AN ANALYSIS OF THE LOCATION OF THE TAKEOFF FOOT IN THE POLE VAULT

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In Partial Fulfillment

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Master of Science Degree

by

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ABSTRACT

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This study observed cinematographically, the takeoff step in the pole vault. Thirty-eight vaults ranging from 13.5 ft. to 15.0 ft. taken from 10 Ss were analyzed with 2 hypotheses being tested. Films were taken at 100 frames per sec. during 4 indoor track meets held at the University of Wisconsin-La Crosse Fieldhouse.

Horizontal distance from the top hand to the toe of the takeoff foot was correlated with the perpendicular distance from the center of gravity of the vaulter to the pole and with the difference in velocities from takeoff foot touch-down to takeoff foot liftoff. The Pearson r was not significant for either relationship, $p > .05$.

The study lends support to the idea that different styles exist for bending the pole and because of these styles horizontal distance has different effects on perpendicular distance from the center of gravity to the pole. Achieving maximum controlled liftoff velocity is important to vaulting and varying ways exist for the vaulter to accomplish this task. Pole vaulting is a multifaceted event and different factors within the event can be performed in varied ways and still yield success for the level of performance of the Ss studied.

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CHAPTER I

INTRODUCTION

Pole vaulting is one of the most dynamic events in track and field. Spectators, coaches, and athletes alike turn their heads to watch as pole vaulters place their bodies in awkward positions trying to get over a crossbar. The pole vaulter must be an excellent all around athlete to perform the skill with any degree of proficiency. He must be strong, fast, agile, durable, and flexible in both body and mind. The event of pole vaulting is generally considered a closed skill. Closed skills according to Lawther (1977) are those in which conformity to a prescribed standard sequence of motor acts is all important. The closed skill activity is generally considered to be relatively independent of external environment and chiefly an automatic pattern. Except for a few variables, the pole vaulter wants to basically duplicate a series of movements over and over again in a prescribed manner.

This event has been studied in many different ways, but a number of questions about pole vaulting remain unanswered. Research has provided a better understanding of the simple as well as complex aspects of the pole vault. Most research involving the pole vault utilizes cinematography. According to Broer (1973), cinematography is a major tool used in analysis of movement. The fundamental principle of cinematography is to obtain the angles of movement, dimensions, time relations, distances, and indirect values of force and velocity from projected film. These analyses give the researcher an opportunity to break down the complete motion into its basic components. The study of pole vaulting cannot be accomplished without some means of recording and playing back slowed movement. High speed filming seems to be the most appropriate tool. This type of filming enables the researcher to look at exact portions of the vault in minute detail. Cinematography was employed in this study to examine one specific aspect of the pole vault.

Statement of the Problem

The purpose of this project was to study location of the takeoff foot in relation to the top hand for the pole vault.

Need for the Study

Pole vaulting is a closed skill and a goal in pole vaulting is to obtain an effective motor program and duplicate this program with each response (Sage, 1977). Many people knowledgeable about the event have written about all of the proper techniques required to perform the skill well. Many authorities (Barlow, 1973; Bush, 1978; Dillman, 1966; Doherty, 1970; Ecker, 1971; Ganslen, 1974;

Hay, 1966; Moore, 1978; Powell, 1965; Ryan, 1965) have indicated the most critical phase of the vault is the plant and takeoff. One technique occurring within the plant and takeoff, that was of particular interest to the author, was the placement of the takeoff foot, and how it is related to the top hand at the time of takeoff. The placement of the takeoff foot and its relationship to the top hand has a prescribed standard position according to many coaches and authorities (Bush, 1978; Caldwell, 1977; Coniam, 1963; Cramer, 1969; Doherty, 1970; Hay, 1966, 1973; Jarver, 1972; Kaufman, 1973; Moore, 1978; Perrin, 1960; Powell, 1965; Railsback, 1968; Santos, 1975; Webb, 1974; Welsch, 1976; Wessels, 1978). They have indicated that the takeoff foot should be directly below the top hand at the time of takeoff. A search of the literature revealed very little evidence supporting this belief. It seemed beneficial that a study be conducted concerning this area in an attempt to determine whether placement of the takeoff foot is a major factor in vaulting performance, and to help substantiate the belief that the hand and the takeoff foot should form a right angle to the ground at the time of takeoff.

Purpose

The purpose of this study was to help substantiate that placement of the takeoff foot in the pole vault is a major factor in vaulting performance. Because of the complexity of the event, the author felt height cleared was not a good indicator for proper foot placement. There are so many other factors contributing to success or failure of the vault, that an element in the vaulting sequence closer in time to the takeoff was used as a measuring factor. Two such factors seemed appropriate for this study. Steben (1970) and Vernon (1974) both concluded that distance from the center of gravity of the vaulter to the pole at the time of takeoff was a major factor in successful vaulting. They concluded it was advantageous for the vaulter to have his center of gravity away from the pole at the time of takeoff to facilitate a better vault. Other authorities (Barlow, 1973; Dillman, 1966; Ecker, 1971; Ganslen, 1974; Rohrbough, 1973) have indicated speed in the approach is a critical factor in vaulting. Each has stated that maintaining and increasing velocity at the time of takeoff can improve vaulting performance. The author is inferring that takeoff foot placement affects distance of center of gravity of the vaulter at the time of takeoff. As the horizontal distance of the toe of the takeoff foot from a point perpendicular to the top hand approaches zero, the length from the center of gravity of the vaulter to the pole becomes greater, and less velocity difference occurs from takeoff foot touchdown to liftoff. Consequently, the closer the takeoff foot moves to the perpendicular point, the further the center of gravity of the vaulter will be from the pole at that time, with less change in velocity occurring during the takeoff from touchdown to liftoff.

Hypotheses

The following hypotheses were recognized:

1. The closer the takeoff foot is to a point perpendicular to the top hand, the greater the distance the center of gravity of the vaulter will be from the pole at the time of takeoff.
2. The closer the takeoff foot is to a point perpendicular to the top hand, the less the difference in velocity from touchdown to liftoff.

Assumptions

The following assumptions were recognized:

1. It was assumed the pole vaulters in the study performed to the best of their ability at the time of filming.
2. It was assumed filming at 100 frames per second provided sufficient speed for analysis.
3. It was assumed the center of gravity of the vaulter could be accurately determined.
4. It was assumed velocities of the vaulters could be accurately determined.
5. It was assumed the perpendicular distance from the center of gravity of the vaulter to the pole could accurately be determined.

6. It was assumed differences in height, weight, and pole size used were not a factor in influencing the results of this study.

Delimitations

The following delimitations were recognized:

1. Only right handed pole vaulters who took off on their left foot were used in the study.
2. Only successful vaults of 13.5 feet or higher were used in the study.

Limitations

The following limitations were recognized:

1. Only pole vaulters that competed during four meets of the 1979 UW-La Crosse indoor track season were filmed.
2. Filming during competition may have put additional pressure on the subjects.
3. A minimum amount of additional lighting was used because the films were taken during actual competition.
4. In order to be included in the study, the vaulter had to successfully clear 13.5 feet.
5. Errors could have been made when digitizing and errors could have been made by the mechanical equipment that were not corrected.

Definition of Terms

Center of Gravity. The theoretical balance point of the body determined by finding 20 segmental endpoints of the subject.

Distance of Center of Gravity to the Pole. The perpendicular distance of the center of gravity of the vaulter from the pole. Two conditions of the pole were present at the time of takeoff. The pole was straight or the pole was bent. If the pole was straight, a perpendicular was determined from the center of gravity to the pole and that distance was measured. If the pole was bent, the deflection was assumed to be a uniform arc. The same technique used in the straight pole was used to find the distance except the length was extended to the pole.

Horizontal Distance. If a line is dropped from the middle of the top hand perpendicular to the ground, the intersection determines a point. The distance from this point to the toe of the takeoff foot at the time of takeoff was defined as the horizontal distance.

Optimal Takeoff Point. The position of the left foot at the time of takeoff which would give the vaulter the best opportunity to have a successful vault.

Plant. That part of the vault where the vaulter puts the pole directly over and in front of his head before takeoff.

Takeoff. The instant before the vaulter left the ground in the pole vault.

Takeoff Foot. That foot which is last to leave the ground during the execution of the vault.

Takeoff Foot Touchdown. The frame which showed the takeoff foot first touching the runway on the takeoff step.

Touchdown Velocity. The average velocity of the center of gravity of the vaulter determined by the FILMDAT program utilizing the takeoff foot touchdown frame and the two preceding frames.

Takeoff Foot Liftoff. The frame which showed the takeoff foot last touching the runway at the time of takeoff.

Liftoff Velocity. The average velocity of the center of gravity of the vaulter determined by the FILMDAT program utilizing the takeoff foot liftoff frame and the two preceding frames.

CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

The review of literature revealed that studies have been conducted utilizing film to analyze the mechanics of the pole vault. This technique has also been employed by coaches who have filmed and observed vaulters in attempts to help the vaulters improve their performance. These studies analyzed one, two, and multiple variables with varying degrees of success. The coaches attempt to put into practice what they and the researchers have learned. All of the research has helped athletes get a clearer understanding of pole vaulting and techniques that could be employed to achieve maximum heights.

Pole vaulting is a continuous action comprised of many movements each totally dependent upon the others for proper execution. This action attempts to achieve one goal, getting over the crossbar at the highest possible height. In this study, the researcher was interested in the part of vaulting to the point where the takeoff foot left the ground. According to Moore (1978), a majority of problems encountered during the vault could be traced back to an improper plant. This study considered events of the takeoff and plant. Since movements in the vault are dependent upon what has preceded it, the review of literature will discuss the action of the vault through the pole bend before takeoff. This will include the approach, plant, takeoff, and pole bend.

Approach

Many factors contribute to successful vaulting. The approach should be a gradual build up until an optimum controllable speed is reached. According to Ganslen (1974), maximum controllable speed is the key to great vaulting. Rohrbough (1973) investigated the horizontal approach velocity of four collegiate vaulters. Each vaulter was timed over four 20 foot intervals of the approach. The results of this study indicated all vaulters analyzed, performed best when their horizontal approach velocity was the greatest in the final 20 foot segment preceding takeoff. The average velocity in this last segment for all vaulting attempts was 28.07 feet per second. The mean velocity for successful vaults in the final segment of the run was 30.76 feet per second.

Dillman (1966), in studying changes in kinetic and potential energy which occurred when vaulting, filmed and analyzed the four best jumps of four varsity pole vaulters. The heights ranged from 12.5 feet to 15 feet. His results indicated three important applications for pole vaulting. One of these applications placed emphasis on obtaining a maximum controlled takeoff velocity.

Ecker (1971) stated that a 20 foot vault was possible with existing poles and techniques. The only factor necessary was to increase velocity at the time of takeoff of the pole vaulter to about 30 feet per second. The current velocity of world class pole vaulters is about 27 feet per second for the entire run.

Barlow (1973) investigated basic mechanical parameters as recorded during different phases of the vault. He filmed eleven vaulters from amateur, collegiate, and inter-scholastic levels of competition with vaults ranging from 13 to 18 feet. His findings led to three implementations for vaulting. First, the vaulter should attempt to have maximum horizontal velocity before and during takeoff and he should try to achieve a larger vertical component of impulse. Second, the pole vaulter should jump at takeoff to emphasize greater vertical impulse without reducing the horizontal component built up in the run. Third, vaulters clearing more than 16 feet initiated the pole plant earlier and accelerated for slightly longer distances into the takeoff area than did those vaulters clearing less than 16 feet.

Plant and Takeoff

In addition to increasing and maintaining velocity during the final steps of the vault, the vaulter must be concerned with the plant. The pole plant is the most important phase of vaulting once the athlete establishes other basic techniques according to Bush (1978). Caldwell (1977) described the plant as starting physically about two strides out but starting mentally four strides out. Welsch (1976) described the plant of Dave Roberts as being high and in front of the body as the takeoff foot hit the ground. The relationship between the hands and the takeoff foot has been the topic of much discussion. Many authorities (Cramer, 1969; Hay, 1966, 1973; Moore, 1978; Perrin, 1960; Railsback, 1968) agree the top hand and takeoff foot should form a line perpendicular with the ground at the time of takeoff.

Hay (1966) filmed and analyzed one vaulter who varied his techniques during vaulting. Comparisons were then made between the different vaults. Six factors were examined, one being the horizontal distance between the vaulter's top hand and his takeoff foot at the moment of takeoff. Hay concluded the relationship between top hand to takeoff foot distance and horizontal velocity was a significant factor in bending the pole, $\underline{r} = .52$, $\underline{p} < .05$.

Champion pole vaulters have agreed the top hand takeoff foot relationship was ideal when the foot was directly over the top hand. Perrin (1960) surveyed six champion vaulters and they all agreed with this belief. Railsback (1968) stated that he strived for this perpendicular hand-foot relationship with the ground.

In a survey of 25 champion pole vaulters, Cramer (1969) found that 12 of the 25 champion pole vaulters surveyed took off with their foot directly below their top hand.

In a practical sense, when coaches have written about learning to vault, they have stated the athletes should strive to have the takeoff foot in line with the top hand (Bush, 1978; Coniam, 1963; Doherty, 1970; Jarver, 1972; Kaufman, 1973; Powell, 1965; Santos, 1975; Webb, 1974; Wessels, 1978).

Hay (1973) describes the importance of this hand-foot relationship when he states:

> The position of the vaulter's left takeoff foot at this time is critical to the success of the vault. If the foot is forward of a perpendicular line through the top hand, the vaulter experiences a sharp jerk at takeoff as he leaps forward against the restraint imposed by his right arm. (Note: This effect is somewhat akin to that of a dog which leaps forward only to be badly jarred to halt by the leash to which he is attached.) If the takeoff foot is placed behind a perpendicular line through the top hand, the vaulter may develop more momentum in his swing than he is able to control later in the vault. In addition, the distant takeoff may result in a reduction in the vertical force he can exert at takeoff and concomitant difficulty in bringing the pole to the vertical. (p. 464).

Other authorities (Bartholomaus, 1967; LeMasurier, 1964; Ryan, 1965) have offered information contrary to that practice. Bartholomaus (1967) filmed, analyzed, and compared five maximal ability vaulters (those vaulters clearing 15 1/2 feet or more) with four submaximal ability vaulters (those vaulters clearing at least 14 feet but less than 15.5 feet) during actual outdoor competition. He considered seven factors, one of which was top hand to takeoff foot distance. He concluded the top hand to takeoff foot distance was not significantly related with the takeoff velocity nor with the takeoff pole bend, $\underline{r} = .162$, $p > .05$.

LeMasurier (1964) contended that it was better to have the takeoff foot closer to the planting box to enable the vaulter to have more bend in the pole. Ryan (1965) suggested that the fiberglass pole gave the vaulter more latitude in the placement of the foot than did the steel pole.

Ganslen (1974) viewed the position of the vaulter's body in relation to the takeoff foot as the most important phase of the takeoff. The vaulter must be in a position to drive effectively forward and upward. Caldwell (1970) described a good takeoff as one which allows the vaulter to run over the takeoff foot. The "sharp jerk" referred to by Hay (1973) occurs because the vaulter reaches the takeoff point with a straight leg and this straight leg will not allow his center of gravity to move over his leg in the same manner as when he runs (Ganslen, 1974).

In addition to the perpendicular hand-foot-ground relationship, Moore (1978) has contended that hand spread and pole carry are important factors for a proper plant and body position at takeoff. If the hand spread is too great it limits the height the athlete can raise the pole. It pulls the takeoff foot closer to the pit and may cause a late plant. As an athlete uses longer poles, pole carry becomes more important. The vaulter should raise the tip of the pole higher than eye level to facilitate a more fluid run and a more efficient body position at takeoff.

During the takeoff phase and the drive phase the location of the center of gravity of the vaulter becomes an important factor. Steben (1970) collected data from 151 successful vaults performed by eight collegiate pole vaulters. A waist band mark was placed on each vaulter and was used to approximate the center of gravity. He considered three relationships, two of which are pertinent to this study. First, the relationship between the mean height attained and the degree of extension of the elbow of the bottom arm from the moment of takeoff to a point where the waist band mark approached the pole was important. Second, the relationship between mean height attained and horizontal velocity of the vaulters before and at takeoff was also important. He concluded it was important to develop some means of keeping the body as far from the vaulting pole as possible at takeoff. This may be helped by increasing the degree of extension of the elbow of the bottom arm.

Vernon (1974) developed a mathematical model of a pole vaulter and, by varying certain parameters, tried to determine the effects they had on the vault. Vernon found that having the center of gravity as far as possible from the hands at the instant of takeoff was more important than having the center of gravity high above the ground at that time.

According to these researchers, the distance from the center of gravity of the vaulter to the pole at the time of takeoff has an important effect on the success of the vault.

Pole Bend

Studies have been conducted concerning the bending of the pole. Hay (1971) stated the best performances in the pole vault at the 1968 New Zealand A.A.A. Championships were those vaults having pronounced bending of the pole and the best vaulters took the greatest amount of time in bending the pole. Jarver (1971) agreed with this philosophy when he discussed greater bend storing more energy in the pole. Pikulski (1964) used cinematography to analyze the vaulting techniques of five University of Maryland vaulters. He studied five parameters in the 24 vaults analyzed, one of which was maximum pole deflection. He reported that a strong positive relationship existed between the amount of pole deflection and the height of the vault.

Summary

The preceding discussion of the pole vault dealt with the approach, plant, takeoff, and pole bend. The related literature was intended to make the reader aware of three main factors. The first was the importance of the relationship of the takeoff foot to the top hand at the time of takeoff. Most authorities (Hay, 1966; Perrin, 1960; Railsback, 1968; Cramer, 1969) and many coaches (Coniam, 1963; Doherty, 1970; Kaufman, 1973; Jarver, 1972; Powell, 1965; Santos, 1975; Webb, 1974; and Wessels, 1978) agree the takeoff foot should be directly over the top hand at takeoff. The second factor, the distance from the center of gravity of the vaulter to the pole at the time of takeoff, was a major influence to successful vaulting (Vernon, 1974; Steben, 1970). The third factor, speed at the time of takeoff, plays a major role in vaulting performance (Barlow, 1973; Dillman, 1966; Ecker, 1971; Ganslen, 1974; Rohrbough, 1973). All of the information cited above has been an attempt to understand vaulting and to enable the reader to understand vaulting in relationship to this research project.

CHAPTER III

METHODS

The purpose of this study was to investigate the takeoff point in the pole vault. The data was obtained by cinematographical analysis of films taken during four indoor track meets held at Mitchell Hall Fieldhouse during the spring of 1979.

This chapter is divided into the following sections: description of subjects, filming procedures, digitizing procedures, computing procedures, data collection procedures, and statistical procedures.

Description of Subjects

Twenty-nine pole vaulters utilizing fiberglass poles were filmed during collegiate competition. Subjects for this study had to compete in one of four indoor track meets held at the Mitchell Hall Fieldhouse during the 1979 season. The subject had to successfully clear 13.5 feet. The subjects were from colleges in Iowa, Minnesota, and Wisconsin. The colleges involved were: Eau Claire, La Crosse, Luther, Oshkosh, Stevens Point, Stout, Superior, Whitewater, and Winona.

Vaults of 13.5 feet and above were filmed during the competition. Only successful vaults at 13.5 feet and higher were used for analysis. Ten vaulters were used as subjects and 38 vaults were analyzed.

Filming Procedures

A Cine-8, super 8 mm high speed motor driven motion picture camera was used to film each subject. The non-panning camera, utilizing an Angineaus 8-64 mm zoom lens with an F/stop setting of 1.9 captured the lateral view of each subject. The image area was adequate to encompass the subject and his pole. No attempt was made to film the complete vault. Kodak 4-X reversal film was used in the study. The filming rate was 100 frames per second with an exposure time of 1/225 of a second per frame.

The normal lighting of the facility was not adequate to get proper film exposure. Consequently, six Lowel Tota-light sockets with 1000 watt, 120 volt Westinghouse Tungsten Halogen Lamps were secured to the ceiling to provide adequate lighting. The camera was located 12 feet from the back of the pole vault box toward the runway and 36 feet at a right angle from that point (see Figure 1). The camera was positioned so the right leg of the subject was closest to the camera. The height of the camera lens was 54 inches. A one second sweep clock was positioned in the foreground to check camera speed and facilitate the analysis procedures. Number cards were positioned beside the clock to identify the subject and the trial being

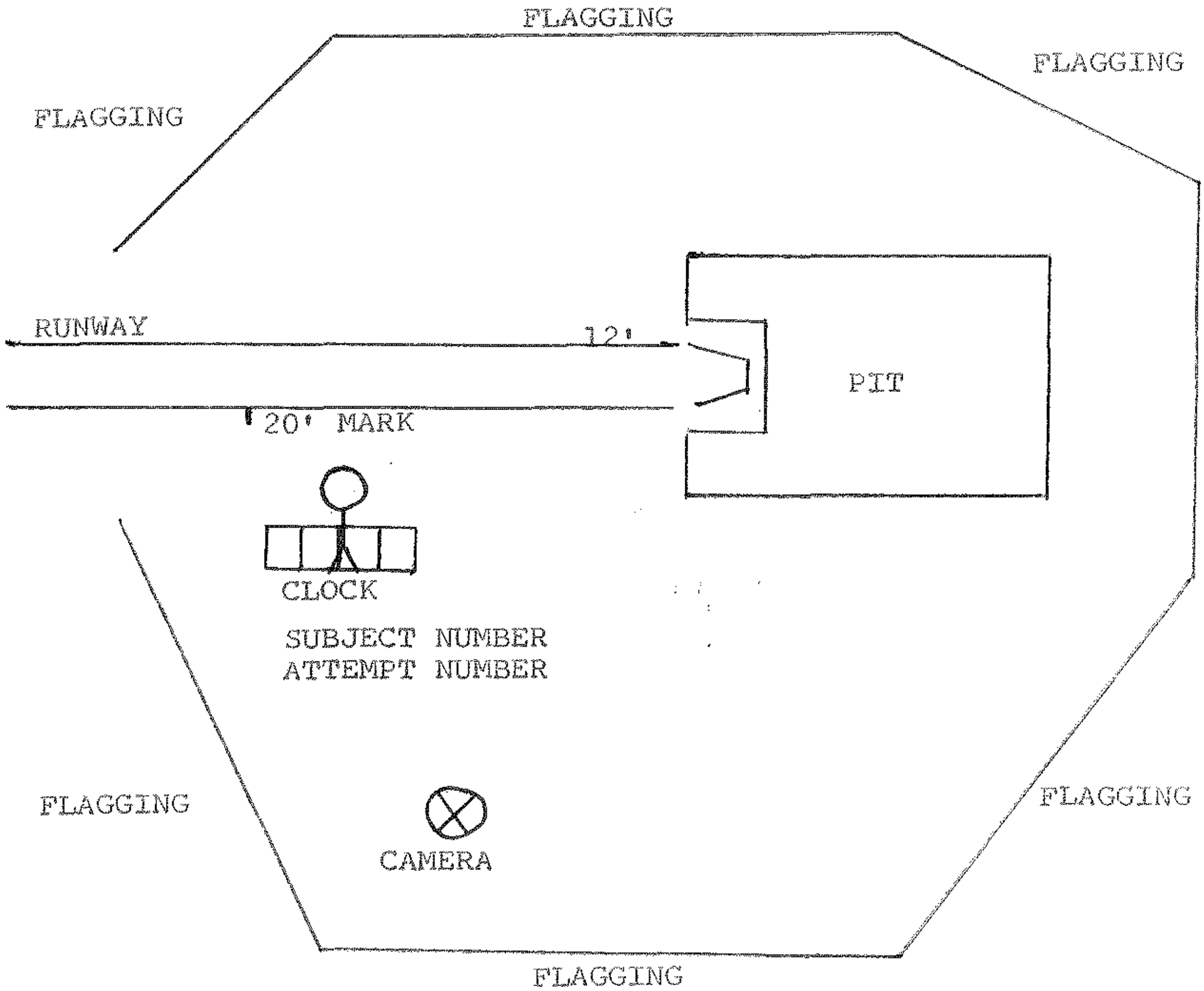

Figure 1

Experimental Setting

filmed. A yardstick was filmed as a reference measure to provide a scaling factor for real displacement. Two tennis court lines running perpendicular to the pole vault runway were used as a second reference measure.

The subjects vaulted in the order determined by the meet officials. Each subject's name was recorded along with trial numbers, height attempted, and success or failure of the vault. The camera was started as the subject passed a 20 foot mark placed alongside the runway and was stopped as the subject cleared or knocked off the crossbar.

Digitizing Procedures

The processed films were viewed with a Lafayette model AAP-927 super 8 mm motion analyzer set up in conjunction with a Numonics 1224 Electronic Digitizer, and a teletype printer with paper tape punching capabilities. The film appeared on a vertical screen and the frames could then be digitized. Six frames were used for each vault analyzed. Each frame was digitized three times for more accurate data. To determine the first three frames to be digitized the researcher single framed the film until the takeoff foot touchdown frame was ascertained. The projector was then put in reverse and backed up two frames. The projector was changed back to the forward mode and these three frames were used in determining the touchdown velocity. The chosen frames were used because they would give the maximum velocity of the vaulter as his takeoff foot touched the runway on his last step. It was felt any frame used into the landing would contaminate this maximum velocity.

The final three frames digitized were fixed by first determining the takeoff foot liftoff frame. With this frame established, the projector was reversed and backed up two frames. It was then put back into the forward mode and these three frames were digitized. These frames gave the researcher the liftoff velocity. It was felt these frames best described the velocity at the time the subject left the ground. Other forces began acting on the subject once he left the runway surface and became airborne. These forces were not part of this study. The sixth frame analyzed was also used to determine the perpendicular distance from the center of gravity of the vaulter to the pole.

The 20 segmental endpoints, object, and reference points as required by the FILMDAT program were located. These coordinates were recorded on paper tape and on the teletype printer.

Computing Procedures

The computing procedures for the data are divided into three stages: (1) storing data in file; (2) editing the data within the file; (3) running the data on the FILMDAT program.

The paper tape was loaded on a paper tape reader. A file was created for each vault and the data were stored in the file.

Errors were corrected through the file editing capabilities of the computer. Two types of errors were corrected: (1) errors made by the researcher when digitizing, and (2) errors made by the teletype when punching and printing data. Cards were punched to edit the file. The file was edited and the new listing was checked for error corrections and other possible errors.

Program, control, and information cards were then punched according to the requirements of the FILMDAT program. The data for each vault were run on the FILMDAT program and a three page printout was received with all the relevant information on it.

Data Collection Procedures

Three sets of data were collected to make the desired correlations. They were: (1) horizontal distance; (2) perpendicular distance from the center of gravity of the subject to the pole; (3) difference in velocity from takeoff foot touchdown to takeoff foot liftoff.

The horizontal distance was taken from the results of the FILMDAT program: Modified X-Y Coordinates in Scale Units. The first segmental endpoint located while digitizing was the fingertips of the right hand, and the sixteenth endpoint was the toe of the takeoff foot. The horizontal distance was calculated by recording the X-coordinates of each of these two endpoints and subtracting. A distance from the perpendicular point towards the pole vault box was considered a positive value and a distance from the perpendicular point away from the pole vault box was considered a negative value.

To obtain the perpendicular distance from the center of gravity of the vaulter to the pole, the films were put back into the projector and again viewed on the screen. The sixth frame of each vault was found using the counter on the projector. The pole was either bent or straight in this frame but the same method of finding the perpendicular distance was used in both cases. The researcher used the continuous length mode available on the digitizer and measured 12 feet from the top of the pole towards the bottom of the pole. This distance was used because of ease in viewing on the screen. A transparent ruler was then taped to the screen to act as a chord if the pole was bent and to help find the perpendicular distance if the pole was straight. One point of the chord was the top end of the pole and the second point of the chord was the 12 foot mark from the top of the pole. After the ruler was taped on the screen, the coordinate mode was reintroduced into the digitizer and the center of gravity of the vaulter was located. The center of gravity coordinates were obtained from the FILMDAT printout. The point to point length mode was then programmed into the digitizer with the first point being the center of gravity of the vaulter. A transparent right triangle was placed on the screen with one leg adjacent to the chord determined by the ruler and the other passing through the center of gravity of the vaulter. The digitizer's cursor was then moved to the second point, where the vertex of the right angle of the triangle coincided with the pole of the vaulter on the screen. This distance was then calculated by the digitizer and recorded by the researcher. The length was defined to be the perpendicular distance from the center of gravity of the vaulter to the pole at the time of takeoff.

The difference in velocity from takeoff foot touchdown to takeoff foot liftoff was obtained from the FILMDAT program printout. The Linear Component-Body Center of Gravity printout was used. The average of the first three frames digitized was used as the touchdown velocity and the average of the last three frames was used as the liftoff velocity. These velocities were recorded in feet per second and subtracted to obtain the velocity difference. A reduction in velocity was considered a negative value and an increase in velocity was considered a positive value.

Statistical Procedures

The Pearson Product Moment Correlation Coefficient was used to determine the relationship between horizontal distance and perpendicular distance from the center of gravity of the vaulter to the pole, and between horizontal distance and velocity difference from touchdown to liftoff at the time of takeoff.

CHAPTER IV

RESULTS AND SUMMARY

The purpose of this project was to study the location of the takeoff foot in relation to the top hand at the time of takeoff in the pole vault. Subjects were filmed during four indoor track meets held at Mitchell Hall Fieldhouse during the 1979 season. A vaulter had to successfully clear at least 13.5 feet during one of the meets to be included in the study. The films were examined, the data were analyzed, and the following null hypotheses tested at the .05 level of significance:

Ho_1: There is no relationship between the horizontal distance from the top hand to the takeoff foot and the distance from the center of gravity of the vaulter to the pole at the time of takeoff.

Ho_2: There is no relationship between the horizontal distance from the top hand to the takeoff foot and the difference in velocity of the center of gravity of the subject from touchdown to liftoff.

The results of the study are presented in the following sections: (1) general results; (2) horizontal distance results; (3) perpendicular distance from center of gravity of subject to the pole; (4) difference in velocity from touchdown to liftoff; (5) horizontal distance correlated with distance from center of gravity of the subject to the pole; (6) horizontal distance correlated with velocity difference; and (7) summary.

General Results

Vaults of twenty-nine subjects were filmed and the vaults of ten of these subjects were utilized in the study. The 38 vaults analyzed ranged from 13.5 feet to 15 feet for the four meets filmed. The mean, median, and mode were all 14 feet. The number of vaults per subject ranged from a maximum of six vaults for two subjects to a minimum of one vault for one subject with the mean being 3.8 vaults per subject. Table 1 presents a breakdown of this general information.

Four meets were filmed. Table 2 presents a breakdown of the vaults taken from each of the four meets. The number of vaults selected per meet ranged from a maximum of 17 vaults for the second meet to a minimum of four vaults for the first meet. Meet 1 was a quadrangular meet, meet 2 was a nine team invitational, meet 3 was a triangular, and meet 4 was a nine team conference meet.

Horizontal Distance

If a line is dropped from the middle of the top hand of the subject perpendicular to the ground, the line would intersect the ground at a point. The distance from this point to the toe of the takeoff foot at the time of takeoff

Table 1

Number of Successful Vaults and Totals at Given Height in Feet

Subject	Height				Total
	13.5	14.0	14.5	15.0	per subject
1	2	1			3
2	1	2	2	1	6
3	2	1			3
4	2	4			6
5	1	2			3
6		1	1		2
7		1			1
8	1	1	1	1	4
9	4	1			5
10		1	2	2	5
Tot./Ht.	13	15	6	4	38

Table 2

Vaulting Information for Each Meet in Feet

Meet	Height				Total
	13.5	14.0	14.6	15.0	per meet
1	3	1			4
2	5	6	4	2	17
3	3	3			6
4	2	5	2	2	11
Tot./Ht.	13	15	6	4	38

was defined to be the horizontal distance. A distance from the point towards the pole vault box was considered a positive value and a distance from the point away from the pole vault box was considered a negative value. The methods for determining this distance were previously defined in Chapter 3.

Horizontal distance ranged from 1.252 feet in front of the point to .205 feet behind the point. The mean was .607 feet and the standard deviation was .541 feet. Table 3 presents the horizontal distances.

<u>Perpendicular Distance from Center of Gravity of Subject to the Pole</u>

The methods for determining the perpendicular distance from the center of gravity of the subject to the pole at the time of takeoff were defined in Chapter 3 of the text.

This perpendicular distance ranged from a maximum of 2.703 feet from the pole to a minimum of 1.736 feet from the pole. The mean was 2.163 feet and the standard deviation was .219 feet. Table 3 presents the perpendicular distance from the center of gravity of the vaulter to the pole for each of the vaults analyzed.

<u>Difference in Velocity from Takeoff Foot Touchdown to Takeoff Foot Liftoff</u>

The difference in velocity from takeoff foot touchdown to takeoff foot liftoff was defined as velocity of the center

Table 3

Horizontal Distance, Perpendicular Distance from Center of Gravity of Subject to Pole, and Velocity Difference in Feet and Feet Per Second

Subject	Meet	Height	Horiz. Dist.	Perp. Dist.	Vel. Diff.
1	1	13.5	1.252	2.703	- 4.05
1	3	13.5	1.215	2.535	- 1.90
1	3	14.0	1.423	2.669	- 6.07
2	2	13.5	- .028	1.963	- 3.37
2	2	14.0	.037	2.056	- .76
2	2	14.5	- .181	2.088	- 3.74
2	4	14.0	- .240	2.080	- 2.84
2	4	14.5	.302	1.986	2.20
2	4	15.0	- .078	2.164	- 3.33
3	2	13.5	.205	2.302	- 1.42
3	4	13.5	1.207	2.023	- 5.17
3	4	14.0	1.371	2.127	- 7.64
4	2	13.5	.791	1.865	- 9.66
4	2	14.0	.265	2.186	- 2.25
4	3	13.5	.325	1.985	- 2.91
4	3	14.0	.947	2.023	- 6.97
4	3	14.0	.521	1.903	- 5.87
4	4	14.0	.652	1.736	- 4.33
5	1	13.5	1.067	1.839	- 2.75
5	1	14.0	1.082	1.955	- 4.26
5	4	14.0	1.215	2.174	-10.76
6	2	14.0	.270	2.321	- 3.27
6	2	14.5	.470	2.400	- 6.22
7	4	14.0	1.861	2.112	- 3.78
8	2	13.5	.488	2.349	- 5.33
8	2	14.0	.907	2.288	- 2.17
8	2	14.5	1.214	2.340	- 6.90
8	2	15.0	.526	2.512	- 4.36
9	1	13.5	.801	2.000	- 5.71
9	2	13.5	.409	2.126	- 3.61
9	2	14.0	.651	2.042	- 5.84
9	3	13.5	.546	2.205	- 2.87
9	4	13.5	1.455	1.981	- 3.84
10	2	14.0	- .205	2.288	- 3.03
10	2	14.5	- .074	2.270	- 8.09
10	2	15.0	.019	2.181	- 7.04
10	4	14.5	.276	2.284	- 6.00
10	4	15.0	.276	2.112	- 4.61
n=38			$\bar{x}$=.607	$\bar{x}$=2.163	$\bar{x}$= 4.49
			s=.541	s= .219	s=-2.47

of gravity of the subject just prior to takeoff foot touchdown, subtracted from the velocity of the center of gravity of the subject just prior to takeoff foot liftoff. A reduction in velocity was considered a negative value and an increase in velocity was considered a positive value. The data for this variable ranged from a 2.2 feet per second increase in velocity to a 10.76 feet per second decrease in velocity. The mean was -4.47 feet per second. Table 3 presents the difference in velocity from takeoff foot touchdown to takeoff foot liftoff.

<u>Horizontal Distance Correlated with Perpendicular Distance of Center of Gravity to Pole</u>

In testing the first null hypothesis, data collected and presented in Table 3 were correlated using the Pearson Product Moment Correlation Coefficient. It was hypothesized that as the horizontal distance decreased the distance from the center of gravity of the vaulter to the pole would increase. The obtained $\underline{r}\ (36) = .107$, $\underline{p} < .05$, was not significant. Therefore, the null hypothesis was not rejected.

<u>Horizontal Distance Correlated with Velocity Difference</u>

When testing the second null hypothesis, data collected and presented in Table 3 were correlated using the Pearson Product Moment Correlation Coefficient. It was hypothesized that as the horizontal distance decreased the difference in velocity from takeoff foot touchdown to takeoff foot liftoff would also decrease. The obtained $\underline{r}$ (36) = .261, $\underline{p} < .05$, was not significant. Therefore, the second null hypothesis was not rejected.

Summary

The following hypotheses were tested at the .05 level of significance:

Ho_1: There is no relationship between the horizontal distance from the top hand to the takeoff foot and the perpendicular distance from the center of gravity of the subject to the pole at the time of takeoff. Fail to reject, $p > .05$.

Ho_2: There is no relationship between the horizontal distance from the top hand to the takeoff foot and the difference in velocity of the center of gravity of the subject from takeoff foot touchdown to takeoff foot liftoff. Fail to reject, $p > .05$.

CHAPTER V

DISCUSSION, CONCLUSIONS, IMPLEMENTATION, AND RECOMMENDATIONS

This chapter is divided into the following sections: discussion, conclusions, implementation, and recommendations.

Discussion

The discussion is divided into the following sections: (1) general overview; (2) horizontal distance; (3) center of gravity to the pole; (4) velocity difference; (5) horizontal distance correlated with center of gravity to the pole; (6) horizontal distance correlated with velocity difference; and (7) general vaulting discussion.

General Overview. The major thrust of this project was to help substantiate the proper placement of the takeoff foot at the time of takeoff. Many researchers, coaches, and authorities (Bush, 1978; Coniam, 1963; Cramer, 1969; Doherty, 1970; Hay, 1966, 1973; Jarver, 1972; Kaufman, 1973; Moore, 1978; Perrin, 1960; Powell, 1965; Railsback, 1968; Santos, 1975; Webb, 1974; Wessels, 1978) agree the top hand and the takeoff foot should form a line perpendicular with the ground at the time of takeoff. This was referred to as horizontal distance in this study. A horizontal distance of zero would mean the top hand was directly over the takeoff foot. Other authorities (Bartholomaus, 1967; LeMasurier, 1964; Ryan, 1965) have offered information in opposition to the aforementioned assertion. Based on this conflict and a strong interest by the author, this project was conducted in an attempt to study position of the takeoff foot at the time of takeoff in actual competition.

Horizontal distance was compared with two accepted vaulting characteristics in an attempt to ascertain a correlation between them. One characteristic was the distance from the center of gravity of the vaulter to the pole at the time of takeoff. Steben (1970) and Vernon (1974) researched this characteristic and suggested it to be an important factor in vaulting performance. The second characteristic was the velocity at takeoff. Many authorities (Barlow, 1973; Dillman, 1966; Ecker, 1974; Ganslen, 1974; Rohrbough, 1973) have researched approach velocity and have concluded it to be of paramount importance in successful vaulting.

Horizontal Distance. Hay (1966) researched horizontal distance and concluded it was important to have a horizontal distance close to zero. In his study he used one pole vaulter who varied his techniques during the study. Bartholomaus (1967) conducted a study using nine vaulters, dividing them into maximal and submaximal ability groups. One factor he considered was horizontal distance. He concluded horizontal distance was not related to takeoff velocity or to takeoff pole bend.

This project analyzed 38 vaults of 10 vaulters and observed the horizontal distance. Horizontal distance ranged from 15 inches in front of a point directly below the top hand to 2.5 inches behind that point. The mean for the group was just over seven inches. For the four vaults of 15 feet, two of the vaults had horizontal distances of less than one inch. The other two vaults had horizontal distances of approximately three and six inches. Two of the three vaulters clearing 15 feet had horizontal distances of less than 4 inches in all vaults but one.

A problem seems to be prevalent when describing horizontal distance among many vaulters. In the study done by Hay (1966) using one vaulter, certain characteristics of the subject always remained the same and he did not encounter the different styles prevalent among many vaulters. The study by Bartholomaus (1967) and this study seem to exhibit the multifaceted characteristics of pole vaulting. Ryan (1965) suggested the fiberglass pole gave more latitude in the placement of the foot. The possibility of analyzing larger numbers of subjects and vaults could further enhance our body of knowledge in this area.

<u>Perpendicular Distance from Center of Gravity to Pole</u>. Steben (1970) and Vernon (1974) concluded that keeping the center of gravity away from the pole at the instant of takeoff was important in good vaulting. Steben (1970)

defined his distance from the vaulter to the pole via a waistband located close to the actual center of gravity of the vaulter to a tangent line drawn on the pole in the constructed drawing. The line, explained as being tangent to the pole, was not defined as to how the arc was determined to ascertain this point of tangency. Vernon (1974) defined his distance from the vaulter to the pole as the distance from the center of gravity of the subject to a point midway between the hands at the time of takeoff. In his computer study the distance was initially 38 inches.

The techniques used in this study to determine distance from the center of gravity of the vaulter to the pole showed two basic states of the pole at the instant of takeoff. In two subjects the poles at this instant were bent to near capacity and most other cases the poles showed little bend at that time and did not reach maximum bend until later in the vault. The perpendicular distance from the center of gravity of the vaulter to the pole ranged from approximately 32 inches to approximately 21 inches and the mean was about 26 inches. The mean perpendicular distance from the two subjects with large pole deflections at takeoff was about 30 inches. Because these two different states of the pole existed, perpendicular distance from the center of gravity of the subject to the pole at takeoff was not a good measure as defined in this study. It seems that two solutions could exist to equalize this condition. One, if the poles were assumed to be straight and a chord used as the pole instead of the actual pole to determine perpendicular distance from the center of gravity of the subject to the pole. The other alternative could be to determine perpendicular distance from the center of gravity of the subject to the pole at the time of maximum pole bend for all subjects. Either of these two alternatives could rectify the dilemma. It would appear that because of the differences in style among vaulters, a different point in time of the vault sequence could be chosen to be the best indicator of the distance from the center of gravity of the vaulter to the pole.

Velocity Difference. The concept concerning approach and takeoff velocity in the pole vault has been discussed by many persons (Barlow, 1973; Dillman, 1966; Ecker, 1974; Ganslen, 1974; Rohrbough, 1973). The notion of a velocity difference from takeoff foot touchdown to takeoff foot liftoff was discussed by Hay (1975) when he researched and discussed the hitch-kick and somersault flight techniques in the long jump. He studied the loss of horizontal velocity from the horizontal velocity of the last stride to the horizontal velocity at takeoff, and concluded a smaller difference occurred in the somersault technique than in the hitch-kick technique. This same type of velocity difference was studied in this research. Hay (1975) recorded mean velocity changes of -3.9 feet per second and -4.5 feet per second for the two techniques. The mean velocity change for the subjects in this study was -4.49 feet per second. These results seem consistent with Hay's (1975) reported results in that both the long jump and the pole vault have similarities in the area of takeoff.

The touchdown velocities for the subjects in this study ranged from 32.47 feet per second to 24.58 feet per second with a mean velocity of 28.28 feet per second. The liftoff velocities ranged from 27.16 feet per second to 19.25 feet per second with a mean of 23.79 feet per second. Although the fastest touchdown velocity was recorded by one of the 15 foot vaulters, other vaulters not vaulting over 14 feet recorded almost equal velocities. The fastest liftoff velocity, 27.16 feet per second, was recorded by subject 2, another 15 foot vaulter. The next fastest liftoff velocity recorded by another subject other than subject 2 was 25.85 feet per second. This was recorded by subject 4. These liftoff velocity results concur with Ecker's (1971) statements in which he discussed the possibility of having 20 foot vaults. He stated the velocity at takeoff needed to be about 30 feet per second to achieve that height.

The velocity differences within the subjects varied greatly. Subject 5 recorded a loss of velocity of -10.76 feet per second during one vault and a loss of velocity of -2.76 feet per second during another vault. While most subjects were not that inconsistent, velocity differences did vary. Subject 10 had the second largest mean velocity difference of all the subjects. The velocity difference was 5.75 feet per second for subject 10.

Horizontal Distance Correlated with Perpendicular Distance of the Center of Gravity of Subject to the Pole. One of the relationships being tested in this study was that as the horizontal distance decreased, the distance from the center of gravity of the subject to the pole would increase. The correlated results yielded $\underline{r}$ (36) = .107, $\underline{p} > .05$.

Subject 1 and subject 8 had the largest and the third largest mean horizontal distances, 1.297 feet and 1.118 feet respectively, and had the largest perpendicular distances from their center of gravity to the pole, 2.636 feet and 2.272 feet respectively. The state of the pole at this time for these two subjects was near maximum deflection. These results support LeMasurier's (1964) contentions that it was better to have the takeoff foot closer to the planting box to enable the vaulter to have more bend in the pole. These subjects literally ran into the pole forcing it to bend by maintaining a solid left arm and a straight right arm, yet keeping their foot on the runway. This was one of the techniques used to bend the pole in this study. The other condition of the pole at the time of takeoff was that the pole was nearly straight. For this group of subjects, those having a small horizontal distance had their center of gravity the greatest distance from the pole and were those clearing the highest heights. The pole bent for this group after they had left the ground. It appeared from viewing the film, those subjects with smaller horizontal distances and greater center of gravity away from the pole distances had the most pole deflection. Ganslen (1974) discussed a possible explanation for these two different styles when he stated:

> The perfect pole vault takeoff may not be perfect. The point of takeoff in the vault becomes of no significance whatsoever if the position of the vaulter's body relative to the takeoff foot is such that he cannot drive effectively forward and upward. (p. 37).

Both groups of vaulters were putting their bodies into a position where they could drive effectively forward and upward and feel comfortable with that style. It seems appropriate to restate Ryan's (1965) suggestion that the fiberglass pole gave the vaulter more latitude in the placement of the foot.

<u>Horizontal Distance Correlated with Velocity Difference</u>. The second relationship being tested in this study was that as the horizontal distance decreased the differences in velocity from takeoff foot touchdown to takeoff foot liftoff would also decrease. The correlated results yielded $\underline{r}$ (36) = .261, $\underline{p} > .05$.

One of the 15 foot vaulters, subject 2, had the smallest mean horizontal distances of -.031 feet and smallest mean velocity differences of -1.97 feet per second. Subject 10, another 15 foot vaulter, had a mean horizontal distance of .058 feet and had the second greatest velocity difference with mean - 5.75 feet per second. The third 15 foot vaulter, subject 8, had a mean horizontal distance of 1.118 feet and a velocity difference of -4.49 feet per second for the entire group.

The results of subject 2 could be explained after having looked at the films. This vaulter's foot was generally below the top hand, thus putting him in a powerful driving position for maintaining his mean touchdown velocity of 27.40 feet per second, to a mean liftoff velocity of 25.43 feet per second as he left the runway. His mean touchdown velocity was below the 28.28 mean touchdown velocity for the group but his liftoff velocity mean was above the mean of 23.79 feet per second liftoff velocity for the entire group. The results of subject 8 seemed explainable because he bent his pole to near maximum deflection before he left the ground. His mean touchdown velocity was 28.25 feet per second and his mean liftoff velocity was 23.56 feet per second. Both velocities were close to the mean for all the subjects. This large amount of pole deflection before leaving the ground would explain the loss in velocity. The results of subject 10 were interesting. He had the highest mean touchdown velocity of 30.13 feet per second and a liftoff velocity of 24.38 feet per second. His liftoff velocity was still above the mean liftoff velocity for the entire group with 23.79 feet per second. Therefore, while he had the second greatest loss in velocity he still had a liftoff velocity above the mean for the entire group. Rohrbough (1973), Barlow (1973), and Dillman (1966) indicated the importance of obtaining maximum takeoff velocity. By observing differences in these three subjects it is possible to understand the varying combinations of vaulting styles all achieving large liftoff velocities when compared with this entire group.

General Vaulting Discussion. Pole vaulting is primarily a closed skill as defined by Lawther (1977) and Sage (1977). For the group of subjects studied, the prescribed standard sequence differed within the group. At this level of performance, larger deviations by the athlete are acceptable and he can remain competitive. Pole vaulting is such a multi-dimensional skill that a deficiency in one area can be compensated by strength in another area. It is when performance approaches world class level that deviations are minimal and deficiencies for the most part are not observed. This study looked at a particular level of vaulters in an attempt to understand more about pole vaulting.

Conclusions

Based on the results of this study, the following conclusions are offered:

1. No significant relationship was observed between horizontal distance from the top hand to the takeoff foot and perpendicular distance from the center of gravity of the vaulter to the pole and between horizontal distance from the top hand to the takeoff foot and velocity difference from touchdown velocity to liftoff velocity of the center of gravity of the subject.
2. Pole vaulting is a multifaceted event and different factors within the event can be performed in different ways and still yield success to the vaulter at this level of performance.
3. Having varying amounts of velocity differences does not seem to be a factor in vaulting, providing the final liftoff velocity is great.

Implementation

Based on the results of this study, the following implementation is offered:

1. The vaulter should attempt to maximize his liftoff velocity. Achieving this maximum liftoff velocity can be accomplished through a number of methods.

Recommendations

The following suggestions are offered for future research:

1. A study be conducted utilizing the same criteria as this study but using a wider range of successful vaults and more subjects.
2. A study be conducted using the same criteria as this study but redefining perpendicular distance from the center of gravity of the vaulter to the pole, eliminating velocity difference, and using liftoff velocity in its place.

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APPENDIX A

Raw Data for Horizontal Distance and Velocity Difference

In Feet and Feet Per Second

Subject	Height	Horiz. Dist. Hand-X	Horiz. Dist. Toe-X	Velocity Diff. *T.D.V.	Velocity Diff. L.O.V.
1	13.5	3.03	5.61	24.58	20.53
1	13.5	2.88	5.42	25.54	23.64
1	14.0	2.82	5.21	25.32	19.25
2	13.5	1.29	1.23	29.57	26.20
2	14.0	.86	.94	25.78	25.02
2	14.5	.56	.17	27.20	23.46
2	14.0	1.03	.57	29.10	26.26
2	14.5	.03	.61	24.96	27.16
2	15.0	.35	.20	27.78	24.45
3	13.5	3.07	3.51	26.39	24.97
3	13.5	2.56	4.53	28.24	23.07
3	14.0	1.85	4.48	28.89	21.25
4	13.5	1.41	3.01	30.89	21.23
4	14.0	1.36	1.93	28.14	25.85
4	13.5	1.02	1.70	28.48	25.57
4	14.0	.68	2.66	30.34	23.37
4	14.0	.32	1.41	28.88	23.03
4	14.0	.33	1.58	29.53	25.20
5	13.5	1.93	4.13	27.89	25.14
5	14.0	1.95	4.18	26.66	22.40
5	14.0	2.40	2.98	27.34	24.07
6	14.0	2.40	2.98	27.34	24.07
6	14.5	2.59	3.60	27.27	21.05
7	14.0	2.16	5.73	29.06	25.28
8	13.5	1.86	2.91	28.89	23.56
8	14.0	1.59	3.54	26.19	24.02
8	14.5	2.42	5.03	28.25	21.35
8	15.0	1.63	2.76	29.68	25.32
9	13.5	3.06	4.71	29.48	23.77
9	13.5	2.82	3.70	26.45	22.84
9	14.0	2.30	3.70	29.52	23.68
9	13.5	2.31	3.49	27.06	24.19
9	13.5	1.86	4.65	28.05	24.21
10	14.0	.68	.24	28.87	25.84
10	14.5	.32	.16	32.47	24.38
10	15.0	.15	.19	31.40	24.36
10	14.5	.10	.62	28.34	22.34
10	15.0	.18	.71	29.58	24.97
n=38	$\bar{x}$=14.0			$\bar{x}$=28.28	$\bar{x}$=23.79

*T.D.V.=Touchdown Velocity L.O.V.=Liftoff Velocity