Upper extremity strength and power field tests as predictors of pole vault performance in female collegiate athletes

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UPPER EXTREMITY STRENGTH AND POWER FIELD TESTS AS PREDICTORS
OF POLE VAULT PERFORMANCE IN FEMALE COLLEGIATE ATHLETES

A Thesis
Presented To
Eastern Washington University
Cheney, Washington

In Partial Fulfillment of the Requirements
for the Degree
Master of Science in Physical Education - Exercise Science

By
Carmen Schluter
Spring 2016
THESIS OF CARMEN SCHLUTER APPROVED BY

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MASTER’S THESIS

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ABSTRACT

The purpose of this study was to determine if select upper-extremity strength and power field tests, and the test battery, predict pole vault performance in female pole vaulters. There is very little research on female pole vault athletes, specifically non-elite athletes. Field tests previously shown to be predictive of performance in males were examined to determine if they were also predictive for females. Four tests were used (8 lb backwards medicine ball (MB) throw, 3 m seated rope pull, three pull-ups for time, and maximum pull-ups) to determine if pole vault performance (season personal record for each athlete) could be predicted by the test results. Nine collegiate female pole vaulters were tested. Pearson correlation and regression analysis were used to determine if there were relationships between the tests and pole vault performance and if the tests could predict performance. Correlation coefficients revealed that the two pull-up tests were highly related ($r = -0.811$), so maximum pull-ups was removed from the remainder of the results. Regression analysis revealed that 82.6% of the variance in personal record was accounted for by the three predictors, 8 lb backward MB throw, 3 m seated rope pull, and three pull-ups for time ($p = 0.024$). Linear regression analysis showed that 71.8% of variance in pole vault performance was accounted for by the test battery ($p = 0.004$). Pole vault performance, in female collegiate athletes, can be predicted by the three predictor variables and by the test battery.
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Chapter 1

Introduction

Coaches and athletes alike are constantly striving to get the competitive edge to achieve peak performance in sport. Every sport has specific skill requirements, and determining these parameters is essential for both programming in strength and conditioning and talent identification. Pole vault is a track and field event that requires strength, speed, and coordination of precise movements for successful completion. Over 60 years ago, technology for pole vault poles advanced (Balmer, Pleasence, Nevill, 2012). As a result, performances, as indicated by maximal jump height, improved rapidly but have since gradually plateaued. As performances have plateaued, more effort has been placed on sports-specific training to enhance performance.

Women’s pole vault was not introduced into the international scene until 1995 at the world championships. The year 2000 was the first year women’s pole vault was in the Olympic Games. Male pole vaulters have been studied for years, but these results cannot be directly generalized to female athletes due to differences in anthropometrics and strength (Schade, Arampatzis, Brüggemann, & Komi, 2004). Studies on male pole vaulters have focused on field test predictors of performance, anthropometric characteristics linked to performance, speed relating to performance, and upper body muscular activity during the vault to name a few (Angulo-Kinzler et al., 1994; Frère, Göpfert, Slawinski, & Tourny-chollet, 2012; Kochanowicz & Klimczyk, 2012; Linthorne & Gemma Weetman, 2012). Kochanowicz and Klimczyk (2011, 2012) conducted two studies on young male pole vaulters, ages 12 - 17, and found certain tests had more of a relationship to pole vault performance than others. The 3 m rope climb ($r = 0.7554$), five pull-ups for time ($r = 0.70$), and the “fly” over the bar in backward extension roll ($r =$
0.98) showed the highest relationships to performance ($p < 0.05$) in males (Kochanowicz & Klimczyk, 2011, Kochanowicz & Klimczyk, 2012). Other upper-extremity tests, in the same studies, that had a moderate correlation coefficient were quantity of pull-ups ($r = 0.5791$) and backward medicine ball throw ($r = 0.68$). To date, no standardized tests that analyze upper-extremity sport-specific strength and power in female pole vaulters have been reported in literature. Continued research may reveal that the same physical tests which are predictive of performance in male athletes can also be predictive in female athletes.

Improving performance requires the identification of skills that correlate to each phase (run-up, takeoff, swing, push-off) of the pole vault. The movements required in the pole vault, after the takeoff phase, challenge primarily the musculature of the upper-extremity and trunk (Arampatzis, Schade, & Brüggemann, 2004; Frère, Göpfert, Hug, Slawinski, & Tourny-chollet, 2012; McGinnis & Bergman, 1986). Pole vaulters rely on the upper extremity to achieve an inverted position quickly and to propel themselves to greater heights (Frère et al., 2012 & Frère et al., 2012). Currently, no study has identified upper-extremity strength and power tests that can predict performance in female pole vaulters, indicating the need for additional research.

**Purpose statement**

The purpose of this study was to determine if select upper-extremity strength and power field tests, and the battery of tests as a whole, predict pole vault performance in female collegiate pole vaulters.
Hypothesis

The first null hypothesis ($H_{01}$) was that there would be no significant linear relationship between any of the upper-extremity strength and power tests and pole vault performance. The second null hypothesis ($H_{02}$) was that there would be no significant linear relationship between the upper-extremity testing battery and pole vault performance.

Operational Definitions

Performance was defined as the maximal jump height (m) achieved in the current competitive season. Training age was defined as the number of years the participant has pole vaulted.

Delimitations and Limitations

This study was delimited to the use of a convenience sample composed of female pole vaulters who are currently a member of a college team in the Greater Spokane, Washington area, and between the ages of 18 – 25 years. The protocol for the study was delimited to current competitive athletes to be able to adequately compare the relationship between strength and power to current pole vault performance. The study was delimited to participants who had at least one year of competitive experience and were free of any injury that would have inhibited the ability to perform the upper-extremity field tests. Lastly, participants were delimited to those who were able to perform a minimum of three pull-ups. Participants’ ability to complete the tests was determined prior to data collection by verbally asking if she was able to perform three or more pull-ups.
Limitations included the range of training ages of the participants. Some participants were in their first year, just beginning their college career, and some were finishing their fourth season in college.

Assumptions

During the introduction and familiarization session a verbal agreement was reached with each participant that the day prior to testing she would refrain from any upper-extremity training of any kind. The head coach and strength and conditioning coach were also made aware of the rest requirements prior to testing. The day of testing, each participant was asked about compliance with this instruction. Additionally, the study assumed all participants were equally motivated to give their best effort.

Significance of Study

The sport of women’s pole vault is relatively new, as women were allowed to compete in the Olympic Games for the first time in 2000. Most research has been conducted on only male pole vaulters, which exposes a significant gap in the literature. There are many differences between men and women in regards to strength, speed, and anthropometrics (Grabner, 1997; Linthorne & Gemma Weetman, 2012; Schade & Arampatzis, 2004). The results of studies using male participants cannot not simply be generalized to female pole vaulters. Currently no standardized testing battery or field tests have been developed to predict performance in female pole vaulters. Although sport-specific upper-extremity strength and power for the pole vault is difficult to assess, its importance for performance is undeniable (Kochanowicz & Klimczyk, 2011; Kochanowicz & Klimczyk, 2012). Research needs to identify sex- and sport-specific field tests of upper-extremity strength and power that may predict success in pole vault.
The results from this study may prove useful for strength and conditioning programs and for talent identification for female pole vaulters.

Summary

This chapter reviewed the significance of the study, provided an overview of the topic, established a null hypothesis, and explained research parameters, including limitations, delimitations, assumptions, and operational definitions.
Chapter 2
Review of Literature

Introduction to Pole Vault

Pole vault is a track and field event that has been in the Olympics for men since the first modern Olympic games in 1896, and for women since 2000 (IAAF, 2015). The origin of pole vaulting dates back to 16\textsuperscript{th} century, possibly to the ancient Greek period, when pole vaulting was a military tactic used to jump over enemy walls. Origins of modern vaulting dates back to the 1850s in Germany. Poles were made of ash or hickory with iron spikes at the end. The first recorded use of bamboo poles was in 1857. Steel poles were implemented in 1940s and finally fiberglass poles were introduced in the late 1950s, with carbon fiber poles being added soon after (IAAF, 2015). Both fiberglass and carbon fiber poles are used still today.

Pole vault is an event with many factors that can affect performance. Maximal performance is based on physical characteristics of the athletes, laws of physics, as well as safety guidelines that need be followed to prevent injury. Anthropometrics, biomechanics, energetics, and safety are all involved to develop ideal conditions for pole vault athletes. Pole vault athletes must be strong enough to bend the pole, fast enough to thrust themselves onto the mat safely, and powerful enough to rotate themselves upside-down while in midair (Angulo-Kinsler et al., 1994; Arampatis et al., 2004; Bergemann, 2003; Frère et al., 2010; Frère et al., 2012; Grabner, 1997; Linthorne & Gemma Weetman, 2012; Morlier & Mesnard, 2007).

Equipment

The importance of fiberglass poles being implemented in 1956 was an immediate improvement in pole vaulting height by 85 to 115 cm (Balmer, Pleasence, Nevill, 2012).
The technique that was developed for pole vaulters who used bamboo and steel poles is not the same technique utilized by current vaulters who use flexible poles composed of fiberglass or carbon fiber (Linthorne, 1994). The downfall of the previous research on bamboo and steel poles is that predictions from one simulation study cannot be applied to the current technique utilized by modern pole vaulters. Pole vault poles are rated for a certain weight of vaulter and below (e.g. A 150 lb athlete should not use a pole rated < 150 lbs). The pole length and stiffness have a significant impact on performance and the jump height the athlete is able to achieve (Angulo-Kinsler et al., 1994; Linthorne & Gemma Weetman, 2012). Research suggests that greater speed from the run enables a higher grip height, and in turn the ability to use a longer or stiffer pole, as long as the athlete is strong enough to control the resulting reaction forces (Angulo-Kinsler et al., 1994; Grabner, 1997; Linthorne & Gemma Weetman, 2012). Percentage of maximum pole bend achieved, which is affected by pole stiffness, is also highly predictive of performance ($r = .87$, $p < 0.01$) and is influenced by forces generated from the run and the upper-extremity during the swing phase (Zagorac, Retelj, & Katic, 2008). The pole vaulting pole is just one of many factors that has an effect on pole vault performance.

**Safety**

Pole vault, which is considered by some to be an extreme sport, has had 18 catastrophic injuries that ended in death in high school and college athletes between the years 1983 to 2006 (Bemiller & Hardin, 2010). Most of these fatalities were due to head trauma from missing the landing mat, also called the pit, or landing partially on the mat then falling off. These notable incidences drew much attention to pole vault, and rules were revised in an attempt to prevent future fatal injuries. Controlling the pole vaulting
environment as much as possible can help reduce the associated risks (Bemiller & Hardin, 2010). Ensuring the size of the mat adheres to the established criteria and reducing hard surfaces around the pit can reduce the chance of injury according to Bemiller and Hardin (2010). One way to reduce hard surfaces around the mat is to use a box collar that covers the area around the plant box (Bemiller & Hardin, 2010). A square, “coach’s box”, is also painted on the vaulting pit which allows the athlete and coach to easily determine if the athlete is landing in a safe zone or not (See Figure 1).

![Figure 1: The white square is called the coach’s box. The yellow mat around the plant box is called the box collar.](image)

A knowledgeable coach who can advise individual athletes about how high to grip the pole will increase the chance of the athlete successfully landing in the “coach’s box” (Bemiller & Hardin, 2010). The higher the grip, the farther the athlete could potentially fall. By maintaining equipment, controlling the environment, and progressing athletes gradually, coaches can keep a safe atmosphere even when considering the extreme nature of the sport (Bemiller & Hardin, 2010).
Predictors of Performance

Pole vault is a complex track and field event that is comprised of many elements that contribute to maximal pole vault performances. Anthropometric and biomechanical factors play an important role in predicting performance (Frère, L'Hermette, Slawinski, & Tourny-Chollet, 2010). In addition, tests for strength, power, speed, and gymnastic ability can indicate athletes’ strengths and weaknesses and where improvements can be made to increase success (Kochanowicz & Klimczyk, 2011; Kochanowicz & Klimczyk, 2012). In most studies women have not been included primarily because women’s pole vault was not considered important until 1995 when female vaulters were finally able to compete in an international championship. When analyzing research in pole vault, one must consider the lack of female subjects in studies and know this limitation exists.

Anthropometrics. Studies have shown that there are ideal anthropometrics that contribute to the prediction of performance of pole vaulters (Angulo-Kinsler et al., 1994; Linthorne, 1994; Linthorne & Gemma Weetman, 2012; Liu, Nguang, & Zhang, 2011). Studies indicate that taller athletes have an advantage which allows for a higher grip on the pole (Angulo-Kinsler et al., 1994; Linthorne, 1994; Linthorne & Gemma Weetman, 2012). While running at a set speed, male vaulters with a body mass < 80 kg performed better than those with a body mass ≥ 80 kg (Liu et al., 2011). This conclusion was based on mathematical models where athletes with a body mass of 60 and 70 kg performed better than athletes weighing 80 and 90 kg. Athletes that have less mass to push over the bar have an advantage because their objective is to push themselves upside-down and over a crossbar.
Biomechanical Principles. Research has identified many biomechanical principles that athletes can implement to increase pole vault performance (Angulo-Kinsler et al., 1994; Arampatis et al., 2004; Armbrust, 1993; Bergemann, 2003; Frère et al., 2010; Frère et al., 2012; Grabner, 1997; Linthorne, 1994; Linthorne, 2000; Linthorne & Gemma Weetman, 2012; Liu & Zhou, 2000; McGinnis & Bergman, 1986; Morlier & Mesnard, 2007; Schade, Arampatzis, & Bruggemann, 2006). Principles such as muscular strength, vertical velocity, angular velocity, horizontal velocity and energy influence the movements of the pole vault.

Muscular strength is required for athletes to keep their center of gravity (COG) as close to the pole as possible (Angulo-Kinsler et al., 1994). Athletes who are unable to keep their COG close to the pole generate rotational velocity, rather than vertical, and “fall off the pole” which leads to decreases in performance (Angulo-Kinsler et al., 1994). Vertical velocity is required to continue the athlete moving in the vertical direction (Angulo-Kinsler et al., 1994). When vertical velocity is maximized, greater heights can be reached (AngULO-Kinsler et al., 1994).

Final total energy (e.g. combination of strain energy, kinetic energy, potential energy, and mechanical energy) is greater than initial energy, produced from the run-up, in both males and female elite athletes (Arampatis et al., 2004). The previous study identifies that the presence of muscular work adds to the final total energy, despite some energy loss. The expected results would be that there is a net energy loss due to the pole hitting the plant box and through the shoulders upon take-off. Mechanical work from the muscles is what contributes to the net gain in energy, identifying the importance of upper-extremity musculature.
Finally, to improve pole vault performance the angular velocity of the body must be increased to allow the athlete to achieve an inverted position more quickly (Angulo-Kinsler et al., 1994; Armbrust, 1993; Bassement, Goss-Sampson, & Garnier, 2007; Grabner, 1997). Achieving the inverted position is important; otherwise, the potential energy from the bent pole is translated into horizontal motion of the body rather than vertical motion (Angulo-Kinsler et al., 1994; Armbrust, 1993; Bassement, Goss-Sampson, & Garnier, 2007; Grabner, 1997). This angular velocity is produced by the arm and shoulder muscles pulling on the pole (Armbrust, 1993).

Another predictor of performance is the horizontal velocity of the COG at takeoff, derived from an effective run-up (Angulo-Kinsler et al., 1994; Armbrust, 1993; Bassement et al., 2007; Linthorne & Gemma Weetman, 2012; Liu & Zhou, 2000). Data indicates the importance of lower body musculature strength which can then produce the adequate amount of horizontal velocity necessary for success (McGinnis & Bergman, 1986). Horizontal velocity can make up for energy that is lost due to the plant phase, and this demonstrates how energy produced during the run is crucial for success (Linthorne & Gemma Weetman, 2012). Another factor that influences horizontal velocity is the distance of approach (Linthorne & Gemma Weetman, 2012). These researchers identified that athletes have an ideal run-up distance that maximizes horizontal velocity and limits deceleration prior to takeoff (Linthorne & Gemma Weetman, 2012). Determining this distance in each athlete is important in order to limit deceleration and achieve maximal horizontal velocity.

**Grip Height.** Grip height can be explained as the height at which each athlete holds onto the pole, which is often different for each athlete. One study identified that
grip height and pole vault performance were strongly correlated ($r = 0.88$, $p < 0.05$) (Sullivan, Knowlton, Hetzler, & Woelke, 1994). For peak performance, grip height needs to be maximized (Angulo-Kinsler et al., 1994; Grabner, 1997; Linthorne & Gemma Weetman, 2012; Zagorac, Retelj, & Katie, 2008) which in turn decreases the pole angle relative to horizontal at takeoff (Linthorne & Gemma Weetman, 2012). The pole angle, relative to horizontal, should be maximized as much as possible despite having a higher grip height. This is achieved by extending the arms overhead and plantar flexing the takeoff foot immediately before and while leaving the ground (Grabner, 1997; Linthorne & Gemma Weetman, 2012). Taking off with the foot under the top handgrip, closer to the plant box than the vaulter should be, is associated with a decrease in performance. Vaulters who take off with the foot directly underneath the top handgrip, creating a 90° angle with the runway, are able to achieve a maximal pole angle, relative to horizontal (Armbrust, 1993; Grabner, 1997; Liu & Zhou, 2000). The COG should be elevated as high as possible on takeoff, which maximizes pole angle relative to horizontal, which is why taking off right underneath the top hand can minimize energy losses. Ultimately, greater run-up speed is what allows the athlete to have a higher grip height (Angulo-Kinsler et al., 1994). For the athlete to maintain the higher grip height, muscular strength and control is also necessary to combat the increased force from the pole on the body (Angulo-Kinsler et al., 1994).

**Takeoff Angle.** Studies have shown varying takeoff angles in the pole vault, ranging from 16 - 32° (Angulo-Kinsler et al., 1994; Linthorne, 1994; Linthorne, 2000; Liu & Zhou, 2000). Many of these studies use a mathematical model to attempt to understand how to limit energy loss in the vault of an elite male (Linthorne, 1994;
Linthorne, 2000). The first model used a rigid pole model resembling the steel poles that were utilized prior to fiberglass and carbon fiber (Linthorne, 1994). This model-derived investigation revealed that 32° is the ideal takeoff angle using the rigid pole model. Rigid poles are no longer used, and the takeoff technique is not the same in the sport; (Linthorne, 1994) therefore this research cannot be applied to current athletes. A flexible pole model, representative of current pole vault conditions, found 18° to be the optimum takeoff angle and allowed for a greater grip height compared to a rigid pole model (Linthorne, 2000). The mathematical model from this study was derived from one world-class male pole vaulter.

The only study on takeoff angles that used data from female athletes ($n = 4$) demonstrated a mean takeoff angle of 23° and discussed that this needed to be less but gave no explanation for this recommendation (Liu & Zhou, 2000). Current research shows that an athlete’s takeoff angle, relative to horizontal, is dependent on horizontal takeoff velocity which allows the athlete to grip higher on the pole (Linthorne & Gemma Weetman, 2012). The previous researchers found that as the athlete’s ($n = 1$) run-up velocity increased, the pole angle decreased. The athlete ultimately reached a velocity of 8.4 m/s, and the takeoff angle decreased to 20°, relative to horizontal, due to increased grip height (Linthorne & Gemma Weetman, 2012). More research is necessary because current studies have small sample sizes and utilize a small population (elite athletes). In addition, many of the studies use models to determine certain characteristics that maximize pole vault performance which use sample size of one, this bring about limitations as well.
Muscular Work. Muscular work helps to make up for energy that is lost in the
takeoff phase of the vault (Armbrust, 1993; Linthorne & Gemma Weetman, 2012;
The left arm pushes initially in the takeoff position, then pulls the remainder of the time
until push-off, indicating an essential ability for the extensor muscles of the shoulder to
be strong in this phase (McGinnis & Bergman, 1986). The “push” force, from keeping
the left arm activated, contributes to performance which allows the vaulter to penetrate
into the safe zone of the mat and clear the bar (Linthorne & Gemma Weetman, 2012;
Morlier & Mesnard, 2007). In both male and female vaulters, there was an increase in
energy between the take-off phase and pole straightening phase, and this increase in
energy was an outcome of muscular work on the pole (Armbrust, 1993; Schade &
Arampatzis, 2004). The center of gravity must remain close to the pole during the swing
phase for there to be an increase in height achieved in the push-off phase (Angulo-
Kinzler et al., 1994; Grabner, 1997; McGinnis, 2008). In doing this, the center of gravity
will be elevated and lead to attaining heights above that grip height, another important
factor for maximal performance (Angulo-Kinsler et al., 1994; Grabner, 1997).

Energetics. Understanding the energetics of the pole vault can assist in
maximizing performance. Kinetic energy is produced by the run, strain energy is stored
in the pole, mechanical energy is lost at take-off, muscular work adds to the total energy,
and potential energy is maximized at the peak height of the vault (Arampatzis et al.,
2004).

Kinetic energy is maximized when the horizontal velocity, achieved by the run-
up, is maximized (Arampatzis et al., 2004). Arampatzis and colleagues (2004) identified
the energies of athletes (male $n = 5$, female $n = 1$) and the pole at different phases of the pole vault. The mechanical energy that was lost at take-off due to energy exchange from the athlete to the pole was between 6 - 10% amongst both male and female subjects (Arampatzis et al., 2004). The total energy of the female vaulter ($41.68 \pm 0.57$ J/kg), defined as the energy of the participant at peak height of the COG, was larger than the initial energy ($34.64 \pm 0.44$ J/kg), despite the mechanical energy loss ($1.28 \pm 0.33$ J/kg) at the plant phase (Arampatzis et al., 2004). This demonstrates that although there was energy loss in the vault, that muscular work had an effect on final energy of the vaulter (Arampatzis et al., 2004). The male participants showed similar results as the female participant in regards to increases in total energy, but the amount of energy varied between vaulters. Participants had a varied percentage of energy loss and energy gain (Arampatzis et al., 2004). This research shows that there may be different energy storage strategies used by different athletes as the energy added to the total energy occurred at different times throughout the vault (Arampatzis et al., 2004).

Energy can be dissipated at various times including take-off and the pole support phase (Linthorne, 1994). Energy is dissipated into the muscles of the vaulters who are unable to maintain a rigid body throughout the takeoff phase (Linthorne, 1994). Energy is also lost due to contact forces from the pole tip hitting and sliding in the pole box, as well as from the pole bending at take-off (Angulo-Kinzler et al., 1994; Linthorne, 2000; Schade et al., 2004)

Muscular work compensates for loss in energy during take-off (Arampatzis et al., 2004; Schade et al., 2004; Morlier et al., 2007; Linthorne et al., 2012). The greater the muscular work, the greater the final energy at the peak of the center of gravity in the
push-off phase (Arampatzis et al., 2004). This understanding can help in determining ways in which an athlete can maximize performance in the pole vault.

**Differences Based on Sex.** There are many biomechanical principles that demonstrate differences between sexes in the pole vault (Grabner, 1997; Linthorne & Gemma Weetman, 2012; Schade, Arampatzis, Brüggemann & Komi, 2004). Pole stiffness has an effect on performance for both males and females (Schade et al., 2004). In a co-ed study \((n = 20)\), females \((n = 10)\) were found to bend softer poles and by identifying the length of the pole chord, explained as the distance between the top hand to the plant box throughout the vault, they shortened their poles to a significantly smaller \((p <0.05)\) percent than males (men 28.0 ± 2.80%, women 24.2 ± 3.60%) (Schade et al., 2004). The energy transferred into the pole was less; therefore, the energy that was transferred back from the recoiling pole was also less (Schade et al., 2004). The differences in energy are because elite female pole vaulters generate less energy during the run approach compared to their male counterparts (Schade, Arampatzis, & Brüggemann, 2006).

Limited research has recommended an ideal bend for the pole indicating the inability to determine a precise pole bend as a predictor of performance (Angulo-Kinsler et al., 1994). The elite male pole vaulter who jumped the highest also produced greater maximum vertical velocity \((4.3 \text{ m/s})\) compared to the best value of elite females \((3.8 \text{ m/s})\) (Grabner, 1997). This ability to achieve a high vertical velocity is important to get the COG as high as possible (Schade et al., 2006). Shade and colleagues (2006) confirmed that elite females were unable to maintain their vertical velocity in order to reach the “free flight phase”, where the athlete’s COG is still traveling upward at pole release, as
the COG had reached peak height before pole release (Schade et al., 2006). Less experienced male vaulters are also unable to reach this phase, and this diminished maximum performance capabilities (Angulo-Kinsler et al., 1994).

Finally, differences between males and females (males n =10, females n =10) are also displayed in grip height (male 5.00 ± 0.07, female 4.25 ± 0.09), (Schade et al., 2004) and horizontal velocity on the approach (male 44.84 ± 0.36, female 34.64 ± 0.44) (Arampatzis et al., 2004). Both of these characteristics are related to performance and may explain reduced pole vault heights seen in female athletes compared to males. De Sousa and colleagues (2013) investigated differences in strength in males and females using 88 twins and found that females had more potential for upper-extremity muscle increases in strength versus males. This finding demonstrates the importance of identifying strength and power tests in female athletes which may lead to increases in performance with proper training.

**Power, Strength, and Speed Tests.** Tests for power, strength, and speed that correlate well with specific parts of the pole vault and maximal performance have been established (Sullivan, Knowlton, Hetzler, & Woelke, 1994; Kochanowicz & Klimczyk, 2011; Kochanowicz & Klimczyk, 2012). Strength and power tests for lower-extremity, trunk, and upper-extremity have been identified and relate to pole vault performance in male athletes.

The lower body musculature must be strong and powerful to produce the adequate amount of horizontal velocity necessary for success (McGinnis & Bergman, 1986). Horizontal velocity is critical for an athlete because kinetic energy is determined by the run velocity, and kinetic energy is the greatest contributor to total energy of the vault
(Armbrust, 1993). Because pole vaulters sprint with a pole in hand, measuring sprint time while carrying the pole has shown to be correlated to pole vaulting success (Angulo-Kinzler et al., 1994; Linthorne & Gemma Weetman, 2012). Tests for power include a standing long jump, where distance measures indicate a significant and strong inverse relationship between jump distance and sprint acceleration ($r = 0.867$, $p = 0.003$) (Moresi, Bradshaw, Green & Naughton, 2011). Physical tests used by Sullivan and colleagues (1994) were strongly correlated to performance when studying 87 males (13 – 18 years). These tests included running speed ($r = 0.71$), standing long jump ($r = 0.69$), and pull-ups ($r = 0.44$). These tests for lower extremity strength and power are easy to administer and have been associated with performance in previous literature.

Strength and power tests for the trunk can display the athlete’s ability to lift his or her legs to the top of the pole to achieve an inverted position (Kochanowicz & Klimczyk, 2011; Kochanowicz & Klimczyk, 2012). Negative high and positive moderate correlations ($r = -0.73$, $r = 0.60$, $p < 0.05$) were found when athletes were asked to raise their feet to the bar five times as fast as possible and as many times as possible (Kochanowicz & Klimczyk, 2012). The previous two tests can be used to identify relationships between trunk strength and power and pole vault performance.

Results of shoulder strength and power tests (i.e. pull-ups, climbing a 3-m rope for time, throwing 4kg ball backward overhead, and “fly” over the bar with rollover backward while doing handstand) demonstrate the ability of the pole vault athlete to utilize the shoulder musculature for activities that relate to the movements in pole vault (Kochanowicz & Klimczyk, 2011; Kochanowicz & Klimczyk, 2012). Pull-ups for time were measured and revealed a negative, high correlation with performance ($r = -0.70$, $p <$
in 15 – 16 year-old males (Kochanowicz & Klimczyk, 2012). The 3 m rope climb identified a negative, moderate correlation ($r = 0.53, p < 0.05$) for 15 – 16 year-old males (Kochanowicz & Klimczyk, 2012) and a negative, high correlation ($r = -0.79, p < 0.05$) in 12 – 17 year-old males (Kochanowicz & Klimczyk, 2011). Throwing a 4 kg ball backward overhead showed a positive, moderate correlation ($r = 0.68, p < 0.05$) to pole vault performance in 15 – 16 year-old males (Kochanowicz & Klimczyk, 2012). The previously listed tests help to identify upper-extremity strength and power field tests that can be used in adolescent male pole vaulters.

Lastly, data suggests that a test for upper-extremity power in males assesses the distance the athlete is able to push off vertically, in a backward roll into handstand, by measuring the crossbeam height the athlete is able to get his hips over (Kochanowicz & Klimczyk, 2011; Kochanowicz & Klimczyk, 2012). Researchers used this skill specifically because it closely mimics the push-off phase of the pole vault and was very highly correlated ($r = 0.98, p < 0.05$) with performance in males (Kochanowicz & Klimczyk, 2012). Researchers have recognized that the achievement of the inverted position is necessary for pole vault (Linthorne & Gemma Weetman, 2012) which can be developed from muscular work.

The aforementioned tests were used by Kochanowicz and Klimczyk (2011, 2012) to identify relationships between tests and performance. The participant who had the highest pole vault performance (4.20 m) scored the highest among his peers on all the previously listed tests except for the 4 kg backward ball throw (Kochanowicz & Klimczyk, 2012). Upper-extremity tests for strength and power have been shown to
correlate with pole vault performance (Kochanowicz & Klimczyk, 2011; Kochanowicz & Klimczyk, 2012) identifying the importance of developing these skills in males.

**Summary**

The aforementioned data suggests that there are certain criteria for achieving maximal performance in the pole vault. Ideal anthropometrics have been shown to increase performances (Angulo-Kinsler et al., 1994; Linthorne, 1994; Linthorne & Gemma Weetman, 2012; Liu, Nguang, & Zhang, 2011), but these characteristics often cannot be changed. Specific biomechanical factors are also associated with increases in performance (Angulo-Kinsler et al., 1994; Arampatis, Schade, & Bruggemann, 2004; Armbrust, 1993; Bergemann, 2003; Frère et al., 2010; Frère et al., 2012; Grabner, 1997; Linthorne, 1994; Linthorne, 2000; Linthorne & Gemma Weetman, 2012; Liu & Zhou, 2000; McGinnis & Bergman, 1986; Morlier & Mesnard, 2007; Schade, Arampatzis, & Bruggemann, 2006). With effort, these can be improved. These studies included small sample sizes which is a limitation. Future research should include larger sample sizes, other levels of pole vaulters besides elite athletes, and should include female pole vaulters. Even slight improvements in many different phases and movements required for the pole vault can increase performance in female pole vaulters.
Chapter 3

Methods

The purpose of this study was to determine if select upper body strength and power field tests predict pole vault performance in collegiate female pole vaulters. Tests previously shown to be predictive of performance in males were examined to determine if they were also predictive for females. Participants, instruments, procedures, and design and analysis are discussed in this chapter.

Participants

Nine female pole vaulters who were currently on a competitive collegiate track and field team were recruited for participation. The participants’ ages ranged from 18 to 22 years. Participants verbally reported no injuries or pain that limited their ability to maximally perform the upper extremity strength and power tests. Prior to participation, athletes were verbally asked if they could complete three full pull ups, as this was necessary for inclusion in the study.

There were a range of experience levels within the two colleges. Schools that were included were Spokane Community College and Eastern Washington University (Division I). Whitworth University athletes chose not to participate because of the distance to the testing site. Coaches from each school were contacted by way of email to request permission to recruit their athletes for participation in the study. A meeting was held with the participants from each school where an explanation of the study purpose and procedures and informed consent were provided. A familiarization period was given during this meeting, in which tests were demonstrated and participants were given a chance to practice on the equipment. Not all participants chose to practice the tests during...
the session. Participants were given 24 to 48 hours to complete and return the informed consent documents to the principle investigator prior to testing.

**Instruments**

This study included four field tests, administered in the following order: 1) 8 lb backward MB throw 2) 3 m seated rope pull of 30% of body mass 3) 3 pull-ups for time and 4) maximum pull-up repetitions. Pull-ups were be performed on a STEELFIT® FREE Bar (STEELFIT® Strength Systems, Mt. Airy, MD) with a diameter of 1.25 in made with powder coated steel. The pull-up bar frame was mounted to the floor using cables for stability. The high bar was set high enough to ensure the athletes were able to have their feet hang down without touching the ground. Other instruments included an 8 lb Trial® medicine ball (Sport Italia, Italy) with a diameter of 21 cm used for the backward MB toss. The Sled Dawg I, which is a 14-guage powder coated steel 20 lb sled (Perform Better, West Warwick, RI) was connected to the Velocity Trainer rope for the seated rope pull (Speed Quest, Harrisburg, OR). TROY® Olympic weights (USA Sports/TROY Barbell, Houston, TX) were used to add weight onto the sled for the seated rope pull. A 100 m Champion Reel measuring tape (Champion Sports, Marlboro, NJ) was used to determine the distance the medicine ball traveled. An Accusplit® A601X PRO SURVIVOR stopwatch (Accusplit Inc., Pleasanton, CA) that measures with a precision of 1/100 sec was used to time the 3 pull-ups for time and seated rope pull. An Apple iPad 2 (Apple, Cupertino, CA) was used for timing using the Dartfish Express (Dartfish, Fribourg, Switzerland) application. This tool has a timestamp, with the precision of 1/100 sec, to determine exact start and stop times of the timed tests. The hand time was only
used as a backup method. Body weight and height were measured using a Health O Meter® 402KLWH - Physician Scale (Health o meter Professional Scales, McCook, IL).

To ensure standardized test conditions, testing took place at the Eastern Washington University Fieldhouse. Thirty-five min of testing time was allotted for each athlete. Included in that time was 21 min total rest time, 3 min to complete the tests, and a 10 min general warm-up prior to testing. Participants were tested in groups and had staggered start times, one every minute, which allowed three participants to be tested at a time.

**Procedures**

Data collection took place in February, at the end of the indoor season. Participants completed a general 10 min warm-up which included dynamic flexibility. Age, year in school, training age (number of years pole vaulting) and body mass and height were determined. After determining body mass, the load (30% body mass) for the rope pull test was determined.

The first test completed was the 8 lb backward MB throw. Participants’ heels were to remain behind the zero meter mark, but participants were allowed to step over the starting mark after ball release. The participants were cued the following: “Your goal is to throw the ball as far as possible without using your legs. Keep your knees slightly bent and engage the core.” Three trials were recorded by measuring the center of the impact point with a tape measure. Participants had 3 min rest between trials. American College of Sports Medicine (ACSM) guidelines indicate 3 – 5 min as adequate rest time between trials for power tests (Pescatello, L., American College of Sports Medicine, 2014).
The second test was the 3 m seated rope pull. This test was in place of the 3 m rope climb that was used in Kochanowicz and Klimczyk’s (2011, 2012) studies. In pilot testing, three of five participants were unable to complete the rope climb which was decreased from 3 m, from Kochanowicz and Klimczyk’s study (2012), to 2 m. Research conducted by Gašic and colleagues (2011) show a statistically significant difference ($p < 0.001$) between males and females in upper-extremity explosive strength. The movement of the seated rope pull was similar to the rope climb and allowed for all participants to complete the test. No research has been done using an upper-extremity sled pull protocol to date. All research on sled pull protocols are used for lower-extremity testing. A study by Bachero-Mena and Gonzalez-Badillo (2014) utilized a sled for resisted sprint training in male students ($n = 19$) and determined that training with 20% of body weight led to significant improvements in the acceleration phase of the sprint. Based on this previous study, 20% of body mass was used for the pilot testing. The participants in pilot testing were not able to consistently grab the rope very well because they said the sled was moving too fast. To combat this situation, the weight was increased to 30% of the body mass. Friction between the sled and the turf was not controlled but all participants were tested at the same location and the surface was the same.

For the rope pull test, participants were seated on the floor with their legs extended and spread hip distance apart. The participant pulled a rope connected to a sled holding 30% body mass, in addition to the weight of the sled which was 20 lbs. The participants choose which side of her body the rope would be on. The 0 m and 3 m markers were be clearly marked on the floor with tape. Participants were cued to: “pull the sled as fast as possible while focusing on pulling from the upper body.” Participants
started with both hands on the rope with the sled behind the starting line tape and were cued, “ready, set, go” after which the participant pulled the sled as quickly as possible until the sled passed the 3 m marker. Each trial was recorded on the iPad to determine the exact start and stop times from the video timestamp. Participants completed three trials with 3 min of rest between trials. If a participant tended to miss the rope while attempting to pull, the trial was re-attempted three minutes later.

The third test was 3 pull-ups for time. Kochanowicz and Klimczyk (2011, 2012) used five pull-ups in their study of young male vaulters. Ryman Augustsson and colleagues (2009) identified sex differences (men \( n = 25 \), women \( n = 38 \)) in upper-extremity strength in college aged subjects using a timed and maximum push-up test. This study identified that males were able to perform significantly more push-ups (39 ± 13) than females (17 ± 10). These results, along with known differences in upper body muscular ability, were the basis for the adjustment to the number of pull-ups.

Participants hung by their hands from the pull-up bar. When cued to “go,” the stopwatch was started and the participant completed three full pull-ups as quickly as possible. Similar to the rope pull test, each trial was video recorded on the iPad using the application with a timestamp. The time stopped once the participant reached the position of the chin over the bar on the third pull-up. Swinging or kipping (using momentum generated from the legs) would have voided the repetition; however, none of the participants kipped or used momentum to swing during this test. All participants used chalk for their hands for this specific test. Three min rest time was given prior to the next test.
The final test was maximum pull-ups. This test was similar to the pull-ups for time test except the participant self-started from the fully extended position and attempted to complete as many pull-ups as possible without swinging or kipping. All participants used chalk for their hands on this test as well.

**Data Analysis**

Statistical Package for Social Sciences Version 20.0 (SPSS Inc., Chicago, IL) was used to perform all statistics including descriptive statistics and multiple regression. The alpha level was set to $p < 0.05$. A repeated measures analysis of variance (ANOVA) was be used for the data from the three trial tests (backward MB throw, rope pull) to determine statistical differences between the trials. If one of the three trials was found to be significantly different from the others, the trial was discarded. Data from Al Haddad, Simpson, and Buchheit (2015) indicated that similar results are obtained by either using the average or the best of the trials. For the current study, the average of the trials were to be used.

Multiple regression analysis was used to determine which field tests were predictive of performance. The test battery underwent linear regression analysis to determine if the test battery had the ability to predict performance. Raw scores were changed to z-scores and then summed to create a composite score that was subjected to analysis.
Chapter 4

Results

The purpose of this study was to determine if select upper-extremity strength and power field tests predict pole vault performance in female pole vaulters. This research sought to determine if there was a significant linear relationship between the individual upper-extremity strength and power tests, and the test battery, with the athletes’ season personal records. This chapter presents the results.

Demographics

Participants \((n = 9)\) for this study were drawn from a convenience sample of female collegiate pole vaulters from Spokane Community College in Spokane, Washington and Eastern Washington University in Cheney, Washington. Based on previous research, four participants per predictor was sought. Multiple attempts were made to reach out to schools beyond Spokane. Only three of the seven universities responded. Whitworth athletes chose not to participate because of the distance to the testing site. This is the reason the study only resulted in nine total participants.

Descriptive data for participant demographics are listed in Table 1.

Table 1.

<table>
<thead>
<tr>
<th>Participant Demographics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic</td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td>Training Age (yrs)</td>
</tr>
<tr>
<td>Personal Record (m)</td>
</tr>
</tbody>
</table>

*Note.  \(N = 9\);  \(M = \text{mean}\);  \(SD = \text{standard deviation}\)*
Descriptive Statistics

Four tests were used to assess upper-extremity strength and power: 8 lb backward MB throw, 3 m seated rope pull at 30% of body mass, 3 pull-ups for time, and maximum pull-ups. The 8 lb backward MB throw and 3 m seated rope pull tests required three trials each. Repeated measures ANOVA was used for each test to determine if there was a significant difference between the three trials. A reliability analysis using Cronbach’s alpha was used to assess internal consistency, which is how closely related the trials were within-subjects. Results indicated excellent internal consistency for the 8 lb backward MB throw (Cronbach’s α = 0.963) and no significant difference between trials (p = 0.799). Similar results for internal consistency were seen for the 3 m rope pull (Cronbach’s α = 0.863) and no significant differences between trials (p = 0.060). With no significant difference between trials in the 8 lb MB throw and 3 m rope pull, the average score was calculated from 3 trials and this value was used for the remaining statistical analyses.

The tests, 3 pull-ups for time and maximum pull-ups, were assessed once. Group means and standard deviations were calculated and reported for each test (Table 2). Individual results for each participant are reported for each test (Table 3). Participant 1 had the best personal record of all the athletes and also had the best raw score for each of the four tests. Participant 9 had the lowest personal record and had the lowest raw scores for the two pull-up tests.
Table 2.

*Test Battery Performance Data*

<table>
<thead>
<tr>
<th>Test</th>
<th>$M$</th>
<th>$SD$</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 lb MB Throw (m)</td>
<td>6.4</td>
<td>0.89</td>
</tr>
<tr>
<td>3 m Seated Rope Pull (s)</td>
<td>2.01</td>
<td>0.47</td>
</tr>
<tr>
<td>3 Pull-ups for Time (s)</td>
<td>5.16</td>
<td>2.0</td>
</tr>
<tr>
<td>Maximum Pull-ups</td>
<td>10</td>
<td>5.9</td>
</tr>
</tbody>
</table>

Table 3.

*Summary of Participant Test Results and Season Personal Record*

<table>
<thead>
<tr>
<th>Participant</th>
<th>PR (m)</th>
<th>MBToss (m)</th>
<th>RPull (s)</th>
<th>3PU (s)</th>
<th>MaxPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</tr>
<tr>
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<td>3.6</td>
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<td>5.30</td>
<td>9</td>
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<td>3</td>
<td>3.8</td>
<td>6.7</td>
<td>1.92</td>
<td>3.94</td>
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<td>4</td>
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<td>7.6</td>
<td>1.76</td>
<td>5.51</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>3.7</td>
<td>6.3</td>
<td>2.66</td>
<td>3.57</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>3.6</td>
<td>6.7</td>
<td>2.21</td>
<td>6.44</td>
<td>6</td>
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<td>7</td>
<td>3.1</td>
<td>5.8</td>
<td>2.76</td>
<td>5.80</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>3.6</td>
<td>5.7</td>
<td>2.09</td>
<td>3.51</td>
<td>15</td>
</tr>
<tr>
<td>9</td>
<td>3.1</td>
<td>5.5</td>
<td>1.79</td>
<td>9.47</td>
<td>3</td>
</tr>
</tbody>
</table>

*Note: PR = Personal Record, MBToss = 8 lb MB toss, RPull = 3 m seated rope pull, 3PU = 3 pull-ups for time, MaxPU = Maximum pull-ups*

**Individual Tests**

The Pearson correlation coefficient indicated a significantly strong association between 3 pull-ups for time and maximum pull-up repetitions ($r = -0.838, p = 0.005$) indicating multicollinearity. The correlation coefficient is negative because 3 pull-ups for time is a timed test, so as the scores get smaller, the scores for maximum pull-ups get larger. The only predictors that that displayed multicollinearity ($p > 0.70$) were maximum pull-ups and 3 pull-ups for time, indicating redundancy. To address the issue of multicollinearity, maximum pull-ups was removed as a predictor based on two findings.
First, the correlation coefficient between the maximal pull-ups test and pole vault performance ($r = 0.767, p = 0.016$) was smaller than 3 pull-ups for time and performance ($r = 0.811, p = 0.008$). Second, the $R^2$ value was smaller for maximal pull-ups ($R^2 = 0.69; p = 0.098$), than 3 pull-ups for time ($R^2 = 0.83; p = 0.024$), when using multiple regression analysis to predict pole vault performance with the other two predictors (8 lb backward MB throw and seated rope pull). Based on the previous findings, maximal pull-ups was removed and only three predictor variables were used for the remainder of the results.

Four bivariate correlations (2-tailed) were run between the original four predictors and pole vault performance (season personal record). The relationship between 3 pull-ups for time and personal record reveals a statistically significant high, negative correlation ($r = -0.811, p = 0.008$). The moderate relationship between personal record 8 lb MB throw was not statistically significant ($r = 0.640, p = 0.063$). The 3 m seated rope pull test and personal record suggested a low, negative correlation that was not statistically significant ($r = -0.365, p = 0.333$). Correlation between the removed predictor, maximum pull-ups and performance revealed a positive, high relationship that was statistically significant ($r = 0.767, p = 0.016$).

Multiple linear regression was used to assess the ability of the three predictors to predict pole vault performance calculated to predict pole vault performance. A significant regression model was found ($p = 0.024$), with an $R^2$ of 0.83. Participants’ predicted performance was equal to:

$$3.9 + 0.73(\text{Med Ball Toss}) - 0.16(\text{Rope Pull}) - 0.096(\text{Pull-ups for Time})$$
Backwards MB toss was measured in meters, rope pull was measured in seconds, and pull-ups for time was measured in seconds. Medicine ball toss ($p = 0.33$) and seated rope pull ($p = 0.24$) were not significant predictors of performance, but 3 pull-ups for time was a significant predictor ($p = 0.020$).

Using the backward selection procedure for multiple regression, 8 lb backward MB toss was removed first ($r = 0.64$), then 3 m seated rope pull ($r = -0.37$). The last remaining variable was 3 pull-ups for time. The full model that was produced, containing all three predictors, had a higher $R^2$ value ($R^2 = 0.83$), than when removing 8 lb MB toss and 3 m seated rope pull ($R^2 = 0.67$). This indicated that 83% of the variance in personal record was accounted for in the full model. The full model also had the highest adjusted $R^2$ value (adjusted $R^2 = 0.72$) compared to the other models (Table 4). The most important variable was the 3 pull-ups for time shown in the full model ($p = 0.020$). If the model with only pull-ups for time was selected, the variance accounting for performance would have been reduced by 17%. Multiple regression analysis using the backward procedure indicated a significant linear relationship between the field tests and pole vault performance. Thus, the first null hypothesis was rejected. These results should be interpreted with caution as the value of $R$ may be overestimated due to the small sample size (Osborne, 2000).
Table 4.

*Backward Method Multiple Regression*

<table>
<thead>
<tr>
<th>Model</th>
<th>$R$</th>
<th>$R^2$</th>
<th>Adjusted $R^2$</th>
<th>SEE</th>
<th>$F$</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>0.81</td>
<td>0.72</td>
<td>0.14</td>
<td>7.9</td>
<td>.024$^b$</td>
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<tr>
<td>2</td>
<td>0.89</td>
<td>0.79</td>
<td>0.72</td>
<td>0.15</td>
<td>11.1</td>
<td>.010$^c$</td>
</tr>
<tr>
<td>3</td>
<td>0.81</td>
<td>0.66</td>
<td>0.61</td>
<td>0.17</td>
<td>13.5</td>
<td>.008$^d$</td>
</tr>
</tbody>
</table>

*Note: SEE = Standard Error of the Estimate*

a. Dependent Variable: Personal Record  
b. Predictors: (Constant), 8 kg MB Throw, 3 m Seated Rope Pull, 3 Pull-ups for Time  
c. Predictors: (Constant), 3 m Seated Rope Pull, 3 Pull-ups for Time  
d. Predictors: (Constant), 3 Pull-ups for Time

**Test Battery**

Due to the number of predictors relative to sample size, the test battery composed of the three remaining tests was correlated to performance. Linear regression analysis was used to determine if there was a relationship between the battery of tests and pole vault performance. First, the scores were standardized to $z$-scores. The $z$-scores of the variables that were timed (seated rope pull and 3 pull-ups for time) were multiplied by -1 because a greater score is a lower number for timed tests. All three $z$-scores were then summed for each participant. The combined $z$-score represents the total score from all three tests. Pearson correlation analysis revealed a high, positive relationship between the combined $z$-scores and pole vault performance that was statistically significant ($r = 0.848, p = 0.004$).

Linear regression analysis was used to predict pole vault performance based on the composite score for the test battery including the 8 lb backward MB throw, 3 m seated rope pull, and three pull-ups for time. A significant regression model was found ($p = 0.004$), with an $R^2$ of 0.72. Participants’ predicted performance was equal to:

$$3.5 + 0.31(\text{combined } z\text{-score}).$$
The battery of tests was found to be a significant predictor of performance; therefore, the null hypothesis was rejected.

**Effect Size and Power**

The post-hoc effect size ($R$) for the full model is 0.909, while the effect size for the battery of tests was 0.848. According to Cohen (1988), these values indicate a large effect size ($ES > 0.8$). The effect size indicates the strength of the relationship (Durlak, 2009).

A post hoc power analysis revealed that the power for the full model ($\beta = 0.96$), that included the three individual variables, was greater than using only the one predictor variable ($\beta = 0.94$), 3 pull-ups for time. Post hoc power analysis showed that the test battery had the largest value of all ($\beta = 0.98$).

**Summary**

Results from this study indicate that the performance on the individual tests are strongly associated with pole vault performance in collegiate female pole vaulters. Furthermore, the test battery was found to be a significant predictor of pole vault performance. The following chapter will discuss conclusions drawn from these results.
Chapter 5
Discussion

Introduction

The objective of this study was to determine if select upper-extremity strength and power field tests were predictive of pole vault performance in female collegiate pole vaulters. The literature search revealed a lack of research on predictors for pole vault performance in this population. This research sought to determine if there was a significant linear relationship between select upper-extremity strength and power tests, or the testing battery as a whole, and the athletes’ current season personal records. This chapter will interpret the results from statistical analyses used to assess the data, relate findings with previous literature, and discuss limitations and recommendations for future research.

Individual Tests

The results of this study indicated that the 8 lb backward MB throw was moderately associated ($r = 0.640$, $p = 0.063$) with pole vault performance. The 8 lb backward MB throw test was replicated from the previous studies by Kochanowicz and Klimczyk (2011, 2012). The movement in this test is not a perfect reproduction of the pole vault movement which could be why the relationship was not as high as other predictors. When three pull-ups for time, backward MB throw, and seated rope pull were entered into a regression analysis independently, the $R^2$ change was 0.106 indicating that the variance in pole vault performance would be decreased by 10.6% if the 8 lb backwards MB throw predictor was not included. Palmer and O’Connell (2009) emphasize the importance of the model that is chosen to result in the highest value for $R^2$,
the coefficient of determination. Additionally, the results indicate that the backward MB throw was not a significant predictor \((p = 0.334)\) in the full model. These results might be due to chance or due to having a small sample size \((n = 9)\). O’Keefe (2007) suggests that the power would increase if the sample size was increased. The increased variance accounted for by including this variable in the model is worth keeping in even if the significance is not \(p < 0.05\). Furthermore, the full model also has a higher power than the model with only one predictor remaining, 3 pull-up for time. Faul, Erdfelder, Lang, and Buchner (2007) explain that the post hoc power analysis allows researchers to understand the probability of the null hypothesis being rejected. These results should be interpreted with caution as the value of \(R\) may be overestimated due to the small sample size (Osborne, 2000).

The 3 m seated rope pull test was modified from the rope climb test used in previous studies (Kochanowicz & Klimczyk, 2011; Kochanowicz & Klimczyk, 2012) to accommodate for sex differences in strength (Ryman Augustsson et al., 2009). This modified test demonstrated a weak and non-significant association with performance. When 3 pull-ups for time, backward MB throw, and seated rope pull were entered into a regression analysis independently, the \(R^2\) change was 0.063 indicating that the variance in pole vault performance would be decreased by 6.3\% if the predictor was not included. The results indicate that the seated rope pull was not a significant predictor \((p = 0.237)\) when all three variables are included in the model. Similar to the backward MB throw, the increase in variance by including this variable is worth keeping in even if the significance is not \(p < 0.05\). As mentioned previously, the power is also greater in the full model. The power would increase if the sample size was increased (O’Keefe, 2007).
The predictor variable, 3 pull-ups for time, demonstrated the highest correlation ($r = -0.811$, $p = 0.008$) to pole vault performance (season personal record). These results are in agreement with previous research that reported a high correlation between this test and pole vault performance in male pole vaulters (Kochanowicz & Klimczyk, 2012). The motion of the pull-up performed as fast as possible is more representative of what pole vault athletes perform during a pole vault jump compared to maximum pull-ups. The results indicate that 3 pull-ups for time was is a significant predictor ($p = 0.02$) with all three predictor variables entered. The difference in the variance when keeping only three pull-ups for time in the model ($R^2 = 0.658$) and using the full model ($R^2 = 0.826$) is 17%.

In the present study, the maximal pull-up test demonstrated a high relationship ($r = -0.811$) with the 3 pull-ups for time test. Nonetheless, due to multicollinearity, this test was removed from the prediction equation. This test demonstrated the most dispersion in the data ($M = 10$, $SD = 5.9$).

**Test Battery**

The regression model including the test battery as one predictor show that there was a statistically significant ($p = 0.004$) relationship to pole vault performance. Because all three predictors were kept in the previous regression analysis, using the battery of tests as one predictor variable does not explain as much of the variance between pole vault performance and the tests ($R^2 = 0.718$) as each test as a the individual tests being used as predictor variables ($R^2 = 0.826$). The test battery did not have as high of $R^2$ value as the full model with each being entered. However, the results from the post hoc power analysis were larger for the test battery ($\beta = 0.98$) than the full model ($\beta = 0.96$). The power determines the probability of getting the correct conclusion (Murphy, Myors, and
Wolach, 2014). Because the power is high, confidence in the result is also high given the large effect size, sample size, and number of predictors.

**Practical Significance**

To date, no studies seeking to identify predictors of performance have used a female sample. Previous research comparing field tests to pole vault performance used 12-17 and 15-16 year-old males (Kochanowicz & Klimczyk, 2011 & Kochanowicz & Klimczyk, 2012). The results of the current study can be generalized to female collegiate pole vaulters which can have an effect on performance, strength and conditioning programming, and talent identification.

The regression model including all three predictors demonstrated a significant \((p = 0.024)\) ability to predict pole vault performance. Removing the backward MB throw and seated rope pull from the regression equation, resulted in a 17% reduction in the variance in vault performance. Statistical power, post hoc, was also higher \((\beta = 0.96)\) than the model with only one predictor \((\beta = 0.94)\).

The regression model including the test battery as one predictor show that there was a statistically significant \((p = 0.004)\) relationship to pole vault performance. The test battery does not explain as much of the variance between pole vault performance and the tests \((R^2 = 0.718)\) as each test as the individual tests \((R^2 = 0.826)\). The test battery did not have as high of \(R^2\) value as the full model with each being entered. What did result was a higher power for the test battery \((\beta = 0.98)\).

Strength and conditioning programs could benefit from the results of this study and help to improve performance in female collegiate pole vaulters. Pull-ups have a strong association with pole vault performance (maximum pull-ups: \(r = 0.767, p = 0.016;\)
pull ups for time: $r = 0.811, p = 0.008$). Previous literature has also found that one of the best indicators of pole vault performance included a timed pull-up test (Kochanowicz & Klimczyk, 2011 & Kochanowicz & Klimczyk, 2012). Training programs should include both pull-ups for time as well as maximum pull-up repetitions. Coaches and athletes, alike, can apply this information to their training. Balmer, Pleasence and Nevill, (2012) have identified trends in performance for pole vault in males from 1948 to 2008. Trends have begun to plateau so more emphasis has been placed on training programming. The results from this study suggest the importance of strength and conditioning coaches implementing these upper-extremity tests into training programs.

The results from this study are also useful for coaches for talent identification purposes. In male elite pole vaulters, maximum performances are achieved by age 25 (Tilinger et al., 2005). Identifying upper-extremity strengths in athletes earlier in their career could assist to maximize performances in athletes. According to Henson and Turner (2000) nations must improve talent selection programs to become more competitive as performances in track and field have continued to improve over time. Results from this study indicate that coaches could identify talent using these upper-extremity tests that assess strength and power.

The results of this study can only be applied to female collegiate pole vaulters. This research, however, may help to provide some evidence to spark further research for pole vault athletes and coaches since female pole vault is an Olympic sport and no research has been conducted on female athletes in regards to upper-extremity predictors of performance.
Limitations

There were several limitations to this study that need to be identified. The first is that the participation rate was lower than expected. Seven universities in the Pacific Northwest area were contacted only three responded and gave permission to use their athletes. After gaining permission from these three coaches, only two schools’ athletes were tested. Athletes from Whitworth University were not included because the distance was deemed too great to drive for testing. This was an unforeseen limitation prior to testing. In an attempt to increase sample size, the researcher visited Whitworth University to examine their fieldhouse for possible testing administration at Whitworth. The researcher felt that leaving the Whitworth athletes out of the study was better than testing the athletes and losing standardization of the tests due to different equipment being used at a different location. This study had adequate power, however if the sample size were increased, the relationship would be expected to remain and the predictor variables would gain significance (O’Keefe, 2007). A way to increase sample size would be to make all tests portable which would enable researchers to travel to the universities.

Research has identified the average years of training of elite male pole vaulters \( n = 20 \) to be 10.5 years at an average age of 25 before reaching maximal performances (Tilinger, Kovár, & Hlavatá, 2005). The previous research suggested that training age has an impact on performance in males; therefore, this may have limited the female athletes’ performance of both the field tests and in pole vault in this study. Some participants were first year college athletes and some were fourth year college athletes. The amount of specialized training that the younger pole vaulters would have gotten to receive would be less than other participants. In male elite pole vaulters, performance between ages 18 to
22 increased by 13.84% (Tilinger, Kovár, & Hlavatá, 2005). The previously stated ages is the range of the participants in the current study.

The third limitation that could not be controlled was the difference in experiences between participants that included coaching opportunities. Both technical and strength and conditioning coaching would differ between colleges as the participants were not on the same training program. Additionally, all participants would experience an adjustment from high school athletics. Bemiller, Hull, & Hardin (2007) mention that a college athlete may have difficulty in his or her college pole vault career due to detrimental habits that were ingrained from previous coaches before college. Performance may not improve due to inconsistency in coaching methods. This inconsistency is shown in a case study on an elite male pole vault athlete between college and his professional career (Bemiller, 2007). Also, a Division I university will have more resources than a community college. Even Division I athletic programs will have funding inequity between them (Dunn, 2013). Funding inequity can lead to differences in facilities, scholarships, quality of coaches, advisors, and recruiters (Dunn, 2013). The previously stated factors may have an influence on performance and account for differences between the two colleges.

The fourth limitation is the time within the season that the testing took place. Testing took place during the end of indoor season in February. Research indicates that there are venue-related factors that can affect performance in elite male track athletes, indoor versus outdoor (Hollings, Hopkins, & Hume, 2012). Peaking occurs around the most important competition of the year (National Championships) which is during outdoor season at the end of May for collegiate track and field athletes. Differences in venue as well as conditioning may have limited the results of this study.
Future Research

There are a variety of ways this research can be improved upon and used. First, since the participation rate was smaller than anticipated, increasing the sample size will be a sure way to increase power. O’Keefe (2007) mentions that the power would increase if the sample size was increased.

The second way to improve upon this research would be to potentially add more weight to the rope pull test. Another option would be to change the test to one all-out pull because the pole vault motion is one all-out effort. A recurring issue that occurred during testing was that participants often would miss grasping onto the rope as they alternated their hands on the rope pull test. The participants mentioned that the sled moved too fast to grasp with their hands. Cormie, McCaulley, Triplett, & McBride (2007) tested one-repetition maximums for a power clean (1RM) and found that 80% of the 1RM was the optimal load for producing peak power. The power clean is a lower-extremity exercise, but could be enough to suggest increasing weight for the rope-pull test.

Third, future research should standardize the years of pole vault experience. Specifically at Eastern Washington University there are more scholarships to give for female track athletes, so athletes may come to Eastern on a scholarship for another event as their primary event and start to learn to pole vault. Starting to learn from more educated coaches initially may help the athlete to improve more and achieve higher performances than colleges that do not have as experienced of a coach. Bemiller and colleagues (2007) indicate that proper progression is critical for an athlete to eventually achieve maximal performances. According to these researchers, learning proper habits early on can help to prevent years of correcting old habits.
Lastly, test the athletes at peak of their conditioning, around the time of the most important competition. The testing would produce different results when performed when the athletes are at their peak of conditioning. Tapering is designed to unload athletes to allow them to achieve maximal performances around the most important competition of the season (Pyne, Mujika, & Reilly, 2009). Testing results would most likely improve as well as season personal records at that time. Often this is when coaches don’t want their athletes doing anything beyond the scheduled workouts as evidenced by the coach from Eastern Washington University asking to test the athletes after the indoor conference competition was over. Testing later in the year would also give opportunity for athletes to improve their season personal record.

Conclusion

Research has only identified upper-extremity strength and power field tests males that correlate with pole vault performance in adolescent males. This study is the first to seek to identify predictors of performance in female collegiate athletes. The results of this study indicate that there is a significant relationship between tests for upper-extremity strength and power and pole vault performance. The model that included the 8 lb backward MB throw, 3 m seated rope pull, and 3 pull-ups for time, revealed a prediction equation that can predict performance. The results of this study can only be applied to female collegiate pole vault athletes, but the results may help to provide evidence to inspire further research for female pole vault athletes and their coaches. Pole vault is an Olympic sport; therefore, there is a need for more research to determine ways in which female athletes can reach peak performance.
APPENDIX

Informed Consent Form
Upper Extremity Strength and Power Field Tests as Predictors of Pole Vault Performance in Female Collegiate Athletes

Principle Investigator
Carmen Schluter
207 Physical Education Building
Cheney, WA 99004
541-350-3928
cschluter1@ewu.edu

Responsible Project Investigator
Christi Brewer Ph.D
Physical Education, Health & Rec Dept.
200 Physical Education Bldg.
Cheney, WA 99004

Purpose and Benefits
You are being invited to participate in a research study that will look at select upper extremity strength and power tests to determine if there is a relationship to pole vault performance in female athletes. The sport of women’s pole vault is relatively new, as women were allowed to compete in the Olympic Games for the first time in 2000. Most research has been conducted on only male pole vaulters. There are currently no standard field test to predict performance in female pole vaulters. The purposes of this study are (1) to determine if select upper body strength and power field tests predict pole vault performance in female pole vaulters and (2) satisfy requirements for the principle investigator, Carmen Schluter, Master’s degree in Exercise Science. Determining the upper-extremity predictors of performance could in turn influence sports training programming and therefore success amongst female pole vaulters.

Procedures
To be eligible to participate in this study you must be between the ages of 17-25 and must be either a high school senior, or on a competitive collegiate track and field team. Participants must report no injuries or pain that limits their ability to maximally perform the following tests. To participate, you must be able to complete three full pull ups.

1. After consent is obtained, the primary investigator will explain each test as well as ask your age, year in school, training age (how long you have been training), and will have you stand on a scale to obtain your body mass so we can determine load for the rope pull exercise.

2. In total, the time required will be 35 minutes. Ten minute general warm up, three trials of backward 8 lb medicine ball throw with three minutes rest in between each trial, three trials of three meter seated rope pull with three minutes rest between each trial, three pull ups for time with three minutes rest, and maximum pull ups.
Risk, Stress or Discomfort

Risk is minimal; however, with any physical activity or test there is a potential for injury. The primary researcher will provide instruction before and throughout the tests to minimize injury. During and after testing you may experience soreness because we will ask you to exert maximal efforts. Soreness is normal and to be expected after testing and may remain a few days following the test. Possible discomfort may arise from having your weight taken and noted for a specific test. Your weight will only be linked to the subject code that is associated with your name and will remain confidential. You will be advised that you may discontinue your participation at any time for any reason.

Inquiries
Any questions about the procedures used in this study are encouraged. If you have any concerns, questions, or would like more information, please contact Carmen Schluter prior to signing the informed consent form. I can be reached at (541) 350-3928; cschluter1@ewu.edu

Other Information
You are requested to not engage in strenuous upper extremity training 24 hours prior to testing. The identity of participants will remain confidential. Participants are free to withdraw at any time without penalty.

Signature of Principle Investigator          Date

Subject Statement
My participation in this study is completely voluntary. I am free to refuse participation and to stop at any point in this study. I understand the study procedures that I will perform and the possible risks that go along with the study. Knowing all of the risks and discomforts, and being allowed to ask questions that have been answered to my satisfaction, I consent to take part in this study. I am not waiting my legal rights by signing this form. I understand I will receive a signed copy of this consent form.

Signature of Participant          Date
References


O'Keefe, D. J. (2007). Post hoc power, observed power, a priori power, retrospective power, prospective power, achieved power: sorting out appropriate uses of statistical power analyses. *Communication Methods and Measures, 1*(4), 291-299.


CURRICULUM VITAE

Carmen Schluter MS Candidate, CSCS, NSCA-CPT, LMP
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NSCS CSCS #201276966
NSCA-CPT #7247877016
WA LMP #MA60242501

EDUCATION

Expected: June 2016
Eastern Washington University, Cheney, Washington
MS in Physical Education - Exercise Science
 Assisting in teaching undergraduate exercise sciences courses
 Emphasis in research and application in Biomechanics
 Application of Exercise Physiology, Psychology, and other periodization principles

September 2011
Oregon State University, Corvallis, Oregon
BS in Exercise and Sport Science
 Exercise testing and prescription
 Aquatic, group fitness, and resistance training program design and direction
 Application of principles in Biomechanics

March 2008
Central Oregon Community College, Bend, Oregon
Associate of General Studies/Massage Therapy
 Massage therapy modality training
 Education in the rules, laws, and ethics for Licensed Massage Therapists
 Hands-on instruction in Anatomy, Physiology, and Kinesiology

TEACHING EXPERIENCE

Jan 2015 – Present
Graduate Assistant
Eastern Washington University, Cheney, WA
Physical Education, Health, and Recreation
WORK EXPERIENCE

September 2014 – March 2016

Graduate Assistant/Personal Training Supervisor
Eastern Washington University

- Oversee and evaluate performance for personal trainers and other fitness center staff
- Develop and implement individual and group personal training programs
- Marketing personal training and fitness center programs and events
- Design, organize, and lead group fitness classes for undergraduate students

August 2011 – Present

Strength and Conditioning Specialist
U-District PT

- Conduct sport-specific testing sessions, design and implement safe and effective strength training and conditioning programs and provide guidance regarding nutrition and injury prevention
- Design, organize, and implement a nutrition and group fitness program for underprivileged families through the non-profit Foundation
- Plan and conduct personal training sessions to meet the individual client’s needs

March 2014 – Present

Head Pole Vault and Assistant Gymnastics Coach
Spokane School District – Joel E. Ferris High School

- Develop and carry out resistance, plyometric, and technical training for high school gymnasts and pole vaulters
- Organize practices and coach in practice and in formal competitions
- Implement psychological principles and adapt coaching styles to meet the needs of each athlete

May 2012 – Dec 2014

Massage Practitioner
Hand to Health Therapeutic Massage

- Assess client’s medical history, symptoms, referral from physician or DC and other relevant information before treatment
- Provide body treatments and therapeutic massage services utilizing various modalities
- Explain method and applicable techniques appropriately to client needs as well as preferences

CERTIFICATIONS AND MEMBERSHIPS

NSCA - Certified Strength and Conditioning Specialist
NSCA - Certified Personal Trainer
National Strength and Conditioning Association - Member
Washington State Licensed Massage Practitioner
YogaFit Level 2 Instructor
TRX Instructor
Zumba Instructor
Adult and Child First Aid/CPR/AED (American Red Cross)

PUBLICATIONS AND PRESENTATIONS

In-Progress:
Master's Thesis: Strength and power field tests as predictors of performance in collegiate female pole vaulters

Oct 2015 Let's Move! - Family Fitness Programs in Schools. SHAPE Washington Conference, Mead, WA

VOLUNTEER SERVICE

2016 Track and Field Coach/Intern
Eastern Washington University, Cheney, WA

2015 Kids Yoga Instructor
Girl Scouts, Spokane WA

2011 Strength and Conditioning Intern
U-District PT, Spokane, WA

2005 Pole Vault Coach
Mountain View High School, Bend, OR
AREAS OF RESEARCH INTEREST

Biomechanics and pole vault and gymnastics
Strength and conditioning and pole vault
Servant Leadership in athletics
Empowering leadership
Nutrition in athletics
Female coaches and athletes’ perceptions of competence

CLASSES TAUGHT

PHED 335  Strength and Conditioning Pro-Lab
            Classroom Instruction
            Online Instruction
            Lab

PHED 352  Mechanical Kinesiology
            Classroom Instruction
            Online Instruction
            Lab

HLED 372  Applied Nutrition and Physical Fitness
            Classroom Instruction

PHED 350  Physiological Kinesiology
            Lab

PHED 150  Fast Fitness
            Facilitator

PHED 152  Strength and Conditioning
            Facilitator

PHED 125  Yoga
            Daily Instruction

PHED 125  Zumba
            Daily Instruction

PHED 125  TRX
            Daily Instruction
# Continuing Education Courses

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