefore, one can conclude that the speed component of power does not correlate well with the strength component of power.

The 1-RM power clean (r = .535) and 1-RM back squat (r = .497) had moderate correlations to body weight. Likewise, Pilis et al. (1997), Miller et al. (2002), and Mayhew et al. (1987) reported that body weight is significantly related to performance in these strength and power assessments; larger athletes have been shown to lift more weight than smaller athletes. On the other hand, speed in the 40-yard sprint has a high inverse (r = -.737) correlation with body weight. Other studies (Swindler, 1999; Davis et al., 2004; Costill et al., 1967; Mayhew et al., 1989; Seiler et al., 1990) had discovered similar relationships. Large body size is moderately associated with high strength scores, but a larger body has a high negative association with speed. Because of body weight's positive relationships to 1-RM power clean and 1-RM back squat, one can conclude that body weight moderately influences the strength component of power production. Because of body weight's inverse relationships to vertical jump, standing long jump, and speed in the 40-yard sprint, one can also conclude that body weight has a negative influence on the speed component of power. Therefore, body weight may have a slight positive affect on strength and a highly negative affect on speed when considering power production.

However, the results of this study show that considering body weight improved the correlation between speed in the 40-yard sprint and both 1-RM power clean and 1-RM back squat. Speed in the 40-yard sprint had a high correlation with both 1-RM power clean per kilogram body weight (r = .764) and 1-RM back squat per kilogram body weight (r = .700). Baker and Nance (1999) also reported relationships of similar strength between sprinting ability and relative vales of both the hang clean and back squat. This information seems to indicate that an athlete's strength and power relative to body size is closely related to sprinting speed.

Table 2 also shows the relationships between the absolute and relative 1-RM scores of the power clean and the back squat. The 1-RM power clean had a very low correlation with both the 1-RM power clean per kilogram body weight ($r = .198$) and 1-RM back squat per kilogram body weight ($r = .054$). The 1-RM back squat also had a very low ($r = .007$) correlation with 1-RM power clean per kilogram body weight and a low ($r = .341$) correlation with 1-RM back squat per kilogram body weight. Since absolute scores do not depend on the subject's body weight and relative scores do, it seems logical that these poor relationships would occur. However, 1-RM power clean per kilogram body weight and 1-RM back squat per kilogram body weight did have a high ($r = .778$) correlation, potentially due to their both depending on body weight and their similarity involving extension of the lower body joints. Therefore, one can conclude that absolute strength has a weak relationship with relative strength.

The 1-RM power clean relative to body weight and body weight had a high inverse ($r = -.711$) correlation, while relative 1-RM back squat and body weight had a moderate inverse ($r = -.630$) correlation. Since the relative values of 1-RM power clean and 1-RM back squat are closely related to the speed component of power production and body weight seems to influence the strength component, it seems logical then that these scores would have negative relationships with one another.

Since the Sayers equation to assess vertical jump power considers both the height of the vertical jump and the body weight of the jumper, it eliminates the larger athlete's disadvantage in jumping ability. An athlete with a large body weight who does not score well on the vertical jump will still score well on vertical jump power because his large size is considered in the calculation. Vertical jump power had a very low correlation to vertical jump (r = .056), a very low inverse correlation to standing long jump (r = -.132), and a low inverse correlation to speed in the 40-yard sprint (r = -.311). This was slightly stronger than the correlation (r = .06) Manning et al. (1988) reported between vertical jump power and the 40-yard sprint. In the vertical jump, standing long jump, and 40-yard sprint, athletes with large body weights are at a disadvantage as described earlier, but this disadvantage is eliminated in the calculation of vertical jump power using the Sayers equation. This difference may have led to the poor relationships between vertical jump power and vertical jump, standing long jump, and speed in the 40-yard sprint.

While vertical jump power had weak relationships with vertical jump, standing long jump, and speed in the 40-yard sprint, vertical jump power did have stronger relationships with both the 1-RM power clean and the 1-RM back squat. As shown in Table 2, vertical jump power had a moderate correlation with both 1-RM power clean (r = .660) and 1-RM back squat (r = .620). Similarly, Stone et al. (1980) reported a high correlation (r = .80) between vertical jump power and 1-RM power clean. This might have occurred because in all three of the assessments, the disadvantage that the large athletes face in other tests was non-existent. In vertical jump power, 1-RM power clean, and 1-RM back squat, large subjects are not penalized because of their body size like they are in other measures. Also, vertical jump power, 1-RM power clean, and 1-RM back squat all involve similar movement patterns. Vertical jump power therefore had strong relationships with the 1-RM power clean and 1-RM back squat.

In addition, vertical jump power had a high (r = .796) correlation with body weight. Mayhew and Salm (1990) found a similar r-value between body weight and vertical jump power. This relationship may have been due to the fact that large athletes are not penalized for their large size in the Sayers equation. Subjects with higher body weights can still score well in vertical jump power, and this might explain the strength of the relationship. Also, vertical jump power and body weight are both associated with the strength aspect of power production, so it seems logical that these two measures would have a high correlation.

Lastly, vertical jump power has low inverse correlations with 1-RM power clean per kilogram body weight (r = -.392) and 1-RM back squat per kilogram body weight (r = -.306). These poor relationships seem logical since vertical jump power correlated well with the absolute values of the 1-RM power clean and 1-RM back squat. Therefore, results of this study show that vertical jump power does not correlate well with relative measures of 1-RM power clean and 1-RM back squat.

## Practical Applications

The vertical jump test has been recognized as a field test measuring lower body power and is frequently used (Klavora, 2000). However, obtaining vertical jumps score for many athletes can be a time consuming process since the coach must measure each athlete's reach height and maximum jump height, and then calculate the difference between the two heights. On the other hand, the standing long jump is an easy test to administer; it requires only a small amount of space and the ability to read a tape measure. The results of this study showed that vertical jump and standing long jump scores had a high correlation to one another, and this information could be quite valuable to strength and conditioning coaches. Since vertical jump and standing long jump have such a strong relationship, it seems as though standing long jump would also be a valid field test of lower body power. A coach could choose to measure lower body power using the standing long jump test instead of the vertical jump test, especially if he or she is short on time or space. Thus, being able to use the standing long jump to assess lower body power is a valuable tool for the strength and conditioning coach to have.

Because lower body power is so critical in athletic competition, a strength and conditioning coach would greatly benefit his or her athletes if the component of power—speed or strength—that was being assessed in each test could be identified. Following that identification, the coach would be able to alter training programs to improve weaknesses of each athlete and make him more powerful. For example, if an athlete scored well on the 1-RM power clean test, but did poorly on the vertical jump test or standing long jump assessment, the strength and conditioning coach could conclude that this athlete had good maximum strength but would need to improve in the speed aspect of power production. He could therefore alter this athlete's training to focus on improving that deficiency. By focusing more training to improving speed rather than maximum strength, the strength and conditioning coach could help this particular athlete's sport performance. Thus, the results of this study allow strength and conditioning coaches to identify which assessments represent which component of power production, and this might prove to be crucial information.

The 1-RM back squat has been shown to be a measure of maximum strength (Ebben, 1998) and has a strong relationship with the 1-RM power clean. The 1-RM power clean has a poor relationship to the speed in the 40-yard sprint, a measure of speed of muscular contraction (Ebben, 1998). One can therefore conclude that 1-RM power clean represents more of the strength component of power production than the speed component. This has practical significance to strength and conditioning coaches in that they can adjust training to match the individual needs of each athlete based on testing results.

Neither the vertical jump nor the standing long jump correlated well with 1-RM power clean and 1-RM back squat, but both of these jumps had strong relationships with the speed in the 40-yard sprint. This shows that the vertical jump and the standing long jump represent the speed component of power, not the strength component. Again, effectively identifying which component of power is being assessed will allow strength and conditioning coaches to train athletes to meet their individual needs.

Since body weight seems to have a negative impact on the speed component of power production and a positive impact on the strength aspect of power, it is difficult to compare large and small athletes' scores on these power assessments. Within a college football team, there is huge variety in the body sizes of the players; according to a 1994 survey by Black and Roundy, the mean body weight of a starting offensive tackle (124.4 ± 11.1 kg.) on an NCAA Division I football team is dramatically higher than that of a starting wide receiver (80.7 ± 5.7 kg.). It therefore seems illogical or inappropriate to compare testing results without considering body weight. Results of this study showed that considering body weight improved the relationships of 1-RM power clean and 1-RM back squat to vertical jump, standing long jump, and speed in the 40-yard sprint. Thus, in addition to absolute 1-RM power clean and 1-RM back squat values, relative values of the weight training tests should be used so that smaller athletes are not at a disadvantage and to reflect the different needs of different positions in football. Making these adjustments in testing will give the strength and conditioning coach a broader view of his athletes' power, and this information will allow him to develop more effective training programs to improve the team's on-field performance.

# CHAPTER 5

## SUMMARY AND CONCLUSIONS

Assessing the lower body power of athletes is of critical importance to the strength and conditioning coach. The need for an athlete to use his lower body explosively exists in nearly every sport at nearly every level of competition, so measuring this construct is crucial. However, there are several testing options for the coach to use. Field tests for lower body power are preferred since they are often more practical and more closely related to competition, yet not all tests are as efficient as others. The vertical jump, the 1-RM of an explosive exercise like the power clean, the 1-RM of a strength assessment like the back squat, or a speed assessment like the 40-yard sprint have been used as predictors of lower body explosiveness, but using these assessments on a large number of athletes can be tedious. This study therefore aimed to show the more-easily administered standing long jump test as a valid field evaluation of lower body power and to examine the relationships between other assessments commonly used by strength and conditioning coaches.

This study used data gathered from the March 2004 testing of the Eastern Illinois University NCAA Division I-AA varsity football team. The subjects were tested on the vertical jump, standing long jump, 1-RM power clean, 1-RM back squat, speed in the 40-yard sprint, and body weight. Scores of these tests—in addition to vertical jump peak power as determined by the Sayers equation, 1-RM power clean relative to body weight, and 1-RM back squat relative to body weight—were used for statistical analysis.

Pearson's correlation coefficient was used to determine the strength of relationships between variables.

This study found that vertical jump, standing long jump, speed in the 40-yard sprint, and relative values of 1-RM power clean and back squat had strong correlations with one another. Absolute 1-RM values of the power clean and back squat, vertical jump power, and body weight had strong relationships with one another and weak relationships with the other assessments.

## Conclusion

Based on the results of this study, the following conclusions were made:

- The standing long jump seems to be a good indicator of lower body power since it correlated highly to the vertical jump, an already-accepted measure of the same construct.
- 1-RM power clean seems to measure the strength component of power since it correlated strongly with 1-RM back squat and correlated weakly with speed in the 40-yard dash. The ability to identify which component of power a field test measures will allow the strength and conditioning coach to better evaluate and train athletes.
- Vertical jump and standing long jump seem to measure the speed component of power since these two jumps had strong relationships with speed in the 40-yard sprint and poor relationships with both the 1-RM power clean and 1-RM back squat. Again, the strength and conditioning

coach can better evaluate and train athletes if he or she is able to identify which component of power is being assessed.

- Relative values of the 1-RM power clean and 1-RM back squat should be used in addition to absolute values because the relative values correlated much higher with vertical jump and standing long jump. This information is crucial when comparing different athletes. There is great variety in body weights within a football team, and ignoring body weight creates disadvantages for smaller athletes.

## Recommendations for Using the Results of the Study

This study showed that the standing long jump correlated well with the vertical jump. Coaches can therefore conclude that the standing long jump is a valid field measure of lower body power like the vertical jump test is. Strength and conditioning coaches looking for a simple and time-efficient way of assessing power ought to consider using the standing long jump with their athletes. While this study's results indicate the standing long jump is a valid field assessment of lower body power, it is not the purpose of this investigation to discourage the use of other lower body power tests. These measures are still effective assessments, but the standing long jump deserves consideration as a result of this study.

Next, coaches ought to consider which component of power each test represents and alter training programs accordingly. Since this study showed vertical jump and standing long jump to measure the speed component of power and 1-RM power clean to measure the strength component of power, strength and conditioning coaches can better identify areas of concern in athletes. For example, if an athlete performs well on the 1-RM power clean test and poorly on the vertical jump and standing long jump tests, the strength and conditioning coach can alter this athlete's training regiment to focus more on improving the speed component of power rather than the strength component. Using the results of this study to identify which component of power is being assessed is therefore recommended.

Strength and conditioning coaches should also consider an athlete's relative 1-RM score for the power clean and back squat according to this study's findings. Since these relative values were more strongly related to vertical jump and standing long jump than the absolute values, considering body weight gives the coach a broader view of his or her athletes' power. This consideration might be even more crucial for those athletes playing positions in which speed plays a major role like a wide receiver or defensive back in football.

## Recommendations for Further Study

This study determined relationships between field measures of lower body power using data gathered from the March 2004 testing of the Eastern Illinois University NCAA Division I-AA varsity football team. Since all fifty-four subjects in this study were college football players, different samples of subjects ought to be studied.

First, athletes who participate in other sports should be studied. Perhaps some confounding variable specific only to football players emerged in this investigation, and using other athletes would allow the results to more easily generalized. Practical applications taken from this study regarding football players would be useful to strength and conditioning coaches if they could apply them to different athletes.

In addition to studying athletes from other sports, further study should include subjects from different universities and from different areas of the county. All subjects in the present study attended the same university, and results of future research could be more easily generalized to other populations if a broader subject pool was considered.

Next, relationships of power assessments should be determined using female subjects. The present study analyzed scores of only male subjects, so its results cannot be generalized to female athletes. However, determining these relationships for female athletes would satisfy a need in the athletic community, as women's athletics has gained support in recent years.

Further investigation might also study athletes competing at other levels of sport. This study looked only at NCAA Division I-AA football players, but studying athletes at other levels would give coaches a broader view of assessing power. Professional athletes, high school athletes, or college athletes at different levels might show different relationships than what was reported in the present study. Knowing how these athletes differ from one another would benefit coaches at different levels or those who train a variety of athletes.

Lastly, future research ought to consider other measures of power. While this study included several tests commonly used in football evaluation, it by no means studied every power assessment available. Researchers could use other measures of lower body power like the Wingate test or the Margaria-Kalamen test, or they might include upper body tests like the bench press or medicine ball throw to determine relationships, for example. Having data from more tests or a wider range of tests may give the strength and conditioning coach a more complete profile of an athlete's power and therefore allow for better evaluation and training.

## REFERENCES


Ashley, C.D., & Weiss, L.W. (1994). Vertical jump performance and selected physiological characteristics of women. Journal of Strength and Conditioning Research, 8, 5-11.

Baechle, T.R., & Earle, R.W. (2000) Essentials of strength training and conditioning (2nd ed.). Champaign, Illinois: Human Kinetics.

Baker, D., & Nance, S. (1999). The relation between running speed and measures of strength and power in professional rugby players. Journal of Strength and Conditioning Research, 13, 230-235.

Beckenholdt, S.E., & Mayhew, J.L. (1983). Specificity among anaerobic power tests in male athletes. Journal of Sports Medicine and Physical Fitness, 23, 326-332.

Black, W., & Roundy, E. (1994). Comparisons of size, strength, speed, and power in NCAA division 1-A football players. Journal of Strength and Conditioning Research, 8, 80-85.

Blazevich, A.J., & Jenkins, D.G. (1998). Predicting sprint running times from isokinetic and squat lift tests: a regression analysis. Journal of Strength and Conditioning Research, 12, 101-103.

Canavan, P.K., Garrett, G.E., & Armstrong, L.E. (1996). Kinematic and kinetic relationships between an Olympic-style lift and the vertical jump. Journal of Strength and Conditioning Research, 10, 127-130.

Considine, W.J., & Sullivan, W. J. (1973). Relationship of selected tests of leg strength and leg power on college men. The Research Quarterly, 44, 404-416.

Costill, D.L., Hoffman, W.M., Kehoe, F., Miller, S.J., & Myers, W.C. (1968). Maximum anaerobic power among college football players. Journal of Sports Medicine and Physical Fitness, 8, 103-106.

Costill, D.L., Miller, S.J., Myers, W.C., Kehoe, F.M., & Hoffman, W.M. (1967). Relationship among selected tests of explosive leg strength and power. The Research Quarterly, 39, 785-787.

Dauty, M., Bryand, F., & Potiron-Josse, M. (2002). Relation between isokinetic torque, jump and sprint in high-level soccer player. Science & Sports, 17, 122-127.

Davis, D.S., Barnette, B.J., Kiger, J.T., Mirasola, J.J., & Young, S.M. (2004). Physical characteristics that predict functional performance in division I college football players. Journal of Strength and Conditioning Research, 18, 115-120.

Ebben, W.P. (1998). A review of football fitness testing and evaluation. Strength and Conditioning, 20, 42-49.

Fry, A.C., & Kraemer, W.J. (1991). Physical performance characteristics of American collegiate football players. Journal of Applied Sport Science Research, 5, 126-138.

Garhammer, J. (1993). A review of power output studies of Olympic and powerlifting: methodology, performance prediction, and evaluation tests. Journal of Strength and Conditioning Research, 7, 76-89.

Garhammer, J., & Gregor, R. (1992). Propulsion forces as a function of intensity for weightlifting and vertical jumping. Journal of Applied Sport Science Research, 6, 129-134.

Guskiewicz, K., Lephart, S., & Burkholder, R. (1993). The relationship between sprint speed and hip flexion/extension strength in collegiate athletes. Isokinetics and Exercise Science, 3, 111-116.

Harman, E.A., Rosenstein, M.T., Frykman, P.N., Rosenstein, R.M., & Kraemer, W.J. (1991). Estimation of human power output from vertical jump. Journal of Applied Sport Science Research, 5, 116-120.

Hedrick, A., & Anderson, J. (1996). The vertical jump: a review of the literature and a team case study. Strength and Conditioning, 18, 7-12.

Keir, P.J., Jamnik, V.K., & Gledhill, N. (2003). Technical-methodological report: a nomogram for peak leg power output in the vertical jump. Journal of Strength and Conditioning Research, 17, 701-703.

Klavora, P. (2000). Vertical-jump tests: a critical review. Strength and Conditioning Journal, 22, 70-75.

Koch, A.J., O'Bryant, H.S., Stone, M.E., Sanborn, K., Proulx, C., Hruby, J., Shannonhouse, E., Boros, R., & Stone, M.H. (2003). Effect of warm-up on the standing broad jump in trained and untrained men and women. Journal of Strength and Conditioning Research, 17, 710-714.

Kukolj, M., Ropret, R., Ugarkovic, D., & Jaric, S. (1999). Anthropometric, strength, and power predictors of sprinting performance. Journal of Sports Medicine and Physical Fitness, 39, 120-122.

Liebermann, D.G., & Katz, L. (2003). On the assessment of lower-limb muscular power capability. Isokinetics and Exercise Science, 11, 87-94.

Manning, J.M., Dooly-Manning, C., & Perrin, D.H. (1988). Factor analysis of various anaerobic power tests. The Journal of Sports Medicine and Physical Fitness, 28, 138-144.

Mayhew, J.L., Bemben, M.G., Rohrs, D.M., & Bemben, D.A. (1994). Specificity among anaerobic power tests in college female athletes. Journal of Strength and Conditioning Research, 8, 43-47.

Mayhew, J.L., McCormick, T., Levy, B., & Evans, G. (1987). Strength norms for NCAA division II college football players. National Strength & Conditioning Association Journal, 9, 67-69.

Mayhew, J.L., Piper, F.C., Schwegler, T.M., & Ball, T.E. (1989). Contributions of speed, agility and body composition to anaerobic power measurement in college football players. Journal of Applied Sport Science Research, 3, 101-106.

Mayhew, J.L., & Salm, P.C. (1990). Gender differences in anaerobic power tests. European Journal of Applied Physiology, 60, 133-138.

Miller, T.A., White, E.D., Kinley, K.A., Congleton, J.J., & Clark, M.J. (2002). The effects of training history, player position, and body composition on exercise performance in collegiate football players. Journal of Strength and Conditioning Research, 16, 44-49.

Nesser, T.W., Latin, R.W., Berg, K., & Prentice, E. (1996). Physiological determinants of 40-meter sprint performance in young male athletes. Journal of Strength and Conditioning Research, 10, 263-267.

Pilis, W., Wojtyna, J., Langfort, J., Zajac, A., Manowska, B., Chmura, J., & Zarzeczny, R. (1997). Relationships between sport results, somatic variables and anaerobic power in elite weight lifters. Biology of Sport, 14, 275-281.

Sawyer, D.T., Ostarello, J.Z., Suess, E.A., & Dempsey, M. (2002). Relationship between football playing ability and selected performance measures. Journal of Strength and Conditioning Research, 16, 611-616.

Seiler, S., Taylor, M., Diana, R., Layes, J., Newton, P., & Brown, B. (1990). Assessing anaerobic power in collegiate football players. Journal of Applied Sport Science Research, 4, 9-15.

Stone, M.H., Byrd, R., Tew, J., & Wood, M. (1980). Relationship between anaerobic power and Olympic weightlifting performance. Journal of Sports Medicine, 20, 99-102.

Stone, M.H., Sanborn, K., O'Bryant, H.S., Hartman, M., Stone, M.E., Proulx, C., Ward, B., & Hruby, J. (2003). Maximum strength-power-performance relationships in collegiate throwers. Journal of Strength and Conditioning Research, 17, 739-745.

Swindler, R.S. (1999). Predicting 40-yard dash time in college football players. Retrieved on June 4, 2004 from www.iowaahperd.org/journal/predicting_40yard.html.

Thomas, M., Fiatarone, M.A., & Fielding, R.A. (1996). Leg power in young women: relationship to body composition, strength, and function. Medicine and Science in Sports and Exercise, 28, 1321-1326.

Ugarkovic, D., Matavulj, D., Kukolj, M., & Jaric, S. (2002). Standard anthropometric, body composition, and strength variables as predictors of jumping performance in elite junior athletes. Journal of Strength and Conditioning Research, 16, 227-230.

Weiss. L.W., Relyea, G.E., Ashley, C.D., & Propst, R.C. (1997). Using velocity-spectrum squats and body composition to predict standing vertical jump ability. Journal of Strength and Conditioning Research, 11, 14-20.

Young, W., McLean, B., & Ardagna, J. (1995). Relationship between strength qualities and sprinting performance. Journal of Sports Medicine and Physical Fitness, 35, 13-19.

Young, W., Wilson, G., & Byrne, C. (1999). Relationship between strength qualities and performance in standing and run-up vertical jumps. The Journal of Sports Medicine and Physical Fitness, 39, 285-293.

APPENDIX

RAW DATA OF TESTING SCORES

| Subject | WT (kg) | VJ (cm) | SLJ (cm) | PC (kg) | VJP (W) | PC/kg | 40 m/s | SQ (kg) | SQ/kg |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 87.73 | 74.93 | 276.86 | 104.6 | 6467.30 | 1.19 | 7.87 | 175.00 | 1.99 |
| 2 | 74.55 | 81.28 | 294.64 | 100 | 6255.61 | 1.34 | 7.92 | 163.64 | 2.20 |
| 3 | 89.55 | 80.01 | 279.4 | 100 | 6858.02 | 1.12 | 7.83 | 175.00 | 1.95 |
| 4 | 76.36 | 77.47 | 283.21 | 102.5 | 6106.70 | 1.34 | 7.62 | 175.00 | 2.29 |
| 5 | 85.91 | 71.12 | 304.8 | 114.6 | 6153.67 | 1.33 | 7.87 | 184.09 | 2.14 |
| 6 | 72.73 | 64.77 | 276.86 | 89 | 5171.08 | 1.22 | 7.51 | 131.82 | 1.81 |
| 7 | 72.73 | 81.28 | 269.24 | 104.6 | 6173.24 | 1.44 | 7.33 | 159.09 | 2.19 |
| 8 | 94.55 | 71.12 | 259.08 | 102.2 | 6544.89 | 1.08 | 7.80 | 159.09 | 1.68 |
| 9 | 75.91 | 71.12 | 256.54 | 104.6 | 5700.67 | 1.38 | 7.65 | 156.82 | 2.07 |
| 10 | 88.64 | 68.58 | 261.62 | 115 | 6123.03 | 1.30 | 7.67 | 152.27 | 1.72 |
| 11 | 76.82 | 71.12 | 274.32 | 90 | 5741.85 | 1.17 | 7.54 | 125.00 | 1.63 |
| 12 | 129.55 | 67.31 | 243.84 | 145 | 7899.13 | 1.12 | 7.13 | 227.27 | 1.75 |
| 13 | 98.64 | 73.66 | 261.62 | 112.5 | 6884.39 | 1.14 | 7.40 | 188.64 | 1.91 |
| 14 | 102.73 | 69.85 | 256.54 | 129 | 6838.44 | 1.26 | 7.17 | 202.27 | 1.97 |
| 15 | 142.27 | 60.96 | 223.52 | 135 | 8090.23 | 0.95 | 6.97 | 184.09 | 1.29 |
| 16 | 127.73 | 76.2 | 269.24 | 140 | 8356.39 | 1.10 | 7.37 | 227.27 | 1.78 |
| 17 | 115.00 | 88.9 | 297.18 | 140 | 8550.73 | 1.22 | 7.85 | 209.09 | 1.82 |
| 18 | 95.45 | 68.58 | 261.62 | 104.6 | 6431.90 | 1.10 | 7.39 | 197.73 | 2.07 |
| 19 | 110.00 | 60.96 | 241.3 | 110 | 6628.27 | 1.00 | 7.09 | 197.73 | 1.80 |
| 20 | 79.55 | 76.2 | 274.32 | 84.6 | 6173.75 | 1.06 | 7.51 | 129.55 | 1.63 |
| 21 | 89.55 | 67.31 | 269.24 | 112.5 | 6087.13 | 1.26 | 7.09 | 143.18 | 1.60 |
| 22 | 95.00 | 64.77 | 261.62 | 110 | 6180.04 | 1.16 | 7.20 | 150.00 | 1.58 |
| 23 | 98.18 | 77.47 | 292.1 | 130 | 7095.07 | 1.32 | 7.57 | 145.45 | 1.48 |
| 24 | 95.91 | 74.93 | 266.7 | 130 | 6837.93 | 1.36 | 7.56 | 206.82 | 2.16 |
| 25 | 92.73 | 87.63 | 292.1 | 120 | 7464.69 | 1.29 | 8.07 | 197.73 | 2.13 |
| 26 | 97.27 | 67.31 | 243.84 | 124.6 | 6437.17 | 1.28 | 6.88 | 177.27 | 1.82 |
| 27 | 131.36 | 50.8 | 236.22 | 110 | 6979.33 | 0.84 | 6.69 | 152.27 | 1.16 |
| 28 | 139.09 | 55.88 | 213.36 | 105 | 7637.73 | 0.75 | 6.18 | 163.64 | 1.18 |
| 29 | 126.82 | 52.07 | 213.36 | 104.6 | 6850.51 | 0.82 | 6.43 | 165.91 | 1.31 |
| 30 | 132.73 | 58.42 | 246.38 | 120 | 7503.64 | 0.90 | 6.90 | 238.64 | 1.80 |
| 31 | 130.00 | 54.61 | 231.14 | 127.2 | 7148.83 | 0.98 | 6.71 | 213.64 | 1.64 |
| 32 | 126.36 | 58.42 | 231.14 | 110 | 7215.37 | 0.87 | 6.67 | 165.91 | 1.31 |
| 33 | 124.09 | 55.88 | 246.38 | 135 | 6958.23 | 1.09 | 7.05 | 193.18 | 1.56 |
| 34 | 120.91 | 74.93 | 261.62 | 110 | 7970.43 | 0.91 | 7.09 | 188.64 | 1.56 |
| 35 | 80.00 | 71.12 | 264.16 | 100 | 5885.98 | 1.25 | 7.64 | 150.00 | 1.88 |
| 36 | 90.00 | 73.66 | 281.94 | 100 | 6493.16 | 1.11 | 7.65 | 181.82 | 2.02 |
| 37 | 84.55 | 72.39 | 261.62 | 135 | 6168.98 | 1.60 | 7.99 | 186.36 | 2.20 |
| 38 | 88.64 | 73.66 | 281.94 | 130 | 6431.39 | 1.47 | 8.16 | 200.00 | 2.26 |
| 39 | 103.18 | 73.66 | 285.75 | 140 | 7090.30 | 1.36 | 7.64 | 204.55 | 1.98 |
| 40 | 100.00 | 63.5 | 246.38 | 110 | 6329.45 | 1.10 | 6.95 | 211.36 | 2.11 |

| Subject | WT (kg) | VJ (cm) | SLJ (cm) | PC (kg) | VJP (W) | PC/kg | 40 m/s | SQ (kg) | SQ/kg |
|---|---|---|---|---|---|---|---|---|---|
| 41 | 107.27 | 73.66 | 254 | 140 | 7275.62 | 1.31 | 7.46 | 193.18 | 1.80 |
| 42 | 117.73 | 60.96 | 233.68 | 120 | 6978.32 | 1.02 | 7.16 | 168.18 | 1.43 |
| 43 | 87.27 | 67.31 | 271.78 | 112.2 | 5984.17 | 1.29 | 7.75 | 165.91 | 1.90 |
| 44 | 87.73 | 68.58 | 267.97 | 106.8 | 6081.85 | 1.22 | 7.65 | 175.00 | 1.99 |
| 45 | 74.09 | 59.69 | 243.84 | 84.6 | 4924.50 | 1.14 | 7.29 | 111.36 | 1.50 |
| 46 | 72.27 | 74.93 | 274.32 | 102.5 | 5767.21 | 1.42 | 8.06 | 152.27 | 2.11 |
| 47 | 80.00 | 78.74 | 284.48 | 105 | 6348.52 | 1.31 | 7.85 | 175.00 | 2.19 |
| 48 | 90.00 | 88.9 | 325.12 | 130 | 7418.23 | 1.44 | 8.07 | 184.09 | 2.05 |
| 49 | 97.27 | 78.74 | 284.48 | 135 | 7130.97 | 1.39 | 7.72 | 206.82 | 2.13 |
| 50 | 128.64 | 63.5 | 259.08 | 120 | 7626.68 | 0.93 | 6.52 | 152.27 | 1.18 |
| 51 | 91.36 | 76.2 | 247.65 | 115 | 6709.11 | 1.26 | 7.82 | 184.09 | 2.01 |
| 52 | 87.27 | 73.66 | 254 | 109 | 6369.62 | 1.25 | 8.07 | 143.18 | 1.64 |
| 53 | 83.18 | 72.39 | 274.32 | 104.6 | 6107.21 | 1.26 | 7.82 | 159.09 | 1.91 |
| 54 | 75.00 | 86.36 | 279.4 | 80 | 6584.55 | 1.07 | 7.99 | 125.00 | 1.67 |

WT: body weight
VJ: vertical jump
SLJ: standing long jump
PC: 1-RM power clean
VJP: vertical jump power
PC/kg: 1-RM power clean per kilogram body weight
40 m/s: speed in the 40-yard sprint
SQ: 1-RM back squat
SQ/kg: 1-RM back squat per kilogram body weight