THE ASSOCIATION BETWEEN POWER AND SPRINT PERFORMANCE IN
COLLEGIATE FEMALE SOCCER PLAYERS

By

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A Thesis

Presented to

The Faculty of Humboldt State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

In Kinesiology: Teaching/Coaching

May 2009
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Abstract

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The purpose of this study was to determine the relationships between measures of power clean (PC) performance, vertical jump height (VJ), and sprint times among Division II collegiate female soccer players. Hypotheses were (1) relative measures of PC and VJ height would be directly related to each other and inversely related to sprint times, and (2) relative measures of PC would distinguish soccer athletes with regard to sprint ability. PC performance was measured using a standard 3-repetition maximum (3-RM) protocol; 1-RM PC was estimated using a standard conversion table. VJ height was measured using a commercial measuring device; absolute and relative (to body mass) peak power were estimated using validated equations. Sprint times for 20 and 40 m distances were measured as best scores from two trials measured using an electronic eye timing device. Scores on relative PC and VJ height were related ($r = .54, p < .05$). VJ height and times in the 20-m ($r = -.59, p < .01$) and 40-m ($r = -.69, p < .01$) sprints were related. The relationships between relative 1-RM power clean and times for the 20-m ($r = -.12$) and the 40-m ($r = -.36$) sprints were not statistically significant. Those with “high” power clean scores performed better in 20- and 40-m sprints than those with “low” power clean scores, but the difference in mean time was not statistically significant for the 20-m sprint ($t [16] = .90, p > .05$) or for the 40-m sprint ($t [16] = 1.54, p > .05$). Lack of
standardization in performance of the PC or inaccuracies in estimating 1 RM PC from multiple repetition max effort may explain why there was not a significant relationship between PC performance and sprint times.
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Chapter One

Significance/Statement of the Problem

One of the primary goals of strength and conditioning professionals is to develop weight training programs that can improve the ability of athletes in a manner that best suits their specific sport. Many strength and conditioning coaches incorporate Olympic-style lifts into their exercise training programs in order to develop lower leg power to improve sprint performance (Sheppard, 2003). The power clean is an Olympic-style lift that closely resembles the explosive action seen in sprinting based on the muscular actions of the two movements (Durck, 1988). There is limited research on the relationship between performance on the power clean exercise and sprint performance in athletes (Baker & Nance, 1999; Hori et al., 2008), and none of the research appears to have been done using female athletes. There is however some research on the relationship between lower body explosive power, measured using a vertical jump, and sprint performance in female athletes (Gabbett, 2007; Sheppard et al., 2008). Additionally, there has been recent controversy over whether or not explosive exercises in training programs transfer well (if at all) to athletic performance (Bruce-Low & Smith, 2007; Harris, Cronin, Hopkins, & Hansen, 2008). For these reasons it is important to investigate the relationships between power clean and sprint performances in a select group of female athletes and determine if established measures of power (i.e., vertical jump height and estimated peak power) relate to these parameters.
Review of Literature/Introduction

Athletic performance in soccer is a function of aerobic fitness, anaerobic fitness, speed, muscular strength, muscular power, and agility (Bangsbo, Mohr, Poulsen, Perez-Gomez, & Krstrup, 2006; Stolen, Charmari, Castagna, & Wisloff, 2005). Sprint speed and explosive lower body muscular power are two high-intensity, interrelated, physiological capacities which contribute to soccer performance (Mujika, Santisteban, Impellizzeri, & Castagna, 2009; Ronnestad, Kvamme, Sunde, & Raastad, 2008; Stolen et al., 2005). Strength and conditioning coaches often direct soccer players to perform explosive exercises as a part of their training program in efforts to improve these parameters, and hence improve sport performance.

Sprint speed is an essential component of being successful in the sport of soccer. Sprinting requires the ability to quickly accelerate (Bompa & Carrera, 2005), and both speed and acceleration are important aspects in field sports such as soccer (Baker & Nance, 1999). Soccer is a sport that has frequent, intermittent bouts of sprinting throughout a 90-min match (Kobayashi, Takeuchi, Hosoi, Arai, & Loeppky, 2006). Glaister (2005) states that soccer consists of less than 6-second maximal/near maximal sprints interspersed with short active recoveries. According to Wisloff, Castagna, Helgerud, Jones, and Hoff (2004), in a soccer match it is common for a sprint to take place every 90 s, generally lasting for two to four seconds, and comprising approximately 11% of the game. The importance of sprinting ability to soccer performance can be illustrated by the fact that soccer performance tests have been developed and validated based, in part, on the relationship between performance scores and components of high-
intensity running and/or sprint distances covered during a soccer match (Bangsbo, Mohr, Poulsen, Perez-Gomez, Krstrup, 2006; Rampinini et al., 2007).

Distances that are used to measure sprint speed vary from sport to sport. The 10-m sprint test in female volleyball players was determined by Sheppard, Young, Doyle, Shepard, and Newton (2006) to be highly reliable (ICC = .87), but this test did not successfully differentiate between high level players and lower level players. The inability of this test to differentiate between playing abilities may be due to its relatively short distance. The 20-m and the 40-m sprint distances are frequently used to measure sprint performance for many different sports (Baker & Nance, 1999; Gabbett, 2007; Gabbett, Kelly, & Pezet, 2007; Hori et al., 2008; Smith, Roberts, & Watson, 1992), including soccer (Ronnestad, 2008; Stolen et al., 2005). Gabbett et al. (2007) determined the 20-m and 40-m test-retest reliabilities to be very high (ICC = .97 for both distances) with relatively low typical errors of measurement (1.3% for the 20-m sprint and 1.2% for the 40-m). Baker and Nance (1999), who studied male rugby players, suggested for sports such as rugby, field hockey, American and Australian football and soccer that speed should be analyzed over two separate distances (10 through 20 m and 40 through 50 m) to indicate both acceleration (between 10 and 20 m) and maximum speed (between 40 and 50 m) capabilities of the athletes.

Success in soccer also depends on the athlete’s ability to develop high levels of power (Stolen et al., 2005). Hall defines power as “the product of muscular force and the velocity of muscle shortening,” and states that explosive movements require muscular power (2007, p. 172). Stolen et al. (2005) consider power, the ability to produce as much
force within the quickest period of time, to be just as important as strength and endurance in soccer players. Explosive power is required for many vital skills in soccer such as striding, turning, kicking, sprinting, and jumping (Bangsbo et al., 2006; Chamari et al., 2008; Rampinini et al., 2007; Ronnestad et al., 2008; Stolen et al., 2005; Wisloff et al., 2004). Some researchers (Kobayasi et al., 2006; Mujika et al., 2009; Rampinini et al., 2007), but not all (Hunter, 2009) have found a significant relationship between power and soccer performance. Mujika et al. (2009), for instance, determined lower body explosive power (measured using vertical jump height) and Yo-Yo test performance to be highly related ($r = .84$) in female soccer players. Lastly, power measures (i.e., vertical jump heights) have been determined to distinguish lower level (junior) female soccer players from upper level (senior) soccer players (Mujika et al., 2009; Todd, Scott, & Chisnall, 2002).

Criterion measures of power are obtained by performing an exercise, such as the vertical jump or weighted squat jump on the force platform (Aragon-Vargas, 2000; Cromie, McBride, McCaulley, 2007; Cronin & Hansen, 2005). Lower body power can also be measured using the gold standard, a 3-camera motion analysis system, which measures vertical jump height from the displacement of the center of mass (Leard et al., 2007). While these lab tests of power are accurate, it may not always be practical to test athletes in a lab. Therefore, one of the more commonly used assessments of power among strength and conditioning professionals is a field test of the vertical jump, which is accurate, practical and cost effective (Leard et al., 2007). Many researchers who have studied soccer players have used the vertical jump test (i.e., the vertical jump using a
countercomovement motion on a force platform to measure height) to measure power (Chamari et al., 2008; Ronnestad, 2008; Stolen et al., 2005; Wisloff et al., 2004).

In the strength and conditioning setting the height of the vertical jump is often measured using a commercial device, the Vertec (Sports Imports, Columbus, OH) (Channell & Barfield, 2008; Sawyer, Ostarello, Suess, & Dempsey, 2002). The Vertec (Figure 1) uses the displacement of vanes to measure the vertical jump height of the participant. Leard et al. (2007) stated that using the Vertec is a valid way to test vertical jump height, but the accuracy may be slightly less than other methods. Still, Leard et al. (2007) determined a high correlation \((r = .91)\) between jump height measured with the Vertec and jump height measured using the 3-camera motion analysis system. Gabbett (2007) used a standardized protocol and a measuring device similar to the Vertec (i.e., the Yardstick vertical jump device) to test female rugby players and found the test-retest reliability was .96 (ICC) and the typical error of measurement was 3.3%. The height that is measured from the vertical jump can be used to estimate peak power using established and validated equations, like the Sayers equation (Adams & Beam, 2008; Carlock et al., 2004).

A 1-repetition max (1-RM) power clean test performed on a force platform can also be used to measure mechanical power (Cromie, McBride, & McCaulley, 2007). Yet, as stated by Cromie, McBride, & McCaulley (2007), there can be miscalculations and misrepresentation of power output with the use of the force platform technique because it tends to under represent velocity and force output of the power clean. Because of this, the power clean is best conceptualized as a dynamic resistance exercise that is used to
develop power in a practical setting, such as in the field of strength and conditioning (Baker & Nance, 1999; Hori et al., 2008; Kilduff et al., 2007). Kilduff et al. (2007) states that the same lower body muscular power that is measured with a vertical jump test is developed through training exercises such as the power clean. Maximal performance in the power clean is often used as a practical (non-mechanical) measure of power in the strength and conditioning setting. In fact, Nuzzo, McBride, Cormie, and McCaulley (2008) describe it as a dynamic “test” of power.

The movement of the vertical jump and the power clean movement are frequently related to each other (Garhammer & Gregor, 1992). These two power movements also have commonalities with sprinting. The musculature and movement profiles of these three activities have been closely examined. Hip extension (glutei and hamstrings), knee extension (vasti and rectus femoris), and plantar flexion (gastrocnemius and soleus) are all similar movements for sprinting, the vertical jump test, and the Olympic-style lift, the power clean (Adams & Beam, 2008; Durck, 1988; Garhammer & Gregor, 1992). These movements (sprinting, the vertical jump, and the power clean) also exhibit similar ground reaction profiles (Tricoli, Lamas, Carnevale, & Ugrinowitsch, 2005). In a study examining the movements of the power clean and sprinting, Irwin, Kerwin, Rosenblatt, and Wiltshire (2007) determined that the hip joint extended continuously during all trials of the power clean and occurred after a short flexion phase during the sprint trials. Power clean outputs have been shown to be highly correlated with the angular kinematics of the lower limb during sprinting (Okanda, Harada, & Tsuchie, 2005). For these reasons, and because the power clean is easy to learn, the clean is used to develop sprinting ability in
athletes. As noted by Gabbett, Kelly, and Pezet (2007) an increase in muscular power is redundant unless there is some transfer to improved leg drive for athletic activities such as sprinting.

According to Harris et al. (2008) there is a substantial body of literature (much of it recent research) focused on clarifying the relationship between mechanical power output and athletic performance. A concern that was raised by Harris et al. (2008) is that the power measurements and protocols used in these studies can vary tremendously. Harris et al. (2008) state that “disentangling the findings is challenging due to discrepancies in research design, terminologies, and methods for calculation of power” (p. 696). Along the same lines, Kilduff et al. (2007) stated that making comparisons between various studies is rather difficult because there are different exercises being used to measure peak power output. In spite of these limitations, there is a growing body of literature on the relationship of power to sprint performance.

A majority of researchers have found moderate to strong correlations between jump height (and/or relative peak power), measured during a vertical jump, and sprinting performance (Cronin & Hansen, 2005; Gabbett et al., 2007; Harris et al., 2008). Theoretically, according to Linthorne, there should be a significant relationship between these parameters, as a rapid stretch-shortening cycle occurs both in jumping and sprinting (2001). According to Adams and Beam (2008) the same muscle power that is necessary for jumping is essential for sprinting, especially during the acceleration phase and while maintaining maximal velocity.
Associations between power and sprint performance have been found across a number of sports. Sawyer, Ostarello, Suess, and Dempsey (2002), for instance, found a high correlation between vertical jump height and 18.2-m dash performance \((r = .79)\) in football players. Cronin and Hansen (2005) examined professional rugby players and determined that countermovement jump height was significantly correlated to 5-m sprint \((r = -.60)\), 10-m sprint \((r = -.62, p < .05)\), and 30-m sprint \((r = -.56, p < .05)\) times. In the same 2005 study by Cronin and Hansen the peak power output measured on a force platform in the squat jump (expressed relative to a subject’s body mass) was determined to be related to the 5-m sprint \((r = -.55, p < .05)\), the 10-m sprint \((r = -.54, p < .05)\), and the 30-m sprint \((r = -.43, p < .05)\) times. Wisloff et al. (2004) determined significant correlations between jumping height measured using a force platform and sprint performance (i.e., 10-m sprint performance \(r = .72\) and 30-m sprint performance \(r = .68\)) in elite soccer players. It appears that there is a significant \((r = .62)\) correlation between vertical jump height and 40-yd sprint performance in female athletes as well (Bradley, 1992). It is important to note that the relationship between power and sprint time has not been found to be statistically significant in all studies (Gabbett, 2007). This has prompted debate about the relationship between vertical jump performance and sprinting performance (Bruce-Low & Smith, 2007).

While numerous researchers have measured the relationship between power and sprint performance, power in these studies has most often been assessed while doing an exercise such as the vertical jump or weighted squat jump. Additionally in practical/applied settings power in female athletes, such as volleyball players (Gabbett &
Georgieff, 2007) and rugby players (Gabbett, 2007) is often measured through the use of the vertical jump height. There is limited literature in which performance on the power clean exercise has been used as a test of power especially for female athletes (Sheppard et al., 2008). On the other hand, a number of studies have been done in which performance on a maximal power clean exercise has been used as a practical measure of power in males (Baker & Nance, 1999; Fry & Kraemer, 1991; Hori, et al., 2008; Young, McClean, & Ardagna, 1995).

The explosive power that is demonstrated in the power clean exercise has been related to vertical jump performance in athletes. In 21 female volleyball players 1-RM power clean scores (as measured relative to body weight) were concluded to be significantly related \((r = .53)\) to vertical jump scores (i.e., countermovement vertical jump height relative to body weight) (Sheppard et al., 2008). Nuzzo et al. (2008) related the power clean and countermovement jump in male football players and track and field athletes. In the study by Nuzzo et al. (2008), the power clean exercise was performed with the bar raised from the floor. When 1-RM power clean scores were expressed in absolute terms there was no significant relationship to countermovement jump height, absolute or relative power, or force, yet a significant relationship was found between 1-RM power clean expressed relative to body mass and relative peak power in the countermovement jump \((r = .86)\). There was also a significant relationship found between the relative 1-RM power clean scores and countermovement jump height and velocity (Nuzzo et al., 2008). Additionally, Channell and Barfield (2008) concluded a high correlation between 1-RM power clean scores expressed relative to body weight and
vertical jump height scores measured using a Vertec \( r = .75, p \leq .05 \) in high school boys.

Similarities in musculature and action of the power clean and sprinting are often noted in studies. Cronin and Hansen (2005) describe the power clean as having acceleration and deceleration profiles that closely simulates the movement profiles of athletic activity, like sprinting. Bezodis, Salo and Kerwin (2007) state that the larger muscles that are active during the power clean may produce muscular and neurological adaptations that facilitate an improvement in sprint performance. Although the commonalities between these two activities have been studied in terms of musculature and movement profiles, there is only a sparse amount of literature concerned with the relationship between performance in these two measures of athletic performance.

Baker and Nance (1999) studied the relationship between common power measures and sprint speed in professional rugby players. The 3-RM test of the power clean was performed from the hang position (i.e., from above the knee) using a standardized procedure. Weight and power output measures from a squat jump performed on a force platform were also obtained. Sprint times (best of three trials) were assessed using the 10-m and 40-m distances. Three trials were given and the best of the times in the 40-m sprint was used for both sprint scores. Although the absolute scores of the power clean from the hang (3-RM PC hang) were not significantly related to sprint performance in the 10-m \( r = -.36 \) (Table 1) and 40-m \( r = -.24 \) (Table 2), when the scores were expressed relative to body mass (3-RM PC hang/kg) there was a significant relationship to 10-m \( r = -.56 \) and 40-m sprint performance \( r = -.72 \) (Baker & Nance,
The relationships between the maximal power recorded on the weighted squat jump and sprint times are also noted in Tables 1 and 2. Baker and Nance (1999) concluded from their findings that no absolute measures of power related to sprint performance, but most power measures that were expressed relative to body mass were related to sprint performance over 10 and 40 m.

<table>
<thead>
<tr>
<th>Table 1: Power Measure Relationship to 10-m Sprint</th>
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<tbody>
<tr>
<td><strong>Absolute scores</strong></td>
</tr>
<tr>
<td>3-RM PC (hang)</td>
</tr>
<tr>
<td>Maximal power</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>Table 2: Power Measure Relationship to 40-m Sprint</th>
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<tbody>
<tr>
<td><strong>Absolute scores</strong></td>
</tr>
<tr>
<td>3-RM PC (hang)</td>
</tr>
<tr>
<td>Maximal power</td>
</tr>
</tbody>
</table>

NS = nonsignificant
Using Australian rules football players, Hori and colleagues (2008) attempted to differentiate between players performance on sprinting and jumping based on a “high or low” power clean maximum score. Power clean was measured as a 1-RM in the power clean from the hang position (i.e., from above the knees) and was expressed as an absolute measure (1-RM PC hang) and relative to body mass (1-RM PC hang/kg). Height and peak power of the vertical jump performed as a countermovement jump was measured on a force platform. Power on the countermovement jump was expressed as an absolute peak power measure (CMJ PP) and also expressed relative to body mass (CMJ PP/kg). The peak power using a 40-kg weighted squat jump was measured and expressed as an absolute measure (CMJ 40 PP) and relative to body mass (CMJ 40 PP/kg). Lastly, the best of two 20-m sprint times (Sprint) was taken as the sprint score (Hori et al., 2008).

In regards to the study, Hori et al. (2008) stated, “the major outcome was that the top half group in the 1-RM hang power clean relative to the subjects’ body mass had higher performance of jumping and sprinting” (p. 416). Additionally, 1-RM hang clean scores (relative to body mass) were significantly related to maximum power (relative to body mass) in both the countermovement jump and weighted squat jump and, 1-RM PC scores (relative to body mass) were inversely related to 20-m sprint time (Hori et al., 2008). Results from this study can be seen in Table 3. Hori et al. (2008) suggests that, based on the significant correlations concluded between performances in the 1-RM hang power clean relative to body mass and jumping and sprinting, the 1-RM hang power clean shares similar strength qualities that are required for jumping and sprinting.
Table 3: Relationships between measurements

<table>
<thead>
<tr>
<th></th>
<th>PC hang 1-RM</th>
<th>PC hang 1-RM/kg</th>
<th>CMJ 40 PP</th>
<th>CMJ 40 PP/kg</th>
<th>CMJ PP</th>
<th>CMJ PP/KG</th>
<th>CMJ Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC hang 1-RM/kg</td>
<td>.68†</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMJ 40 PP</td>
<td>.58†</td>
<td>.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMJ 40 PP/kg</td>
<td>.38*</td>
<td>.60†</td>
<td>.63†</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMJ PP</td>
<td>.21</td>
<td>.13</td>
<td>-.01</td>
<td>-.09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMJ PP/kg</td>
<td>.3</td>
<td>.58†</td>
<td>.50†</td>
<td>.92†</td>
<td>-.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMJ height</td>
<td>.41*</td>
<td>.51†</td>
<td>.54†</td>
<td>.75†</td>
<td>-.12</td>
<td>.81†</td>
<td></td>
</tr>
<tr>
<td>Sprint</td>
<td>.43</td>
<td>-.57†</td>
<td>-.49†</td>
<td>-.62†</td>
<td>.19</td>
<td>-.58†</td>
<td>-.69†</td>
</tr>
</tbody>
</table>

*p = .05; †p = .01

In summary, only a few researchers have examined the relationship between power clean and sprint performance in athletes, and it appears that no one has studied females regarding this same relationship. Additionally, there is little research that exists reporting on the relationship between power clean and vertical jump performance in females (Sheppard et al., 2008). Hence, the primary purpose of this study was to investigate the relationship between power clean performance, vertical jump performance (height and estimated peak power) and 20- and 40-m sprinting ability among Division II collegiate female soccer players. A secondary purpose of this study was to determine whether or not power clean performance can distinguish female soccer athletes with regard to sprint ability.

Substantive Hypotheses
The primary hypotheses were that relative measures of power clean and vertical jump height would be directly related to each other and inversely related to sprint times. Additionally, those with “high” power clean scores were expected to perform significantly better in 20- and 40-m sprints than those with “low” power clean scores.

Practical Applications

The importance of Olympic-style lifting for the enhancement of sports performance is of interest to strength and conditioning coaches who are tailoring training programs for the growing numbers of female athletes to increase their athletic performance. It has been recommended by Warpeha (2007) that coaches should make the training for maximal sprinting speed similar to the training for maximal power (that is done in the weight-room), since both maximal speed and maximal power production rely heavily on a high rate of force production. As stated by Sawyer et al. (2002), the primary goal for the training programs that strength and conditioning coaches administer is to increase the athlete’s performance. Practically, this study will benefit the knowledge of the growing female athlete population, as well as enhance the knowledge of coaches, strength and conditioning specialists and researchers about the relationship between power and sprinting.

Operational Definitions

1) Power clean three-repetition maximum (3-RM) - Successful completion of three repetitions of the power clean (i.e., starting from the floor position and catching in an upright, semi-squat position at the shoulders) with a maximum
of 30 seconds between each repetition while testing (measured in pounds and converted to kilograms).

2) *Estimated power clean 1-repetition maximum (1-RM)* - The 1-RM load was calculated using the National Strength and Conditioning Association’s chart (Appendix F) from the 3-RM load (measured in pounds and converted to kilograms).

3) *Absolute power clean score* - The estimated 1-RM load (which was calculated from the participant’s 3-RM power clean) served as the participant’s absolute power clean score.

4) *Relative power clean score* - The estimated 1-RM load (which was calculated from the participant’s 3-RM power clean measured in kilograms) was then divided by the participant’s body mass (in kilograms) to be used as a relative power clean score.

5) *Vertical jump height* - Vertical jump height was taken as the participant’s the measured vertical jump height (using a countermovement motion in centimeters) with their standing reach subtracted from this height.

6) *Absolute peak power* - Using the validated Sayers equation (Sayers, Harackiewicz, Harman, Fryman, & Rosenstein, 1999) and the participant’s vertical jump height, absolute peak power will be calculated (in Watts).

7) *Relative peak power* - Using the validated Sayers equation (Sayers et al., 1999), the participant’s body mass, and the participant’s vertical jump height, relative peak power was calculated (in Watts per kilogram).
8) *Sprint times* - The sprint time was measured by the principal investigator using the electronic timing device and the best (the fastest) of the three trials for the 20-m sprint time was taken as the sprint speed for the 20 m, and the best (the fastest) of the three trials for the 40-m sprint times was taken as the sprint speed for the 40 m to the nearest .01 second.

9) *High and low power clean scores* - The athletes were divided into two groups based on their relative power clean scores. The group with the high power clean scores was those scoring in the top 50%. The group with the low power clean scores was those scoring in the bottom 50%. This method of dichotomizing the group was used by Hori et al. (2008).
Chapter Two

Methods

Participants

Participants were recruited from Humboldt State University’s women’s soccer team \((N = 22)\). The primary investigator approached the coaches of the team for approval to recruit athletes at a regularly scheduled practice time. Athletes between the ages of 18 to 25 years were asked to volunteer. Informed Consent (Appendix A) was required of each volunteer athlete to participate. The athletes were tested during their off-season. Participants were asked to have one full day’s recovery prior to testing session (i.e., no weight lifting 24 hours previous to testing and no more than 15 minutes of cardiovascular training on the day of testing).

To be included in the study participants had to be: (1) be female, (2) be NCAA Division II athletes of Humboldt State University’s soccer team, (3) be free from current injury, (4) have a minimum of 3 months sprinting experience, and (5) have minimum of 3 months Olympic weightlifting experience (which constitutes the learning phase for proper technique of the power clean). Three months Olympic-style lifting experience was required. According to Baker and Nance (1999), there may be a less significant relationship between power clean and sprint performance for athletes who are not as familiar with the proper technique of the power clean as there is with athletes who practice it regularly.
Research Design

This study used a quasi-experimental, cross-sectional approach to examine the relationship between power measures (vertical jump height, absolute peak power, relative peak power, power clean 3-RM, and power clean 3-RM relative to body weight) and 20- and 40-m sprint ability in NCAA Division II female soccer players. The magnitude of the relationships was established by using Pearson $r$. In addition, a comparison was made of mean sprint scores between athletes who score “high” on the power clean versus those who score “low” on the power clean.

Measures/Instruments

Demographics and Athletic Background. Demographic information was collected using a self-reported survey (Appendix B) that included questions regarding ethnicity, date of birth, current injury status, sport, year of participation on team, position, number of months of sprint experience, and number of months of Olympic lifting experience.

Height and Mass. Participant’s height and mass were taken prior to testing without sneakers, wearing regular practice attire, using a calibrated scale (Health-o-Meter, Illinois). Mass was measured to the nearest 0.5 lb. Standing height was taken with participants standing barefoot on the weight platform in position with backs, heels, and buttocks against the Health-o-Meter stadiometer. The measuring device was laid over the tallest point of the participant’s head, and height was measured to the nearest 0.5 cm.

Vertical Jump. Each woman performed a warm-up by doing a 5-min Precor recumbent bike exercise at a pedal cadence of 70-80 revolutions per minute at a resistance level 3. After completing the warm-up participants moved to the back of the
weight room to perform the vertical jump testing. A Vertec (Sports Imports, Columbus, OH) device was used to measure vertical jump height in the current study (Figure 6). The Vertec was positioned against a wall to measure counter movement jump height in a way that is similar to the protocol used by Sayers et al. (1999). Participants were familiarized verbally with the aforementioned vertical jump protocol by a certified strength and conditioning specialist.

First the participants had their standing reach measured (with their feet flat on the ground, shoulders level, standing 6 inches away from the apparatus), and then they raised their dominant arm against the Vertec apparatus. The Vertec standing reach height marker was adjusted to the tip of their dominant hand’s middle finger. Once the Vertec was properly adjusted, participants were asked to perform a standard countermovement jump standing 1.5 ft away from the apparatus (measured from the outside edge of their dominant foot). With feet flat on the ground and about shoulder width apart, participants started from an upright position and quickly move their hips down and backwards into a semi-squat position and immediately change directions upwards to jump. As this is taking place the arms also moved back as the participant moves downwards, and the arms moved upwards as does the participant. When the participant is on the upward phase of the jump they extended their dominant hand into the air in attempt to displace the Vertec measuring vanes. The displacement of the vanes was used to measure a participant’s vertical jump height, per ½-inch increments. The participant was allowed more jump trials until they were unable to displace measuring vanes on two consecutive jumps. The participants were allowed 30 seconds rest in between jump trials. The vertical jump
height was measured as the difference between standing reach and jumping reach of the participant. The Sayers’ equations were used to calculate absolute peak power and relative peak power in the vertical jump. The Sayers’ equations can be found in Appendix C (Sayers et al., 1999).

*Power Clean.* A 5-min re-familiarization of proper power clean technique was given by a National Strength and Conditioning Association Certified Strength and Conditioning Specialist. Baechle and Earle’s (2000) description of NSCA proper technique for the power clean (Appendix D) was used (pp. 384-385). The women then performed 5-repetitions of jump shrugs with an Olympic weightlifting bar (an Ivanko [20 kg] Olympic Weightlifting Barbell model OBS-20 kg). After 1-min of rest participants performed 5-repetitions of power high pulls with the bar. After an additional 1-min rest, using an Olympic weightlifting bar, the 3-RM power clean max test was performed using a standard protocol. The three-repetition maximum (3-RM) testing of the power clean was performed under the supervision of a Certified Strength and Conditioning Specialist.

The weights used in the 3-RM power clean testing were determined from current records kept by the strength and conditioning coaches. Accordingly, each of the 4-5 submaximal sets (consisting of 1-5 repetitions) were estimated by a Certified Strength and Conditioning Specialist and the athlete. Following the successful completion of each submaximal set, the load progressively increased up to the prescribed 3-RM for the athlete, with 2 min of rest between trials. If the athlete successfully completed 3-5 repetitions with proper National Strength and Conditioning Association-prescribed technique (Appendix D) at this load they were allowed to attempt another load until both
the athlete and the strength coach were confident that the representative 3-RM was attained. Successful completion of the power clean (as is consistent with the National Strength and Conditioning Association) was considered as beginning from the proper starting position, in which the load (i.e., weight) that was being lifted was in contact with the ground, participant’s arms were straight, and their buttocks were below their shoulders. The participant lifted the mass using triple extension (i.e., extension at the ankles, knees, and hips) from the floor to shoulder height (i.e., the “catch”) with the knee in a slightly bent (semi-flexed) position. If the participant was unsuccessful at catching the prescribed load at shoulder height, they were given 30 seconds of rest and two subsequent opportunities to successfully complete the power clean with the currently prescribed load. This methodology was similar to that used in the studies done by Baker and Nance (1999) and Hori et al. (2008).

Final mass lifted was expressed in units of kilograms (kg). The extrapolation of a 1-RM load from loads that are equal or less than 10-RM is accurate, but predictions that are closer to the actual 1-RM have higher accuracy (Baechle & Earle, 2000). The calculation of the estimated 1-RM loads from the 3-RM loads was done using the NSCA’s extrapolation table (Appendix F: National Strength and Conditioning Association’s Table 18.8) (Baechle & Earle, 2000).

40-m Sprint Testing. Participants were requested to wear practice cleats for the sprint testing. Sprint testing took place in the university’s indoor facility on turf that is comprised of rubber-pellets and artificial grass. Immediately prior to sprint testing, each athlete was asked to complete a 5-min dynamic warm-up protocol, which was done over
repeats of a 20-m distance (i.e., jog, backwards jog, shuffle, carioka, skips, backwards skips, high knees, lunges, butt-kicks, A-march).

For the sprint trials an electronic timing device (Solo Time electronic timing system model 450 A) was used. A timing foot pad was placed at the 0-m mark (i.e., the start), with an electronic eye at the 20-m and 40-m mark. Before any sprint testing began, it was explained to the women (as a group) that the timer would start as soon as their foot leaves the pad, and an electronic eye would take their time at the 20-m mark as they passed. A final time was taken as the participants passed the 40-m mark. Participants were encouraged to complete the two 40-m sprints as quickly as possible. The 20-m sprint time was captured while the participants crossed the 20-m mark as they were completing each 40-m all out sprint, as opposed to simply performing 20-m sprints. Participants started in an upright position, with their dominant foot over the foot pad. Two 40-m sprint trials were taken for each subject. There was a 2-min recovery between sprints, during which the participant was asked to slowly walk up and down the parameter of the indoor facility. The 20-m sprint speed was recorded by electronic eye at the 20-m mark while completing the all-out 40-m sprint. Time was measured to the nearest 0.01 second, and the best of the 20- and 40-m sprint times was used as the participant’s score for the 20-m and 40-m sprint.

*Procedures*

This study was approved by the Institutional Review Board at Humboldt State University. The researcher obtained informed written consent from all participants (Appendix A). All participants who meet the inclusion criteria were asked to participate
in the study. Participants were asked to have one full day’s recovery prior to testing session (i.e., no weight lifting 24 hours previous to testing) and no more than 15 minutes of cardiovascular training on the day of testing. Each group of four to five participants was asked to arrive every 20 minutes to expedite the testing process.

Participants first completed the self-reported demographic and athletic experience survey. After survey completion, the researcher measured the height and mass of the participants. Next, the participants were asked to complete a recumbent bicycle warm-up. Then in the back of the weight room, participants were re-familiarized with vertical jump procedures using a countermovement jump, and had their standing reach and vertical jump height measured by a Certified Strength and Conditioning Specialist. Vertical jump height was taken they completed the previously mentioned dynamic sprint warm-up in the university’s indoor facility. Power clean technique familiarization was then lead by a Certified Strength and Conditioning Specialist. Participants then completed the previously described 3-RM max testing protocol for the power clean. Finally, participants completed two 40-m sprints. The faster of the two times for the 20 m and 40 m was used as the sprint speed. The testing order and time period between tests was the same for all participants. All of each participant’s testing information was kept on a separate collection sheet (Appendix E).

Analysis of data

The relationships between 1-RM PC, relative 1-RM PC, vertical jump height, absolute peak power, relative peak power, 20-m sprint, and 40-m sprint ability were established using Pearson $r$. Given an effect size $r = .57$ (value of $r$ between relative
power clean and sprint performance determined by Hori et al. (2008)), an alpha level of .05, and beta level of .20, it was estimated that the total sample size need to achieve a significant correlation would be $N = 17$ (G*Power). In addition, an independent groups $t$-test was done to determine the mean difference in sprint times between a group scoring “high” on the power clean and a group scoring “low” on the power clean, based on relative power clean scores. The data was analyzed using the Statistical Package for the Social Sciences (SPSS) version 16 (SPSS, 2008). The criterion for significance was set at an alpha level of $p \leq .05$.

*Limitations/Assumptions*

This study is limited by the following factors/assumptions:

1. The primary researcher had a dual role to the participants, strength and conditioning coach and researcher.

2. The Sayers equation is a valid equation for calculating absolute peak power and relative peak power from vertical jump/countermovement jump height (Sayers et al., 1999).

3. The prediction of 1-RM power clean from a 3-RM power clean is valid (Baechle & Earle, 2000).

4. The shoulder flexibility of the participants did not interfere with the vertical jump height attained using the Vertec apparatus (Klavora, 2000).

5. The conditions for all participants were the same during each testing session.

6. The participants displaced the Vertec vanes at the peak of their jump (Klavora, 2000).
7. All participants followed the prescribed pre-test conditions.

8. All participants did perform 3-RM power clean testing, vertical jump/countermovement jump testing, and the two sprint trials to the best of their ability.

9. All participants were healthy and free from injury.

Delimitations

This study was delimited by the following factors:

1. Participants only represented female student-athletes 18-25 years.

2. Participants had variable levels of training in sprint technique.

3. Participants had variable levels of Olympic weightlifting experience.

4. The testing may not have accurately depicted the true levels of maximal power output or fastest sprinting ability, due to the cross-sectional nature of this study.
Chapter Three

Results

Participants in this study were 18 volunteers out of 22 team members from the Humboldt State University NCAA Division-II women’s soccer team. Testing was completed during the period of off-season training and over the course of one day from 7:20 a.m. to 9:20 a.m. According to the assistant soccer coach, practice on the previous day (8:00 a.m. to 9:00 a.m.) consisted of light plyometrics, core training, combination soccer play of “eight versus eight” in a 50- by 30-yd grid, and additional technical drills for the goalie. No weightlifting was performed on the day prior to testing.

The participants averaged 1.94 years of experience on the current team, with a minimum of 1 and maximum of 3 years experience. With regard to Olympic-style lifting the women averaged 19.6 months of experience of Olympic-style weightlifting, with a minimum of 3 months and maximum of 48 months. Descriptive statistics for age, body mass, and height are presented in Table 4.

Table 4: Descriptive Characteristics of Participants (N = 18)

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
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</thead>
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<tr>
<td>Age (yr)</td>
<td>18.0</td>
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<tr>
<td>Body Mass (kg)</td>
<td>47.0</td>
<td>76.0</td>
<td>63.2</td>
<td>7.20</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>153.5</td>
<td>177.0</td>
<td>166.1</td>
<td>7.0</td>
</tr>
</tbody>
</table>
Test Variables

The major test variables for this investigation were estimated 1-RM power clean (PC), relative 1-RM PC, vertical jump height, absolute peak power, relative peak power, 20-m sprint, and 40-m sprint times. Descriptive statistics for the aforementioned test variables are listed in Table 5.

The estimated 1-RM PC was determined by using the National Strength and Conditioning Association’s 1-RM extrapolation chart (Baechle & Earle, 2000). The relative 1-RM PC was measured as the estimated 1-RM PC score (in kg) divided by the body mass of the participant (in kg) (i.e., the same expression for this parameter used by Hori et al. [2008] and Baker and Nance [1999]). Vertical jump was measured as height expressed in cm. Absolute peak power (as Watts) was calculated using the equation from Sayers et al. (1999). Relative peak power was the absolute peak power in W divided by the body mass of the participant (in kg). The 20- and 40-m sprint was measured in seconds.
Table 5. Descriptive Characteristics of Performance N = 18.

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated 1-RM PC (kg)</td>
<td>40.8</td>
<td>59.0</td>
<td>49.0</td>
<td>5.1</td>
</tr>
<tr>
<td>Relative 1-RM (kg)/BM (kg)</td>
<td>.60</td>
<td>1.02</td>
<td>.79</td>
<td>.12</td>
</tr>
<tr>
<td>Vertical Jump Height (cm)</td>
<td>44.50</td>
<td>63.50</td>
<td>54.34</td>
<td>5.71</td>
</tr>
<tr>
<td>Absolute Peak Power (W)</td>
<td>3192.51</td>
<td>4415.01</td>
<td>3901.73</td>
<td>365.63</td>
</tr>
<tr>
<td>Relative Peak Power (W)/ BM (kg)</td>
<td>53.86</td>
<td>86.20</td>
<td>63.51</td>
<td>7.84</td>
</tr>
<tr>
<td>20-m Sprint (s)</td>
<td>3.15</td>
<td>3.76</td>
<td>3.43</td>
<td>.18</td>
</tr>
<tr>
<td>40-m Sprint (s)</td>
<td>5.78</td>
<td>6.67</td>
<td>6.22</td>
<td>.28</td>
</tr>
</tbody>
</table>

Correlations

Pearson product-moment correlation coefficients were used to examine the relationships among key test variables. The first hypothesis of the current study was that relative measures of power clean and vertical jump height would be directly related to each other and inversely related to sprint time. Relative measures of power clean and vertical jump height were significantly related to one another ($r = .54, p < .05$). The scatter plot of this relationship can be seen in Figure 1. Additionally, in regard to the relationships between vertical jump height and time in the 20-m ($r = -.59, p < .01$) and 40-m ($r = -.69, p < .01$) sprints, there were indeed significant inverse relationships. The
scatter plot and line of best fit for the relationship between the 20-m sprint time and vertical jump height can be seen in Figure 2. The scatter plot and line of best fit for the relationship between the 40-m sprint time and vertical jump height can be seen in Figure 3.

As expected, there was an inverse relationship between relative 1-RM power clean scores and 20-m sprint times ($r = -.12, p > .05$), but the relationship was not statistically significant. As an exploratory approach, those who did not complete a 3-RM power clean under previously specified standards were excluded (bringing the sample size to $n = 12$) from statistical analysis and a stronger inverse relationship was found between their extrapolated 1-RM relative power clean scores and 20-m sprint times ($r = -.37, p > .05$). The relative 1-RM power clean scores and 40-m sprint times were also inversely related ($r = -.36, p > .05$), but the relationship was not statistically significant. As an exploratory approach, those who did not complete specifically a 3-RM power clean were excluded from statistical analysis and a stronger inverse relationship was determined between relative power clean scores and 40-m sprint times ($r = -.44, p > .05$). The scatter plot and line of best fit for the relationship between 20-m sprint times and the relative 1-RM power clean can be seen in Figure 4. The scatter plot and line of best fit for the relationship between 40-m sprint times and the relative 1-RM power clean can be seen in Figure 5.

Although not critical to the research question, it is of interest to note that the relative 1-RM power clean scores and absolute peak power estimated from the vertical jump were inversely related ($r = -.27, p > .05$), but this was not statistically significant.
The relative 1-RM power clean and relative peak power were related \( r = .34, p > .05 \), but this was not statistically significant. Absolute peak power was inversely related to 20-m sprint times \( r = -.39, p > .05 \) and 40-m sprint times \( r = -.38, p > .05 \), but neither relationship was statistically significant. Relative peak power was inversely related to 20-m sprint times \( r = -.36, p > .05 \) and 40-m sprint times \( r = -.38, p > .05 \), but neither were statistically significant.

*Independent groups t-test*

Independent groups t-tests were used to determine if there were differences in the mean 20-m sprint time between groups scoring “high” or “low” on relative power clean. A similar analysis was done to determine if there were differences in the mean 40-m sprint time between groups scoring “high” or “low” on relative power clean. The group was split in half (“high” and “low”) based on relative power clean scores for analysis. Although those with “high” power clean scores did perform better in 20-m \( M = 3.39, SD = .20 \) and 40-m \( M = 6.12, SD = .26 \) sprints than those with “low” power clean scores in the 20-m \( M = 3.47, SD = .16 \) and the 40-m \( M = 6.31, SD = .27 \), the differences were not statistically significant. For the 20-m sprint times \( t (16) = .90, p > .05 \) and for the 40-m sprint times \( t (16) = 1.54, p > .05 \). Hence, the null hypothesis failed to be rejected at the alpha level of .05, and the conclusion is that there was no significant difference between sprint times in the two independent groups of “high” and “low” relative power clean. Although these differences were not statistically significant, they represent a small-to medium-sized effect \( r = .22 \) in the case of the 20-m sprint distance, and a medium-sized effect \( r = .36 \) in the case of the 40-m sprint distance.
Figure Caption

*Figure 1.* Scatter plot and line of best fit showing the relative 1-RM power clean scores as a function of vertical jump height.
Figure Caption

*Figure 2.* Scatter plot and line of best fit of 20-m sprint times as a function of vertical jump height.
Figure Caption

Figure 3. The scatter plot and line of best fit for the 40-m sprint times as a function of vertical jump height.
Vertical Jump Height (cm)

40-m Sprint Time (s)
Figure Caption

*Figure 4.* The scatter plot and line of best fit of relative power clean scores as a function of 20-m sprint times.
Figure Caption

*Figure 5.* Scatter plot and line of best fit for relative power clean scores as a function of 40-m sprint times.
40-m Sprint Times (s) vs. 1-RM Power Clean (kg) / Body Mass (kg)
Chapter Four

Discussion

The primary purpose of this study was to determine the relationships between measures of relative power clean, vertical jump height, and sprint performance among Division-II collegiate female soccer players. Relative power clean scores and vertical jump height were positively and significantly related to each other, as expected. As hypothesized, vertical jump height was inversely and significantly related to both 20- and 40-m sprint times. Inverse relationship between relative power clean scores and 20- and 40-m sprint times were determined, yet both relationships failed to reach statistical significance.

The significant relationship determined between relative 1-RM power clean scores and vertical jump ability (measured as height) in the current study supports finding of previous researchers (Channell & Barfield, 2008; Nuzzo et al., 2008; Sheppard et al., 2008). Channell and Barfield (2008), who studied high school males, determined a higher correlation ($r = .75$) between relative 1-RM power clean scores and vertical jump height than was concluded in the current study ($r = .54$). When studying male collegiate football and track and field athletes, Nuzzo et al. (2008) found a strong relationship ($r = .64$) between relative 1-RM power clean and counter movement jump height. Sheppard et al. (2008), who studied elite female volleyball players, found a correlation between a true measured relative 1-RM power clean and counter movement jump height ($r = .53$) of similar magnitude as the current study. Still, it appears that across the different sexes and
sport groups that there is a moderately strong relationship ($r$ values ranging from .53 to .75) between power clean and vertical jump performance.

The moderate relationship between these two measures of power is not surprising, in that the musculature used to perform these two activities is similar. For instance, hip extension which uses the glutei and hamstrings, knee extension which uses vasti and rectus femoris, and plantar flexion which uses the gastrocnemius and soleus are used in the power clean and the vertical jump (Adams & Beam, 2008; Durck, 1988; Garhammer & Gregor, 1992). For sports that involve some form of jumping, such as basketball, volleyball, or soccer it seems appropriate to use the power clean as a training exercise; this idea has been suggested by Bompa and Carrera (2005). Further supporting evidence for the use of the power clean in strength training programs for improvement in jumping ability comes from Tricoli et al. (2005), who administered a training program using Olympic-style weightlifting over the period of 8-weeks to a group of males, and concluded that they were able to significantly improve their counter movement jump heights.

With regard to the relationship between vertical jump height and times in the 20- and 40-m sprints, the significant inverse relationships established in the current study are in agreement with the findings of multiple researchers (Bradley, 1992; Cronin & Hansen, 2005; Sawyer et al., 2002; Wisloff et al., 2004). The researchers that examined this relationship used sprint distances that were typically between approximately 5 and 36.58 m, and the correlations ranged from approximately -.56 to -.72 which is consistent with the results of -.59 and -.69 determined in the current study. For instance, Sawyer et al.
(2002) determined a significant correlation between vertical jump height and 18.2-m sprint times in collegiate football players. Cronin and Hansen (2005), who determined significant correlations as well, examined male rugby players and used sprint distances of 5, 10, and 30 meters. Wisloff et al. (2004) found significant correlations in male soccer players at distances of 10 and 30 meters. Bradley (1992) used a 40-yd (36.58-m) sprint to test a variety of collegiate female athletes and also determined a significant correlation with vertical jump height.

In the current study approximately 41\% of the variance in sprint times could be explained by vertical jump height. Hence, it appears that the development of lower body anaerobic power is key to optimizing sprint performance. Glaister (2005) noted the importance of phosphocreatine degradation for energy production for both the vertical jump and maximal sprinting in shorter distances. Although sprinting and vertical jump mechanically use similar muscle groups, involve some similar movements, and are both anaerobic activities (Adams & Beam, 2008; Durck, 1988; Garhammer & Gregor, 1992), sprinting involves horizontal power, whereas vertical jumping involves vertical power. Thus, the use of the long jump, as is suggested by Adams and Beam (2008), may result in an even stronger relationship to sprinting performance than was determined in the current study.

Significant relationships between relative 1-RM power clean and both 20-m and 40-m sprint performances were expected in the current study, yet no significant relationship was determined. These results differed from the findings in studies by Baker and Nance (1999) and Hori et al. (2008). There are a number of reasons for why the
discrepancies may exist between findings in the current study compared to the only other known studies of this relationship. Both Baker and Nance (1999) and Hori et al. (2008) asked the subjects to perform the power clean from the “hang” position, which is from above the knees as opposed to in the current study in which the Olympic weightlifting bar was lifted from the floor.

The difference in starting positions for this exercise may have had more of an impact upon results than initially expected. Although the hang clean is a simplified variation of the power clean according to USA Weightlifting (2003), an important aspect is missing from the hang clean. The power clean involves a lengthened first pull from the floor, requiring participants to have proper back management technique and adequate flexibility to have their hips below the height of their shoulders at the starting position. On the other hand, the hang clean has a much shorter first pull, which limits the velocity of the participant’s barbell and thus maximal load lifted; yet, this simplified lift may be better suited for a beginning lifter, according to USA Weightlifting (2003). Still the hang clean may be a more sprint specific exercise compared to the power clean due to the fact that the participant must start the second pull from a static position, hence eliciting a more forceful and explosive contraction from the hips which is an important muscle group involved in sprinting. According to the co-investigator who tested athletes in the power clean in the current study, many of the participants had limitations in hamstring flexibility and maintaining an erect spine (“back management”). Thus, some of these women may have been better suited to perform the hang clean, because of the position at the start when performing this lift. When selecting the exercise to use in testing of the
athletes in the current study a decision was made to use the power clean, and not the hang clean, because that was the test the athletes had experience in.

Another significant difference between the methods used in the current study and previous studies (Baker & Nance, 1999; Hori et al., 2008) was the power clean measure used. Baker and Nance used an actual 3-RM measure and not a predicted 1-RM. Hori et al. (2008) used a true measured 1-RM power clean as opposed to a predicted measure. Hori et al. (2008) thus had 1-RM maximal power clean measures that did not reflect the error of prediction when extrapolating to the 1-RM power clean using the NSCA’s 1-RM prediction chart (Baechle & Earle, 2000). Furthermore, in the current study four of the participants had a 4-RM power clean taken, one participant had a 2-RM power clean taken, one participant had a 1-RM power clean taken, and the remaining twelve participants had a 3-RM power clean score taken. The added variance in predicting from these different repetition maximum scores may explain why the correlations between the power clean scores and sprint times in the current study were not significant. It is generally agreed upon that the greater the repetition maximums used in predicting 1-RM the greater the error (Baechle & Earle, 2000).

Upon further examination of the references (Baker, 1995; Chapman, Whitehead, & Binkert, 1998; Mayhew et al., 1992; Morales & Sobonya, 1996) that were compiled to derive the NSCA’s extrapolation chart (Baechle & Earle, 2000), it was clear that there is potential error in using the predicted 1-RM. For instance, the only study referred to in the NSCA’s chart (Baechle & Earle, 2000) to predict the 1-RM in which a power clean was used as the exercise was done by Morales and Sobonya (1996). Morales and Sobonya
(1996) stated that the best predictor for the 1-RM for the power clean (from repetitions ranging from 11 to 2) was 90% of the 1-RM (i.e., a 4-RM). The use of a 4-RM power clean was only able to account for 19.1% ($r = .44$) of the variance in the true measured 1-RM tested. Also noted by Morales and Sobonya (1996) was that the corresponding lifting intensities (% 1-RM) that represented the best predictors of 1-RM strength differed between different lifts used in the study. Thus, the number of repetitions used to predict a 1-RM should be different for various lifts.

All but one of the references used to develop the NSCA chart used a male population of athletes (Baker, 1995; Chapman, Whitehead, & Binkert, 1998; Morales & Sobonya, 1996). There was only one reference used to develop the NSCA’s chart that measured 1-RM’s in females, and the exercise used was a bench press (Mayhew et al., 1992). Still, Mayhew et al. (1992) determined no significant difference between the accuracy of multiple RMs used to predict 1-RM between men and women (with an accuracy of $r = .98$, $SE = 4.8$ kg). The bench press is a more controlled resistance exercise that does not involve as much technical mastery as the power clean. This implies that there is less error using a multiple repetition max in the bench press than there would be when using a multiple repetition max to predict a 1-RM in the power clean. It should be noted that a $SE = 4.8$ kg is significant with regard to predicted 1-RMs. Additionally, the training level or experience of participants can also influence the accuracy of a submaximal test, and thus the 1-RM extrapolation (Baker & Nance, 1999; Chapman, Whitehead, & Binkert, 1998; Morales & Sobonva, 1996). The limitations in the accuracy
of the power clean measure may also have influenced the previously mentioned correlation between power clean and vertical jump in the current study.

Seeing as sprinting involves a high power output, it would be wise to examine the relationship of sprinting with the peak power output of the power clean. The optimal load required to observe peak power output within the power clean remains a relatively new research question within the literature. Kilduff et al. (2007) examined (through the use of a force platform) the optimal loading for the power clean from the hang position in male professional rugby players. It was determined that peak power output was achieved at 80% of the subjects’ 1-RM, hence relative load had a significant effect on power output (Kilduff et al., 2007). The results from Kilduff et al. (2007) are in line with Cormie, McBride, and McCaulley (2007), who also reported that the optimal load (determined through kinematic and kinetic data) for peak power output in the power clean was 80% of the 1-RM. It was also concluded that although relative load had no effect on velocity or peak rate of force development, it did have a significant effect on peak force which was produced at 90% 1-RM (Kilduff et al., 2007). In relation to the current study, the power clean was measured as a 3-RM which is 93% of a subject’s 1-RM, as opposed to an 8-RM load which is 80% of a subject’s 1-RM. Although this load may have produced peak force in the power clean, the load did not produce peak power output among the participants. If relative load has a significant effect on peak power output during the power clean, then a potentially stronger relationship between sprinting and the power clean may have been found if this prescribed load (80% of participants’ 1-RM) had been used.
The discrepancy in findings on the relationship between power clean and sprint performance across studies may also be due to the difference in sex of the subjects. Both Baker and Nance (1999) and Hori et al. (2008) were able to show this relationship in males, yet no significant relationship was determined in the females in the current study. A possible explanation for this difference comes from a study by Linnamo, Pakarinen, Komi, Kraemer, & Hakkinen (2005). Linnamo et al. (2005) determined that during maximal explosive exercise (performing the leg press explosively), females did not activate as much of their available muscle mass as males did. Based on the fact that only minor neuromuscular changes were shown in women after explosive exercises, Linnamo et al. (2005) inferred that women were less capable than men of exhausting themselves through explosive exercise. The inability of females to activate as much muscle mass as males did during explosive exercises may provide insight into the differences regarding the relationship between power clean and sprint times that were determined between the current study and the studies of Baker and Nance (1999) and Hori et al. (2008). Hakkinen (1993) stated that men were able to more aggressively activate their muscles than females proving further evidence of differences in neuromuscular activation between the sexes.

Further explanation for the non significant relationship between power clean and sprint performance in the current study involves mechanical differences in sprinting between the sexes. Biomechanical differences (including differences in the center of gravity) exist between males and females during sprinting. As stated by Anderson (1996) the biomechanical profile of an athlete is a major component that affects running performance. The biomechanical profile “is influenced by anthropometric dimensions,
limb morphology and learned developed movement patterns” (Anderson, 1996, pp., 78-79). Differences between the sexes, with regard to running mechanics, include higher knee abduction angles and higher knee valgus angles in females (Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001). Hip adduction and internal rotation angles are also higher in females than males as well (Ferber, McClay, Davis, & Williams, 2003). According to Hamilton and Luttgens, “in the transverse plane, the center of gravity in females is located at approximately 55 percent of their standing height, whereas in males the center of gravity is at 57 percent of standing height” (2002, p. 373). Such differences between the sexes can result in differences in the magnitude of the correlation determined between sprint time and power clean.

Additional factors which might have played a role in the findings of the current study relative to other studies is the distances covered in the sprints, the heterogeneity of scores on the power clean and sprints, the influence of practice on the previous day on performance of the tests, and fatigue caused by the 3-RM power clean protocol. In regards to these differences, Baker and Nance (1999) captured sprint acceleration capacity in males using a 10-m sprint distance in their study as opposed to the 20-m sprint distance used in the current study. Hori et al. (2008) only used a 20-m distance in their study and did not report on the 40-m distance. The strength of the relationship involving a set sprint distance may be affected by where the participant’s time is captured. For instance, in the current study the 20-m sprint time was captured while the participants crossed the 20-m mark as they were completing a 40-m all out sprint, as opposed to simply performing a 20-m sprint. Psychologically this may have affected the
all-out effort of the participant’s, hence affecting the optimal speed of their 20-m performance. Practice on the previous day may have affected the speed of the sprints that were performed by the participants. The 3-RM power clean warm-up protocol did prove to be fatiguing for some of the participants, as stated by the co-investigator that participants’ noted a low level of energy by the time their final 3-RM attempts were made due to the extensive weightlifting warm-up within their sets.

The final reasoning for the lack of a relationship between relative power clean scores and 20- and 40-m sprint times in the current study may be due to the lack of technical mastery of the power clean in this specific population. According to the co-investigator, although many of the participants were able raise the bar to shoulder height when attempting a 3-RM they were unable to catch the load on their shoulders in the proper finishing position. This may be attributed to the participants’ lack of technical ability or a possible limitation of upper body strength with regards to this specific population. This explanation is derived from the notion that the final stage of the power clean involves more upper body strength than earlier stages of the power clean do. In addition, even though all participants were required to have at least 3 months of Olympic-style lifting, the technique of the participants varied according to the subjective observations of the co-investigator. For instance, it was observed that those women with 3 years of Olympic-style lifting experience possessed the highest level of mastery of technique. Hence, the 3-RM power clean of the women with at least 3 years of Olympic-style lifting experience was probably the most accurate. Future investigators should require athletes to have more experience in Olympic-style lifting (e.g., at least one year).
A secondary purpose of the current study was to determine if “high” or “low” relative power clean performance would distinguish soccer athletes with regard to sprint ability. Although those with “high” power clean scores did perform better in 20- and 40-m sprints than those with “low” power clean scores, the differences were not statistically significant. In a similar comparison done by Hori et al. (2008) there was an odd number \((N = 29)\) of participants, thus the middle score was excluded from the statistical analysis, creating a more defined difference between the groups of “low” and “high” relative power clean. In the current study there was an even number \((N = 18)\) of participants, and the difference between the mean time of the two groups was not statistically significant, but it could be argued that these differences in times were practically significant. Furthermore, small and medium sized effects were seen in the 20-m and 40-m sprint, respectively. When an exploratory approach was used where the middle two scores of relative power clean were excluded from statistical analysis, the difference in both the 20-m and 40-m sprint times between high vs. low groups were statistically significant.

**Conclusions**

In conclusion, the findings of the current study demonstrate relationships between vertical jump and relative power clean scores, as well as vertical jump to 20-m and 40-m sprint times, which are in accord with previous studies. To the knowledge of the investigator, this was the first study in which the relationship between relative power clean and sprint times was studied in female athletes, even though no significant relationship was determined. From a practical perspective the results from the current study should not limit the potential for further examination of this relationship given a
more diverse sample in females. Possibilities for the lack of agreement with previous researchers may be attributed to limitations in the measurement methods for the 3-RM power clean, the error in the extrapolation of a 1-RM from a 3-RM, or the participants’ individual levels of fatigue. Overall, further investigation is required, as the concept of relating relative power clean scores to sprint times is relatively new and literature supporting the evidence obtained in the current study is limited, especially for females.

Future research suggestions include developing a more accurate way to predict a 1-RM power clean, such as a more precise equation where the repetitions and weight could be entered to predict the 1-RM of the power clean exercise specifically. This is especially important for females, in that only one study was used involving women to develop the NSCA’s 1-RM extrapolation table (and in that study they only tested the bench press on the participants). The warm-up protocol for the power clean testing should also be reconsidered, and it probably should follow a less strenuous regimen so as not to fatigue participants before testing, which may have affected results in the current study. Lastly, it would be beneficial to test a large number of athletes across a wide range of sports and within each gender to be able to tease apart differences that might exist in the relationship between relative power clean and sprint times. This information will help the practitioner to develop appropriate and tailored strength programs for athletes.
References


Hunter, J. (2009). Lower-limb explosive power and physical match performance in collegiate female soccer players. Unpublished Master’s. Theses, Department of Kinesiology, Humboldt State University, Arcata, CA.


Appendix A: Informed Consent
HUMBOLDT STATE UNIVERSITY
INFORMED CONSENT

Project Title:
The Association between Power and Sprint Performance in Female Collegiate Soccer Players

Principal Investigator:
Erin C. White, CSCS, USAW, B.S.
Humboldt State University
203-494-9296
cgw17@humboldt.edu

Purpose:
The purpose of this study is to investigate the relationship between power clean performance, vertical jump height, and 20-m and 40-m sprinting performance among Division II collegiate female soccer athletes.

Consent:
You must be at least 18 years old to participate in this study. Your participation in the research study is voluntary, you may choose not to participate at all, or may refuse to participate in certain procedures or answer certain questions or discontinue your participation at any time without penalty or loss of benefits.
**Procedures:**

You will be asked to complete a brief survey that will include demographic information, date of birth, sport, and months of experience of Olympic weightlifting. Height and mass measurements will be taken prior to the commencement of data collection on one of these physical tests (approximately 10 minutes). Participants will complete a 5-min recumbent bicycling warm up at resistance setting of 3 at a cadence of 70-80 revolutions per minute. Then vertical jump height will be measured (approximately 5 minutes). Power clean data collection will consist of a basic familiarization of power clean technique, and a standardized protocol for power clean 3-Repetition Maximal testing (approximately 20 minutes). Sprint speed data collection will consist of a 5 minute basic warm-up protocol, timing device familiarization, and two separate all-out 40-meter sprints (approximately 15 minutes).

**Possible Risks:**

This study involves bouts of all-out efforts in the power clean lift, vertical jump and the 40-m sprint. There may be discomfort that is associated with this type of strenuous exercise. There is possibility of injury while performing any of these activities. There may be muscle soreness that lasts for up to 72 hours from performing these activities. Demographic information will be collected using a self-reported survey that will include questions regarding ethnicity, date of birth, current injury status, sport, year of participation on team, position, number of months of sprint experience, and number of months of Olympic lifting experience. Please be assured that you may choose to not answer certain questions and still continue to participate in this study. **Results of testing will be confidential and will not be released unless individual participant consent is**
given; otherwise your name will be assigned a number to analyze data for anonymity purposes.

**Benefits:**

You will receive your scores for power clean and vertical jump, as well as your best time in the 20-m and 40-m sprint. This information might help you determine strengths or weaknesses you may have in your individual training state. These scores can also help your strength and conditioning coach write a more appropriate strength training program for you.

**Confidentiality/Anonymity:**

Participation in this study is completely voluntary. The only people who might access your scores are National Strength and Conditioning Association Certified Strength and Conditioning Coaches collecting data, and the Principal Investigator. Only the Principal Investigator will have access to your cultural background data. Your identity and information recorded during the study will remain confidential at all times. Confidentiality will be protected by: (a) results will be presented as group data in any presentations and publications; and (b) all data will be stored in a computer that is password-protected and accessible only to the Principal Investigator. You may discontinue participation at any time without penalty. Your participation in this research project will not involve any additional costs to you. You understand that you will not receive any compensation to participate in this study.
Institutional Contacts:

For questions regarding this study, please contact the Principal Investigator using the contact information above. If you have any additional questions concerning your rights as a volunteer or are dissatisfied at any time with any aspect of this study you may contact anonymously, if you wish - Chris A. Hopper, Ph.D., Interim Dean; Research, Graduate Studies, and International Programs; Humboldt State University; (707)826-3949; cah3@humboldt.edu

Signature:

Your signature below indicates your voluntary agreement to participate in this study.

I, ______________________________ have read and agree to participate in this study as described above.

(Please PRINT Your Name Here)

____________________________________  _____ / _____ / ______

(Please SIGN Your Name Here) (Date)
Appendix B: Demographic & Athletic Background Survey
Athlete Demographics and Athletic Background Information

1. Name: ________________________
2. Date: _________________________

Please circle/mark ONE of the following:

3. ( ) Yes or ( ) No: Are you currently injured (muscle, joint, ligament)?
4. ( ) Yes or ( ) No: Do you have an orthopedic condition (muscle, joint, ligament) made worse by exercise?
5. ( ) Yes or ( ) No: Do you have any medical condition made worse by exercise?
   a. If Yes please describe: ______________________________________
6. ( ) Yes or ( ) No: Do you have any previous injury that may impair your ability to perform a 3-repetition maximal power clean, vertical jump test, or two 40-m sprints?
   a. If Yes please describe: ______________________________________
7. ( ) Yes or ( ) No: Are you currently pregnant?
8. Which ONE of the following ethnicities best represents you:
   a. African American
   b. Asian
   c. Caucasian
   d. Latina
   e. Middle Eastern
   f. Native American
   g. Other
   h. Pacific Islander
9. Date of birth expressed as Month/Day/Year:____________________
10. Sport team:____________________
11. Years of experience on current team:_______________________
12. Position:_______________________
13. Months of Olympic weightlifting experience:___________________
14. Months of sprint experience:_________________________
Appendix C: Sayers absolute and relative power equations
Absolute peak power:

Sayers equation (W) = [51.9 * CMJ height (cm)] + [48.9 * body mass (kg)] - 2007

Relative peak power:

Sayers equation (W / kg) = Absolute peak power (W) / (kg)

(Sayers et al., 1999)
Appendix D: NSCA’s prescribed power clean technique
**Power Clean**

This exercise consists of quickly and forcefully pulling the bar from the floor to the front of the shoulders—all in one movement. Although the ascent consists of four phases, the upward movement of the bar occurs in one continuous motion without interruption.

**Beginning Position**

Stand with the feet placed between hip- and shoulder-width apart with the toes pointed slightly outward.

Squat down with the hips lower than the shoulders and grasp the bar with a closed, pronated grip.

Place the hands on the bar slightly wider than shoulder-width apart, outside of the knees, with the elbows fully extended.

Place the feet flat on the floor and position the bar approximately 1 in. (3 cm) in front of the shins and over the balls of the feet.

Position the body with the
- back flat or slightly arched,
- trapezius relaxed and slightly stretched,
- chest held up and out,
- scapulae retracted,
- head in line with the vertebral column or slightly hyperextended,
- shoulders over or slightly in front of the bar, and
- eyes focused straight ahead or slightly upward.

**Upward Movement Phase: First Pull**

Lift the bar off the floor by forcefully extending the hips and knees.

Keep the torso-to-floor angle constant.

Do not let the hips rise before the shoulders.

Maintain a flat-back position.

Keep the elbows fully extended, the head neutral in relation to the vertebral column, and the shoulders over or slightly ahead of the bar.

As the bar is raised, keep it as close to the shins as possible.

**Upward Movement Phase: Transition (Scoop)**

As the bar rises just above the knees, thrust the hips forward and slightly re-flex the knees to move the thighs against the knees under the bar.

Keep the back flat or slightly arched, the elbows fully extended and pointing out to the sides, and the head in line with the vertebral column.

**Upward Movement Phase: Second Pull**

Forcefully and quickly extend the hips and knees and plantar-flex the ankles.

Keep the bar near or in contact with the front of the thighs.
Keep the bar as close to the body as possible. Keep the back flat, the elbows pointing out to the sides, and the head in line with the vertebral column.

Keep the shoulders over the bar and the elbows extended as long as possible. When the lower-body joints reach full extension, rapidly shrug the shoulders upward, but do not allow the elbows to flex yet.

As the shoulders reach their highest elevation, flex the elbows to begin pulling the body under the bar. Continue to pull the arms as high and as long as possible.

Due to the explosive nature of this phase, the torso is erect or slightly hyperextended, the head is tilted slightly back, and the feet may lose contact with the floor.

**Upward Movement Phase: Catch**

After the lower body has fully extended and the bar reaches near-maximal height, pull the body under the bar and rotate the arms around and under the bar. Simultaneously, the hips and knees flex into a quarter-squat position.

Once the arms are under the bar, lift the elbows to position the upper arms parallel to the floor. Rack the bar across the front of the clavicles and anterior deltoids.

Catch the bar with:
- an erect, tight torso;
- a neutral head position; and
- flat feet.

Stand up by extending the hips and knees to a fully erect position.

**Downward Movement Phase**

Lower the bar by gradually reducing the muscular tension of the arms to allow a controlled descent of the bar to the thighs.

Simultaneously flex the hips and knees to cushion the impact of the bar on the thighs.

Squat down with the elbows fully extended until the bar touches the floor.

**Major Muscles Involved**

Gluteus maximus, Semimembranosus, Semitendinosus, Biceps femoris, Vastus lateralis, Vastus intermedius, Vastus medialis, Rectus femoris, Soleus, Gastrocnemius, Deltoids, Trapezius

(Baechle, & Earle, 2000, pp. 384-385)
Appendix E: Data collection sheet
Participant Data Collection Sheet

This area will be used by the Principal Investigator

Name: ___________________
Date: ____________________

Height: ___________________
Mass: ___________________

Vertical Jump Height: ____________
Absolute peak power: ____________

Sayers equation (W) = [51.9 * CMJ height (cm)] + [48.9 * body mass (kg)] - 2007
Relative peak power: ____________

Sayers equation (W / kg) = Absolute peak power (W) / (kg)

Power clean 3-RM score: ____________
Estimated power clean 1-RM score: ____________

20-m sprint speed score: ________ sec __________ sec
40-m sprint speed score: ________ sec __________ sec
Appendix F: NSCA’s Table for 1-RM extrapolation
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(Baechle, & Earle, 2000, p. 410)
Figure 6: Vertect Apparatus (Adams & Beam, 2008, p.81)
Figure 8.1 An example of a commercial jump test instrument (Vertec) showing the jumper descending after displacing the swatted vanes.