

SUNY College Cortland

## Digital Commons @ Cortland

---

Master's Theses

---

5-2018

### Effects of competition variables and prior attempts on approach run velocity during a pole vaulter's final clearance

Nathaniel S. Ashton

Follow this and additional works at: <https://digitalcommons.cortland.edu/theses>



Part of the [Biomechanics Commons](#), [Exercise Physiology Commons](#), [Exercise Science Commons](#), [Sports Sciences Commons](#), and the [Sports Studies Commons](#)

---

#### Recommended Citation

Ashton, Nathaniel S., "Effects of competition variables and prior attempts on approach run velocity during a pole vaulter's final clearance" (2018). *Master's Theses*. 43.  
<https://digitalcommons.cortland.edu/theses/43>

This Open Access Thesis is brought to you for free and open access by Digital Commons @ Cortland. It has been accepted for inclusion in Master's Theses by an authorized administrator of Digital Commons @ Cortland. For more information, please contact [DigitalCommonsSubmissions@cortland.edu](mailto:DigitalCommonsSubmissions@cortland.edu).

Effects of Competition Variables and Prior Attempts on  
Approach Run Velocity during a Pole Vaulter's Final Clearance

by

Nathaniel S. Ashton

Submitted in Partial Fulfillment of the  
Requirements for the Master of Science in Exercise Science Degree


Kinesiology Department

STATE UNIVERSITY OF NEW YORK COLLEGE AT CORTLAND


May 2018

Approved:

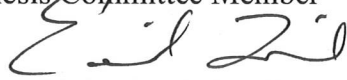
5/1/2018  
Date

  
Peter M. McGinnis, Ph.D.  
Thesis Advisor


4-27-18  
Date

  
Kevin Dames, Ph.D.  
Thesis Committee Member

4-27-18  
Date

  
Erik Lind, Ph.D.  
Thesis Committee Member

5-10-18  
Date

  
Eileen Gravani, Ph.D.  
Associate Dean, School of Professional Studies



## ABSTRACT

Approach run velocity of a vaulter is strongly correlated to the highest height a vaulter clears in pole vault competition and the number of attempts taken throughout a competition influences pole vault strategy. Since approach run velocity greatly affects the crossbar height cleared and number of attempts affects time spent in the competition, perhaps a better approach to determine optimal competition strategy is to first identify how competition variables influence approach run velocity. The purpose of this study was to determine if the approach run velocity during a pole vaulter's last clearance can be predicted by: (1) the number of previous attempts by the vaulter in the competition, (2) the range of approach run velocities in the vaulter's previous attempts, and/or (3) the time elapsed from the vaulter's first attempt to the vaulter's final clearance. It was hypothesized that the total number of attempts, range of approach run velocity, and total time elapsed from first attempt to final clearance can adequately predict approach run velocity for a pole vaulter's final clearance. Number of attempts was the lone statistically significant variable for predicting the Z-score of final clearance velocity. The prediction equation for the Z-score of the final clearance velocity using number of attempts is:  $V_{\text{clearance}} = 0.124 (\text{Attempts}) - 0.676$ . A second prediction equation formulated from the Z-score final clearance equation can predict real clearance velocities (m/s). The prediction equation for real clearance velocity is:  $V_{\text{predicted}} = [0.124 (\text{SD})](\text{Attempts}) - 0.676(\text{SD}) + V_{\text{Ravg}}$ . However, number of attempts only explains a very small percentage of variance in final clearance approach run velocity (6.3%). National caliber coaches and athletes may use the formulated Z-score prediction equation and/or real velocity prediction equation to estimate approach run velocity and make decisions regarding competition strategies to maximize performance.

## ACKNOWLEDGEMENTS

I would like to thank the SUNY Cortland Kinesiology staff members for giving me guidance and providing me the opportunity to learn and grow throughout my Bachelor's degree and while pursuing my Master's degree. I would like to thank my committee members, Dr. Peter McGinnis, Dr. Kevin Dames, and Dr. Eric Lind. I would like to thank my mentor Dr. Peter McGinnis for giving me an opportunity to work along-side him with USA Track & Field pole vault and giving me extensive opportunities to learn as much as possible from him. I would especially like to thank Dr. Eileen Gravani for giving me guidance and advice through a tough freshman year where I may not have stayed in school, without you, this would have never been possible. Lastly, I owe many thanks to my family, friends, and fellow exercise science professionals who have all supported me through this journey and have always pushed me to the best version of myself.

## TABLE OF CONTENTS

ABSTRACT .....	iii
ACKNOWLEDGEMENTS .....	iv
TABLE OF CONTENTS .....	v
LIST OF TABLES AND FIGURES .....	vii
CHAPTER 1 INTRODUCTION .....	1
Statement of the Problem .....	2
Purpose of the Study .....	3
Hypothesis .....	3
Limitations .....	3
Delimitations .....	4
Assumptions .....	5
Definition of Terms .....	5
Significance of the Study .....	6
CHAPTER 2 LITERATURE REVIEW .....	8
Rules and Regulations .....	8
Strategy .....	10
Approach Run Velocity .....	12
Physiological Effects of Repeated Sprints .....	14
Summary .....	18
CHAPTER 3 RESEARCH BRIEF .....	19
Introduction .....	19
Methods .....	19

Results .....23

Discussion and Recommendations.....28

Conclusion.....33

REFERENCES.....34

APPENDIX Institutional Review Board Approval Letter .....37

## LIST OF TABLES AND FIGURES

## TABLES

1. Combined Descriptive Statistics for Men and Women .....	23
2. Descriptive Statistics for Men .....	23
3. Descriptive Statistics for Women .....	24
4. Model Summary of Multiple Regression Analysis .....	24
5. ANOVA of Multiple Regression Analysis .....	25
6. Regression Equation Coefficients .....	25

## FIGURES

1. Pole Vault Set-up with Approach Run Velocity Measurement Lines .....	21
2. Athlete Screenshot Showing Velocity Measurement Technique .....	22
3. Z-score Clearance Velocity Versus Number of Attempts Scatterplot .....	26
4. Z-score Predicted Clearance Velocity Versus Residual Scatterplot .....	27
5. Residual Histogram .....	27
6. Men Frequency of Peak Velocities .....	30
7. Women Frequency of Peak Velocities .....	30
8. Combined Frequency of Peak Velocities .....	31



## CHAPTER 1

### INTRODUCTION

Pole vaulting is one of four jumping events in the sport of track and field. The objective of the event is to use a pole to vault over a crossbar, with the winner determined by who achieves the highest vault. To achieve this objective, vaulters use an approach run to first develop kinetic energy which is then secondly transferred during the vault to strain energy in the flexible pole and finally to potential energy of the vaulter. The approach run velocity of a vaulter has been shown to be strongly correlated to the highest height a vaulter clears in pole vault competition (McGinnis, 2004).

Pole vault competitors jump at progressively higher crossbar heights during a competition. Prior to the competition, the starting crossbar height and incremental increases in crossbar height are determined. The order in which the vaulters compete is also predetermined. Each vaulter then has the opportunity to vault at the starting height. After one round, any vaulter who missed an attempt may make a second attempt. If any vaulters miss a second attempt, a third round is offered and those who missed a second attempt may try a third attempt to clear the height. A vaulter missing three attempts in a row is eliminated from the competition. A vaulter may choose to pass the first, second, or third attempt. Once there is a pass of an attempt at a height, the next attempt will have to be at a higher crossbar height. After the third round of attempts or after all vaulters have cleared a height, the crossbar is raised to the next height. The competition progresses until all the vaulters have been eliminated from the competition. The winner is the vaulter who cleared the highest height. If more than one vaulter cleared the highest height, the winner is the person who took the fewest number of attempts at the winning height. If a tie still remains, then the

winner is the vaulter who had the fewest total misses in the competition. If a tie still remains, there is a jump off to determine the winner at championship competitions. USA Track & Field (USATF) and National Collegiate Athletic Association (NCAA) rule books describe the procedures for a jump off.

The nature of a pole vault competition means that a pole vaulter has little control over how many vaults he or she makes in a competition or when these vaults must occur. However, vaulters can control when they enter a competition by passing attempts at lower heights. They can also increase the time they have between vaults by passing attempts, but at higher heights a passed attempt may put them at a disadvantage, as higher heights are more challenging and a vaulter's physical or mental readiness to vault may be adversely affected if the break between jumps is too long. Ladany (1975) and Hersh and Ladany (1989) tried to determine the optimal strategy a vaulter should employ to maximize performance. Their linear models were based on number of attempts and determined that a vaulter's optimal range of clearance ability extended from the vaulter's starting competition height up to five raises of the bar (Ladany, 1975; Hersh & Ladany, 1989). From these findings a vaulter would be able to calculate what the best starting height should be relative to the vaulter's personal best vault height. Since approach run velocity greatly affects the crossbar height cleared, perhaps a better approach to determine optimal competition strategy is to first identify how competition variables affect approach run velocity.

### **Statement of the Problem**

A pole vaulter must consistently produce a fast approach run velocity during each vault in a competition to be successful. Does the number of previous attempts by a vaulter affect the magnitude of the approach run velocity during the vaulter's final clearance? How

does a vaulter's approach run velocity vary during a competition and does this variation influence the magnitude of the approach run velocity during the vaulter's final clearance? Does the duration of the competition effect the magnitude of the approach run velocity during a vaulter's final clearance?

### **Purpose of the Study**

The purpose of the study was to determine if the approach run velocity during a pole vaulter's last clearance could be predicted by: (1) the number of previous attempts by the vaulter in the competition, (2) the range of approach run velocities in the vaulter's previous attempts, and/or (3) the time elapsed from the vaulter's first attempt to the vaulter's final clearance.

### **Hypothesis**

It was hypothesized that the total number of attempts, range of approach run velocity, and total time elapsed from first attempt to final clearance can adequately predict approach run velocity for a pole vaulter's final clearance.

### **Limitations**

Data from USA Track & Field's database of pole vault approach run velocities were used in this study. This database includes measures of average approach run velocity over the 5 m interval from 10 m to 5 m from the back of the pole vault box for men and from 9 m to 4 m from the back of the box for women. Although the database includes data from competitions as early as 1986, the database only includes time data for competitions between 2009 to 2017. The database includes the time of day for each vault attempt and these time data are only accurate to the nearest minute. The total time elapsed from first attempt to last clearance for a vaulter is thus only accurate to the nearest minute.

The database does not include peak height reached by the center of gravity (COG) of each athlete. An athlete may have had a peak COG height well above the set crossbar height but only the highest crossbar height cleared by each athlete was considered in this study. The highest cross bar height cleared by a vaulter is greatly dependent on approach run velocity, technique, and set progression of crossbar height.

### **Delimitations**

The subjects for the study were elite male and female pole vaulters who had competed in at least one of the following competitions: U.S. Olympic Trials in 2012 or 2016, or the USA Track & Field Outdoor Championships between 2009 and 2017. To be included in this study, vaulters must have attempted at least two vaults prior to a final clearance. If vaulters had run through attempts, where they did not attempt a vault, these attempts were excluded from analysis. If any of the vaulters met these qualifications in more than one of these competitions, the competition where the competitor vaulted the highest was selected for inclusion in the study. The vaulters in these competitions were the best U.S. vaulters at the time of the competition and they were competing at a national caliber level.

The researcher decided to look at total number of jump attempts in a competition, range of approach run velocity, and total time elapsed from first jump attempt to final clearance as predictors of approach run velocity. It was assumed that these were relevant performance variables that a coach or athlete could monitor in real-time to make decisions regarding performance strategy. The researcher chose to examine the velocity data from the final 5 meters before take-off in a jump approach. Due to the national caliber of vaulters used, the data may not be relevant to non-national caliber vaulters.

## Assumptions

The following assumptions were made:

- a. The velocity measurements in the database were accurate.
- b. The video time records were accurate to the nearest whole minute.
- c. All athletes were motivated equally in attempting to jump to their best ability.
- d. All athletes were in their best physical conditioning during the competition of their best jump.

## Definition of Terms

<i>Approach Run Velocity</i>	The average velocity for the last 5 m of a pole vaulter's approach run. In this study, the last 5 m was of the approach run was 10 - 5 m from the back of the pole vault box for men and 9 - 4 m from the back of the pole vault box for women. Approach run velocity was calculated by dividing 5 m by the time it took the vaulter to run the 5 m.
<i>Crossbar</i>	A 30 mm diameter cylindrical bar that is placed upon the uprights at a set height for competitors to vault over. Vaulting over the bar without knocking it down is a successful attempt.
<i>Crossbar Height</i>	The vertical distance from the horizontal plane of the runway to the lowest point on the top of the crossbar.
<i>Grip Height</i>	The distance from the top of the uppermost hand placement on the pole to the bottom of the pole.
<i>Opening Height</i>	The height at which a vaulter enters the competition.
<i>Pole Vault Pole</i>	A pole made of out of fiberglass or other composite materials. Poles vary in length and stiffness characteristics. Most national caliber men use 5 m poles or longer and national caliber women use 4.3 m poles or longer.

<i>Pole Vault Box</i>	A sloped trough, at the end of the runway into which the athlete places the end of their pole. This box acts as the point of rotation for the athlete as they jump off the ground.
<i>Run Through</i>	A run through is any trial in which the athlete runs past the box without an attempt to clear the crossbar and does not vault.
<i>Runway</i>	The length of track that leads to the vaulting area. It has a width of 1.22 m and a minimum length of 40 m. It is usually made out of rubberized asphalt or synthetic material (NCAA, 2017; USATF, 2017).
<i>Starting Height</i>	The first (lowest) height where vaulters may begin jumping during competition. This height is agreed upon by the rules committee or meet officials before the start of competition (NCAA, 2017; USATF, 2017).
<i>Uprights/Standards</i>	Structures that hold the crossbar in place. They may be moved by the vaulter anywhere between 45 cm to 80 cm behind the vertical plane through the top of the back of the box (i.e., toward the landing pit) (NCAA, 2017; USATF, 2017).

### **Significance of the Study**

To the researcher's knowledge, this is the first study of its kind to investigate the effects of pole vault competition variables on approach run velocity. There are numerous variables to consider when developing a pole vault strategy. This study may provide helpful information to pole vaulters and their coaches regarding the effects of number of previous attempts, range of approach run velocity in previous attempts, and time elapsed from first attempt to last clearance on approach run velocity of a vaulter's final clearance. In turn, this information may help national caliber coaches and/or athletes determine opening height, pole selection, grip height, standard setting, and whether or not to pass an attempt during a pole vault competition. Pole selection, grip height, and standard settings are influenced by

approach run velocity. For example, if an athlete is running slower the athlete may choose a shorter pole, a less stiff pole, a lower grip height, a standard setting closer to the runway, or any combination of these choices. If an athlete is running faster they may use a longer pole, a stiffer pole, a higher grip, a standard setting closer to the pit, or any combination of these choices (Rogers, 2000).

## CHAPTER 2

### LITERATURE REVIEW

The purpose of this study was to determine if the approach run velocity during a vaulter's last clearance can be predicted by relevant competition variables. These include the number of previous attempts by the vaulter in the competition, the range of approach run velocities in the vaulter's previous attempts, and the time elapsed from the vaulter's first attempt to the vaulter's final clearance. This literature review includes an overview of the rules for pole vault competitions set forth by the National Collegiate Athletic Association (NCAA) and USA Track & Field (USATF). Review of relevant research that describes the importance of approach run velocity on vaulting performance and strategy is also included. Finally, research regarding the effects of repeated sprint efforts is also reviewed.

#### **Rules and Regulations**

Pole vaulting has advanced in many ways since its inclusion as an Olympic sport in 1896. Vaulting poles have progressed from wood to bamboo to steel and finally to fiberglass or carbon fiber composite poles used by the vaulters in this study. Vaulters now land in foam padded pits instead of sod, sawdust, or sand. The NCAA and USATF have rules and regulations in place for the purpose of safety and fair competition among athletes. All of the athletes included in the present study have competed at a collegiate and/or professional level in the United States. Thus, it is important to have an understanding of the rules and regulations set forth by these governing organizations for the pole vault event.

The NCAA and USATF regulations that pertain to warm-up, height progressions, and time given for jumps are similar. Before the start of a competition, the pole vault runway and pit are open for warm-up jumps by all vaulters for a specific time period. The USATF rules state that all athletes in competition will be given one hour for warm-up, while



the NCAA rules allow the games committee to determine the length of the warm-up period, which is generally one hour and thirty minutes for championship competitions (NCAA, 2017; USATF, 2017). After the start of competition, the NCAA allows a second warmup opportunity for vaulters who have not attempted their opening height after an hour of competition has elapsed. This includes a two-minute period for each competitor, individually, where the runway and pit are open to perform additional warm-up jumps without an official attempt before their opening height attempt. USATF does not allow additional warm-up time in regular USATF competitions.

Pole vault competitions governed by the NCAA and USATF rules have a pre-determined height progression that is set by the meet committee (NCAA, 2017; USATF, 2017). The competition height will increase by increments of 5 cm or more until there is only one vaulter remaining (NCAA, 2017; USATF, 2017).

During a competition, vaulters have time limits for each attempt to prevent long delays. After the crossbar is up the standards are set to the vaulter's requested setting, the NCAA (2017) rules state that once the official calls a vaulter's name, that vaulter has one minute to begin an attempt if there are more than three competitors, two minutes if there are two or three competitors, and five minutes if that vaulter is the only competitor remaining. In contrast, the USATF (2017) rules state that once the official calls a vaulter's name, the vaulter has one minute to begin an attempt when there are more than three competitors, three minutes if there are two or three competitors, and five minutes if the vaulter is the final competitor eligible for an attempt. However, a rule common between the two organizations is that if a vaulter has two attempts in a row, that athlete has three minutes between attempts.

If a vaulter does not initiate an attempt within the time window, the expected attempt will be ruled as a miss (NCAA, 2017; USATF, 2017).

### **Strategy**

The aforementioned rules influence a vaulter's performance strategy for a variety of reasons. For example, a meet's pre-determined height progression may begin at a competitor's personal best vault height. This may not affect certain vaulters who have personal bests well above the starting height. Given this, the question is how can vaulters optimize their pole vault strategy to perform to their best ability? Several researchers have investigated that question.

In 1975, Ladany investigated the optimal starting height for pole vaulting. He developed a model (i.e., regression equation) to predict the height a pole vaulter should clear based on a pre-determined opening height (Ladany, 1975). The subjects for this study were vaulters who jumped at heights of 200 to 340 centimeters (Ladany, 1975). The model used joint probabilities to predict optimal height from any one of three attempts taken at a specific height. At the time of the study, the competition rules stated that after a vaulter entered a competition, the vaulter could attempt the next incrementally increased height only after the vaulter had successfully cleared the previous height within three attempts. Ladany (1975) concluded that the probability of clearing a height decreased as a vaulter's number of attempts increased. His findings suggest that vaulters who attempt heights within five bar raises of their starting height will have the best probability of success. However, rule changes to the sport made this threshold less applicable to modern athletes.

Fourteen years later, Hersh and Ladany (1989) re-examined the optimal strategy for pole vaulting. They returned to Ladany's 1975 prediction after the application of

international rules to all U.S. and international competitions. The rule change allowed vaulters to pass heights after they took their opening height jump instead of having to attempt all heights once they made an initial attempt. Hersh and Ladany (1989) reported that the initial investigation of a probability model performed by Ladany (1975) was validated as a preferable strategy based on old pole vault rules. This subsequent study included the same range of vault heights (200-340 cm) to create a new model that incorporated three attempts into one equation (Hersh & Ladany, 1989). The results showed that the new equation raised the maximal expected height clearance by 1%. However, given the change in competition rules, Hersh and Ladany (1989) stated that there was no possibility of validating the updated model for optimal vaulting strategy (Hersh & Ladany, 1989). A limitation of these two studies is that the participants were not elite vaulters. At the time of Ladany's first investigation (1975), elite men had jumped over 5.60 m, and in 1985, Sergey Bubka had jumped over 6.00 m (IAAF, 2018).

Sullivan, Knowlton, Hetzler, and Woelke (1994) recorded anthropometric measurements (height, weight, percent body fat, calf circumference, and bicep circumference) and best vault height and grip height on the pole for 87 adolescent (13-18 years old) pole vaulters. The vaulting heights for the subjects ranged from 1.98 m to 4.72 m, which were similar to the minimum but higher than the maximum vault heights in the study conducted by Ladany (1975). The results showed that grip height was the strongest predictor of vault success and was significantly correlated to several anthropometric and performance characteristics (Sullivan et al., 1994). The findings suggest that coaches should focus on promoting the highest grip height possible and developing running speed (Sullivan et al.,

1994). The suggestion of developing running speed supports the importance of approach run velocity described by Steinacker (1989).

In 2004, Decker and Bird studied 165 adolescent pole vaulters (13-19 years old). The average personal best for the males was 3.76 m and 2.79 m for the females (Decker & Bird, 2004). The study evaluated how well reported personal best height, 30 m sprint time, ten step long jump distance, and an isometric measure of strength could predict vault height. The last of these predictors required vaulters to hold their body in a straight line at 45 degrees above horizontal with their arms fully extended above their head while gripping a small section of pole. Time, in seconds, was measured while stable at 45 degrees and not pulling with the arms for an isometric measure of strength used to invert on a pole (Decker & Bird, 2004). The results showed that 30 m sprint time and ten step long jump distance accounted for 73% of the variance in vault height achieved in this sample population. This was comparable to previous equations reported by McGinnis (1995, 1997) and Adamczewski and Perl (1997) that used approach run velocities as their single explanatory variable. Decker and Bird (2004) suggested that future studies incorporate elite level vaulters.

### **Approach Run Velocity**

Select published works about pole vault have focused on the importance of approach run velocity. Steinacker (1989) examined approach run velocity for several world-class vaulters, including the aforementioned Sergey Bubka. Run-up velocities had steadily increased for world leading vaulters from 8.80 m/s in 1940 to 9.90 m/s in 1988 (Steinacker, 1989). During this period, the men's pole vault world record increased from 4.60 m to 6.06 m. The increase in both the approach run velocity and world record height appeared to share

a strong relationship. Steinacker (1989) emphasized the importance of developing sprint performance for elite vaulters.

Further investigation of sprint performance came in 1995 when McGinnis formulated a prediction equation that would calculate potential vaulting height from a specific approach run velocity. McGinnis (1995) performed a simple linear regression analysis to predict highest crossbar height cleared from approach run velocity for vaults by 48 elite male vaulters for crossbar heights ranging from 4.80 to 5.97 m. The theoretical limit line was defined as:  $H = 0.519 (V) + 1.06$  m, where H represents the maximum crossbar height a vaulter can theoretically clear given the approach run velocity (V) (McGinnis, 1995). This provided further evidence for the importance of run velocity in achieving high vaults.

Subsequent investigations continued to evaluate elite vaulters in the United States and Germany, respectively. McGinnis (1996, 1997, 2004) and Adamczewski and Perl (1997) used velocities from the final 10 m to 5 m of the approach run before take-off, which was similar to Steinacker (1989). McGinnis (1996, 1997, 2004) used video analysis and Adamczewski and Perl (1997) used timing lights to calculate approach run velocity for competitors, while Steinacker (1989) did not describe the measurement technique, only reported the velocities used. Validation of the approach run velocity measurements over the final 10 m to 5 m interval was investigated by McGinnis in 1991. McGinnis (1991) tested the accuracy of four primary time measurement systems that included a stopwatch, infrared timing light system, commercially available timing system, and video camera recordings. Walking (~2 m/s), jogging (~4 m/s), running (~6 m/s), and sprinting (~9 m/s) speed measurements were tested over six intervals of 2.5 m, 5 m, 7.5 m, 10 m, 12.5 m, and 15 m.

Correlations were computed to test the accuracy of experimental measures to criterion velocity measures. These criterion velocities were computed from temporal and two-dimensional center of gravity locations of the walking or running subject derived from digitized frames from a 200 Hz fixed view video camera over each of the interval distances. The most accurate results were for the 200 Hz panning camera sampling at 200 Hz and 100 Hz. Both sampling rates had a correlation of 1.00 with the criterion. The standard deviations of the velocities measured from the 200 Hz and 100 Hz sampling rates were 0.076 m/s and 0.077 m/s, respectively (McGinnis, 1991).

Adamczewski and Perlt (1997) created prediction equations for 725 male and female vaulters of 16 years old up to elite pole vaulters who competed at the German Championships between 1991 and 1996. They found a consistent linear relationship between pole vault performance and approach run velocity. Approach run velocity explained approximately 65% of the variance in vault height based from prediction equations of  $H = 0.5 (V) + 1.25$  for men and  $H = 0.5 (V) + 0.50$  for women, where H represents vaulting height (m) and V represents run-up velocity (m/s) (Adamczewski & Perlt, 1997). The authors encouraged coaches to use these equations as a reference with their athletes. This work was similar to McGinnis (1995), who suggested that coaches could use the plot to predict the achievable height from a given velocity. Thus, approach run velocity is a critical variable in predicting how high an individual can vault.

### **Physiological Effects of Repeated Sprints**

Research may continue to refine these regression equations for predicting height from approach run velocity as more information is collected on vaulters. Given the importance of approach run velocity, it is important to understand the factors that may

influence that critical measure. Currently, there is a lack of research on how variables throughout a meet, such as elapsed time and number of attempts, affect a vaulter's final clearance approach run velocity. For example, is approach run velocity negatively affected by short recovery periods between vaults?

The human body primarily uses two energy systems during high intensity, short duration exercise (Scott, 2005). These anaerobic pathways resynthesize adenosine triphosphate (ATP) during fast or powerful bursts of exercise without the reliance on oxygen. In contrast, aerobic respiration resynthesizes ATP when an adequate oxygen supply (and time to utilize it) is present, as in longer duration and low intensity exercise (Scott, 2005). Spencer et al. (2005) explained that during high intensity exercise, the available ATP is depleted and phosphocreatine (PCr) is broken down. The free phosphate is used to resynthesize ATP very quickly. Second, glucose is catalyzed to resynthesize ATP via anaerobic glycolysis. This pathway dominates as the energy source in quick bursts of intense exercise beyond the capacity of the PCr pathway. Following the first 6 to 10 seconds of activity, the aerobic system resynthesizes ATP in the mitochondria of muscle cells, from substrates already available in the cell (e.g., glucose, glycogen) or from metabolic byproducts of exercise itself (e.g., lactic acid) (Spencer et al., 2005). Depletion of readily available ATP or reduced re-synthesis of this molecule from one or more of these pathways results in reduced muscular force production. With an approach run in pole vault lasting about 4 to 6 seconds (Steinacker, 1989), vaulters can be classified as power athletes. Therefore, anaerobic pathways (PCr, anaerobic glycolysis) are the primary mechanisms of ATP re-synthesis during the task. However, during the rest periods between jump attempts the aerobic pathway will dominate recovery of the ATP supply.

Recovery between bouts of activity is crucial in power sports. Aguiar, Turnes, Oliveira Cruz, Salvador, and Caputo (2015) studied eight sprinters with an average 100 m personal record of 11.14 seconds. Sprint performance decreased by 9% after the sprinters completed 10 consecutive 35 m maximal sprints with 20 seconds of active jogging recovery. Balsam, Seger, Sjodin, and Ekblom (1992) studied the effects of 120 seconds, 60 seconds, and 30 seconds of standing and/or sitting passive recovery on seven moderately to well-trained male subjects. The test protocol consisted of subjects performing 15 by 40 m repeated maximal sprints on an indoor track (Balsam et al., 1992). Sprinting speed decreased by ~2% with 120 seconds recovery, decreased by ~5% with 60 seconds recovery, and decreased by ~15% with 30 seconds recovery from the first trials to the last, respectively (Balsam et al., 1992). These results support the importance of adequate recovery duration to sustain repeated sprint performance.

Monks, Compton, Yetman, Power, and Button (2017) examined how recovery affected power output during 10-second repeated sprints on a cycle ergometer. Subjects performed 10 repetitions of 10-second sprints with either 30 seconds or 180 seconds of recovery between each sprint. Power output decreased by 12.5% for the 30 seconds recovery when compared to 180 seconds of recovery. Power output decreased by 20% from the first to last sprint for the 30 seconds recovery when compared to 180 seconds of recovery (Monks et al., 2017). Billaut, Giacomoni, and Falgairette (2003) examined a wide range of recovery durations in a manner similar to the previous study. They studied the effects of 15 seconds, 30 seconds, 60 seconds, 120 seconds, and 240 seconds recovery stages on peak power output of four series of two 8-second maximal cycle ergometer efforts for men and women. Peak power output decreased 6.4% and 7.4% for men and women, respectively,



during the 15 second recovery stage. Peak power decreased by roughly 19% and 30% for men and women, respectively, from first to last sprint during 15 seconds and 30 seconds recovery. There was no statistical significance found between 60 seconds, 120 seconds, and 240 seconds of recovery on decrements of peak power output. Billaut et al. (2003) reported that 30 seconds of recovery was needed to maintain peak power during two consecutive 8-second sprints on a cycle ergometer. Billaut et al. (2003) and Billaut and Basset (2007) observed the most commonly used recovery duration following repeated all-out cycling exercise was 30 seconds. A follow up to the Billaut et al. (2003) study was completed in 2007 when Billaut and Basset used various recovery durations after 10 repetitions of 6 seconds of cycle sprinting. They implemented three different recovery patterns between successive repetitions: consistent 30 seconds, increasing from 10 to 50 seconds by increments of 5 seconds, and decreasing from 50 to 10 seconds by increments of 5 seconds. Power output decreased by 10.4% in the increasing recovery group from sprints 2 to 8, decreased by 8.7% in the constant recovery group from sprints 8 to 10, and decreased by 10.3% in the decreasing recovery group from sprints 9 to 10 (Billaut & Basset, 2007). Following sprint 5, none of the recovery conditions returned power output back to baseline. All three recovery patterns were statistically significantly different from one another. Decreasing recovery pattern was most beneficial for sprints 1 to 8 while increasing recovery pattern showed to be the most beneficial pattern during sprints 9 and 10 for power output. Given the influence of recovery time on repeated sprint performances, it is appropriate to assume that the number of attempts and varying recovery times between attempts may affect the pole vault performances of national caliber pole vaulters.

**Summary**

Further refinement of prediction equations in pole vaulting are necessary. This work will address limitations in prior investigations. To date, prediction equations have primarily considered running speed but neglected competition factors that may influence this metric, such as the amount of rest between attempts. It is important to consider additional factors given the above literature that demonstrates number of attempts and amount of rest between attempts of a high intensity activity reduce effectiveness of subsequent bouts. Vaulters should consider these factors when selecting their opening height.

## CHAPTER 3

### RESEARCH BRIEF

#### **Introduction**

Research conducted on pole vaulters has used approach run velocity, anthropometric measurements, and technique factors, independently, as experimental variables for predicting vault height (Decker & Bird, 2004; McGinnis, 1995; Sullivan et al., 1994). Some of these equations were developed using non-elite vaulters as subjects (Decker & Bird, 2004; Ladany, 1975). Existing research has not considered the effects of the number of prior attempts or elapsed time between first attempt and final clearance on approach run velocity. The purpose of this study was to determine if the approach run velocity during the vaulter's last clearance can be predicted by the number of previous attempts by the vaulter in the competition, the range of approach run velocities in the vaulter's previous attempts, and the time elapsed from the vaulter's first attempt to the vaulter's final clearance. No previous study has focused on predicting approach run velocity for the final clearance of national caliber pole vaulters. Therefore, this work broadens the spectrum of variables considered in predicting performance and addresses a population previously not considered.

#### **Methods**

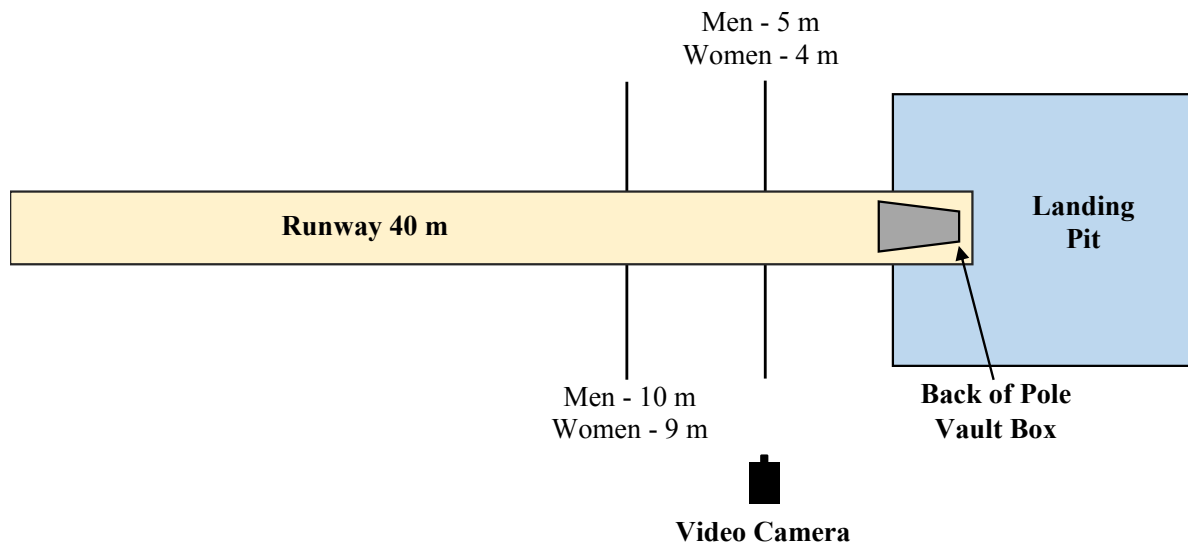
**Participants.** The USA Track & Field database was used to gather information on number of attempts, result (successful or unsuccessful), velocity, and time of attempt(s) for 59 (28 male, 31 female) national caliber pole vaulters. A vaulter was classified as "national caliber" if he or she had qualified for and competed in the competitions selected for use in the study: U.S. Olympic Trials in 2012 or 2016, or the USA Track & Field Outdoor Championships between 2009 and 2017.

The 2017 USA Track & Field Outdoor Championship meet qualifying marks were 5.60 m for men and 4.55 m for women (USATF, 2017). For reference, the world record in the pole vault is 6.16 m for men and 5.06 m for women (IAAF, 2018). Each vaulter included in the analysis completed at least two attempts prior to their final clearance attempt, during one of the above competitions.

**Design and procedures.** Data analyzed in this study came from USA Track & Field's database. This database includes measures of average approach run velocities over the 5 m interval from 10 m to 5 m from the back of the pole vault box for men and from 9 m to 4 m from the back of the box for women. Inclusion parameters eliminated some subjects from consideration. In order to be considered for analysis in the study, subjects had to have attempted at least three jumps, including at least one clearance, in at least one of the above competitions. The database was scanned over a nine-year period (2009-2017) to compile results of vaulters who fit these criteria. If a vaulter appeared in more than one of the above competitions in the nine-year period, data for their best performance (i.e., highest height cleared) were analyzed and all other data were removed.

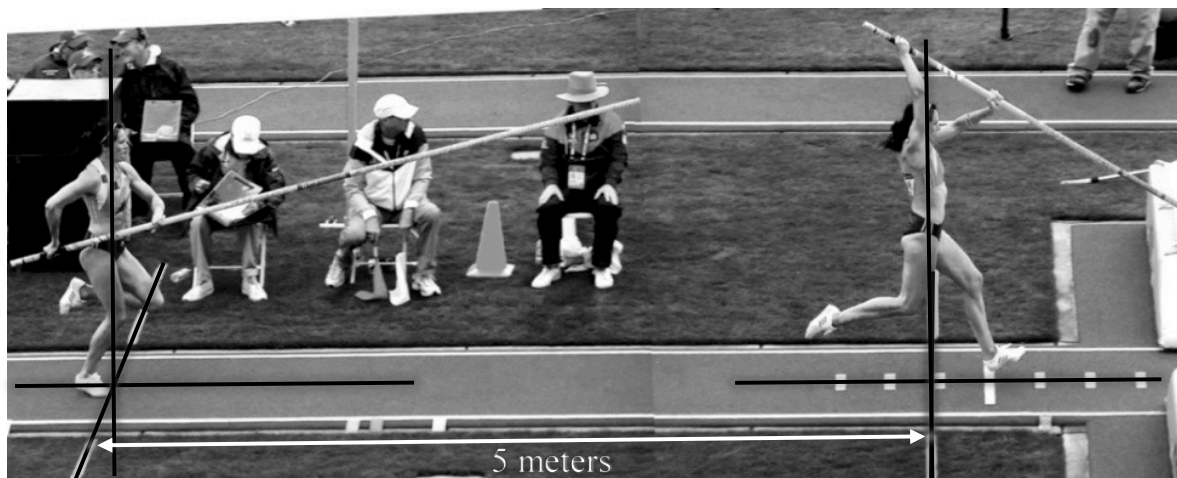
For each vault, the information recorded included the attempt number, result (successful or unsuccessful), approach run velocity, and time of attempt. The number of attempts along with the result of each attempt were recorded in live time of the event by a member of USA Track & Field's sport science services. The time used was determined by analyzing video of each attempt. The videos were recorded at 299.7 frames per second by a tripod mounted panned video camera set various distances and heights to the right or left of the runway in a position such that its optical axis was perpendicular to the runway somewhere between 5 and 15 m from the back of the pole vault box. The video camera was

panned to follow the vaulter during the runup through bar clearance. Figure 1 shows the placement of the last 5 m interval markings perpendicular to the runway.



*Figure 1.* Diagram featuring the pole vault runway, pole vault box, and landing pit. Perpendicular line to the runway are approach run velocity measurement markers from the back of the pole vault box.

To find the vaulter's 5 m run time, the times at which the athlete reached the initial mark (10 m or 9 m) and final mark (5 m or 4 m) were recorded. The difference in these times was used in calculating the 5 m velocity. These times were determined using one of three different video-based motion analysis programs (Dartfish, Tracker, or Kinovea). Four lines were drawn on the video: a line parallel to the ground along the long axis of the runway, one line parallel to the ground but perpendicular to the long axis of the runway at the beginning and end of the 5 m interval, and a line vertically aligned through the midline of the vaulter as shown in Figure 2.



*Figure 2.* A screenshot from Tracker showing an approach run showing velocity measurement marks (10 m or 9 m on the left, 5 m or 4 m on the right from the back of the pole vault box) on the pole vault runway and three lines to determine calculation for approach run velocity.

The times of the video frames where these three lines intersected were used to compute the time the vaulter took to run the 5 m interval. Velocity was computed by dividing 5 m by this interval time. Time of day of each attempt was taken from the digital memory card in the video camera. McGinnis (1991) verified the accuracy of this method for determining the velocity of a sprinter over a 5 m interval when using a video camera sampling at 200 Hz.

**Data analysis.** JASP version 0.8.5 (2018) was used for all statistical analyses. A multiple regression was performed using approach run velocity in the vaulter's last clearance as the dependent variable. To combine both men and women in the analysis, clearance velocities were converted to Z-scores separately for men and women prior to performing the regression. This allowed the average of women and men to be equal at zero once their data were combined. This prevented expected sex differences in absolute velocities from confounding the final model. Independent variables were the number of previous attempts by the vaulter in the competition, the range (maximum – minimum) of

approach run velocities in the vaulter's previous attempts, and the total time elapsed from the vaulter's first attempt to the vaulter's final clearance. It was expected that these independent variables would not be influenced by sex so these were entered into the model without conversion to Z-scores. Furthermore, retaining these independent variables in their absolute form increases usability by the intended population (i.e., athletes and coaches at a competition). The most beneficial set of these independent variables was identified using the backward elimination approach with exclusion level set at  $\alpha = .10$ .

## Results

The combined descriptive statistics for men and women are presented in Table 1.

Separate descriptive statistics for men and women showing actual final clearance velocity (m/s) are presented in Table 2 and Table 3, respectively.

Table 1  
*Combined Descriptive Statistics for Men and Women (N = 59)*

	Clearance Velocity (Z-score)	Attempts (#)	ARV Range (m/s)	Elapsed Time (min)
Mean	-0.001186	5.4	0.17	57.5
Std. Deviation	0.9923	2.0	0.09	32.4
Minimum	-2.500	3	0.04	6
Maximum	1.780	10	0.57	150

Note: Clearance Velocity = velocity of final clearance as Z-score, Attempts = number of attempts, ARV Range = approach run velocity range, Elapsed Time= amount of time competing in competition.

Table 2  
*Descriptive Statistics for Men (N = 28)*

	Clearance Velocity (m/s)	Attempts (#)	ARV Range (m/s)	Elapsed Time (min)
Mean	9.27	6.0	0.18	68.4
Std. Deviation	0.22	2.1	0.08	33.0
Minimum	8.72	3	0.05	21
Maximum	9.54	10	0.34	150

Note: Clearance Velocity = velocity of final clearance, Attempts = number of attempts, ARV Range = approach run velocity range, Elapsed Time= amount of time competing in competition.

Table 3  
*Descriptive Statistics for Women (N = 31)*

	Clearance Velocity (m/s)	Attempts (#)	ARV Range (m/s)	Elapsed Time (min)
Mean	8.21	4.9	0.17	47.77
Std. Deviation	0.24	1.7	0.11	29.01
Minimum	7.72	3	0.04	6
Maximum	8.63	9	0.57	117

Note: Clearance Velocity = velocity of final clearance, Attempts = number of attempts, ARV Range = approach run velocity range, Elapsed Time= amount of time competing in competition.

The global test of model adequacy was significant for Model 3 ( $p < .10$ ) (Table 4).

The tests of regression equation coefficients revealed that number of attempts was the lone statistically significant variable in Model 3 to predict the Z-score of final clearance velocity (Table 5). Both range of approach run velocities and elapsed time were not significant contributors to the model. The final prediction equation for the Z-score of the final clearance velocity using number of attempts is:

$$V_{\text{Clearance}} = 0.124 (\text{Attempts}) - 0.676 \quad (1)$$

Table 4  
*ANOVA of Multiple Regression Analysis for the Investigated Independent Variables*

Model		Sum of Squares	df	Mean Square	F	p
1	Regression	3.634	3	1.211	1.246	0.302
	Residual	53.473	55	0.972		
	Total	57.107	58			
2	Regression	3.618	2	1.809	1.894	0.160
	Residual	53.489	56	0.955		
	Total	57.107	58			
3	Regression	3.582	1	3.582	3.814	0.056
	Residual	53.525	57	0.939		
	Total	57.107	58			

Note: ANOVA = analysis of variance, df = degrees of freedom, p = statistical significance.



Table 5  
Regression Equation Coefficients

Model		Unstandardized	Standard Error	Standardized	t	p
1	intercept	-0.667	0.387		-1.725	0.090
	Attempts	0.140	0.101	0.282	1.383	0.172
	Range	-0.294	1.600	-0.027	-0.184	0.855
	ElapsedTime	-0.001	0.006	-0.025	-0.128	0.898
2	intercept	-0.661	0.380		-1.738	0.088
	Attempts	0.131	0.073	0.264	1.789	0.079
	Range	-0.307	1.583	-0.029	-0.194	0.847
3	intercept	-0.676	0.368		-1.838	0.071
	Attempts	0.124	0.064	0.250	1.953	0.056

Note: Unstandardized = express model in original outcome variable, p = statistical significance.

Though the above regression equation was significant, number of attempts only explains 6.3% of the variance in approach run velocity (Table 6, Figure 3).

Table 6  
Model Summary of Multiple Regression Analysis

Model	R	R <sup>2</sup>	Adjusted R <sup>2</sup>	RMSE
1	0.252	0.064	0.013	0.986
2	0.252	0.063	0.030	0.977
3	0.250	0.063	0.046	0.969

Note: R = correlation coefficient, R<sup>2</sup> = R squared, Adjusted R<sup>2</sup> = adjusted R squared, RMSE = root-mean-square error.

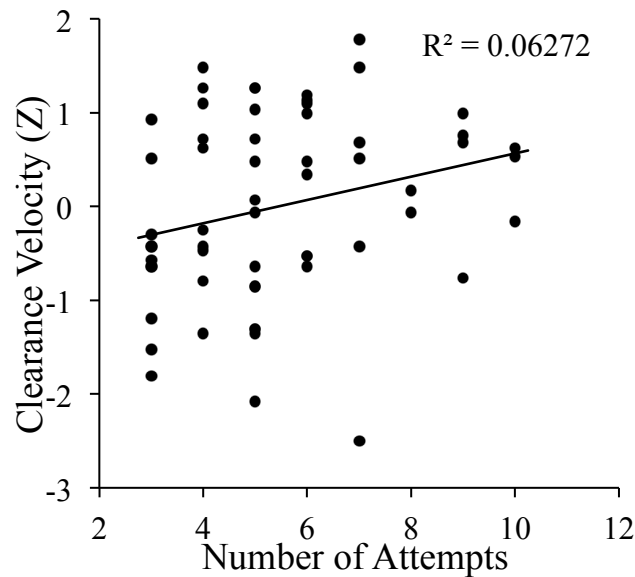


Figure 3. Z-score clearance velocity versus number of attempts.

Figure 4 shows the Z-score predicted clearance velocity versus residual. The figure shows a higher concentration of residuals in the range of -0.3 to 0.1 for Z-score predicted clearance velocity. Z-score predicted clearance velocity was calculated by substituting the actual numbers of attempts into Equation 1. The residuals were obtained by subtracting the predicted Z-score velocity from the observed Z-score velocity of each individual. The frequency of residuals as a histogram is presented in Figure 5. The histogram shows the frequency distribution of occurring calculated residuals with the highest concentration between -0.5 to 0. This is in line with the data as the average for the residuals is approximately zero ( $1.69 \times 10^{-4}$ ). The distribution of residuals is approximately normal.

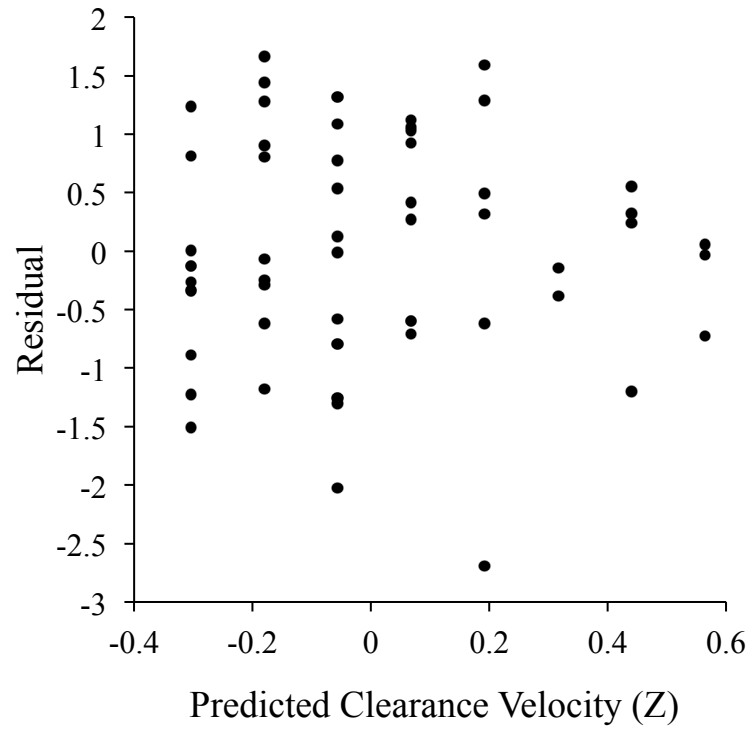


Figure 4. Z-score predicted clearance velocity versus residual.

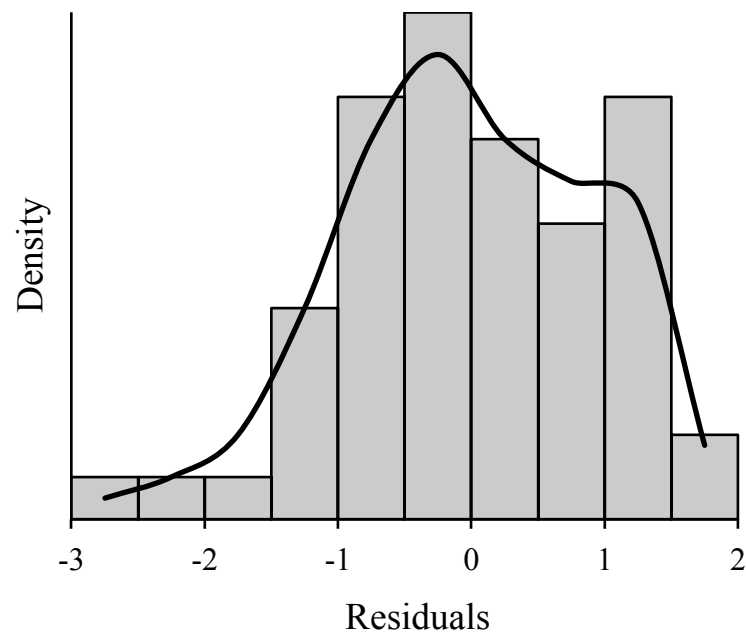


Figure 5. Residual histogram showing the normative distribution.

Including the standard deviations of attempts and the average of approach run velocities into the regression equation and algebraically rearranging the terms yields a more user-friendly prediction equation that predicts absolute clearance velocities in m/s. Given that the maximum number of attempts used in developing the regression model is 10, no more than this number should be used for predicting scores (Table 1). The modified prediction equation for absolute clearance velocity is:

$$V_{\text{predicted}} = [0.124 (\text{SD})](\text{Attempts}) - 0.676(\text{SD}) + V_{\text{Ravg}} \quad (2)$$

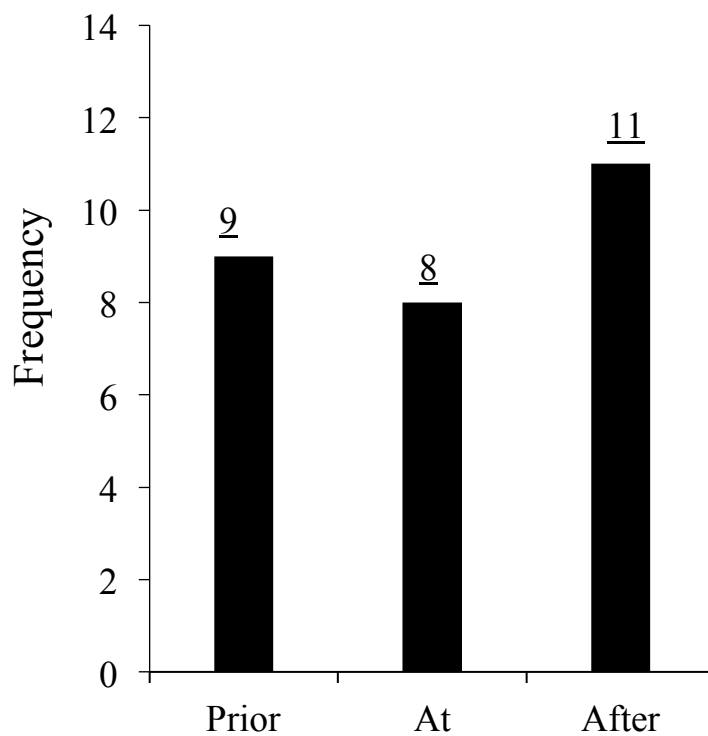
### **Discussion and Recommendations**

To the knowledge of the researcher, this study was the first of its kind to evaluate how competition variables affect approach run velocity from first attempt to final clearance during a pole vault competition. For male and female national caliber pole vaulters, a backward elimination multiple regression determined that number of attempts was a significant predictor of approach run velocity ( $p < .10$ ). However, it only accounted for 6.3% of the variance in approach run velocity. The results support the stated hypothesis, as one of the three independent variables included was a significant predictor of approach run velocity. This relationship yielded a prediction equation for Z-score final clearance velocity of:  $V_{\text{clearance}} = 0.124 (\text{Attempts}) - 0.676$ .

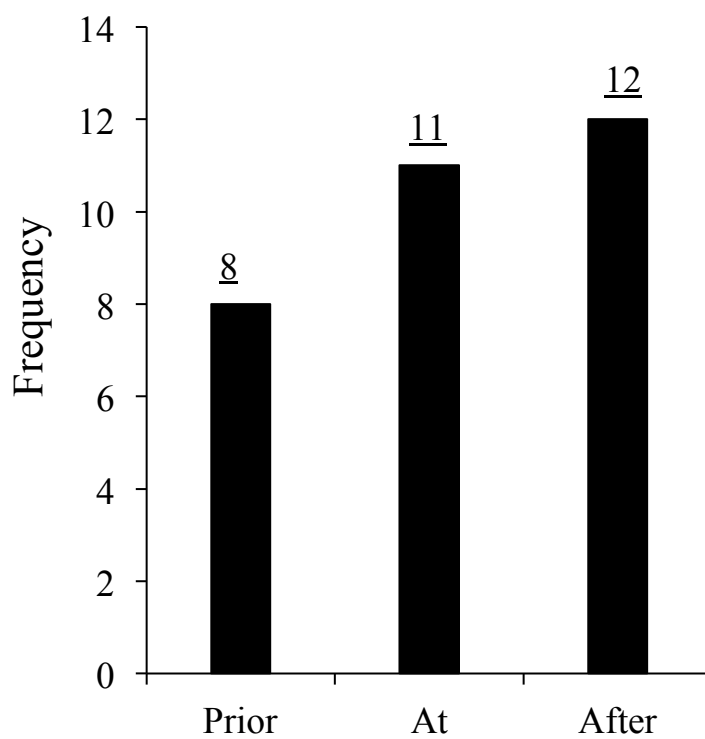
One reason why range of approach run velocity was not a significant predictor may have been because the deviation of approach run velocities for elite pole vaulters was minimal. The combined mean range of ARV was 0.17 m/s, for men only the mean range of ARV was 0.18 m/s, and for women only the mean range of ARV was 0.17 m/s. Whereas it is expected that larger variability in a data set will result in greater statistical power and

stronger observed relationships (Steyerberg, Harrell, Borsboom, Eijkemans, Vergouwe, and Habbema, 2001). In contrast, elapsed time may not have been an effective predictor in the analysis due to the fact that the combined men's and women's average time spent in competition was 57 minutes, with an average of 5 attempts taken. This results in an attempt, on average, every 11 minutes and 24 seconds. The amount of recovery time vaulters could have had in that time would be sufficient to prepare for another maximum effort vault (Spencer et al., 2005).

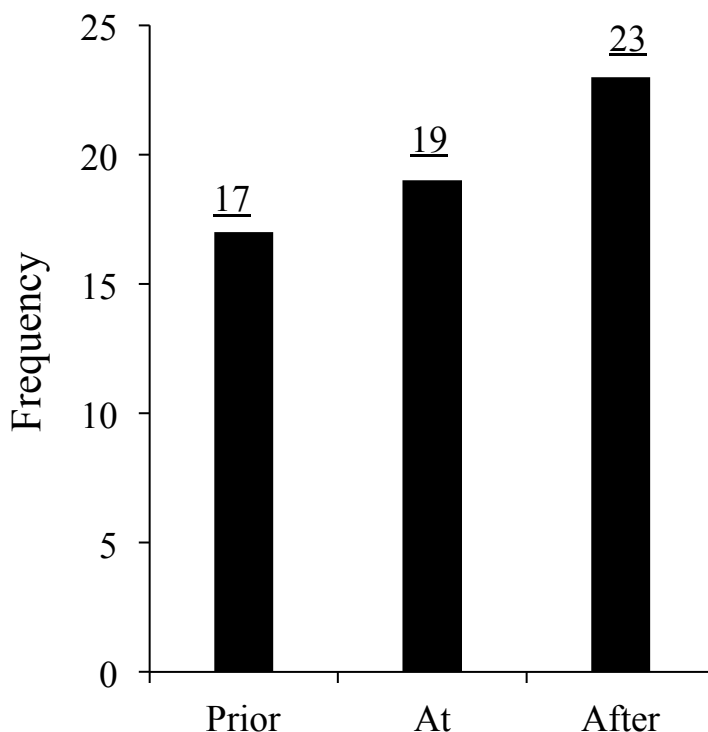
An examination into individual clearance velocities was also performed. Figures 6, 7, and 8 show frequency distributions of peak approach run velocities prior to, at, or after final clearance attempt for men alone, women alone, and men and women combined, respectively. The figures showed that the 39% of men and women had their fastest approach run velocity following their final clearance. The reason behind these findings is unclear. It may be due to competitors being more excited as they attempt a height they have never cleared or as simple as they were more warmed-up as they were taking jumps with less time between each attempt. Only 28% of male competitors ran their fastest approach run velocity at their final clearance (Figure 6). For the women, 35% of competitors ran their fastest approach run velocity at their final clearance (Figure 7). The data pertaining to attempts taken after final clearance was not included in the backward elimination multiple regression analysis. Future work may wish to include these attempts in the analysis.



*Figure 6.* Frequency of peak velocities occurring prior to, at, or after best clearance attempt for men (N = 28).



*Figure 7.* Frequency of peak velocities occurring prior to, at, or after best clearance attempt for women (N = 31).



*Figure 8.* Combined results for frequency of peak velocities occurring prior to, at, or after best clearance attempt (N = 59).

The approach run velocity of a vaulter has been shown to be strongly correlated to the highest height a vaulter clears in pole vault competition (McGinnis, 2004). Prior research has used approach run velocity of elite vaulters, anthropometric measurements, and technique factors of non-elite vaulters, independently, as their experimental variables for predicting vault height (Decker & Bird, 2004; McGinnis, 1995; Sullivan et al., 1994). The determination of number of attempts from first to final clearance as a predicting factor of velocity can make a connection with previous studies conducted by Ladany (1975) and Hersh and Ladany (1989). Though these studies were performed with non-elite vaulters, both studies concluded that the probabilities of clearing a height decrease as a vaulter's number of attempts increased. Using the prediction equation formulated in the present study, (1)  $V_{\text{clearance}} = 0.124 (\text{Attempts}) - 0.676$ , a second equation was formulated, (2)  $V_{\text{predicted}} = [0.124 (\text{SD})](\text{Attempts}) - 0.676(\text{SD}) + V_{\text{Ravg}}$ , that can calculate real velocities (m/s). Actual

velocity can be predicted by calculating the average of approach run velocities from first attempt to final clearance and standard deviation (SD) throughout a competition for a vaulter. These calculated velocities from the second equation may be plugged into McGinnis' (1995) equation,  $H = 0.519 (V) + 1.06$  m, to predict achievable vaulting height. An example calculation from an individual male's data is shown below:

$$V_{\text{predicted}} = [0.124 (0.07 \text{ m/s})](9) - 0.676(0.07 \text{ m/s}) + 9.11 \text{ m/s}$$

$$V_{\text{predicted}} = 9.14 \text{ m/s}$$

The actual velocity of the vaulter for his final clearance at was 9.10 m/s. Using this predicted velocity in McGinnis' equation predicts maximal crossbar height cleared:

$$H = 0.519 (9.14 \text{ m/s}) + 1.06 \text{ m}$$

$$H = 5.80 \text{ m}$$

The final clearance height of the vaulter was 5.75 m. During his last attempts at 5.80 m his approach run velocities were; 9.10, 9.14, and 8.97 m/s, respectively. The results predicted by these two equations are in close agreement with the actual velocity and height achieved by the vaulter. Information from previous competitions or even live calculations during a competition may aid in strategy decisions for a coach and/or athlete.

The competitors whose data were used in this study were national caliber. This may limit the population that will be able to utilize the given information for pole vault strategy purposes. A future study may be conducted to understand how number of attempts, approach run velocity range, and elapsed time predict approach run velocity of final clearance for non-elite pole vaulters. Indeed, a more heterogeneous sample would likely have greater predictive power than the homogenous sample included here. Further research of national caliber vaulters should include data from attempts after final clearance. Lastly, variables



such as pole selection (i.e., stiffness, length), hand grip height, standard settings, environmental concerns (e.g., wind, temperature, precipitation, sun, etc.), and anthropometric measurements (e.g., height, weight) may contribute to a more complete understanding pole vault performance and allow stronger recommendations of optimal strategy for a given individual.

### **Conclusion**

In conclusion, the findings from this study suggest that number of attempts is a predictor of final clearance approach run velocity. However, this variable only explains a very small percentage of variance in final clearance approach run velocity (6.3%). Though number of attempts explains a small percentage of final clearance approach run velocity, national caliber coaches and athletes may use the formulated *Z*-score prediction equation and/or the modified equation for real velocity prediction to utilize data from current or previous competitions to calculate approach run velocity and make decisions regarding competition strategies to maximize performance.

## REFERENCES

- Adamczewski, H., & Perlt, B. (1997). Run-up velocity of female and male pole vaulters and some technical aspects of women's pole vault. *New Studies in Athletics*, *12*(1), 63–76.
- de Aguiar, R. A., Turnes, T., Santos de Oliveira Cruz, R., Salvador, A. F., & Caputo, F. (2015). Repeated sprint performance and metabolic recovery curves: Effects of aerobic and anaerobic characteristics. *Applied Physiology Nutrition and Metabolism*, *40*, 433–440. <https://doi.org/10.1139/apnm-2014-0431>
- Balsam, P., Seger, J., Sjodin, B., & Ekblom, B. (1992). Maximal-intensity intermittent exercise: Effect of recovery duration. *International Journal of Sports Medicine*, *13*(7), 528-533. <https://doi.org/10.1055/s-2007-1021311>
- Billaut, O. I. S., & Basset, F. A. (2007). Effect of different recovery patterns on repeated-sprint ability and neuromuscular responses. *Journal of Sports Sciences*, *25*(8), 905–913. <https://doi.org/10.1080/02640410600898087>
- Billaut, F., Giacomoni, M., & Falgairette, G. (2003). Maximal intermittent cycling exercise: Effect of recovery duration and gender. *Journal of Applied Physiology*, *95*, 1632 – 1637.
- Decker, A., & Bird, M. (2004). Predicting potential jump height in the pole vault from four variables. In M. Lamontagne, D. G. E. Robertson, & H. Sveistrup (Eds.), *Proceedings of the 22nd International Symposium on Biomechanics in Sport*, (250-252). Ottawa: International Society of Biomechanics in Sports.
- Hersh, M., & Ladany, S. P. (1989). Optimal pole-vaulting strategy. *Operations Research*, *37*(1), 172–175.

- IAAF. (2018). World records. Retrieved from <https://www.iaaf.org/records/by-category/world-records>
- JASP Team (2018). JASP (Version 0.8.1.2)[Computer software].
- Ladany, S. P. (1975). Optimal starting height for pole vaulting. *Operations Research*, 23(5), 968–978.
- McGinnis, P. M. (1991). The accuracy of devices and techniques for measuring speed of athletes. In C. L. Tant, P. E. Patterson, & S. L. Yorks (Eds.), *Proceedings of the 9th International Symposium on Biomechanics in Sport*, 177–181. Ames, IA: International Society of Biomechanics in Sports.
- McGinnis, P. (1995). Predicting performance potential in the pole vault from approach run velocity. In *Third IOC World Congress on Sport Sciences Congress Proceedings* (pp. 182-183). Atlanta: Atlanta Committee for the Olympic Games.
- McGinnis, P. M. (1996). *The biomechanics of pole vaulting*. In ‘96 KNUPE International Symposium Program, 13-28. Seoul, Korea: The Research Institute of Physical Education & Sports Science, Korean National University of Physical Education.
- McGinnis, P. M. (1997). Approach run velocities of female pole vaulters. In J. Wilkerson, K. Ludwig, and W. Zimmermann (Eds.), *Biomechanics in Sports XV: Proceedings of the 15th International Symposium on Biomechanics in Sports*. (pp. 101–105).
- McGinnis, P. M. (2004). Evolution of the relationship between performance and approach run velocity in the women’s pole vault. In M. Lamontagne, D. G. E. Robertson, & H. Sveistrup (Eds.), *Proceedings of the 22nd International Symposium on Biomechanics in Sport*, 531–534. Ottawa: International Society of Biomechanics in Sports.

- Monks, M. R., Compton, C. T., Yetman, J. D., Power, K. E., & Button, D. C. (2017). Repeated sprint ability but not neuromuscular fatigue is dependent on short versus long duration recovery time between sprints in healthy males. *Journal of Science and Medicine in Sport*, 20(6), 600–605. <https://doi.org/10.1016/j.jsams.2016.10.008>
- NCAA. (2017). *Cross Country/Track And Field: 2017 and 2018 Rules*.
- Rogers, J. L. (2000). Pole vault. In L. Hambly, L. LaHood, S. Seyfert (Eds.), *USA Track & Field Coaching Manual* (pp. 199-216). Champaign, IL: Human Kinetics.
- Scott, C. (2005). Misconceptions about aerobic and anaerobic energy expenditure. *Journal of the International Society of Sports Nutrition*, 2(2), 32–37.
- Spencer, M., Bishop, D., Dawson, B., & Goodman, C. (2005). Physiological and metabolic responses of repeated-sprint activities specific to field-based team sports. *Sports Medicine*, 35(12), 1025–1044.
- Steinacker, U. (1989). The run-up speed in the pole vault. *Modern Athlete and Coach*, 28(39), 1–5.
- Streyerberg, E. W., Harrell, F. E., Borsboom, G. J. J., Eijkemans, M. J., Vergouwe, Y., & Habbema, J. D. F. (2001). Internal validation of predictive models: Efficiency of some procedures for logistic regression analysis. *Journal of Clinical Epidemiology*, 54(8), 774-781. [https://doi.org/10.1016/S0895-4356\(01\)00341-9](https://doi.org/10.1016/S0895-4356(01)00341-9)
- Sullivan, J. J., Knowlton, R. G., Hetzler, R. K., & Woelke, P. L. (1994). Anthropometric characteristics and performance related predictors of success in adolescent pole vaulters. *Journal of Sports Medicine and Physical Fitness*, 34(2), 179-184.
- USATF. (2017). *USATF 2017 Competition Rules*.

## APPENDIX

## Institutional Review Board Approval Letter



## MEMORANDUM

To: Nathaniel Ashton  
Peter McGinnis

From: Wendy Hurley, Reviewer *on behalf of*  
Institutional Review Board

Date: 3/21/2018

RE: Institutional Review Board Approval

In accordance with SUNY Cortland's procedures for human research participant protections, the protocol referenced below has been approved for a period of one year:

**Title of the study:** Effects of Competition Variables and Prior Attempts on Approach Run Velocity during a Pole Vaulter's Final Clearance

<b>Level of review:</b>	Exempt	<b>Protocol number:</b>	171848
<b>Project start date:</b>	Upon IRB approval	<b>Approval expiration date*:</b>	Note: Exempt research

\* **Note: exempt research does not require continuation requests;** the SUNY Cortland IRB only requests annual email notification (to [irb@cortland.edu](mailto:irb@cortland.edu)) indicating that the research continues. The purpose of the continuation notification is to alert the IRB Administrator that the records of the original IRB approval must remain available. Unlimited continuations can be registered for exempt research under federal and SUNY Cortland IRB guidelines.

The federal Office for Research Protections (OHRP) emphasizes that investigators play a crucial role in protecting the rights and welfare of human subjects and are responsible for carrying out sound ethical research consistent with research plans approved by an IRB. Along with meeting the specific requirements of a particular research study, investigators are responsible for ongoing requirements in the conduct of approved research that include, in summary:

- obtaining and documenting informed consent from the participants and/or from a legally authorized representative prior to the individuals' participation in the research, unless these requirements have been waived by the IRB;
- obtaining prior approval from the IRB for any modifications of (or additions to) the previously approved research; this includes modifications to advertisements and other recruitment materials, changes to the informed consent or child assent, the study design and procedures, addition of research staff or student assistants, etc. (except those alterations necessary to eliminate apparent immediate hazards to subjects, which are then to be reported by email to [irb@cortland.edu](mailto:irb@cortland.edu) within three days);
- providing to the IRB prompt reports of any unanticipated problems involving risks to subjects or others;
- following the principles outlined in the Belmont Report, OHRP Policies and Procedures (Title 45, Part 46, Protection of Human Subjects), the SUNY Cortland College Handbook, and SUNY Cortland's IRB Policies and Procedures Manual;
- notifying the IRB of continued research under the approved protocol to keep the records active; and,
- maintaining records as required by the HHS regulations and NYS State law, for at least three years after completion of the study.

Institutional Review Board  
Page 2

In the event that questions or concerns arise about research at SUNY Cortland, please contact the IRB by email [irb@cortland.edu](mailto:irb@cortland.edu) or by telephone at (607)753-2511. You may also contact a member of the IRB who possesses expertise in your discipline or methodology, visit <http://www.cortland.edu/irb/members.html> to obtain a current list of IRB members.

Sincerely,

A handwritten signature in black ink, appearing to read 'W. Hurley', with a long horizontal flourish extending to the right.

Wendy Hurley, Reviewer *on behalf of*  
Institutional Review Board  
SUNY Cortland