A COMPARATIVE CINEMATOGRAPHICAL ANALYSIS OF MALE AND FEMALE FOSBURY FLOP HIGH JUMPERS

by

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B.S. California State University, Fullerton

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements of the degree

MASTER OF SCIENCE

Department of Health, Physical Education and Recreation

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1975

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DEDICATION

This thesis is dedicated to the one person
most responsible for its completion
John Murray.
Thanks, Grandpa!

ACKNOWLEDGEMENT

The investigator of this study would like to individually acknowledge and thank the many people who contributed to the completion of this study. The contributions made by these people came in many forms, all of which were essential.

Thanks are extended to Dave O'Brien and Keith Trobridge for putting up with my constant inquires as to the scheduling and reserving of the fieldhouse for each filming session. The investigator is deeply indebted to the following people for their assistance during the filming sessions: Brenda Ball, Kathy Biege, Don Carter, John Charles, Mary Phyl Dwight, Brad Gibson, Mike Kitch, Greg Kohrs, Joni Luthie, Bonnie McMullen, Tabor Medil, Dr. Janice Merriman, Kathy Olson, Mary Jo Prochazka, Jan Reuser, Lance Reed, Paul Shimon, and Jan Smith. A special thanks is given to Dr. William H. Honstead for loaning to the investigator five Berkley Colortram Multi-Beam Photography lamps. The professional assistance of the people at photographic services, who processed the film for this study was greatly appreciated.

The investigator is very grateful to Bob Umholtz who developed the "Wildcat" computer program. The program saved the researcher many long and tedious hours of mathematical computations.

The author was tremendously aided in locating many valuable resources for his "Review of Related Literature" by

Dr. Ken Doherty, Dr. James G. Hay, Berny Wagner, Fred Wilt, and Sergio Zanon.

The particular advice and suggestions indirectly related to this thesis by Dr. David Laurie and Dr. John Merriman was greatly appreciated. This investigator is deeply indebted to Barry Anderson, Deloss Dodds, John Hardwick, and Karen Wallace for they supplied the subjects for this study. In addition to their cooperation each of these persons made valuable suggestions for improving this study. A deep appreciation is acknowledged to Cheryl Friesen, Ann King, Allan Moore, and Rick Sliefer for consenting to participate as subjects in this study.

Thank you's are extended to the researcher's committee members Dr. Charles B. Corbin, Dr. Larry M. Noble and Dr. Mike Holen, for their valuable advice and suggestions. In addition a tremendous debt is owed to Dr. Janice Merriman for her professional advice and guidance throughout this investigation, as well as for putting up with the author's needy grammar, atrocious spelling and faulty writing style.

A special thanks goes to Don Carter for editing and proofreading the rough drafts of this thesis. A final thanks is given to Pat Routh for typing the final manuscript of this thesis. The author's name appears on the title page, but this was definitely a group effort.

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CHAPTER 1

INTRODUCTION

In the 1968 Olympics Dick Fosbury and his Fosbury flop revolutionized Track and Field by breacking the world's record in the high jump. The Fosbury flop is a unique high jump technique in which the jumper turns his back to the crossbar and the body crosses the bar at a right angle. Since the 1968 Olympics many high jumpers, novice and pro, male and female, have developed their own variation of the Fosbury flop. At the present time both the men's (7' 6 3/4") and women's (6' 3 5/8") world records are held by jumpers who use a variation of the Fosbury flop.

While Fosbury was receiving his gold medal in Mexico, a second revolution was in the making back in America. Little girls were trying to break the sex barrier into Little League Baseball. Females began playing on male tennis, waterpolo and football teams. The female athlete was making her demands for increased competition and a chance to perfect her well-known skills, all of which eventually resulted in the Renaissance of Women's Athletics.

With the growth of women's athletics, people began to recognize the improved performances of the female athlete. Comments such as, "She high jumps just like a boy!" could be heard at female track meets. But, do male and female athletes perform a motor skill just alike? And if they do, do they perform the skill correctly?

STATEMENT OF THE PROBLEM

The specific problem of this investigation was to determine the biomechanical differences between male and female Fosbury flop high jumpers. Men and women have been high jumping for many years and men have consistently jumped greater heights than women. Other than the fact that men have cleared higher heights than women, little is known about the differences in the biomechanical performance between the male and female high jumpers.

PURPOSE OF THE STUDY

The purpose of this study was to compare the biomechanics of male and female Fosbury flop high jumpers using cinematographic analysis. The criteria used to compare the performance of male and female jumpers were selected factors considered to be the most important in the performance of the Fosbury flop. More specifically, the purpose of this study was to determine if males clear greater heights than females because they have a more effective vertical velocity at take-off, and/or a more efficient manipulation of body segments during bar clearance. Cinematography, segmental analysis, and the "Wildcat" computer program were used to record, gather and analyze the kinematic and kinetic data to make the comparison of male and female Fosbury flop high jumpers.

NEED FOR THE STUDY.

Today, more than ever before, physical education and coaches are recognizing that individual needs of students and athletes should be considered if optimal motor skill performance is to occur. These needs may stem from individual student variations in physical ability, sociability, psychological stability, intelligence, body type, previous experiences, age and sex. The intent of this investigation was to examine the variable of gender on the biomechanical performance of the Fosbury flop. Even though individual differences will occur within a specific sex, there is a great need to know the biomechanical differences between male and female high jumpers. Knowing these specific biomechanical differences enables the deduction of reasons as to why these differences occur, and enables the practictioner establish training programs to meet the specific needs of the learner.

The lack of biomechanical research data initiated the need to determine the differences between male and female Fosbury flop high jumpers. Physiological and anatomical research has shown some of the differences between the two sexes that affect one's ability to jump high. However, research has failed to determine the biomechanical differences between male and female high jumpers.

The biomechanical research specifically related to this investigation was especially limited. A study comparing novice male and female long jumpers was the only biomechanical investigation that has examined the variable of gender on motor skill performance (27). Four investigations have been performed concerning the Fosbury flop, all of which recommend that further research be conducted on the Fosbury flop (3,20,25,49).

Not only was the quantity of scientific information specifically related to the problem of this investigation limited, but the quality of the available information was questionable. Other than a few biomechanical investigations the majority of the information available at the present time has been based on observations of motor skill performances. Observations of a motor skill performance is a very inaccurate method of gathering kinematic and kinetic data. "It is almost impossible, without cinematographic records, to accurately view through the naked eye the distal ends of the limbs in a fast action" (9:1). Thus the investigator should not use observations as the foundations of his research. The researcher needs to use high speed cinematography to slow down the movement of a motor skill performance for accurate analyzation.

DELIMITATIONS OF THE STUDY

Due to the nature of this type of study, the following delimitations were selected and incorporated into the procedures.

1. The scope of this study was delimited to the sexual differences in the biomechanical performance of the Fosbury flop.

2. The skill was filmed indoors, under a non-competitive situation at Kansas State University's Ahearn Field House.

3. The subjects voluntarily participating in this study were two males and two females. All subjects were highly skilled Fosbury flop high jumpers for their sex.

4. The cinematographic analysis of the skill began during the last stride of the approach and ended as soon as the entire body had cleared the crossbar.

LIMITATIONS OF THE STUDY

Several limitations were presented in this study. These limitations were uncontrollable by the investigator due to time, facilities and equipment.

1. Some measurement and computational errors may have occurred when marking and reading the film, enlarging the film images, and/or transferring the data.

2. A small sample size, consisting of two males and two females, may have biased the results.

3. The study was limited by the accuracy and quality of the camera and the other equipment used.

4. The use of one camera to film the skill in its major plane of action limited measurement and analysis to the horizontal and vertical components of the jump.

5. The film was taken at the beginning of the track season, thus the athletes were not in peak condition physically or mentally.

6. Two filming sessions were required and not all subjects were filmed on the same day.

7. The film was taken in a non-competitive laboratory situation, thus preventing the same type of stress as in the competitive environment.

8. The stress of the laboratory situation was new and different to all subjects, and may have affected their performance.

BASIC ASSUMPTION OF THE STUDY

For the purpose of this study it was assumed that cinematographic analysis would be a valid and reliable measurement device to analyze the biomechanics of the Fosbury flop.

DEFINITION OF TERMS

For the purpose of this study, the terms listed below were defined as follows.

Cinematography

The use of a motion camera to record motion for the purpose of analysis.

Center of Gravity

"Within every mass there is a point about which the gravitational forces on one side will equal those on the other side. This balance point determined in three planes of the mass is the center of gravity" (7:165).

Heel Strike

The initial contact of the foot with the ground during the plant phase.

Kinematic

". . . the geometry of motion, which includes displacement, velocity, and acceleration without regard for the forces acting on a body . . . "(43:111).

Kinetic

". . . incorporates the concepts of mass, force, and energy as they affect motion"(43:11).

Plant Foot

The plant foot is the foot of the take-off leg. The plant or take-off foot is the foot farthest away from the crossbar during take-off.

Segmental Analysis

A method used to determine the center of gravity of a human body by finding the center of gravity of the body's segments.

Swing Foot

The swing foot is the foot of the swing leg.

Swing Leg

The swing leg is the leg opposite of the take-off leg. The swing leg is also referred to as the lead leg or free leg.

Take-Off Leg

The take-off leg is the supporting leg during the take-off phase of the jump.

Take-Off Time

The elapsed time from heel strike of the take-off foot to when the big toe of the take-off foot leaves the ground during the take-off phase of the jump.

The Wildcat

The "Wildcat" is a computer program, developed at Kansas State University, to calculate the body's and body segments' center of gravity and velocities while in motion (see Appendix A).

CHAPTER 2

REVIEW OF RELATED LITERATURE

A review of the related literature specific to the problem of this investigation was performed to establish the movement and mechanics of the Fosbury flop, biomechanical differences based on gender, and the validity and reliability of cinematographic analysis. The literature presented here was based on observations, opinions and various methods of biomechanical research. This chapter was divided into four sections: high jumping and the Fosbury flop, biomechanical differences between males and females, cinematographic analysis, and a summary.

HIGH JUMPING AND THE FOSBURY FLOP

Describing the movements of a physical activity provides the information necessary to understand "how" the activity is performed. Explaining the mechanics of a physical activity gives the reasons for "why" those movements are necessary. To understand the interrelationship between the movements and mechanics of high jumping and the Fosbury flop this section was divided into four areas: the objectives of high jumping, factors contributing to the effectiveness of take-off, factors that contribute to the efficiency of bar clearance, and an analysis of the Fosbury flop.

The Objectives of High Jumping

As the name of the event indicates the object of high jumping is to jump as high as possible. To jump high or to raise your center of gravity as high as possible is not the only objective in high jumping. The jumper should raise his center of gravity as high as possible and position himself for the most efficient bar clearance. Ryan (44:3) accurately describes this relationship.

> An effective lift! An efficient clearance! These two points form the entire basis of good high jumping. The task is to get the body high in the air and then make the most of that height by a good clearance.

When jumping for the greatest height possible it is impossible to obtain both a maximum height of the center of gravity and maximum efficiency of bar clearance. Dyson (15:139) explains how this phenomena occurs.

> . . . maximum efficiency in one can be obtained only at the expense of the other. All good high jumping is therefore a compromise; to obtain economy of the lay-out good jumpers drive eccentrically at take-off slightly reducing their effective spring, but in the process gaining more through their position over the bar.

Thus, the true objective of high jumping is to produce the most effective and efficient compromise between the height that the center of gravity can be raised and the positioning of the center of gravity during bar clearance. In addition, the height that the jumper clears is determined by the factors contributing to the effectiveness of take-off and the efficiency of bar clearance.

Factors Contributing to the Effectiveness of Take-Off

The factors contributing to the effectiveness of take-off include the height of the jumper's center of gravity at take-off (H_1) and the maximum height that the athlete raises his center of gravity after take-off (H_2) (17:437). The effectiveness of these factors is a result of many smaller components that will be discussed in this section.

The higher the center of gravity at take-off results in a higher elevation of the center of gravity after take-off; since the center of gravity is being projected from a higher point. Hay (18:439) describes how the jumper can position his body segments to achieve the optimum position for take-off.

> . . . the optimum body position in terms of the height of the center of gravity at take-off is one with the trunk errect, both arms high, lead leg extended and high, and jumping leg fully extended and vertical.

The only variation from the above description in the Fosbury flop is a flexed lead leg (at the knee joint) rather than an extended lead leg. Dyatchkov (14:439) found that the center of gravity at take-off was 3.2 inches lower when the knee joint of the swing leg was flexed. The flexed swing leg lowers the height of the center of gravity at take-off and reduces the vertical force at take-off, but it increases the vertical velocity at take-off by decreasing the take-off time.

The height that the jumper's center of gravity rises in flight, from the point of the center of gravity at take-off, is governed by the vertical velocity at take-off, and the angle of projection. The components of the vertical velocity at take-off include: the vertical velocity at heel strike and the vertical impulse at take-off (18:439).

Hay (18:439) explains the movements and mechanics necessary to obtain the most efficient vertical velocity at heel strike (touchdown).

> The athlete's vertical velocity at touchdown depends primarily on his actions during the last one to two strides of his run-up. If at the end of his penultimate stride the athlete has sunk low over his supporting leg and then taken a low fast step onto his take-off foot, his center of gravity is likely to have little or no downward vertical velocity at the instant this foot touches down. On the other hand, if by failing to sink low at the end of his penultimate step he makes his last step like those that have preceeded it, the athlete's downward vertical velocity at touchdown is likely to be relatively large. And, since the athlete must first arrest this downward motion before he can begin to drive his body upward, this large downward velocity acts to his detriment. In fact, although it has yet to be convincingly demonstrated in practice, the ideal would be to have the athlete's center of gravity moving upward at the instant his take-off foot contacted the ground.

Theoretically an upward vertical velocity at heel stride indicates that less force is being absorbed during the plant of the take-off foot, and thus less time is required to perform the movements of take-off, because the downward vertical velocity does not have to be overcome.

The magnitude of the vertical impulse at take-off is determined by the vertical force exerted against the ground and the take-off time. A maximal vertical impulse is attained by increasing the magnitude of the vertical force exerted, while decreasing the take-off time (18:439).

A jumper projects himself into the air by exerting a force greater than the force of supporting his weight. The magnitude of the vertical forces developed during take-off are dependent on the simultaneous swinging of both arms and the swing leg with the extension of the hip, knee, ankle, and phalangeal joints of the take-off leg.

The rapid concentric contraction necessary for extension of the hip, knee, ankle, and phalangeal joints of the take-off leg is dependent on the strength, elasticity, and eccentric contraction of the extensor muscles of the take-off leg. The eccentric contraction of the extensor muscles at heel strike places these muscles on stretch, which yields a greater contractile force in these muscles during the concentric contraction of the take-off (21:74). The jumpers must possess a tremendous amount of strength in the take-off leg or the leg will collapse during the plant and take-off phases of the jump (15:144). The greater the elasticity of the extensor muscles of the take-off leg, results in less force being absorbed into the ground, and causing greater vertical force at take-off and a shorter take-off time (36:267).

Hay (18:448) says there are three functions of the upward swing of the swing leg and arms.

1. It increases the magnitude of the vertical force exerted against the ground, the vertical force that the ground exerts on the athlete in reaction and thus the athlete's vertical velocity at take-off.
2. It imparts angular momentum to the athlete's body. As the swing of the lead leg and arms slow down, the angular momentum that these limbs possess is transferred to the body as a whole.
3. It increases the heights of the athlete's center of gravity at the instant of take-off.

The third function listed above was discussed earlier in this section and needs no further explanation. The first two functions of swinging the arms and swing leg are dependent on each other. The angular momentum developed by swinging these free limbs is transferred to the body as a whole, which increases the magnitude of the vertical force exerted against the ground.

The flexed swing leg that is used in the Fosbury flop decreases the height of the center of gravity at take-off and reduces the vertical force exerted at take-off. Research by Dyatchkov (14:449) with straddle roll jumpers, showed that those jumpers who used a straight swing leg at take-off exerted between 236-258 pounds of force at take-off and a jumper who used a flexed swing leg exerted 106 pounds of force at take-off.

The vertical impulse at take-off increases as the take-off time decreases. The take-off time can be decreased by conserving the angular momentum of the swing leg and arms during take-off. Angular momentum can be conserved by shortening the length of the swing leg and arms (flexion at the knee and elbow joints). Hay (20:4) has reported a faster take-off time for flop jumper's who used a flexed swing leg (0.13-0.15 of a second), than straddle roll jumpers who used a straight lead leg (0.18-0.22 of a second). Hay (20:5) then concluded that,

> Efforts to incorporate the . . . straight-lead leg action of the straddle roll into the Fosbury flop are unlikely to be successful in producing greater vertical impulses for they eat away at the very strength of the Fosbury technique--short time of take-off.

The angle of projection is the resultant velocity of the combination of the horizontal velocity of the approach run and the vertical velocity of take-off (17:24). Cooper (8:107) explains the problem of the ideal angle of projection and the compromised angle of projection.

> Ideally a 90 degree angle of take-off would project the jumper upward, but would not enable him to rotate over the bar so he must sacrifice a certain amount of optimum angle position to get over the bar. A 78 degree angle of take-off is the largest angle yet recorded by the writer of any outstanding jumper. The possibility of a higher angle of take-off in the future is not beyond the theoretical realm of accomplishment.

The angle of projection cited by Cooper was for a straddle roll jumper. The angle of projection for Fosbury flop high jumpers has not been studied as yet.

Factors Contributing to the Efficiency of Bar Clearance

The factor that indicates bar clearance efficiency is the difference between the maximum height reached by the jumper's center of gravity and the height of the crossbar (H_3) (18:437). Bar clearance efficiency is considered to be most efficient when the distance between the crossbar and the jumper's center of gravity is minimal (15:151). Excellent bar clearance occurs when the jumper's center of gravity passes through or below the crossbar.

Once a human body has become air borne, the flight path of the center of gravity has been determined and can not be changed by body movements. However, body movements can change the position of the center of gravity within the body. Thus, the jumper does not change the parabolic curve of the jump, but the athlete can change the position of the center of gravity within his body, in relation to a point along this predetermined parabolic curve (16:32-33).

Changing the position of the center of gravity within the body is a result of manipulating various body segments. The center of gravity will move within the body in the direction of the greatest amount of body mass. Thus maximal bar clearance efficiency is achieved by placing the greatest amount of body mass below the crossbar at the peak of the jump (15:151). Fosbury flop jumpers place part of their thighs, lower legs, and feet below the crossbar. Those jumpers who use an exaggerated back hyperextension place their head, shoulders, and parts of their upper back below the crossbar during bar clearance. The manipulation of these body segments in this manner places the center of gravity outside of the body and closer to or below the crossbar (46:261). Hay (19:277) had a high jumper pose atop a trestle in a variety of bar clearance positions to see the relationship of the center of gravity to the crossbar. His data showed that the ideal Fosbury flop bar clearance position placed the center of gravity 3.3 inches below the crossbar. Whether such a position can be achieved in practice has yet to be determined.

Kerssenbrook (22:1292) explains why the flop jumpers are able to place their center of gravity outside their body, so as to pass through or below the crossbar.

> Fosbury's position over the bar is . . . a model of perfect economy . . . In accordance with this opinion of many authorities, the center of gravity in the normal attitude of the body (errect) is found about 3/4" before the sacral vertebra in the direction of the stomach wall i.e. nearer to the back-side than to the stomach-side. With regard to this fact, it is possible to get into a position in which the center of gravity falls behind or outside the jumper's body. To reach the same advantage in the direction of the stomach-wall would necessitate such an extreme body position that it would (for other biomechanical reasons) not be advantageous at all.

Analysis of the Fosbury Flop

Literature measuring and describing the movements and mechanics specific to the Fosbury flop will be presented in this section. This section will be divided into five catagories: approach, plant, take-off, flight and bar clearance.

Approach.

The approach or approach run consist of the movements from the jumpers first stride, to heel strike of the plant foot just prior to take-off. The approach run used in the Fosbury flop is a fast curved approach, that begins perpendicular to the crossbar and curves so the last three to four strides are at an angle of 40 degrees to the crossbar. Factors that will influence the approach run include: angle of the approach, speed of the approach, length of the approach, and centrifugal force of the approach.

As mentioned above, the angle of the approach for the last three or four strides is 40 degrees to the crossbar. Dyson (15:140) makes two observations as to the benefits of such an approach angle.

> An angled approach can be advantageous to all high jumpers regardless of style, because (i) it facilitates a greater range of free leg swing at take-off and (ii) it makes possible the throwing of some part of the body over and below the bar before the center of gravity reaches its high point.

The speed of the approach is determined by the height of the crossbar, the angle of the approach, the length of the approach run, and the individual jumper's abilities (15:141). The speed of the approach is increased as the bar is raised, as the angle of the approach decreases, and/or as the length of the approach run increases (18:444). This is true if positive acceleration is maintained through out the approach run.

The most important factor in selecting an optimum speed of the approach is the abilities of the individual jumper. Hay (18:444) cites a case in which the individual abilities of the jumper must be considered for producing the best results.

> If, by using too long a run-up the athlete develops more speed than his legs have the strength to control at take-off the height of the resulting jump will inevitably be less than he is capable of producing.

The curved approach used by the flop jumpers develops a centrifugal force that throws the jumper off at a tangent from approach curve after take-off. The centrifugal force will increase as the radius of the approach curve is shortened (1:63). To prevent the athlete from being prematurely thrown off at a tangent, the jumper tends to lean in towards the center of the arc, to counter the centrifugal force (20:5).

Wagner (46:259) points out the advantage of the curved approach. "Approaching the bar on a curve . . . puts the jumper in a position from which he can exert all of his upward thrust through the body's center of gravity." Very little eccentric thrust is used during take-off to create rotation thus a greater height can be attained.

The Plant. The plant consists of the movements from heel strike of the take-off foot, to when the take-off foot is flat on the jumping surface. The purpose of the plant phase is threefold: to minimize the downward vertical velocity at heel strike, to put the extensor muscles of the take-off leg on stretch, and to initiate the forward rotation of the body over the take-off foot. Since the downward vertical velocity at heel strike and placing the extensor muscles on stretch were discussed earlier they will not be discussed here.

The forward body rotation over the take-off foot is initiated by checking the linear motion of the approach run. "Linear motion is checked when the take-off foot is planted, and the upper body continues to travel forward giving the body the rotation necessary for achieving the lay-out position" (16:65).

The take-off foot plays a very important role in checking the linear motion during the plant phase. Cooper (7:104) explains the role of the take-off foot during the plant phase.

> The take-off foot acts as a fulcrum over which the body rotates . . . In a sense the whole body rotates about an axis at a point where the take-off foot contacts the ground.

<u>The Take-Off.</u> The take-off consists of the movements from when the take-off foot is flat on the jumping surface, to when the toes of the take-off foot leave the ground. The purpose of the take-off is twofold: to impart maximum vertical velocity to the jumper's center of gravity at take-off, and to initiate body rotation for bar clearance. All movements of the approach and plant phases have been preparatory movements necessary to achieve these two objectives. Since the vertical velocity at take-off and the angle of projection were discussed earlier, only the initiation of rotation for bar clearance will be discussed here.

The rotation necessary for the jumper to achieve the most efficient bar clearance position is initiated during the plant and take-off phases of the jump. Checking linear motion, transference and eccentric thrust are the three methods used to initiate rotation from the ground. The forward rotation initiation by checking linear motion was discussed earlier in the plant phase and will not be discussed here.

Transference is a means of creating rotary momentum in high jumping by transferring momentum from one part of the body to the entire body (16:68). "The rotation around the longitudinal axis, assisted by the run-up, is achieved mainly by the movement of the swing leg towards the run-up curve" (22:1292). The upward lift of the swing leg across the body transfers rotary momentum to the entire body around the vertical axis, to turn the jumper's back to the crossbar during the flight for an efficient bar clearance.

The third method of initiating rotation during take-off is vertical eccentric thrust.

> Vertical eccentric thrust comes about at take-off when the resultant line of force from the ground does not pass directly through the body's center of mass.
>
> . . . .
>
> Vertical eccentric thrust creates rotary momentum, but it also must reduce the effective force. In fact the more eccentric thrust at take-off, the less the effective force (and thus the less height or distance attained). (16:61).

Vertical eccentric thrust does not play a major role in the Fosbury flop because of the nature of the curved approach. The curved approach of the flop places the center of gravity over the take-off foot at take-off (44:261).

The Flight. The flight consists of the movements from when the toes of the take-off foot leave the ground to when the jumper has positioned himself atop the crossbar. The objective for the athlete during the flight phase is to continue the body rotation around the vertical axis.

The continuation of body rotation during the flight phase occurs as a result of applying the conservation of angular momentum principle. The radius of rotation can be shortened by bringing the arms and legs close to the axis of rotation, to increase the angular momentum of rotation. Thus as the jumper swings his arms upward during take-off, the arms should be kept ". . . close to the longitudinal axis" (44:261). After take-off the legs should be, brought together, to shorten the radius of rotation and thus increase the momentum of rotation.

Bar Clearance. Bar clearance consists of the movements from when the body is atop the crossbar to when the entire body has cleared the crossbar. The two objectives of the bar clearance include: attaining the most efficient bar clearance position and completion of the body rotation over the crossbar. Since bar clearance efficiency was discussed earlier, it will not be discussed here.

During the flight phase of the jump, the rotation of the body is primarily occurring around the vertical axis. During bar clearance the rotation around the vertical axis has been completed and the horizontal axis has become the primary axis of rotation. The rotation around the horizontal axis is inititated during the plant of the take-off foot. Horizontal rotation initiated during the plant brings the body forward over the take-off foot and the rotation continues throughout the jump until landing in the pit (17:65-67).

Once the body is atop the crossbar the lower legs and feet are the only segments that need to clear the crossbar. The body rotation around the horizontal axis necessary to clear the lower legs and feet is aided by the reaction of the body to the hyperextending of the lower back. The equal and opposite reaction to the hyperextension of the lower back is flexion at the hip joint and extension at the knee joint to raise the lower legs and feet above the crossbar (17:67).

Summary

The objective of high jumping is to produce the most effective and efficient compromise between the height that the center of gravity can be raised and the positioning of the center of gravity during bar clearance. Factors contributing to an effective take-off include the height of the center of gravity at take-off and the height the center of gravity is raised (vertical velocity at take-off). The factor contributing to bar clearance efficiency is the distance between the height of the crossbar and the maximum height of the center of gravity. The checking of linear motion, transference, and some eccentric thrust are used to initiate and continue the rotation necessary for attaining an efficient bar clearance position in the Fosbury flop.

BIOMECHANICAL DIFFERENCES BETWEEN MALES AND FEMALES

A review of literature pertaining to the differences between males and females was performed to speculate the biomechanical differences between male and female Fosbury flop high jumpers. To what extent the sociological and cultural factors have contaminated the biomechanical differences between males and females is not yet known. Research has indicated some anatomical and physiological differences between the sexes that may have some influence on the biomechanical performance of a motor skill. In addition, biomechanical research has provided some information as to the biomechanical differences and similarities between males and females. This section has been divided into two areas: anatomical and physiological differences between the sexes and biomechanical studies.

Anatomical and Physiological Differences Between the Sexes

Literature pertaining to the specific anatomical and physiological differences between males and females that may influence the biomechanical performance of the Fosbury flop are presented in this section. These anatomical and physiological factors include: muscular strength, flexibility, reaction time and movement time, and standing center of gravity.

Muscular Strength. In the human body the primary source of generating a force is one's muscular strength, which is directly related to the cross-sectional area of the muscle (4:49). The strength per square centimeter of muscle tissue is the same for males and females (2:95). Thus, the quality of the muscle tissue for both sexes is of the same value. But the quantity of muscle tissue is strongly in the favor of the male. Since females have a larger percentage of adipose tissue, they have less relative muscle tissue and a lower strength to weight ratio (13:402). More importantly males have a larger cross-sectional area of the muscle than do females (24:27). Thus the male jumpers are expected to generate a greater take-off force than the female jumpers.

Flexibility. Flexibility of the back and hip joint can aid in the bar clearance efficiency of the Fosbury flop. The greater flexibility of the back and hip joint allows for a greater degree of back hyperextension during bar clearance, which places a greater amount of body mass below the crossbar, thus placing the center of gravity outside the body and closer to or below the crossbar.

The female has a greater range of motion in the hip joint than does the male. This is a result of the broader and shallower pelvis of the female allowing the femur to articulate at a more acute angle (25:128).

Research by Phillips (39:325) and Kerchner and Glines (23:25) using the Kraus-Weber test which included an upper and lower back flexibility test, found that elementary school age girls were more flexible than boys. De Vries (13:368) has hypothesized that similar results would be found for all ages and through out adult life.

The literature seems to indicate that the female is more flexible than the male. Thus it would seem that the female jumpers have a greater potential for an efficient bar clearance.

Reaction Time and Movement Time. Research by Pierson and Lockhart (38:725) showed no significant difference in the reaction time of males and females to a visual stimulus, although the males did have a faster movement time. Thus the male's approach velocity may be faster than the female's approach velocity.

Standing Center of Gravity. In male subjects the mean standing center of gravity is located at a point 56.7 percent of the male's height above the ground (24:25). The female's mean standing center of gravity was 56.1 percent of the female's height above the ground (24:25). The male's mean standing center of gravity is 0.6 percent higher than the female's.

Based on the above information it can be assumed that the height of the male's center of gravity at take-off will be higher than the female's. Having a higher center of gravity at take-off will help enable the male jumper to clear higher heights than the female jumper.

Biomechanical Studies

The results of biomechanical studies on female subjects while running or jumping will be presented here and compared to the literature available on the performance of male jumpers. This comparison should indicate the possible biomechanical differences between male and female Fosbury flop high jumpers. This section is divided into three areas: running studies, female high jump studies, and a male verses female study.

Running Studies. Teeple (45) analyzed the biomechanical running patterns of 28 college women. Cinematography was used to record the performance of each subject. The film was analyzed for stride rate, stride length, angle of take-off, touchdown, trunk lean, leg lift and time of support and nonsupport. These factors were correlated with maximum running velocity to determine if any of these variables were related to running ability. Time of support was determined to be the primary factor associated with running ability. The affects of speed change on these biomechanical factors was also analyzed. The results showed that as the running velocity increased, so did the stride rate, stride length, and angle of the leg lift. The results of this study indicate no biomechanical differences from what was already known about the male running pattern (32:392). Thus the stride length, stride rate, angle of leg lift and time of support are of equal importance to both sexes while running for maximum speed.

Female High Jump Studies. Kuhlow (26) did a study comparing the take-off features of the Fosbury flop and the straddle roll high jump techniques. A force platform which measures forces in the three orthogonal planes was used to record the take-off force. The features of the take-off that were analyzed include: take-off time, quotient for two vertical forces, the temporal position of the positive vertical acceleration force, distribution of vertical force, vertical impulse, take-off economy, and reduction of horizontal velocity. The results of the study indicated that the ". . . straddle technique is mainly influenced by the time of the take-off, and the flop is influenced by the velocity of the run-up" (26:408). Hay (20) and Nix (33) have indicated that similar expected results would occur when comparing male flop and straddle roll jumpers but no research has been performed confirming these assumptions.

Peiniger (37) cinematographically analyzed two good and two fair women straddle roll high jumpers. The following factors were used to compare the performance of these subjects: distance of the approach run, velocity of the approach, take-off time, path of the center of gravity, take-off velocity, and angular velocity of the kicking leg. It was concluded that the mechanical factors studied did not significantly differentiate between the mechanics utilized by good and fair women straddle roll high jumpers. Peiniger's (33:33) analysis of results found the following factors to be true of good female straddle roll high jumpers.

1. The height of the jumper appeared to be directly related to the height achieved on the jump.
2. The two good jumpers did not demonstrate identical patterns of mechanics in the jump.
3. The good jumpers projected their center of gravity a greater vertical distance than the fair jumpers.
4. Velocity and change in velocity during the approach and take-off phases of the jump showed no significant correlation with the height of the jump for good and fair jumpers.
5. Increased distance and decreased time of the approach were related to the velocity of the approach, but did not differentiate between the good and fair jumpers.
6. Decreased time in contact with the ground prior to take-off indicated an increased height of the jump, which differentiated one good jumper from the two fair jumpers.

Even though no studies have been performed comparing good and fair male straddle roll jumpers all of the results found related to good female straddle roll high jumpers are also true of good male straddle roll high jumpers (32:393). Thus it would seem that the physical height of the jumper, the angle of projection, the approach velocity, and the take-off time all affect the performance of the male and female jumpers in a similar manner.

Male Verses Female Study. Laird (27) conducted an investigation comparing the biomechanical performance of five male and five female long jumpers. Electrogoniometry was used to measure maximum flexion, extension, and angular velocity of the hip, knee, and ankle joints. A special attachment to the physiograph was used to determine the approach speed at the time of take-off. The distance of each jump was also measured. The following conclusions were drawn as to the biomechanical differences between male and female long jumpers.

1. Men perform better than women in the long jump.
2. Movement of the hip, knee and ankle joints are comparable in both sexes with regard to action on the take-off board.
3. The only mechanical factor contributing to the better performance of the men was their ability to attain greater approach speed at the time of take-off (27:55).

Even though long jumping has a completely different objective than high jumping, the approach speed at the time of take-off may be an important factor that will influence the biomechanical differences between male and female Fosbury flop high jumpers. Especially since Kuhlow's (26) research indicated that the approach velocity was techo-specific to the Fosbury flop technique of high jumping.

Summary

Based on the limited available research the following biomechanical differences are expected to occur between male and female Fosbury flop high jumpers. The anatomical and physiological differences indicated that the males should generate a larger take-off force, a faster approach velocity, and a higher location of the center of gravity at take-off. The females are expected to have a more efficient bar clearance than the male jumpers because of their greater flexibility. The biomechanical research indicated that females biomechanically perform running and jumping activities in much the same manner as males. The approach speed at the time of the take-off for long jumpers was the only biomechancal difference found between males and females while performing a jumping event.

CINEMATOGRAPHICAL ANALYSIS

Cinematographical analysis has three major components: recording the performance of a skill via cinematography, gathering the raw data from the film by plotting reference points on a positive horizontal (X) and vertical (Y) coordinate system, and analyzing the raw data gathered by segmental analysis and various mathematical formulas. For ease in identifying the related literature pertaining to a specific component of cinematographical analysis this section has been divided into the three areas: cinematography, gathering raw data, and analyzing the raw data.

Cinematography

"Cinematography involves the use of the camera to record motion for subsequent kinesiologic analysis" (28:195).

". . . cinematography is widely employed in kinesiology as a means of recording the events associated with muscular action" (6:376).

The two definitions of cinematography given above have one word in common that identifies the function of cinematography. The word is record. Cinematography gives the student, teacher, coach, and/or researcher a permanent record of the performance of a motor skill. "The use of motion pictures is probably the best single technique for obtaining kinetic and kinematic data related to whole body motion" (42:81). Three advantages of having a permanent record of the performance of a motor skill are: the film is more accurate than the unaided eye, measurements can be taken directly from the film, and high speed photography can slow down or stop the performance of the skill.

> In the larger context, it provides a pictorial record of events that occur so rapidly that careful analysis is impossible by observation alone. The human eye is a notoriously poor recorder; accounts of the same action by several observers frequently results in discrepancies. However with the use of special photographic equipment, a record can be obtained of the movement that can be used later for detailed analysis (6:376).

Logan and Mc Kinney (28:196) explain the advantage of taking measurements from the film.

> In addition, cinematographic techniques allows the physical educator to make relatively accurate measurements of joint movements as well as velocity of the body and its moving parts directly from the projected image.

Wallace (47:19-20) indicates how high speed cinematography slows down the movements of the skill to increase the accuracy of the observations and measurements taken.

> The primary objective of cinematography in the study of motion is to supplement the visual process. One way the visual apparatus is supplemented is through time magnification. "Time magnification is achieved by taking motion pictures of an action at a picture repetition rate greater than the frame rate used in projecting the films" (23:2). In this way, the movement is slowed down or stopped and in all actuality, a moving body is made to appear stationary.
>
> Only when a rapid motion is slowed down or stopped can it be effectively evaluated. The characteristics of human vision limit the observer's ability to discern rapidly moving objects.

For these reasons cinematography has been an accepted method in performing biomechanical research.

Gathering the Raw Data

Plotting is used to gather raw data for a more accurate analysis. Plotting requires the location of various anatomical landmarks of the body that serve as reference points. These reference points are plotted on a positive X-Y coordinate system. The X-Y coordinates of these reference points consist of the raw data necessary to compute the center of gravity.

The anatomical landmarks plotted are the proximal and distal ends of various body segments. By locating the proximal and distal ends of various body segments the center of gravity of the body and body segments can be determined. Velocities and accelerations of the body and body segments can be determined by knowing the time required to move the center of gravity of the body or body segments a certain distance. Angle of projection can be computed by measuring the angle of the changed position of the center of gravity before and after take-off.

Ward (48:131) summarizes both the advantage and disadvantages of plotting.

> Motion plotting provides a means by which important mechanical factors could be determined.
>
> Plotting errors could not be completely erradicated due to: (a) hidden segments, (b) the difficulty in plotting specific points in the identical spot each time, and (c) the movement of segments in other than a line perpendicular to the camera.

Much of the error that occurs when gathering the raw data (positive X-Y coordinates) from the film is a result of the reliability of the investigator's plotting abilities. Noble and Kelley(34:643) measured the reliability of the investigator's ability to plot consistantly. A correlation of 0.99 was recorded to insure the reliability of the investigator's plotting ability.

Analysis of Raw Data

The analysis of raw data is computed by various mathematical formulas. Segmental analysis is a method of computing center of gravity of a body in motion. This method is used to determine the path of the center of gravity, velocity, acceleration, and angles. Clarke and Clarke (6:390) explain the importance of studying the center of gravity.

> As applied to problems of motion, plotting the flight of the center of gravity through space is often helpful in order that the proper arrangement of body parts can be made; although the center of gravity will follow a predetermined path depending upon such factors as velocity and angle of take-off the body may be performing certain coordinative movements.

Some research has been performed indicating the accuracy of the analyzed raw data. Davis (11:21) performed an investigation to determine reliability, objectivity, and validity of the segmental method. His finding indicated that the reliability of determining the X-Y coordinates of the center of gravity was Rx= 0.9682, Ry= 0.9443. Davis concluded that "the reliability of the segmental method is acceptable but the objectivity of the method is valid for kinematic analysis, but not for kinetic analysis." Plagenhoef

(41:103) reports an error of 0-10 percent for slow movement patterns and an error of 0-15 percent for fast movement patterns.

Noble and Kelley(34:645) reported errors of 3-4 percent in distance transverse, 2-3 percent in elapsed time, 1-6 percent in velocity and 35 percent in deceleration. Noble and Kelley concluded that cinematographic precision was adequate in measuring all of the parameters except acceleration.

Summary

Good research is dependent upon the reliability and validity of the measurement devices used in the investigation. Cinematographic analysis was assumed to be a valid and reliable measurement device in this investigation. This assumption was necessary because of the lack of research available to indicate the validity and reliability of cinematography, and because of its general acceptance in the field of biomechanics. Of the available research pertaining to validity and reliability of cinematographic analysis only kinetic analysis and acceleration measurements were neither reliable or valid measurements. However more research pertaining to the validity and reliability of cinematographic analysis is needed to confirm these results.

SUMMARY

The intent of this chapter was to review the literature necessary to establish the movements and mechanics of the Fosbury flop, biomechanical differences based on gender and the validity and reliability of cinematographic analysis. The literature showed that the height the athlete jumps is dependent on the jumper's height of the center of gravity at take-off, the vertical velocity at take-off, the angle of projection and the manipulation of body segments during bar clearance. The literature also indicated the possibility of a greater take-off force, approach velocity, and a higher center of gravity at take-off in male jumpers. However, females are expected to have a more efficient bar clearance than males because of their greater flexibility. The literature has also indicated that with the exception of measuring kinetic data and acceleration, cinematographic analysis is both a valid and reliable measuring device.

CHAPTER 3

PROCEDURES

The specific problem of this investigation was to determine the biomechanical differences between male and female Fosbury flop high jumpers. Cinematography, film analysis, and a computer program were incorporated into this investigation to record, gather, analyze, and compare the performance of the subjects. A step by step account of the procedures used in this investigation are presented in this chapter. The chapter has been divided into the following four categories: pilot studies, subjects and their preparation, filming procedures, and film analysis procedures.

PILOT STUDIES

Two pilot studies using the proposed procedures for this study were performed by the investigator in order to become acquainted with the equipment and filming procedures. The results of the first pilot study indicated that camera speeds above 300 frames per second were too fast for the amount of available light and that the bottom of the timing clock was out of the photographic field. The second pilot study indicated there was adequate available light for a camera speed of 200 frames per second and the entire timing clock was within the photographic field.

SUBJECTS AND THEIR PREPARATIONS

Two male high jumpers and one female high jumper attending Kansas State University, Manhattan, Kansas, and a second female high jumper attending Tabor College in Hillsboro, Kansas, served as subjects for this study. The subjects who volunteered to participate in this study were the best available subjects to the investigator.

The subjects in this study were considered to be highly skilled Fosbury flop high jumpers for their sex. The skill ability level of the subjects was most aptly expressed by listing their best lifetime marks. Table 1 lists each subject's best lifetime mark and the height jumped in this study.

TABLE 1

THE SUBJECT'S BEST LIFETIME MARK AND THE HEIGHT CLEARED IN THE STUDY

Subjects	Best lifetime mark	Height cleared in this study
1	7'1"	6'8"
2	6'11"	6'4"
3	5'0"	4'11"
4	5'8"	5'2"

It should be noticed that mone of the subjects jumped as high as their best lifetime mark in this study.

Subject three came the closest (1 inch) to jumping a height equal to her best lifetime mark.

To facilitate film analysis the subjects were marked with white pieces of tape on both the right and left sides of the body at the following anatomical landmarks: acromion process, medial and lateral epicondyle of the humerus, styloid process of the ulna and radius, medial and lateral epicondyles of the femur, and the malleolus of the fibula and tibia. The small pieces of tape were placed over the appropriate landmarks, with a black dot being placed on the center of the landmarks. After placing the tape on these landmarks, the distances between the landmarks was measured to be used as a measurement unit. All subjects wore a sleeveless shirt and gym shorts to avoid the possibility of covering up any of the pieces of tape with their clothing.

Prior to filming all subjects were informed that the crossbar must be cleared for the jump to be considered good and that three good jumps would be filmed. The subjects were told to determine the height of each jump.

FILMING PROCEDURES

The two filming sessions necessary for this study took place in Kansas State University's Ahearn Fieldhouse. The procedures for each filming session were identical.

Equipment and Its Placement

Since the jumpers approached the crossbar from both the right and left sides, the camera and other equipment had to be set-up on both the right and left sides of the crossbar. Regardless of which side the equipment was placed on, the same equipment set-up and filming procedures were used. Figure 1 illustrates the placement of all the equipment.

A 15'x8'x3' foam rubber Porta-Pit served as the landing area. Gill Golden high jump standards were used to support a 13' steel triangular crossbar. All measurements were taken in relation to the center of the farthest high jump standard from the camera.

All filming was done with a 51-0002 Redlake Locam 16mm camera. The camera was equipped with a 25mm lens, a reflex lens bore sight, and a variable film speed contr l which was set at 200 frames per second. The camera was loaded with a 400 foot reel of black and white Kodak Tri-X Reversal 7277 film with an indoor ASA of 400. For maximum light exposure the lens aperture was set at f/1.9 and the shutter factor was set at 160 degrees.

The camera, placed on a heavy duty tripod, was leveled and positioned so that the camera was filming perpendicular to the end of the crossbar. The film in the camera was 41 feet 2 1/2 inches from the center of the farthest high jump standard and 18 inches in front of the center of the farthest high jump standard. The height of the camera from

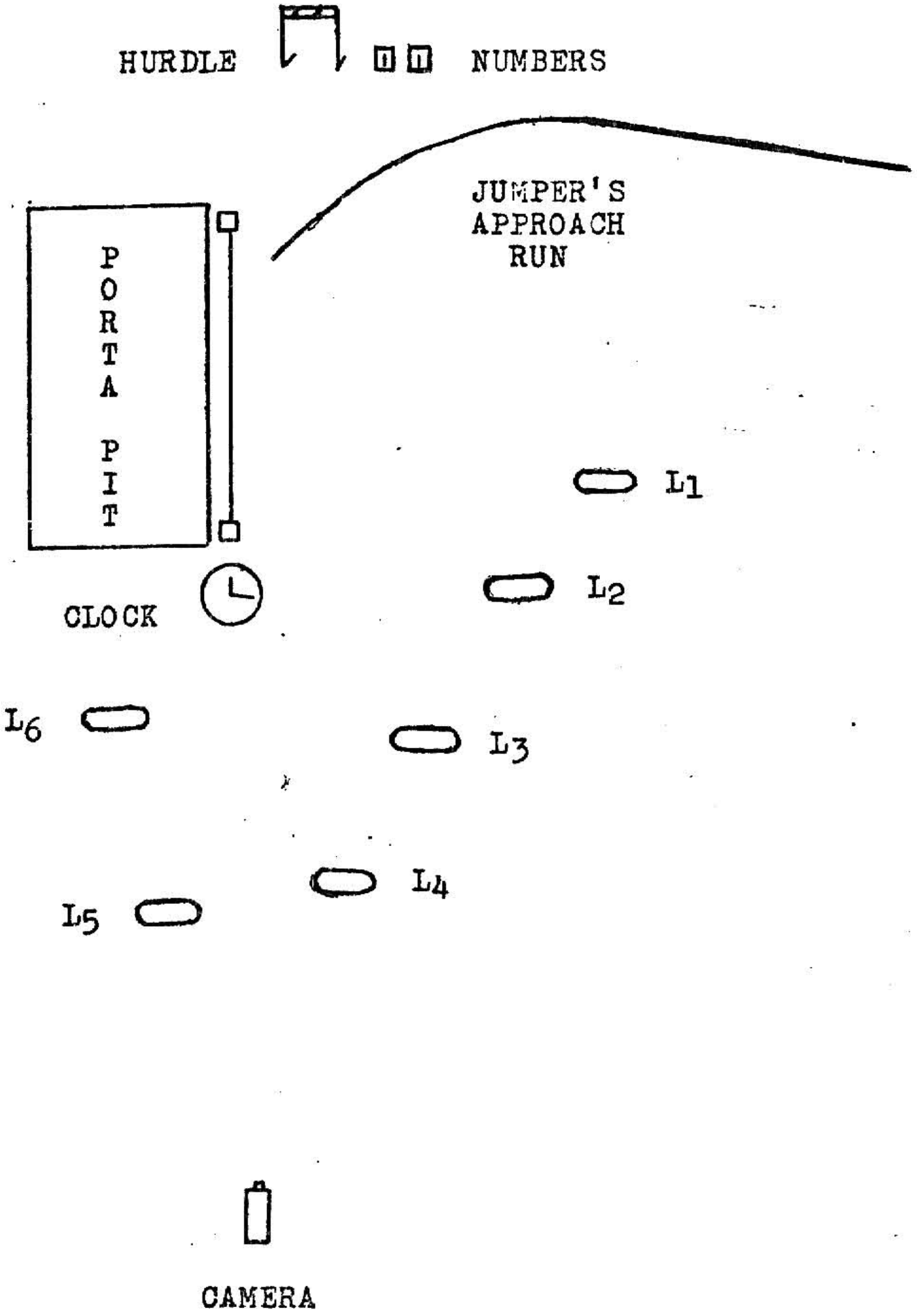

FIGURE 1

THE FILMING EQUIPMENT SET-UP

the floor to the middle of the lens aperture was 52 1/4 inches.

A timing clock, readable to 0.01 of a second accuracy, was placed 18 feet 9 inches from and directly in line with the center of the farthest high jump standard.

Numbers were assigned to each subject according to his or her order of testing. Numbers were also assigned for every trial filmed. These numbers were placed 21 feet 2 1/2 inches away and 5 feet in front of the center of the farthest high jump standard on the side opposite of the camera.

A leveled track hurdle was placed 21 feet 2 1/2 inches away and 18 inches in front of the center of the farthest high jump standard on the side opposite of the camera. The top edge of the hurdle was 41 1/16 inches long and 30 inches above the floor. The top edge and the right side of this hurdle were used to establish a true horizontal and vertical constant.

In addition to the overhead lighting of the fieldhouse, six lamps were used to illuminate the photographic field. Four of these lamps were Aceme-Lights 711ML of 1100 watts quartz with 39,000 lumens each. The two remaining lamps were Berkley Colortram Multi-Beam LQF-10 of 1000 watts and 8.3 amps. All six lamps were placed on tripods. The light from all the lamps was directed perpendicular to the filming plane and parallel to the floor.

Table 2 lists the height and distance of each lamp.

TABLE 2

THE HEIGHT AND DISTANCE OF THE PHOTOGRAPHY LAMPS USED IN THIS STUDY

Light number	Height	Distance * A	 ** B
L1	3' 11 3/4"	13' 1"	11' 7 5/8"
L2	4' 4 1/4"	14' 8"	8' 8"
L3	5' 1 1/4"	18' 8"	6' 6"
L4	6' 7 1/2"	24' 4"	4' 11"
L5	6' 2"	28' 5"	3' 6 1/2" ***
L6	4' 8 1/2"	24' 1"	7" 3 1/4" ***

* Distance 'A' represents the distance from the center of the farthest high jump standard to the lamp.

** Distance 'B' represents the distance the lamp is in front of the center of the farthest high jump standard.

*** These lamps were placed behind the center of the farthest high jump standard and the distance represents that measurement.

The lamps with the closer 'B' distance to the crossbar were taller, so as to light the subjects as they cleared the crossbar. The lamps farther in front of the crossbar were lower, so as to light the subjects during their approach run.

Filming Day Procedures

The film for this investigation was taken on two separate days. All procedures for both sessions were exactly the same. The following is an account of the procedures followed on the days of the filming.

One hour before the filming of the subjects, the investigator and three assistants met in the Biomechanics Laboratory at Kansas State University. The necessary equipment in the laboratory was then transported to the fieldhouse (see Appendix B).

After transporting all the necessary equipment to the fieldhouse, the high jump pit, standards, and crossbar were put into place. This was followed by the measuring and the setting up of the camera, lights, clock and other equipment. The equipment was then checked to see if it was operating properly. A light meter reading was taken to check the available light. A light meter reading of 4 foot candles was recorded.

The subjects were asked to read and sign the Rights of Welfare of Human Subjects Informed Consent Form (see Appendix C) for this study. After signing the consent form the tape was placed on the subject's joint centers, and the distance between these joint centers was measured. The subjects were then instructed to warm-up and practice jumping with the lamps turned on, so as to become adjusted to the high intensity light of the lamps while jumping.

Meanwhile the investigator was checking the photographic field to insure that the entire jump would be filmed. The investigator also determined as to when the camera should be turned on, to allow the camera time to build up to maximum speed.

Before each trial the settings for the f/stop, focusing, and camera speed were checked. At the completion of each trial the height of the jump and the success of the jump were recorded. A subjective evaluation of the jump by the athlete was also recorded (see Appendix E).

At the completion of the filming sessions all the equipment was disassembled and returned to the Biomechanics Laboratory. The film was removed from the camera and taken to photographic services at Kansas State University for processing.

FILM ANALYSIS PROCEDURES

After recording the performance of the subjects on film, it was necessary to gather and analyze the raw data from the film. These procedures are explained here.

Gathering the Raw Data

Upon its return from processing the film was viewed a number of times with the 00300 Lafayette Analyzer projector to thoroughly acquaint the investigator with the contents of the film. The best trial of the three good trials was then selected for each subject. The following criteria were used to determine which trial would be selected: the height of the jump, the subjective evaluation of the jump by the athlete, body position at take-off, and body position during bar clearance. The trial with the highest combination of these four criteria was selected for analyzation.

The first and last frames to be analyzed were then selected. The first frame to be analyzed was that of the initial contact of the swing foot with the ground, during the last stride of the approach run. Analyzation ceased when the entire body had completely crossed the crossbar. These frames were located for each subject and the time on the clock was recorded for frame identification at a later date. The raw data was gathered from every sixth frame from the beginning to the completion of analyzation.

A 16mm Recordak film reader was used to project the film on a 15x20 inch piece of graph paper. The graph paper was readable to the nearest 1/20 of an inch. A positive horizontal (x) and vertical (y) coordinate system was placed on the graph paper for accurate location of the joint centers and to facilitate mathematical computations.

The reference points for the horizontal and vertical constants were then placed on the graph paper and recorded on the data sheet. Before analyzing any of the frames, the horizontal and vertical constants on the film were aligned with the horizontal and vertical reference points on the graph paper.

The horizontal and vertical coordinates of the proximal and distal ends of each body segment were then located and recorded on the data sheet (see Appendix D for sample data sheet). The body segments for which the x and y coordinates were recorded included: head and neck, trunk, right thigh, right lower leg, right foot, left thigh, left lower leg, left foot, right upper arm, right lower arm, right hand, left upper arm, left lower arm and left hand. These coordinates were recorded for every sixth frame of each trial. In addition to recording these coordinates, the time appearing on the clock and the film length of the measurement unit were also recorded.

Analyzing the Raw Data

After gathering the raw data, factors selected specifically for the purpose of this investigation were analyzed. These factors included: the path of the center of gravity, displacement of the center of gravity, elapsed time, linear velocities and angles. All of these factors were compared between the sexes to determine the biomechanical differences in performing the Fosbury flop.

Path of the Center of Gravity. Using Dempster's (12) data and the horizontal and vertical coordinate values listed above, the center of gravity of the body was then calculated by means of the Wildcat computer program (see Appendix F for details in calculating the center of gravity). Calculating the center of gravity every sixth frame provided the information necessary to plot the path of the center of gravity.

<u>Displacement of the Center of Gravity.</u> The x and y coordinate values provided a method for calculating distances via the Wildcat computer program. Pure horizontal and vertical distances covered by the athlete's center of gravity from one particular frame to the next frame were measured by subtracting the coordinate values. Distances neither purely horizontal or vertical were determined by calculating the hypotenus of the right triangle formed by the pure horizontal and vertical displacement of the center of gravity. Distances not measured by the Wildcat computer program were simply measured with a clear plastic ruler. A multiplier specific to each individual was used to return the film image distance back to real life distance (see Appendix I). The following distances were measured:

1. The height of the jumper's center of gravity at the instant of take-off (H_1).

2. The maximum height that the jumper elevates his center of gravity (H_2).

3. The difference between the maximum height reached by the jumper's center of gravity and the height of the crossbar (H_3).

<u>Times.</u> By counting the number of frames required for a particular phase of the jump and multiplying this number by the

frame rate (.005 of a second/frame) the elapsed time of this phase was determined. The time showing on the clock during a particular phase of the jump was used to check the time measured. The take-off time was determined.

Linear Velocities. All linear velocities were calculated by dividing the displacement of the center of gravity by the time elapsed during the displacement ($V= {}^D/T$). The linear velocities calculated included:

1. The forward velocity of the center of gravity during the last stride of the approach run.
2. The vertical velocity of the center of gravity during the heel strike of the plant phase.
3. The vertical velocity of the center of gravity at take-off.

Angle of Projection. The angle of projection was measured by the angle formed between the true horizontal and a line connecting the points of the body's center of gravity just before and just after the loss of ground contact, during the transition from the take-off phase to the free flight phase. A protractor was used to measure the angle formed by these two lines, representing the angle of projection.

Biomechanical Differences

Because of the limited number of subjects the investigator determined that statistical analysis would not be an appropriate method of interpreting the findings. Thus a qualitative method of analysis was chosen as the best means for interpreting the data in this investigation.

SUMMARY

Four highly skilled Fosbury flop high jumpers volunteered, to be subjects for this study. To facilitate film analysis the subjects were marked with white pieces of tape on various anatomical landmarks. High speed cinematography was used to record the performance of each subject. Three good trials were filmed for each subject and the best trial was analyzed. The raw data was gathered by utilizing a 16mm Recordak film reader, graph paper, and a positive horizontal and vertical coordinate system placed on the graph paper. Selected factors were then analyzed, to compare the biomechanical performances of male and female Fosbury flop high jumpers.

CHAPTER 4

ANALYSIS OF RESULTS AND DISCUSSION

The purpose of this investigation was to compare the biomechanics of male and female Fosbury flop high jumpers using cinematographic analysis. More specifically, the purpose of this study was to determine if males clear higher heights than females because they have a more effective linear velocity at take-off, and/or a more efficient manipulation of body segments during bar clearance. This chapter has been divided into three sections: analysis of results, discussion of results, and summary.

ANALYSIS OF RESULTS

Because of the small sample size the results of this investigation may be biased. Thus, when referring to male and female jumpers the investigator was referring to only the subjects of this study. The reader is cautioned not to extend the results of this investigation beyond the subjects of this study.

The criteria used to compare the performance of the male and female Fosbury flop high jumpers were selected factors considered to be the most important in the performance of the Fosbury flop. The comparison of these selected factors will be presented in four categories: the quality of movement, the approach velocity, the center of gravity, and the factors of take-off

The Quality of Movement

The quality of movement in the performance of each subject was evaluated by observing the film taken for this study. The major points specific to the quality of the performance for each subject will be examined in this section.

Subject One. During take-off subject one forcefully swung his right arm up and in the direction of the crossbar. The arm was extended at the elbow joint, and flexed and abducted at the shoulder joint. Having this type of arm movement has its advantages and disadvantages. The advantages of such a movement are a higher placement of the center of gravity at take-off and a greater take-off force than if there was no arm swing, but less than if he had swung both arms (the left arm is not being forcefully swung upwards). The disadvantages of such a movement with the right arm include a lower angle of projection, and a hinderance to the rotation around the vertical axis after take-off. By having the right arm abducted from the midline of the body, the center of gravity moves horizontally away from the midline of the body, rather than vertically higher on the midline of the body, and thus flattens the angle of projection. Since the arm is abducted from the midline of the body, the radius of rotation becomes longer and slows down the velocity of the vertical rotation after take-off. Thus the arms should remain close to the midline of the body to increase the angle of projection and aid the rotation around the vertical axis after take-off.

Subject one had an excellent thrust of the swing leg up and across the body. He drove the knee of the swing leg completely across the body and beyond the left side of the pelvis. The drive of the knee across the body aids the rotation of the body around the vertical axis. Subject one compensated for the abduction of his right arm which slows down the vertical rotation by having a strong drive of the swing leg up and across the body.

Subject Two. Subject two had an excellent double arm swing during take-off to help generate a more effective take-off force. Both arms were flexed at the elbow joints to shorten their radius of rotation and increase the angular momentum of the arm swing. The hands were swung up to a height just above the head, which raised the height of the center of gravity at take-off. The arms were placed close to the midline of the body to aid the vertical rotation after take-off.

The bar clearance efficiency of subject two was hindered by his failure to hyperextend his lower back during bar clearance. Observation of the film indicated two reasons why subject two failed to hyperextend his lower back: flexion of the hip joint, and flexion of the cervical spine. After take-off subject two did not relax the hip flexors in the swing leg to allow the thighs of the legs to hang below the crossbar, but rather flexed the take-off leg at the hip joint to raise the take-off leg parallel to the swing leg. This movement resulted in the thighs of the legs being parallel to the ground during bar clearance, thus preventing the hyperextension of the lower back and a less efficient bar clearance position. In this position subject two would be unable to have efficient bar clearance because of the lack of body mass placed below the crossbar. As the literature points out, an efficient bar clearance is dependent on the amount of body mass hanging below the crossbar (46:261). Hyperextension of the cervical spine aids and initiates the hyperextension of the lower back. Subject two did not hyperextend his cervical spine but flexed his cervical spine to prevent the hyperextension of the lower back. Subject two will have to learn to relax the hip flexors and hyperextend the cervical spine before he will be able to hyperextend his lower back.

Subject Three. Subject three had three basic errors that prevented her from jumping higher. These errors include: a take-off position too close to the crossbar, incorrect arm action at take-off, and lack of back hyperextension during bar clearance. When subject three took off too close to the crossbar, she limited the range she had to perform the movements of take-off. Taking-off close to the crossbar hinders both the swinging movements of the arms and swing leg, and the vertical rotation after take-off. The jumper does not have the time or the distance to either forcefully swing his leg, or to complete the vertical rotation after take-off. Wagner (46:258) says that Fosbury took off from a point four feet from the crossbar.

The vertical rotation was also hindered by the flexion and abduction of the right arm at the shoulder joint toward the crossbar. This movement by subject three was almost identical to that of subject one and has the same effect on the success of the jump. But unlike subject one, subject three was unable to drive her knee forcefully across her body to aid vertical rotation after take-off. Thus subject three did not complete the vertical rotation after take-off for an efficient bar clearance.

Like subject two, subject three did not hyperextend her back during bar clearance. The reasons for her lack of back hyperextension were the same as those for subject two: flexion of the cervical spine and the hip joints. Thus subject three needs to hyperextend her cervical spine and relax her hip flexors to hyperextend her back during bar clearance.

Subject Four. Subject four had one major fault in her high jumping technique which caused her to misdirect her forces at take-off. The radius of her curved approach run was too long and she took off too late along her curved approach, which caused her to travel more parallel than perpendicular to the crossbar after take-off. Bunn (1:63) says that a centrifugal force such as that developed in the curved approach will increase as the radius of the curved approach decreases. The direction in which the centrifugal force throws one off at a tangent is at a right angle to the radius of the approach curve (1:63). Subject four took off at a point on her approach run where the radius of the curve was nearly perpendicular to the crossbar and thus the centrifugal force developed in her approach run threw her off at a tangent nearly parallel to the crossbar. This was probably why subject four's maximum height of the center of gravity was 3.7 inches in front of the crossbar.

Subject four kept her arms close to the midline of her body and forcefully drove her swing leg up and across her body for a very effective and efficient vertical rotation after take-off. Subject four had tremendous back hyperextension during bar clearance. This gave her the most efficient vertical bar clearance position of all subjects.

Approach Velocity

The approach velocity consisted of the average velocity of the center of gravity during the final stride of the approach run. The linear approach velocity and the height of the crossbar for each subject are presented in Table 3 on page 57.

In Table 3 and the other tables in this chapter subjects one and two are the male jumpers and subjects three and four are the female jumpers. Table 3 indicates that the jumpers with the greater approach velocity jumped a greater height than the subjects with the slower approach velocity. Subject one had the fastest approach velocity and jumped the highest. Subject two had the second fastest approach velocity

TABLE 3

THE AVERAGE VELOCITY OF THE CENTER OF GRAVITY DURING THE FINAL STRIDE OF THE APPROACH RUN

Subject number	Approach velocity in feet/second	Height of crossbar
1	8.62	80"
2	8.54	76"
3	5.64	59"
4	6.71	62"
Male mean	8.58	
Female mean	6.17	
Difference	2.41	

and jumped the second highest height. Subject four had the third fastest approach velocity and the third heighest jump. Subject three had the slowest approach velocity and jumped the lowest height. Based on these results it appears that there was a high relationship between the approach velocity and the height of the crossbar cleared in the Fosbury flop. The results of this study were harmonious with those of Kuhlow (26:407) in that it appears that the approach velocity was "techo-specific" or an essential factor for successful Fosbury flop high jumping.

Subject one jumped the highest of the male jumpers and subject four jumped the highest of the female jumpers. Both of these jumpers had the fastest approach velocity for their respective sexes. Apparently the importance of the approach velocity in the Fosbury flop was just as important for the male jumpers as it is for the female jumpers. The mean approach velocity for the male jumpers was appreciably greater than the female jumpers. It appeared that the greater approach velocity of the male jumpers was one of the principle reasons for the male subjects jumping 17.5 inches higher than the female subjects.

The Center of Gravity

In this investigation, the path of the center of gravity was calculated from heel strike of the final stride to when the entire body of the jumper had crossed the crossbar. Figure 2 illustrates the path of the center of gravity for all subjects (see page 59).

Figure 2 indicates that there was a pattern of movement specific to the Fosbury flop. The path of the center gravity for all subjects was very similar. During the approach run the center of gravity for each subject moved horizontally forward. A small dip in the path of the center of gravity occurred just after heel strike and then the center of gravity suddenly rose during take-off. After take-off the center of gravity followed its own predetermined path. When looking more closely at specific points along the path of the center of gravity, differences in the paths of the center of gravity between the subjects were evident.

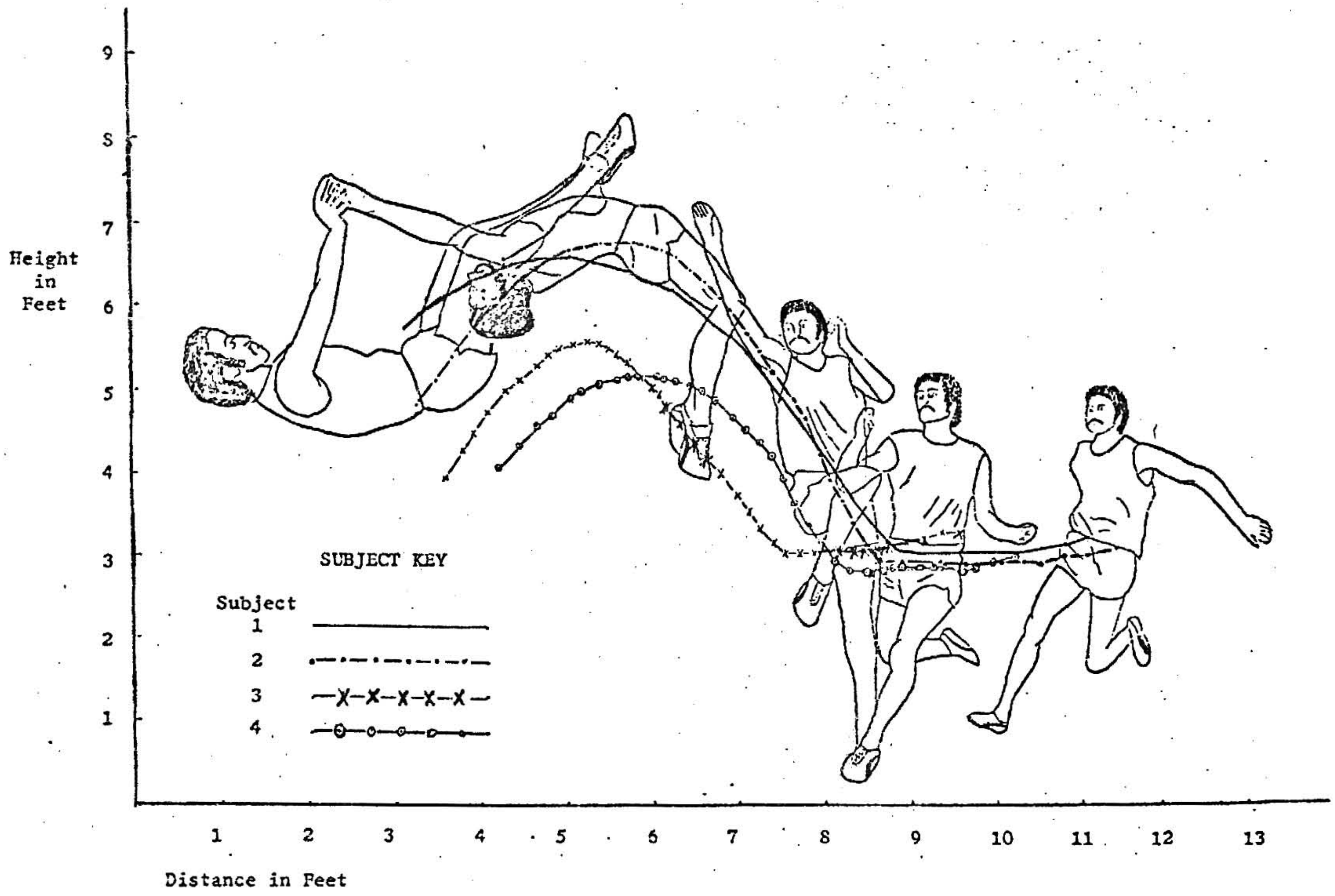

FIGURE 2

THE PATH OF THE CENTER OF GRAVITY FOR ALL SUBJECTS

The positions of importance in the path of the center of gravity included: the height of the center of gravity at take-off (H_1), the maximum height that the jumper elevates his center of gravity (H_2), and the difference between the maximum height reached by the jumper's center of gravity and the height of the crossbar (H_3). Table 4 provides these three displacements of the center of gravity for all subjects.

TABLE 4

THE DISPLACEMENTS OF THE CENTER OF GRAVITY IN THE FOSBURY FLOP FOR ALL SUBJECTS

Subject number	H_1	H_2	H_3	Height of crossbar
1	46"	32"	-2.0"	80"
2	42"	35"	-1.0"	76"
3	41"	18"	0.5"	59"
4	39"	18"	-0.4"	62"
Male mean	44"	33 1/2"	-1.5"	78"
Female mean	40"	18"	-2.0"	60.5"
Difference	4"	15 1/2"	-0.5"	17.5"

Table 4 shows that none of the three displacements of the center of gravity were highly related to the height jumped to clear the crossbar. The reason for the lack of such a correlation, between one or more of these displacements with the height of the jump, was the difference in individual strengths and weaknesses. The jumpers who minimized their strengths produced the most effective and efficient compromise between the height that the center of gravity was raised and the positioning of the center of gravity during bar clearance.

Subject one cleared the highest height of all subjects but did not raise his center of gravity as high as subject two. To compensate for this weakness, subject one had to exploit his strengths: the high placement of the center of gravity at take-off and a more efficient bar clearance position. Subject four, the best female jumper, had the lowest placement of the center of gravity at take-off of all subjects. To compensate for this weakness, subject four not only displaced her center of gravity the same distance as subject three, but also had the most efficient vertical bar clearance position of all subjects. Subject two was unable to clear a height as high as subject one even though he displaced his center of gravity a greater distance than subject one. This displacement was not large enough to compensate for the lower height of the center of gravity at take-off and lack of bar clearance efficiency. Subject three failed to minimize her weaknesses and maximize her strengths. Subject three had the higher position of the center of gravity at take-off of the two female subjects, but a less efficient bar clearance and the same displacement of the center of gravity after take-off. Subjects one and four were able to jump higher than the other jumpers of their respective sexes by being able to minimize their weaknesses and maximize their strengths with more effectiveness and efficiency than the other jumpers. It appeared that no one particular displacement of the center of gravity was more important than any of the other displacements. The jumper's ability to compensate for his weaknesses by exploiting his strengths will determine the effectiveness and efficiency of his or her performance. These results are consistent with logic of Dyson (15:139) "All good high jumping is therefore a compromise . . ."

The male subjects cleared a height 17.5 inches higher than the female subjects. The male jumpers were able to accomplish this by exploiting their strengths: the height of the center of gravity at take-off and the displacement of the center of gravity after take-off. The difference between the sexes in the height of the center of gravity at take-off may be a result of the male's taller stature and higher placement of the center of gravity in males. The differences in the displacement of the center of gravity after take-off are directly related to the factors of take-off, which will be analyzed later in this section.

The negative sign in the H_3 column indicates that the center of gravity crossed below the crossbar. The better male and female jumpers (subjects one and four) both had the best bar clearance efficiency for their respective sexes. There was no distinct difference in the mean bar clearance efficiency between the sexes. Even though this was true, an interesting point about bar clearance efficiency was uncovered. The factors of importance during bar clearance include the distance that the maximum height of the center is both vertically and horizontally from the crossbar. Table 5 presents both the horizontal and vertical distance between the center of gravity and the crossbar.

TABLE 5

THE VERTICAL AND HORIZONTAL DISPLACEMENT OF THE MAXIMUM HEIGHT OF THE CENTER OF GRAVITY FROM THE CROSSBAR

Subject number	Vertical displacement	Horizontal displacement
1	-2.0"	-6.1"
2	-1.0"	-0.8"
3	0.5"	-3.5"
4	-4.5"	3.7"
Male mean	-1.5"	3.5"
Female mean	-2.0"	0.2"
Difference	-0.5"	3.3"

Most of the literature has dealt with bar clearance efficiency as the vertical distance between the maximum height of the center of gravity and the crossbar (18:439). The horizontal distance between maximum height of the center of gravity and the crossbar has been neglected by researchers. The results of this investigation indicated that the center of gravity passed through or below the crossbar for all jumpers except subject three. All of the jumpers except subject three were considered to have good vertical bar clearance efficiency. In Table 5 the negative numbers in the horizontal displacement column indicated the distance that the maximum center of gravity occurred behind the crossbar, the positive numbers indicate the distance the maximum center of gravity occurred in front of the crossbar. The maximum height of the center of gravity for subjects one and three occurs behind the crossbar. Subject four's maximum height of center of gravity occurs in front of the crossbar. Only subject two's maximum height of the center of gravity occurred directly over the crossbar. This may indicate one of two things, either subject two is the only jumper with good horizontal bar clearance efficiency, or that good horizontal bar clearance efficiency occurs when the maximum height of the center of gravity is behind the crossbar. There was no distinct difference in vertical bar clearance efficiency, but an appreciable difference occurred in horizontal bar clearance efficiency between the sexes.

The Factors of Take-Off

The factors of importance during take-off that contribute to the displacement of the center of gravity after take-off include: the downward vertical velocity at heel strike (H S vel), the take-off time (T O time), the linear velocity at take-off (T O vel), and the angle of projection from the horizontal (A P). Table 6 provides the individual and group results of these factors of take-off.

TABLE 6

THE FACTORS CONTRIBUTING TO THE EFFECTIVENESS OF TAKE-OFF

Subject number	H S vel ft/sec	T O time in sec	T O vel ft/sec	A P in degrees
1	2.04	0.15	13.64	62
2	10.55	0.215	10.44	69
3	4.55	0.22	10.56	55
4	8.21	0.19	10.73	66
Male mean	6.27	0.18	12.04	65.5
Female mean	6.38	0.21	10.65	60.5
Difference	0.11	0.03	2.59	5.0

Table 6 shows that subject one, the best male jumper, had the smallest downward vertical velocity at heel strike. This was in agreement with the literature by Hay (18:439) which says the jumper with the smaller vertical velocity at heel strike will be able to arrest this downward movement sooner and generate a greater linear velocity at take-off.

There was no distinct difference in the mean downward vertical velocity at heel strike between the sexes.

Table 6 also indicates that subjects one and four had a faster take-off time and they both jumped the higher height for their respective sex. These results were harmonious with the researched literature. The jumpers who have the faster take-off time tend to jump higher because they generate a greater vertical impulse at take-off (18:448). The male's mean take-off time was slightly faster than the female's, which might account for the male's appreciably greater linear velocity at take-off.

These subjects also had a greater linear velocity at take-off for their respective sex. This was in agreement with the present literature and the law of falling bodies. After take-off the velocity of the center of gravity for all object's will decelerate at a rate of 32 feet per second (1:29). The center of gravity of the subjects with the greater take-off velocity will travel a greater distance before the center of gravity begins its descent. An appreciable difference occurred in the linear velocity at take-off between the means of the male and female subjects. It appeared that this difference between the male and female jumpers was large enough to be considered as one of the principle reasons for the male jumpers clearing a height 17.5 inches higher than the female jumpers.

The results of the angle of projection measurement deviated from the pattern of the results in the two previous factors of take-off. Subjects two and four (not subjects one and four) had the highest angle of projection for there respective sex. Since subject one jumped four inches higher than subject two, it would be expected that subject one would have a greater angle of projection, but this was not the case. Subject two compensated for his relatively low linear velocity at take-off by having a greater angle of projection. Subjects three and four had approximately the same linear velocity at take-off as subject two, but subject two's greater angle of projection enabled him to jump a higher height than subjects three and four. The male's mean angle of projection was appreciably greater (5 degrees) than the female's angle of projection. It appears that the angle of projection was another principle reason for the male jumpers clearing a height 17.5 inches higher than the female jumpers. The male jumpers cleared a higher height because their centers of gravity were projected at a point four inches higher and at an angle five degrees higher than the females'. The better jumpers for the respective sexes (subjects one and four) were more successful than subjects two and three because subjects one and four were able to produce a more effective and efficient compromise between the factors of take-off.

DISCUSSION OF RESULTS

The better male and female jumpers were able to jump higher because they compensated for their weaknesses by exploiting their strengths to produce the most effective and efficient compromise of the factors of take-off and bar clearance. Subject one, the best male jumper, compensated for his weakness, a low angle of projection, by compensating with the fastest approach velocity, the highest placement of the center of gravity at take-off, the smallest downward vertical velocity at heel strike, the fastest take-off time, the greatest linear velocity at take-off, and an efficient vertical bar clearance. Subject four, the best female jumper, compensated for her weakness, the lowest height of the center of gravity at take-off, by exploiting her strengths, the fastest approach velocity, the shortest take-off time, the greatest linear velocity at take-off and the greatest angle of projection for the female subjects, plus the most efficient vertical bar clearance of all subjects. Because of their greater effectiveness and efficiency in producing a better compromise in the factors of take-off and bar clearance, subjects one and four were able to jump higher than subjects two and three.

Why were the male jumpers able to clear a crossbar 17.5 inches higher than the female jumpers? The results of this study seem to indicate that the male jumpers were able to integrate the factor of take-off more effectively than the female jumpers, to produce a greater linear velocity at take-off, and to apply that velocity in a more vertical direction. The male jumpers combined a faster approach velocity and a shorter take-off time to generate a greater linear velocity at take-off. In addition, this velocity was projected from a greater height and in a more vertical direction than the female jumpers. All of these factors resulted in the male jumpers clearing a 17.5 inches higher than the female jumpers. In short, the male jumpers had a more effective and efficient compromise between the factors of take-off and bar clearance.

Why were the male jumpers able to integrate these factors of take-off more effectively than the female jumpers? The taller stature and higher placement of the center of gravity of the male jumpers enable the males to have a higher placement of the center of gravity during take-off. It appears that the greater relative muscular strength in the male jumpers enabled them to generate a faster approach velocity, as well as the ability to convert this greater horizontal component of the approach run into a greater vertical component, in a shorter period of time and in a more vertical direction. It takes more relative strength to convert a faster approach velocity into a greater vertical velocity at take-off, with a shorter take-off time and to project this velocity in a more vertical direction. Thus the male jumpers were able to take advantage of their greater relative muscular strength by using this strength to generate a faster approach velocity, greater linear velocity at take-off and higher angle of projection.

Because of the differences in the roles of the male and female in our society, the female jumpers have not been exposed to the same quality and quantity of motor experience as the male jumpers. The quantity and quality of training and conditioning for the male jumper has been much better than the female jumpers. The male jumpers were exposed to serious competition at a much earlier age than the female jumpers and have been competing a longer period time than the female jumpers. If the female jumpers had the same or similar childhood motor experiences, the same quality and quantity of training in the factors of speed, flexibility, strength, and technique, as well as being exposed to serious competition at the same age as the male jumpers, then the degree of difference between the sexes might not be as great.

SUMMARY

The following is a summary of the findings of this investigation:

1. The factors limiting the jumping performance of the subjects included: abduction of their right arm during take-off which hindered their jumps by producing a lower angle of projection and hindering the vertical rotation after take-off, failure to hyperextend their back during bar clearance is a result of cervical spine flexion and flexion in the hip joint, take-off too close to the crossbar which limits the distance in which he has to perform the movements of take-off and complete the vertical rotation, after take-off, and when the radius of the approach curve was too long and take-off

occurred too late along the approach curve which caused to travel down the crossbar rather than over the crossbar.

2. The jumpers with the greater approach velocity jumped a higher height than the subjects with the slower approach velocity. This is true regardless of the jumper's sex.

3. The mean approach velocity for the male jumpers was appreciably greater than the female jumper's approach velocity.

4. The path of the center of gravity for all subjects were very similar, indicating a pattern of movement specific to the Fosbury flop.

5. The best male and female jumpers were able to jump higher by minimizing their weaknesses and maximizing their strengths with more effectiveness and efficiency than the other jumpers.

6. The male subjects cleared a height 17.5 inches higher than the female subjects.

7. The better male and female jumpers (subjects one and four) both had the best vertical bar clearance efficiency for their respective sexes.

8. There was no distinct difference in either vertical or horizontal bar clearance efficiency between the two sexes.

9. The best male jumper had the smallest downward vertical velocity at heel strike.

10. There was no distinct difference in the mean downward vertical velocity at heel strike between the sexes.

11. The male and female jumpers who jumped the highest also had a greater linear velocity at take-off for their respective sex.

12. An appreciable difference occurred in the linear velocity at atke-off between the means of the male and female subjects.

13. The male's mean angle of projection was appreciably greater than the female's angle of projection.

14. The male's center of gravity was projected from a height 4 inches higher than the females center of gravity.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

To summarize this investigation the problem, purpose and procedures are restated succinctly. The findings, conclusions, and recommendations of this study are presented in this chapter.

SUMMARY

The Problem

The specific problem of this investigation was to determine the biomechanical differences between male and female Fosbury flop high jumpers. Men and women have been high jumping for many years and men have consistently jumped greater heights than women. Other than the fact that men have cleared higher heights than women, little is known about the differences in the biomechanical performance between the male and the female high jumpers.

Purpose of the Study

The purpose of this study was to compare the biomechanics of male and female Fosbury flop high jumpers using cinematographic analysis. The criteria used to compare the performance of male and female jumpers were selected factors considered to be the most important in the performance of the Fosbury flop. More specifically, the purpose of this study was to determine if males clear greater heights than females because they have a more effective vertical velocity at take-off, and/or a more efficient manipulation of body segments during bar clearance. Cinematography, segmental analysis, and the "Wildcat" computer program were used to record, gather and analyze the kinematic and kinetic data, to make the comparison of male and female Fosbury flop high jumpers.

Procedures

Two maleand two female, highly skilled, Fosbury flop high jumpers volunteered to be subjects for this study. To facilitate film analysis the subjects were marked with white pieces of tape on the following anatomical landmarks: acromion process, medial and lateral spicondyles of the humerus, styloid process of the ulna and radius, medial and lateral epicondyles of the femur, and the malleolus of the fibula and tibia.

A 51-0002 Redlake Locam 16mm camera equipped with a 25mm lens, reflex lens bore sight, and a variable film speed control, which was set at 200 frames per second, was used to record the performance of each subject. Three good trials were recorded for each subject. Then the best trial for each subject was selected to be analyzed.

A 16mm Recordak film reader was used to project the film image on a 15x20 inch of graph paper. The graph paper was readable to the nearest 1/20 of an inch. The horizontal and vertical coordinate values of the proximal distal ends of each body segment were gathered by means of a positive horizontal and vertical coordinate system placed on the graph paper.

The raw data gathered was then used to analyze the following selected factors: the path of the center of gravity, displacement of the center of gravity, elapsed time, linear velocities, angles of projection, degrees of back hyperextension during bar clearance. The center of gravity and linear velocities were calculated by the Wildcat computer program.

CONCLUSIONS

Within the limitations of this investigation the following conclusions were drawn from the data analyzed.

1. Male Fosbury flop high jumpers are able to clear higher heights than female jumpers because of their faster approach velocity, their greater vertical velocity at take-off, and their higher angle of projection.

2. The efficient manipulation of body segments during bar clearance was not considered to be a principal reason for male Fosbury flop high jumpers clearing a higher height than the female jumpers.

RECOMMENDATIONS

As an appropriate follow-up to this study the following recommended research is presented below.

1. To investigate the factors influencing the performance of the Fosbury flop. These factors should incompass all aspects of the performance of the Fosbury flop: anatomical, physiological, biomechanical, sociological, motor learning, training, and any other factors that would influence the performance.

2. To investigate the biomechanical differences of male and female Fosbury flop high jumpers using a larger sample size, triaxial cinematography, electromyography, electrogoniometry, and/or a force platform under a high stress competitive environment.

3. To investigate the biomechanical difference of male and female high jumpers using either the straddle roll or the Fosbury flop.

4. To investigate the variable of gender on the biomechanical performance of any motor skill.

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APPENDICES

APPENDIX A

"WILDCAT" COMPUTER PROGRAM

```
Card
Number

  1        JOB CARD
  2        /*ROUTE PRINT OS
  3        //EXEC FORTGCLG
  4        //FORT.SYSIN DD *
  5       REAL*8 FMTSPC(10),SEGMNT(14),POINT(24),TITLE(10)
  6       REAL PSEG(14),PBW(14),XO(14),YO(14),XP(14),YP(14),X(50,
          24),Y(50,24),VELX(50,24),VELY(50,24),VELXY(50,24),XBOD
          (50),YBOD(50),XBOC(50),YBODC(50),XYBODC(50)
  7       INTEGER LC(14),UC(14)
  8       READ(5,18)TITLE,NFRAME,FMTSPC,(LC(I),UC(I),I=1,14),TIME
  9       DO 1 I=1,14
 10     1 READ(5,19)SEGMNT(I),PSEG(I),PBW(I)
 11       DO 2 I=1,24
 12     2 READ(5,19)POINT(I)
 13       DO 6 IFRAME=1,NFRAME
 14       READ(5,FMTSPC)(X(IFRAME,I),Y(IFRAME,I),I=1,24)
 15       XBOD(IFRAME)=C
 16       YBOD(IFRAME)=C
 17       DO 3 I=1,14
 18       XC(I)=X(IFRAME,LC(I))+PSEG(I)*(X(IFRAME,UC(I))-X(IFRAME,
          LC(I)))
 19       YC(I)=Y(IFRAME,LC(I))+PSEG(I)*(Y(IFRAME,UC(I))-Y(IFRAME,
          LC(I)))
 20       XP(I)=XC(I)*PBW(I)
 21       YP(I)=YC(I)*PBW(I)
 22       XBOD(IFRAME)=XBOD(IFRAME)+XP(I)
 23     3 YBOD(IFRAME)=YBOD(IFRAME)+YP(I)
 24       IF(IFRAME/3*3.EQ.IFRAME-1)GO TO 4
 25       WRITE(6,20)
 26       GO TO 5
 27     4 WRITE(6,21)TITLE
 28     5 WRITE(6,22)IFRAME,(I,SEGMNT(I),PSEG(I),XC(I),YC(I),PBW
          (I),XP(I),YP(I),I=1,14)
 29       WRITE(6,23)XBOD(IFRAME),YBCD(IFRAME)
 30     6 CONTINUE
 31       WRITE(6,24)
 32       DO 7 IFRAME=1,NFRAME
 33     7 WRITE(6,25)IFRAME,XBOD(IFRAME),YBOD(IFRAME)
 34       WRITE(6,26)
 35       DO 10 I=1,17,8
 36       17=I+7
 37       WRITE(6,27)(POINT(J),J=I,17)
 38       DO 9 IFRAME=2,NFRAME
```

```
Card
Number

39        DO 8 J=I,17
40     8  VELX(IFRAME,J)=(X(IFRAME,J)=X(IFRAME-1,J))/TIME
41     9  WRITE(6,28)IFRAME,(VELX(IFRAME,K),K=I,17)
42    10  CONTINUE
43        WRITE(6,29)
44        DO 13 I=1,17,8
45        17=I+7
46        WRITE(6,27)(POINT(J),J=I,17)
47        DO 12 IFRAME=2,NFRAME
48        DO 11 J=I,17
49    11  VELY(IFRAME,J)=(Y(IFRAME,J)-Y(IFRAME-1,J))/TIME
50    12  WRITE(6,28)IFRAME,(VELY(IFRAME,K),K=I,17)
51    13  CONTINUE
52        WRITE(6,30)
53        DO 16 I=1,17,8
54        17=I+7
55        WRITE(6,27)(POINT(J),J=I,17)
56        DO 15 IFRAME=2,NFRAME
57        DO 14 J=I,17
58    14  VELXY(IFRAME,J)=SGRT(VELX(IFRAME,J)**2+VELY(IFRAME,J)
          **2)
59    15  WRITE(6,28)IFRAME,(VELXY(IFRAME,K),K=I,17)
60    16  CONTINUE
61        WRITE(6,31)
62        DO 17 IFRAME=2,NFRAME
63        XBODC(IFRAME)=XBOD(IFRAME)-XBOD(IFRAME-1)
64        YBODC(IFRAME)=YBOC(IFRAME)-YBOD(IFRAME-1)
65        XYBODC(IFRAME)+SGRT(XBODC(IFRAME)**2+YBODC(IFRAME)**2)
66    17  WRITE (6,32)IFRAME,XBODC(IFRAME),YBODC(IFRAME),XYBODC
          (IFRAME)
67        WRITE(6,21)
68        RETURN
69    18  FORMAT(10A8/12/10A8/2812,F6.0)
70    19  FORMAT(A8,F8.8,F4.4)
71    20  FORMAT(' ')
72    21  FORMAT('1',10A8/)
73    22  FORMAT(' FRAME', 11,'SEGMENT',T21,'BODY',T41,'%',T49,'
          X',T57,'Y'T64,'PROP',T73,'X',T81,'Y'/' NUMBER',T11,
          'NUMBER',T20,'SEGMENT',T40,'GEG',T48,'C/G',T56,'C/G',
          T64,'BODY',T72,'PROD',T80,'PROD'/T65,'WT'/T4,12,(' ',
          T13,12,T20,A8,8X,3F8.4,F9.4,2F8.4))
74    23  FORMAT(' THE CENTER OF GRAVITY OF THE BODY IS (',F12.4,
          ' , ', F12.4,' )')
75    24  FORMAT('1THE COORDINATES OF THE THEORETICAL CENTER OF
          GRAVITY', 2(/),' FRAME',5X,'X COORDINATE',5X,'Y
          COORDINATE'/)
76    25  FORMAT(' ',14,12,T1r,F7.4,T31,F7.4)
77    26  FORMAT('1VELOCITIES OF BODY PARTS IN HORIZONTAL PLANE')
78    27  FORMAT('-FRAME',5X,8(A8,5X)/)
```

```
Card
Number

79 28 FORMAT('  ',12,2X,8F13.4)
80 29 FORMAT('1VELOCITIES OF BODY PARTS IN VERTICAL PLANE')
81 30 FORMAT('1VELOCITIES OF BODY PARTS IN A LINEAR DIRECTION')
82 31 FORMAT('1VELOCITIES OF CENTER OF GRAVITY IN THREE
      DIRECTIONS',2(/),' FRAME',T12,'HORIZONTAL',5X,'VERTICAL',
      5X,'LINEAR'/)
83 32 FORMAT('  ',12,F17.4,F13.4,F11.4)
84    END
85 FOSBURY FLOP MALES VS FEMALES: SUBJECT # TRIAL #
86 NUMBER OF FRAMES CARD
87 FORMAT CARD
88 1 2 2 3 4 5 5 6 6 7 8 9 10101112131314141516171718181919 .03
```

DATA DECK

SEGMENT CARDS

POINT CARDS

/*

To retrieve data from the computer the following cards must be fed into the computer after input is fed into the computer.

1. VMPRT JOB CARD
2. JOB CLASS CARD NUMBER
3. VMPRT JOB CARD
4. JOB CLASS CARD NUMBER SKIP 20

APPENDIX B

LIST OF EQUIPMENT

- 220 volt adapter
- Locam camera and tripod
- Six photography lamps
- 4 fifty foot extension cords
- Timing clock and tripod
- Light meter
- Subject and trial numbers
- Adhesive tape
- Magic marker
- 2 measuring tapes
- Level
- Filming data sheet and clip board
- Tuf-Skin
- Masking tape
- Porta-Pit, high jump standard, crossbar
- Hurdle
- Film
- One-foot ruler
- Informed consent form
- Camera manual

APPENDIX C

RIGHTS AND WELFARE OF HUMAN SUBJECTS

A COMPARATIVE CINEMATOGRAPHIC ANALYSIS OF MALE AND FEMALE FOSBURY FLOPPERS

Read the information on this sheet and if you wish to be a participant in this study fill-in the information on the following page entitled "Informed Subject Consent."

Purpose

To compare male and female Fosbury floppers using cinematographic analysis.

Procedures

The subjects will be asked to perform the Fosbury flop under a laboratory situation. During these sessions film will be taken of their performance. The film will be analyzed for results and conclusions.

Risks

There is no risk involved concerning the filming of the high jump.

Alternative Procedures

There are alternative procedures of gross observations, still photographs, and graph check photographs, but all are inferior to motion picture filming in gaining benefits for analysis. The risks are the same for all methods.

Benefits

At the convenience of the researcher and the athlete the film will be analyzed for a better understanding of his or her technique.

Questions and Inquiries

The researcher makes the offer to answer all questions and inquiries of the subjects concerning the procedures of the study, and any other questions that the subjects might have.

Withdrawing from the Study

The subjects are free to withdraw their consent and discontinue participation in the study at any time.

INFORMED SUBJECT CONSENT

As indicated by my signature below and being of sound mind, I do hereby voluntarily consent to serve as a subject in the proposed procedure identified and explained in the document dated 10/1/74 and entitled "A Comparative Cinematographic Analysis of Male and Female Fosbury Floppers" which document is attached to and is hereby made a part of this consent.

	Subject Name	Age	Subject Signature	Date
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				

Witnessed By:

APPENDIX D

PLOTTING DATA SHEET

Subject #_____
Trial #_____

Constants _____ _____ _____

Reference Points		Frames								
		1	2	3	4	5	6	7	8	etc.
Crotch	x									
	y									
Strenum	x									
	y									
Tragus	x									
	y									
Right hip	x									
	y									
Right knee	x									
	y									
Right ankle	x									
	y									
Right foot	x									
	y									
Left hip	x									
	y									
Left knee	x									
	y									
Left ankle	x									
	y									
Right shoulder	x									
	y									
Right elbow	x									
	y									
Right wrist	x									
	y									
Right fingers	x									
	y									
Left shoulder	x									
	y									
Left elbow	x									
	y									
Left wrist	x									
	y									
Left fingers	x									
	y									
Time										
C/G of Body	x									
	y									

APPENDIX E

FILMING DATA SHEET

Subject Data:

Name:____________________ I.D.#____________________

Phone #____________________ Address____________________

Best lifetime mark ________

Measurement Units:

Shoulder to Elbow-	R________	L________
Elbow to Wrist-	R________	L________
Hip to Knee-	R________	L________
Knee to Ankle	R________	L________

Bar Height (H), Success (S), Evaluation (E):

Trial			
1	(H)________	(S)________	(E)________
2	(H)________	(S)________	(E)________
3	(H)________	(S)________	(E)________
4	(H)________	(S)________	(E)________
5	(H)________	(S)________	(E)________
6	(H)________	(S)________	(E)________

Equipment:

Camera: Height-______ Distance_______ Speed_______

f/stop ______ Shutter _______

Lights:	Height	Distances (A/B)
L_1		/
L_2		/
L_3		/
L_4		/
L_5		/
L_6		/

Clock: Distance________ Height________

Numbers: Distance________ Height________

Hurdle: Distance________ Height________ Width______

Pit, Standards, Crossbar

Mark Jumper:

Comments:

APPENDIX F

THE SEGMENTAL METHOD AS REPORTED BY WALLACE (47:64-65)

The segmental method is a method used to determine the center of gravity of a total body, especially when that body is in motion. To use the segmental method, the following information is needed: the percentage of the total body weight of each segment; the location of the center of gravity of each segment; the horizontal distance of each center of gravity from a vertical line; and, the vertical distance of each center of gravity from a horizontal line. (8:172)

Each body segment was defined as listed below:

Trunk - The top of the sternum to the crotch.
Head and Neck - The tragus of the ear to top of the sternum.
Right Thigh - The greater trochanter of the right femur to the lateral condyle of the tibia.
Right Lower Leg - Lateral condyle of the tibia to the lateral malleolus of the fibula.
Right Foot - The lateral malleolus of the fibula to the end of the great toe of the right foot.
Left Thigh - The greater trochanter of the left femur to the lateral condyle of the tibia.
Left Lower Leg - The lateral condyle of the left tibia to the lateral malleolus of the left fibula.
Left Foot - The lateral malleolus of the left fibula to the end of the great toe of the left foot.
Right Upper Arm - The acromion process of the right scapula to the lateral epicondyle of the humerus.
Right Lower Arm - The lateral epicondyle of the right humerus to the styloid process of the right ulna.
Right Hand - The styloid process of the right ulna to the tip of the middle finger.
Left Upper Arm - The acromion process of the left scapula to the lateral epicondyle of the humerus.
Left Lower Arm - The lateral epicondyle of the left humerus to the styloid process of the left ulna.
Left Hand - The styloid process of the left ulna to the tip of the middle finger of the left hand.

Given next is a list of the body segments, the percentage of the segment that its center of gravity is located in, and the proportion that the segment contributes to the total body weight.

Body Segment	% Segment	Prop. Body Weight
Trunk	0.4500	0.5140
Head and Neck	0.5000	0.0790
Right Thigh	0.4330	0.0965
Right Lower Leg	0.4330	0.0450
Right Foot	0.4290	0.0140
Left Thigh	0.4330	0.0965
Left Lower Leg	0.4330	0.0450
Left Foot	0.4290	0.0140
Right Upper Arm	0.4360	0.0265
Right Lower Arm	0.4300	0.0155
Right Hand	0.5060	0.0060
Left Upper Arm	0.4360	0.0265
Left Lower Arm	0.4300	0.0155
Left Hand	0.5060	0.0060

By knowing the X-Y coordinates of each segment, the center of gravity of the total body can be located. To find the X-coordinate, the proximal X-coordinate of the segment is subtracted from the distal X-coordinate. This difference is then multiplied by the percent of the segment. This product is added back to the proximal X-coordinate for the center of gravity of the segment. Then to find the center gravity of the total body, each X-coordinate for the center of gravity of the segment is multiplied by its proportion of body weight and then all of these segment products are added together to yield the X-coordinate of the center of gravity for the total body. The same procedure is followed to obtain the Y-coordinate of the center of gravity of the total body.

APPENDIX G

TABLE 7

HEIGHT, SUCCESS, AND SUBJECTIVE EVALUATION OF EACH TRIAL

		Trials							
Subject		1	2	3	4	5	6	7	8
1	Height	6'2"	6'4"	6'6"	6'8"	6'8"	-	-	-
	Success	good	good	good	miss	good	-	-	-
	Evaluation	ok	good	good	poor	best	-	-	-
2	Height	6'2"	6'4"	6'4"	6'4"	6'4"	6'8"	-	-
	Success	good	good	miss	miss	good	miss	-	-
	Evaluation	ok	good	poor	poor	best	poor	-	-
3	Height	4'8"	4'8"	4'8"	4'10	4'10	4'11	5'0"	-
	Success	miss	good	good	miss	good	good	miss	-
	Evaluation	poor	ok	ok	poor	good	best	ok	-
4	Height	5'0"	5'2"	5'4"	5'4"	5'4"	5'2"	5'2"	5'2"
	Success	good	good	miss	miss	miss	good	good	good
	Evaluation	ok	good	poor	poor	poor	good	best	good

APPENDIX H

TABLE 8

SEGMENT LENGTHS OF BOTH THE UPPER AND LOWER ARMS AND LEGS

	Shoulder to elbow length		Elbow to wrist length		Hip to knee length		Knee to Elbow length	
Subject	Right	Left	Right	Left	Right	Left	Right	Left
1	13 1/4"	13 1/2"	11"*	11 1/2"	17"	17 1/4"	18 1/4"	19 1
2	11 1/2"	11 1/2"	11"*	11"	18 1/2"	18 1/2"	18"	18"
3	12"	12 1/2"	10"*	10"	18"	18"	16"	16"
4	11"	11"	9 1/2"	9 1/2"	16 1/4"	16 1/4"	16 1/2"	16 1

* The length of this body segment was used as a measurement unit.

APPENDIX I

TABLE 9

MEASUREMENT UNITS AND MULTIPLIERS FOR EACH SUBJECT

Subject number	Measurement unit in real life	Measurement unit on film	Multiplier
1	11 inches	2.1 units	5.23
2	11 inches	2.2 units	5.00
3	10 inches	2.1 units	4.76
4	9.75 inches	1.9 units	5.13

A COMPARATIVE CINEMATOGRAPHICAL ANALYSIS OF MALE AND FEMALE FOSBURY FLOP HIGH JUMPERS

by

PATRICK L. MURRAY

B.S. California State University, Fullerton

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Health, Physical Education and Recreation

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1975

ABSTRACT

The purpose of this study was to compare the biomechanics of male and female Fosbury flop high jumpers using cinematographic analysis. The criteria used to compare the performance of male and female jumpers were selected factors considered to be the most important in the performance of the Fosbury flop. Four (two male and two female) highly skilled Fosbury flop high jumpers volunteered to be the subjects for this study. To facilitate film analysis the subjects were marked with white pieces of tape on various anatomical landmarks. High speed cinematography was used to record the performance of each subject. Three good trials were filmed for each subject and the best trial was analyzed. The raw data was gathered by the uses of a 16mm Recordak film reader, graph paper and a positive horizontal and vertical coordinate system placed on the graph paper. Selected factors were then analyzed, to compare the biomechanical performance of male and female Fosbury flop high jumpers. Distinct mean differences between male and female Fosbury flop high jumpers were found in: the approach velocity (2.41 feet per second), the displacement of the center of gravity after take-off (15 1/2 inches), and the vertical velocity at take-off (2.59 feet per second). In conclusion, the principle reasons why the male jumpers were able to clear greater height than the female jumpers include: a faster approach velocity, a greater vertical velocity at take-off, and a higher angle of projection.