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AN ANALYSIS OF SELECTED MECHANICAL FACTORS THAT CONTRIBUTE TO VERTICAL JUMPING HEIGHT OF FOUR BASKETBALL PLAYERS

by

Charles Roger Higgins

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Approved by

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APPROVAL SHEET

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HIGGINS, CHARLES ROGER. An Analysis of Selected Mechanical Factors That Contributed to Vertical Jumping Height of Four Basketball Players. (1971) Directed by: Dr. Gail Hennis. Pp. 100.

The purpose of this investigation was to study, through cinematography, selected mechanical factors that contribute to vertical jumping performance. The investigation included an analysis of the angular measurements of the elbow, shoulder, hip, knee, ankle, and body lean. In addition to the angular measurements the velocities of the arm movement, hip extension, knee extension, and plantar flexion were also investigated as was the sequential order of the position, velocity, and acceleration of body parts during the selected jumps.

Movie pictures were taken of three professional basketball players and one university varsity player performing the vertical jump. Each subject's best and poorest jump, from a series of seven trials, were selected, analyzed, and compared on an individual basis. Similar mechanical factors which may have contributed to the subjects' poorest jumping performance were then identified.

As a result of the analysis it was found that during the poorest jump, all subjects showed lower hyperextension of the arms at the preparatory position. Less shoulder flexion at both the point of take-off and at the apex of the jumps was also evident. The knees, hips, and ankles displayed equal or less extension at the point of take-off while the angle of body lean was equal to or greater at this same point.

A slower rate of arm velocity was displayed just prior to take-off while on the other hand the rate of arm velocity was faster at the point of take-off.

The arms had less elevation and a slower rate of velocity during the

beginning phases of knee extension. Lower elevation combined with a faster rate of arm velocity was experienced at the point of greatest rate of knee and hip extension and plantar flexion. This occurred at the point of take-off.

Within the limitations of this study and from the analysis of data included in this study the following conclusions seem appropriate.

1. The point of take-off is the point where the greatest number of similar mechanical factors not conducive to maximum jumping performance occur. These are:

   a. lower elevation of the arms,

   b. greater body lean,

   c. less extension of the hips, the knees, and the ankles,

   d. a faster rate of arm velocity.

2. Failure of the arm position, velocity, and acceleration of hip and knee extension to function together seems to be important to performance of the vertical jump.

3. Increasing the range of arm motion would appear to be conducive to attaining maximum height during the jump.

DEDICATION

To the four greatest cheerleaders a coach ever had: my wife, Shirley; my two daughters, Lisa and Lori; and to my son, Craig.

ACKNOWLEDGMENTS

This writer wishes to express his sincere appreciation to his adviser, Dr. Gail Hennis, for her guidance throughout this study.

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Randy Mahaffey, George Peeples, Bob Verga, professional basketball players, and Gary Marschall, college player, were the subjects in this study. The writer extends his thanks to these young men and to the Carolina Cougars professional basketball organization for their cooperation.

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CHAPTER I

INTRODUCTION

While there are many skills of value in the game of basketball the ability to jump and rebound is of paramount importance to the individual player. To be able to out-jump or out-rebound an opponent may determine ball possession and ultimately the outcome of many games. Because of this jumping deserves the attention of both player and coach.

The mechanics involved in the performance of the vertical jump have been virtually overlooked as a means of improving jumping height. There is a mechanically efficient way of performing any sport skill. The application of sound mechanics when executing the vertical jump is vitally important to the attainment of maximum height. (4:216-217)

Underlying mechanical factors that govern vertical jumping height are: (1) preparatory stance, (2) range and velocity of joint movement, (3) angle of body parts and body lean, and (4) sequential timing in the movement of the arms and legs. (4, 6, 9, 14) There is little cinematographic information in the literature relating the above mechanical factors to vertical jumping performance. For this reason, the writer felt there was a need for further study in this area. It was his hope that through scientific investigation greater clarity and understanding could be gained about the mechanically complex skill of jumping.

To conduct a thorough mechanical analysis, a method must be used that will allow a more critical analysis of the performance at a later date. Ruth Glassow indicated the potential value of pictures for analysis when she wrote "pictures can be used to show whether the execution conforms to the concept of execution." She stated further, "pictures can be used to correct concepts which have been developed by tradition and authorities." (1:206)

Motion pictures have been useful in the mechanical analysis of human movement. The process of analysis utilizing motion pictures is called cinematography. Analyzing a performance by using film has an advantage over observation in that the film can be viewed and studied frame by frame through a stop action view finder or projector. Every aspect of a performance may be observed and evaluated by using cinematographical technique.

STATEMENT OF THE PROBLEM

It was the purpose of this investigation to study, through cinematographic analysis, selected mechanical factors that contribute to the vertical jumping performance of four basketball players.

Sub-Problems

The sub-problems of this study were:

1. To identify the best and poorest jumps of each subject.

2. To compare angles of body parts and body lean with their relative changes during the two jumps.

3. To study the velocity and acceleration of selected body parts with

their relative changes during the two jumps.

4. To compare the sequential order of the position, velocity, and acceleration of body parts during each jump.

5. To identify common mechanical factors, if any, which may have decreased the subject's jumping performance.

LIMITATIONS OF THE STUDY

The following limitations were placed on the collection and analysis of data:

1. Analysis was limited to the following selected mechanical factors:
   a. Angles of the shoulder, hip, knee, elbow, and ankle at various points throughout the jump.
   b. Velocity of the arm, hip extension, knee extension, and plantar flexion.
   c. Angles of body lean.

2. The basic anterior-posterior foot position was predetermined without regard to individual preference. See Figure 1, page 28, for foot position.

3. The subjects were a combination of professional and college basketball players.

4. The jumps were viewed from only one lateral side. It is assumed that body parts on both sides of the body are functioning simultaneously.

5. The subjects' best and poorest jumps, selected by the investigator from a series of seven performances, were used in the analysis.

6. Cinematographical analysis was limited to selected frames during the different phases of the jump.

This study was further limited in that body movements caused the body markings on the subjects, made to facilitate analysis, to be moved or completely hidden from view at some points during the jump. Therefore, some of the landmarks used in this study had to be approximated and marked on the photographs. However, it is unlikely that this resulted in an error of measurement of any magnitude.

DEFINITIONS OF TERMS

For purposes of this study the following definitions were accepted.

Acceleration

The rate at which a body segment changes velocity. This may be positive or negative.

Apex of the Jump

The highest point during the jump as measured by the height attained by a piece of tape placed at a point slightly above the waist line.

Angular Velocity

The angular speed of the body segment as calculated from the number of degrees moved in a specific number of frames.

Best Jump

The jump that attained the greatest height.

Extension

Any movement resulting in an increase of a joint angle. The complete extension of a body part will approximate 180 degrees. (10:16)

Flexion

Any movement resulting in a decrease of a joint angle. The two body segments of a joint are approaching each other. (10:16)

Frame

A single picture produced by the camera.

Plantar Flexion

The movement (at the ankle joint) of the foot downward. The term "plantar flexion" is an exception to the previous definition of flexion. In reality, plantar flexion is extension of the ankle. (10:17)

Poorest Jump

The jump that attained the least height.

Preparatory Stance

That period in the jump when the subject is in a crouch position and when his arms have reached their maximum height behind his back just prior to moving downward.

Range of Motion

The amount of movement, expressed in degrees, which occurs in a given joint.

SIGNIFICANCE OF THE STUDY

Coaches are constantly looking for ways to improve the vertical jumping height of their players. There is an apparent lack of studies involving the mechanics of the jump. This study was designed to add to present knowledge concerning the vertical jump by revealing why the subjects, mechanically speaking, did not attain maximum height on their poorest jump. Greater clarity and scientific understanding of the complex skill of jumping should result and as a result the coach should be better prepared to consider the mechanical factors that may lead to improvement in a player's jumping performance.

CHAPTER II

REVIEW OF LITERATURE

The review of literature for this study has been divided into the following sections: mechanics of the vertical jump; cinematographical techniques; and cinematographic studies of the vertical jump.

MECHANICS OF THE VERTICAL JUMP

Textbooks in the field of kinesiology and mechanics of sports skills were consulted to gain greater insight into the mechanics of the vertical jump. (3, 4, 6, 9, 11, 13, 14)

In describing the two foot vertical jump Godfrey and Kephart stated: "Both arms swing downward and back as all the leg joints bend in preparation, then both arms swing strongly forward and upward as both legs straighten forceably to propel the child into the air." (9:67)

Jumping is the act of projecting the body into the air. It is a coordinated effort of leg and arm movement having a definite starting position, an active phase, and a terminal position. (9:66)

The jump is performed when a propulsive force is exerted by one or both feet and the whole body is lifted into the air with the legs fully extended. The force is produced by quick extension of the legs aided by forceful arm movement. (3:152) The most significant aspect of the vertical jump is the action of the arms and legs. (9:67)

The arms initiate the upward movement in the jumping action and also contribute balance when performing the action. (14:52) The arms must swing into a preparatory position (raised behind the back) to initiate the forward and upward movement of the arms which aids in propelling the body through the air. (3:152)

> If the purpose is to gain height, the arms are dropped with the elbows somewhat flexed to allow for movement to develop momentum . . . . The flexion of the arms makes it possible to swing them more nearly upward in the direction of desired movement and shortens the lever, making it easier to move them rapidly. (3:152)

In preparation for the production of the force the hip, knee, and ankle must bend to put the extensor muscles of the leg in a position to exert force. A deeper crouch gives a greater distance over which acceleration may take place and consequently more force at take-off. The optimum depth of the crouch, however, is an individual matter. This will depend on the strength of the leg muscles. (3:153, 4:216) Morehouse and Cooper (11:164) feel that the hips, knees, and ankles should be flexed to approximately right angles in the starting position.

The legs are extended suddenly as the arms swing in an upward direction. The momentum of the arm swing is transferred to the upper body and if timed properly with leg extension will add force to the jump. (3:153) The timing of any subsequent action of body parts follows so there is a summation of the forces projecting the body upward. If there is a lack of timing the force of the preceding movement is partially dissipated when the succeeding force or action is applied. Consequently the total resultant force is lessened. The sequence of the vertical jump is: extension of the hips, knees, and ankles; and upward movement of the arms. (11:251)

The laws that govern the movement of projectiles also apply to the vertical jump. (11:250) A projectile will move in the direction in which force is applied. (3:153) The angle or direction at which the force is applied to the body during the vertical jump is determined by the line from the point of application (feet) through the center of gravity of the body. (3:154) Because height in a vertical direction is desired, the angle of take-off is an important factor when performing the vertical jump. The more nearly vertical all forces are applied at take-off, the greater will be the effective force for the jump. (3:154, 4:216) A nearly vertical take-off is accomplished by an erect trunk with the weight centered over the feet rather than forward. (13:219) In this position the center of gravity will be directly over the feet.

By spreading the feet in a posterior-anterior direction, up to a point, it is easier to keep the center of gravity over the base (feet) thus increasing stability and will allow the force to be exerted in a more vertical direction. (3:154)

The fundamental pattern of the vertical jump may be summarized in the following manner. (14:51)

1. There is flexion at the hips, knees, and ankles in preparation for the jump.

2. The jump begins with a vigorous forward and upward thrust of the

arms.

3. The thrust is continued by forceful extension at the hip, knee, and ankle.

Several mechanical principles apply to the performance of the vertical jump. The following principles are arranged to coincide with the movement pattern involved when performing the vertical jump. (14:63)

1. Additional linear and angular velocity may be gained by increasing the distance over which force is applied (the preparatory stance).

2. When several forces are applied in succession, each succeeding force must be applied at the point where the preceding one has made its greatest contribution in imparting velocity (succession of forces to thrust the body into the air).

3. The final direction of a moving body is a resultant of the magnitude and direction of all the forces which have been applied (direction of movement at take-off).

Certain aspects of the vertical jump have been investigated and clarified. Wilson (36) investigated the influence of both lateral and anterior-posterior spacing on vertical jumping performance. He tested 160 male junior high students on 16 different foot spacings. Foot spacings ranging in 5 inch intervals from no lateral or anterior-posterior spacings to spacings of 15 inches by 15 inches were used. He concluded that vertical jumping scores decreased progressively as the anterior-posterior foot spacings increased and also decreased when the lateral foot spacings exceeded 10 inches.

Heess (26) tested 108 eighth grade boys to determine the relative effectiveness of two styles of vertical jumping and also to determine the relative effects of various angles of knee flexion on vertical jumping performance. The two styles of vertical jumping were: (1) palms of the hands were placed on the thighs just above the knees so that the hands could push from the thighs at the beginning of the jump and (2) arms were raised behind the back in preparation for the jump and were swung forward and upward during the jump. In addition, he attempted to determine the relative effectiveness of these two forms of jumping when the preliminary knee angles were 45, 65, 90, 115, and 135 degrees. He concluded that either style of vertical jumping is equally effective to initiate the jump. He also concluded that knee angles of 65 and 90 degrees seem to be more effective in enhancing jumping than are knee angles of 45, 115, or 135 degrees. The extreme angle of 135 degrees appears to be the least conducive to vertical jumping performance.

The effects of both knee angle and foot spacing combinations were investigated by Martin and Stull. (19) Thirty young adult males performed the vertical jump with preliminary knee stance angles at 65, 90, and 115 degrees while using lateral and anterior-posterior foot spacings of 0, 5, 10, and 15 inches. The evidence obtained indicated that the most effective preliminary stance was one in which the knee angles was approximately 115 degrees with the feet spread from 5 to 10 inches laterally and slightly in excess of 5 inches anteriorly-posteriorly. The investigators concluded that knee angle and foot spacing act independently on jumping performance.

Lewis (29) studied the influence of the arm movement on vertical jumping height. She used one hundred subjects performing two variations of the vertical jump. In one, the arms were used to aid in getting more height. In the other variation the arms were restricted by having the subjects place their thumbs in the front of their belts. A total of 6 jumps per subject were investigated. It was concluded that for the most part a greater height was reached when the jumps were executed with the arms rather than when the arms were restricted.

VanDalen (20) also concentrated on the influence of the arms on vertical jumping height. He used 106 senior high school boys between the ages of 15 and 17. He controlled the arm movement in varying forms of the jump. He concluded that the arm movement (swing) is exceedingly important to successful execution of the vertical jump.

CINEMATOGRAPHICAL TECHNIQUES

Pictures have been used as a medium for research as early as the 1870's when Marey (1:217) and Mybridge (12) made use of photography to study motion of animals and man. Industry has been using it since the turn of the century when Gilbreth's book Motion Study (7) created interest in the use of photography as a means of analyzing the movement patterns of workers. Later Gilbreth and Gilbreth (8) suggested the value of miro-motion studies. In these studies both pictures and a timing device were used for studying the speed of movement. Two of their conclusions were that motion pictures are more complete and accurate than any other method of study, and that both direction and time can be studied. In more recent years cinematography has proved to be a functional method for analysis of the techniques employed by athletes in skill execution and an effective means of demonstrating the mechanical factors involved during the performance of athletic skills.

Cureton (15) expressed the general value of cinematography to the mechanical analysis of athletic skills. He wrote:

> Fairly precise analysis of the external mechanics of many acts of skill may be made by cinematography. The fundamental principle is that direction of movement (angles) dimensions, time relations, and indirect values of force and velocity may all be obtained from projected film.

Equipment

To facilitate interpretation of human movement in terms of basic mechanical principles any ordinary 8 millimeter or 16 millimeter camera mounted on a tripod may be used for filming purposes. A 16 millimeter camera may be preferred because the original image, as well as positive prints, are larger thus providing greater detail and a 16 millimeter camera is usually calibrated to run at a faster speed. (10:196, 15) However, both will provide permanent records for cinematographical analysis. Floodlights may be additional equipment needed when filming indoors.

The use of an editing viewer is helpful in studying the film. This will facilitate editing, splicing, and preparing the film for future use. (10:199) By using negative film pictures may be produced directly from the film enlarger.

Effective analysis may be accomplished using speed variance of 32 to 64 frames per second. However, the slower the camera speed the more likely blurring will occur while the gross perception of movement occurring within body segments is less pronounced as the frames per second are increased. (10:196)

Experimental Technique

In using motion pictures as a research tool for studying human movement, the first problem is to record comparable spatial relations and the second is adequate timing in spatial relations.

Only movements occurring in one plane, perpendicular to the axis of the camera are directly comparable. To insure comparable images it is necessary to establish the major plane of motion and have the camera set at a right angle (90 degrees) to that plane of action. Also the camera should be set in the center of the plane of action and the height of the camera centered on the subject to be photographed. (2:129-130)

If for analytical purposes multiple views are desired, this may be accomplished by using a second synchronized camera. By using more than one camera the subject may be viewed from a different plane of action (from the top, from the side, from the front, or from the back). (10:197)

The measurement of linear distance from the film frequently is a primary parameter for distance *per se* or for the ultimate determination of velocity. (16) However, when obtaining measurements from pictures it must be remembered that these projected images are not true size. The size or distance that appears on the projected pictures must be converted to actual size measurements. To do this, an object of known size must be photographed in the field of view. By measuring the apparent size on the projected image conversion of measurement to exact size or distance is possible. A conversion factor or scale factor is derived by dividing the known measurement of the object (usually in centimeters) by the projected size that appears on the screen. The measurement on the screen is then multiplied by the scale factor to bring the measurement up to true life size. (2:130, 15, 16) If the distance from the object to the camera is kept uniform only one conversion factor is necessary.

It is also helpful to have an accurate measurement of a body part, such as a forearm, to use as a reference to assist in determining the actual size of the subject in various positions, the velocity of linear motion, and the range of motion of the joints under investigation. (10:197)

The use of a grid as a frame of reference for measurement of distance is a most important consideration when analyzing movement. A common standard for a grid is to section it in 1-foot sections (with various subdivisions as needed). The grid is placed in the photographic field so distance may be calculated. (5:381) Through the use of a grid a subject may be photographed in a practice situation and more accurate measurements recorded.

If some part of the subject is closer to the camera or if movement should occur to or from the camera, perspective errors or distortions will result and the size of the object will appear smaller or larger. (2:129, 15) These distortions are not comparable. Perspective errors are magnified if the camera is set too close. By using a telephoto lens and increasing the distance from subject to the camera investigators have found this error will be minimized. (10:196, 15, 16)

Preparation of the subject must receive careful attention if the analysis is to include changes of body segments. The specific body parts must be differentiated from the rest of the body. One method of doing this is to place contrasting marks, such as tape, on selected anatomical landmarks. This should be done directly on the skin whenever possible. Placing marks over loosely fitting clothing will usually result in less than accurate measurements. (5:382)

Angular measurements are necessary in order to measure angular relations of body parts, range of motion of body parts, body lean and other similar relations. These measures have the distinct advantage of not requiring a correction factor to obtain true measurements. They can be scaled directly from the projected images or positive prints with a protractor.

Among the more important types of measurements in cinematographic analysis is that of velocity. Measurement of velocity is based on the following relation. (15)

$$\text{Velocity} = \frac{\text{Distance}}{\text{Time}}$$

To calculate the velocity of an object or body part it is necessary to measure the distance moved by the object or body part being studied and to count the number of frames elapsing during the action. (15) Angular velocity of a body part may be calculated by dividing the number of degrees the body part traveled by the time it took to travel that distance (degrees).

Indirect measurement of force may be computed from motion pictures by using the following formula:

$$\text{Force} = \frac{\text{weight of object}}{\text{Gravity (32.2)}} \times \text{Acceleration}$$

Acceleration is calculated from the motion pictures and then by determination of the weight-gravity ratio one can compute the propelling force. Force may be computed, by applying photographic data, for such techniques as batting a ball, putting the shot, hitting a tennis ball and other similar sports skills. (15)

Verification of Camera Speed

Because of the above, timing within films is an essential aspect to be considered. While cameras may be advertised as running at 64 frames per second this does not guarantee that the actual speed is that rate. Thus it becomes necessary to verify the actual speed of the camera used so that accurate measurements of velocity will prevail.

Cureton (15) described one method of verifying camera speed. He suggested filming a falling object (anything solid, round, and reasonably heavy) dropped from a known height. Then by using the formula $S = gt^2/2$ one may calculate the length of time the object takes to fall the known distance. An object dropped 8 feet will take .705 seconds using 16.1 as g/2. This time is then divided by the number of frames from release to contact with the floor to get time per frame. The reciprocal (one divided by time per frame) is frames per second or the camera speed. By dividing the distance an object traveled by the elapsed time will give the average velocity.

Another method described by several authors (2, 5, 10) consists of placing a clock in the field of study and photographing the sweep second hand, preferably a hundreth second timer, and then counting the number of frames elapsing between seconds.

Film Analysis

Once the film has been developed it must be viewed in order to get an impression of the useable sequences and to make choices for the selection of pictures for additional analysis. Data may be collected from images projected directly onto a flat surface or from positive prints made from negative film.

Two methods have been employed for film analysis. One commonly used method is that of tracing the contour or body outline onto paper. The film is viewed frame by frame and the tracings made directly onto paper or transparencies. Measurements are then derived from these outlines. (10:200)

Another method is that of using stick figures or point and dot technique. (2:135, 10:200) Anatomical points on the subject, such as the tip of the toes, the outer malleolus of the ankle, the center of the hip, knee, and shoulder or any other reference point may be chosen. If these points are marked with tape prior to filming, the reference points will be easily definable on the film or positive prints. Starting from some definable point in the movement sequence, the reference points are plotted successively frame by frame. The corresponding reference points for a given frame are then connected with a straight line, thus forming a stick figure. This will be less cluttered than a series of body outline tracings and more accurate joint angle measurements will usually result. Stick figures show the successive body positions and movement of body parts clearly in their essential relationship. They also reveal the velocity changes of body parts that could very easily remain hidden. By measuring successive distances the body part travels one can measure the velocity changes of body parts during various phases of the performance. Acceleration, either positive or negative, can be determined rather than just an average velocity for a total performance or sequence of action.

Comparisons between performances will show the differences upon which successful coaching points can be deduced. (2:138)

Regardless of which method is used to analyze the film it is unnecessary to use every frame for analysis. The selection of frames for contour drawings or stick figures used during the analysis is arbitrary. (10:211) To select the desired frames for analysis one may take the total number of frames of the performance and then divide this number by the number of frames desired for analysis. If eight drawings are desired and the total performance required 40 frames this would mean every fifth frame would be selected for analysis. This would allow for consistent time intervals for each drawing. However, with this method crucial movements could be missed.

Another method of selecting frames for study is to determine crucial phases or points of the performance and then to select those frames for analysis. This will allow for a more critical observation at a most crucial point in the performance that might otherwise go unnoticed. (10:201)

CINEMATOGRAPHICAL STUDIES OF THE VERTICAL JUMP

Couper (24) used cinematography to study the vertical jump performed following a running start. His primary concern was to analyze how horizontal momentum is transferred to the vertical jump. His subjects were 10 high school girls. They were permitted to use any style of jump they wished. It was concluded that in the best jumps, as measured from a reaching height and jumping height, there was greater arm hyperextension; more erect trunk at the low point in the crouch; later initiation of arms, more vertical projection and greater backward inclination of trunk at the high point of the jump.

Echert (17) studied the angular velocity and range of motion in the vertical jump and standing broad jump through the use of cinematographical techniques.

The isometric strength of the hip, knee, and ankle extensor muscles was measured by the cable tensiometer. Motion pictures were then taken of one vertical jump and one standing broad jump for each of 18 men and 11 women subjects. A camera set at 64 frames per second was used. A clock was placed in the field of view for use as a timing device. Stick figure drawings were made from the film and the angles of the hip, knee, and ankle joints were measured using a protractor. From these data, the range of joint movement and angular velocity of the joints were calculated.

Echert found in all instances that angular velocity occurred immediately before or at take-off. Also it was evident that maximum extension of the joints coincided with or occurred shortly after maximum angular velocity.

The author concluded further that there was no general relationship between isometric extensor strength and maximum angular velocity of the hip, knee, or ankle joint in either the vertical jump or standing broad jump.

In another study Eckert (18) examined the effects of added weights on the joint action in the vertical jump through the use of cinematography. In this study she investigated the maximum angular velocity and range of motion of the hip, knee, and ankle joints during weighted and unweighted performances in the vertical jump.

Seventeen male varsity basketball players each performed four jumps using no weights, a 6 pound weight, a 12 pound weight, and an 18 pound weight fastened at the belt. A synchronized clock was photographed in the field of view so that accurate timing of the camera could be calculated.

Stick figures consisting of the trunk, thigh, lower leg, and foot were drawn. The angles of the hip, knee, and ankle joints were measured for each frame with a protractor. The angle measurements were taken from the point of deepest flexion to maximum extension. The angular velocity of the joints were also calculated.

It was found that maximum angular velocity occurred immediately before or at take-off while in some cases maximum extension occurred after the foot had left the floor. It was further noted that decreases in maximum angular velocity and increases in range of motion and time of the joint actions of the hip, knee, and ankle result with increasing amounts of weight.

Haldeman (25) investigated the various angles of body flexion during the vertical jump as related to the jump ball situation in basketball. He studied, cinematographically, five subjects selected from a group of 806 junior and senior high school boys on the basis of the best jump and reach scores.

The angles of the hip, knee, and ankle at three phases of the vertical jump were analyzed. The analysis consisted of determining the range of measurement, the mean of the measurement, and the variation of the measurements. The following conclusions were made: (1) body action or form was similar for all five subjects, (2) the degree of flexion in the trunk and at the hip joint was not related to success in jumping vertically, (3) there was no one specific action of the non-tapping arm which seemed to be most successful, (4) no one specific method of jumping vertically was superior.

A mechanical analysis of the height and initial velocity in the Sargent jump was conducted by Henry. (27) He secured data on 16 male students at the State University of Iowa. Motion pictures were taken of three trials performed by each of the subjects. From measurements taken on the projected pictures, the following values were computed: (1) velocity, (2) height jumped, (3) increase in height due to arm snap, and (4) distance over which jump accelerated.

The author found that in each case the actual height jumped was greater than the theoretical height. He concluded that the vigorous arm snap of the arm downward caused the body to rise thus gaining additional height.

Hill (28) conducted a study of special interest to the writer. He compared the best and poorest jumps as performed by one subject. For analysis, selected points during the jump were chosen and compared. Analysis consisted of angular measurements of the ankle, knee, hip, arm, elbow, and body lean along with the linear velocity of the hip, knee, and arms. Finally a sequential analysis was made of the different phases during the two jumps.

His study showed: (1) the best jump had the greatest overall arm velocity while the poorest jump had the greatest hip and leg velocity in all phases of the jump, (2) the arms were in as nearly vertical position as possible in the best jump, (3) excessive flexion of the ankle, knee, hip, shoulder, and elbow seemed to decrease jumping height in the poorest jump.

He concluded that the crucial difference in the two jumps was effective use of the arms.

CHAPTER III

PROCEDURES

This investigation was conducted to study, through cinematography, selected mechanical factors that contribute to the vertical jumping performance of four basketball players. The procedures below were followed in order to conduct this investigation.

SELECTING AND MARKING OF SUBJECTS

Selection of Subjects

The subjects used for this investigation were three basketball players from the American Basketball Association Carolina Cougars professional basketball team and one member of The University of North Carolina at Greensboro varsity basketball team. These subjects were selected because they were considered in good physical condition, were participants in an activity which involves a considerable amount of jumping, and because of their familiarity with the skill of jumping.

Subject one. Subject one was a 6'7", 210 pound, 25 year old forward for the Carolina Cougars professional basketball team. A graduate of Clemson University in South Carolina he was an Atlantic Coast Conference all-star selection (1967) and a member of the American Basketball Association all-star team (1968).

Subject two. A center for the Carolina Cougars professional basketball team and a three year letterman from the University of Iowa (1964-65-66), subject number two was 6'8", and weighed 210 pounds. He was 27 years of age.

Subject three. At 6'1" and 190 pounds subject number three was a guard for the Carolina Cougars professional basketball team. While an undergraduate at Duke University he was an Atlantic Coast Conference all-star selection (1965-66-67) and an All-American selection (1967). He was also a member of the American Basketball Association all-star team (1968 and 1970). He was 25 years of age.

Subject four. The fourth subject was a 22 year old guard-forward for the University of North Carolina at Greensboro varsity basketball team. At 5'11" and 165 pounds he was a three year letterman (1969-70-71) and a Dixie Conference all-star selection (1971).

Marking the Subjects

White adhesive tape one inch wide was used for all body markings. The markings were placed on the lateral side of the body exposed to the camera. The left side of subjects one, two and four were marked. Subject three was marked on the right side. This variation was necessitated because of a deformity of the left elbow of the latter subject which affected the elbow angle.

The tape extended from the acromium process of the shoulder joint at the lateral aspect at the head of the humerous to the lateral epicondyle of the humerous at the elbow joint. The tape then was used to mark a line from the lateral aspect of the head of the radius at the elbow, continuing between the radius and ulna, to the lateral side of the wrist at a point halfway between the styloid process of the radius and the ulna process. Next the tape was attached under the arms and extended down across the ribs to the greater trochanter at the hip joint. The tape then extended down the lateral condyle of the femur to the anterior aspect of the head of the fibula at the knee joint. From the head of the fibula the tape was attached along the anterior shaft of the tibia stopping at a point on the lateral malleolus. Tape was then placed along the side of the foot from a point across the lateral malleolus and extending to the small toe.

In order to locate the desired joints, tape was placed horizontal to the previous markings at the following points:

1. around the wrist, connecting the styloid process of the radius and ulna.

2. around the elbow joint, connecting the medial and lateral epicondyle of the humerus.

3. across the greater trochanter of the femur.

4. around the knee joint, connecting the medial and lateral condyle of the femur and tibia passing across the patella.

5. one piece of tape was attached at a point just above the waist as a reference point to be used in determining the actual height of the jump.

In order that the desired parts of the body could be marked for analysis the only attire worn by the subjects was a pair of basketball shorts. Also because of the floor condition gym shoes were worn.

The above markings enabled the writer to locate the desired joint to measure the angles accurately. However, tape placed in a cross fashion at the desired joints only would suffice in any further studies as a means of locating anatomical landmarks thus eliminating considerable taping. Figure 1 shows the body markings.

PHOTOGRAPHY PROCEDURES

Location of the Filming

The filming for this investigation took place inside Rosenthal Gymnasium on the campus of The University of North Carolina at Greensboro. Trial jumps were conducted to be sure the subjects were in view of the camera throughout the entire performance of the jump. The filming was conducted between 12:00 noon and 3:00 p.m. on February 27, 1971. Mr. Emil W. Young Jr., director of The University of North Carolina at Greensboro Radio and Television studio, served as photographer.

Grid

For use as a background a grid was constructed using three pieces of one-fourth inch plywood each measuring four feet by eight feet. The pieces were mounted on a wooden frame and measured eight feet by twelve feet when completed. The grid was marked off in one foot squares with one inch tape.

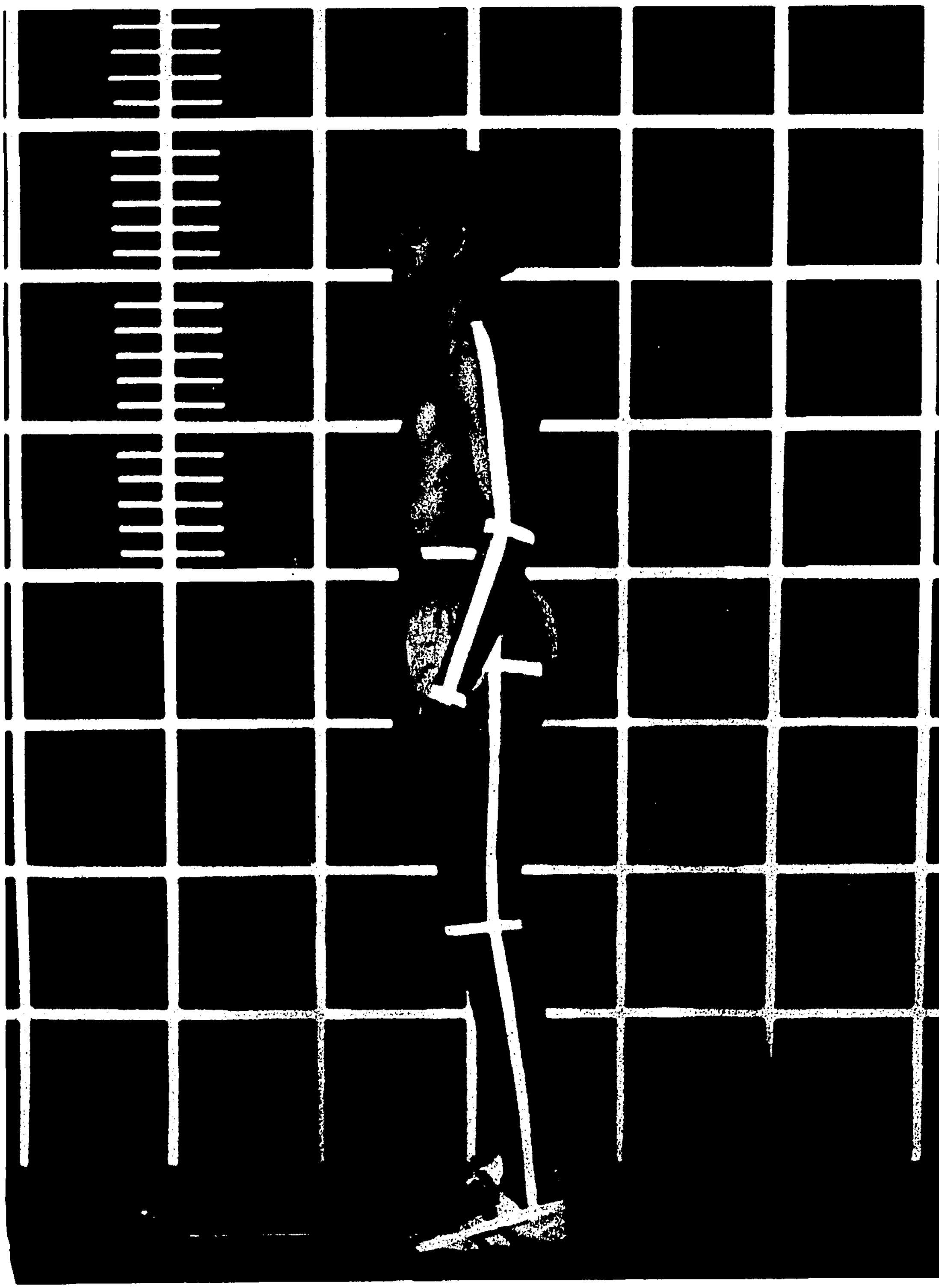


Figure 1

Body Markings and Foot Position

At a position four feet above the floor tape measuring ten inches by one-half inch was placed every two inches to a height of eight feet. These markings enabled the writer to more accurately determine the height of each jump. The grid was fastened to the rim of the basketball hoop for support during the filming. Figure 2 shows the grid.

Camera and Film

A Bolex H-16 camera equipped with a twenty-five millimeter view-finder lens and a Kodak millimeter f 1.9 lens was used for the actual filming. The camera was set to record at sixty-four frames per second. The lighting required a setting of an f 2.8 lens opening with the lens focused at infinity. Kodak plus X negative sixteen millimeter type 7231 film was used. A negative film was chosen because it is more practical for motion study and also facilitates processing for producing and enlarging positive prints.

Two Smith Victor 650 Watt Quartz flood lights were placed on either side of the grid to insure adequate lighting.

The camera, mounted on a tripod, was placed at a ninety degree angle to and forty-eight feet from the center of the grid. The height from the floor to the bottom of the lens measured five feet six inches. The distance and height was established after the camera was focused on the filming area and subject. The camera position remained constant throughout the filming. Figure 3 shows the filming situation.

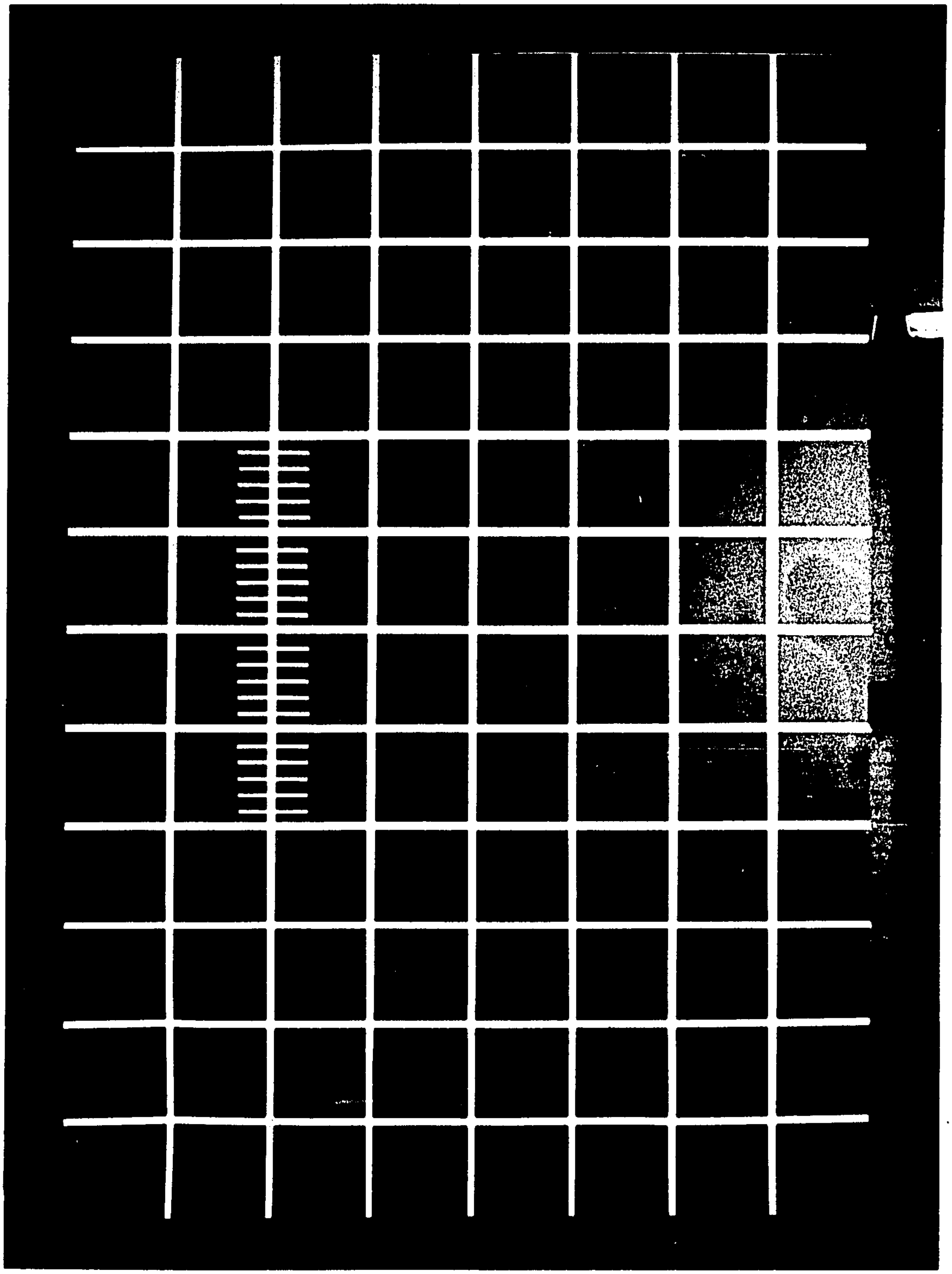


Figure 2

Grid

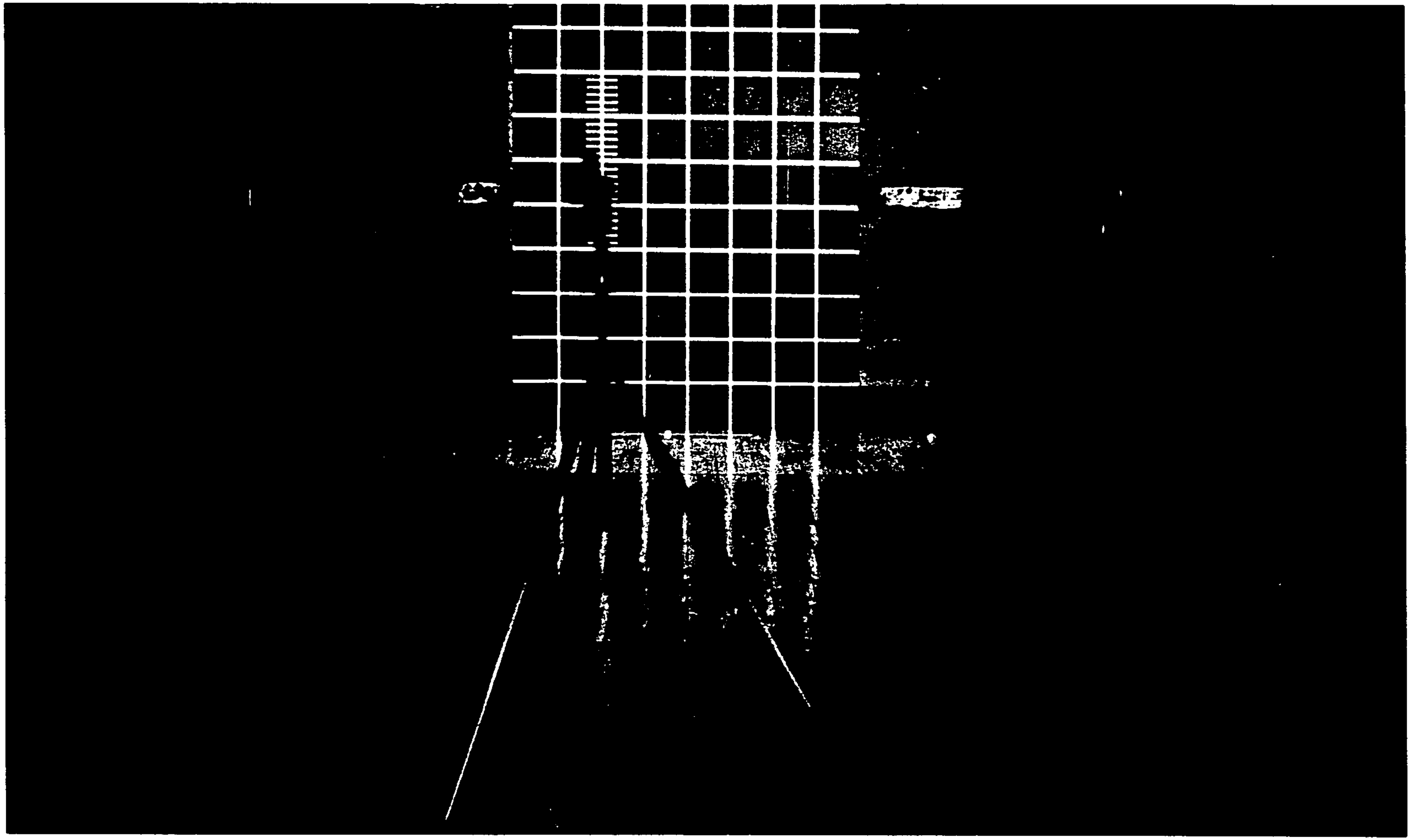


Figure 3

Filming Set-up

Measurement Frames

Several series of measurement frames were taken in order to calibrate the actual speed of the camera. A shot, held at a point seventy-two inches above a rubber mat, was dropped three times prior to the filming and again three times at the conclusion of the filming. The one inch rubber mat was placed in front of the grid to cushion the impact of the shot when dropped. The formula $S = 1/2gt^2$ was used to determine the speed of the camera.

The actual speed of the camera was determined by solving for t and dividing t by the number of frames it took for the shot to hit the mat. This procedure was followed for each of the six series of measurement frames recorded. An average was calculated and was considered the actual speed of the camera. This factor was necessary for calculation of velocity.

Filming Procedures

With the camera focused on the filming area each subject assumed an erect position with both feet parallel to and straddling the marked position on the floor in front of the grid. The lateral side with body markings was exposed to the camera.

The subjects were instructed to jump in their normal style attempting to jump and reach to as great a height as possible extending both arms upward as they might in reaching for a rebounding basketball. Prior to the actual filming each subject was free to perform several trial jumps to accustom himself to the procedure.

Selection and Processing of Frames for Specific Analysis

The processed film was viewed frame by frame on a sixteen millimeter movieola viewer. The height of each jump was determined by measuring the distance from the floor to the tape mark placed just above the waist. This point of reference was chosen because it would not be influenced in any way by body movement or action and would give a true measurement of the actual height attained during the jump. Each subject's best and poorest jumps were selected for analysis.

From the selected trials (best and poorest) six individual positions or points during the jump were chosen for the specific analysis and comparison. These positions were:

1. Point A: The point when the subject was in a crouched position with his hands raised to their maximum height behind his back in preparation to moving downward to gather momentum for the jump.

2. Point B: The point midway between point A and point C as measured by degrees the arm traveled between point A and point C.

3. Point C: The point when the subject had obtained the greatest knee flexion just prior to the upward movement of the body.

4. Point D: The point midway between point C and point E as measured by degrees the arm traveled between point C and point E.

5. Point E: The point when the subject was on tiptoe just prior to his actually losing contact with the floor. This was the subject's last chance to build up momentum necessary for the upward thrust.

Each subject performed seven jumps, with the subject pausing one minute between each jump. To insure consistency in the speed of the camera it was tightly wound after each jump.

The writer used the command "ready" for the subject to assume his pre-jump position. The command "set" alerted the subject and served as a signal for the photographer to start the camera. The final command of "jump" was the signal for the execution of the jump. The camera ran until the subject completed his jump and actually landed on the floor.

ANALYTICAL PROCEDURES

Verification of the Camera Speed

The actual speed of the camera was calculated by using the formula $S = 1/2gt^2$ and the ratio

$$\frac{\text{number of frames the shot took to fall}}{t} = \frac{X}{1} \text{ second or frames/sec.}$$

Solving for X in the ratio gave the actual speed of the camera which was to be 62.29 frames per second. By inverting the ratio

$$\frac{t}{\text{number of frames the shot took to fall}} = \frac{X}{1} \text{ frame or time/frame}$$

Solving for X in the ratio gave the time per frame. This time was .016 seconds.

6. Point F: The point when the body had obtained its maximum height. The apex of the jump.

The selected frames were then placed in a sixteen millimeter Minox enlarger and locked at one position so that all images would be developed to four by five inch positive prints. The image was exposed on Kodak enlarger paper, held in a premier 4-in-1 Easil, for thirty seconds and developed in Dektol developer. The prints were rinsed in water and placed in Hypo (fixer) solution for five minutes. They were then rinsed again and placed in a Premier Model 110 Photo Dryer.

Spotting Body Joints

On the enlarged positive prints the anatomical landmarks representing the body joints were located and marked with a ballpoint pen. The anatomical landmarks were:

1. The lateral malleolus of the ankle.

2. The lateral epicondyle of the femur at the knee.

3. The greater trochanter of the femur at the hip.

4. The head of the humerus at the shoulder.

5. The lateral epicondyle of the humerus at the elbow.

6. A point one-half way between the styloid process of the radius and ulna at the wrist.

7. The outer part of the shoe at the small toe.

In a few instances body movement and skin stretching caused certain markings to be moved or completely hidden from view. This was especially noticeable when the arms were extended above the shoulder causing the tape, marking the head of the humerus, to be rotated or blocked from view. When the markings were not readily discernible on the positive prints the landmarks were approximated and marked in the center of the body segment.

Diagramming the Body Joints

Lines, representing the body segments, were drawn, using a ballpoint pen and plastic straight edge, connecting the final markings or points representing the anatomical landmarks thus forming the angles of the body joints. The body angles that were formed were:

1. Elbow joint: This was formed using the lateral epicondyle of the humerus at the elbow as the vertex of the angle and the shoulder and wrist joints as the two rays of the angle.

2. Shoulder joint: This angle was formed using the head of the humerus as the vertex of the angle and the elbow and hip as the two rays of the angle.

3. Hip joint: This angle was formed using the greater trochanter of the femur as the vertex of the angle and the shoulder and knee joints as the two rays of the angle.

4. Knee joint: This angle was formed using the lateral epicondyle of the femur at the knee as the vertex of the angle and the hips and ankle joint as

the two rays of the angle.

5. Ankle joint: This angle was formed using the lateral malleolus of the ankle as the vertex of the angle and the knee and the foot as the two rays of the angle.

6. Body lean: This angle was formed using the hip joint as the vertex of the angle and the shoulder joint as one ray and the vertical line bisecting the hip as the other ray. Figure 4 shows the body angles.

Measurement of Body Joints

The angles formed were measured on the positive prints with a protractor. The angles were measured to the nearest one-half degree and always in a positive direction. In order to be consistent in the measurement of the angles, the writer used the measurement of less than 180 degrees when there was flexion of body parts and more than 180 when there was extension of the body parts.

Velocity Calculations

The angular velocity of body movement was figured for the arms at points B, C, D, and E. Hip extension, knee extension, and plantar flexion were calculated at points D and E. Throughout the remainder of the study wherever the word velocity is used it refers to angular velocity.

To calculate the actual velocity at the selected points, rather than an average velocity for the entire phase between the selected points, positive prints were produced of the pictures two frames prior to each of the selected points B, C, D, and E. These latter prints were also marked and measured.

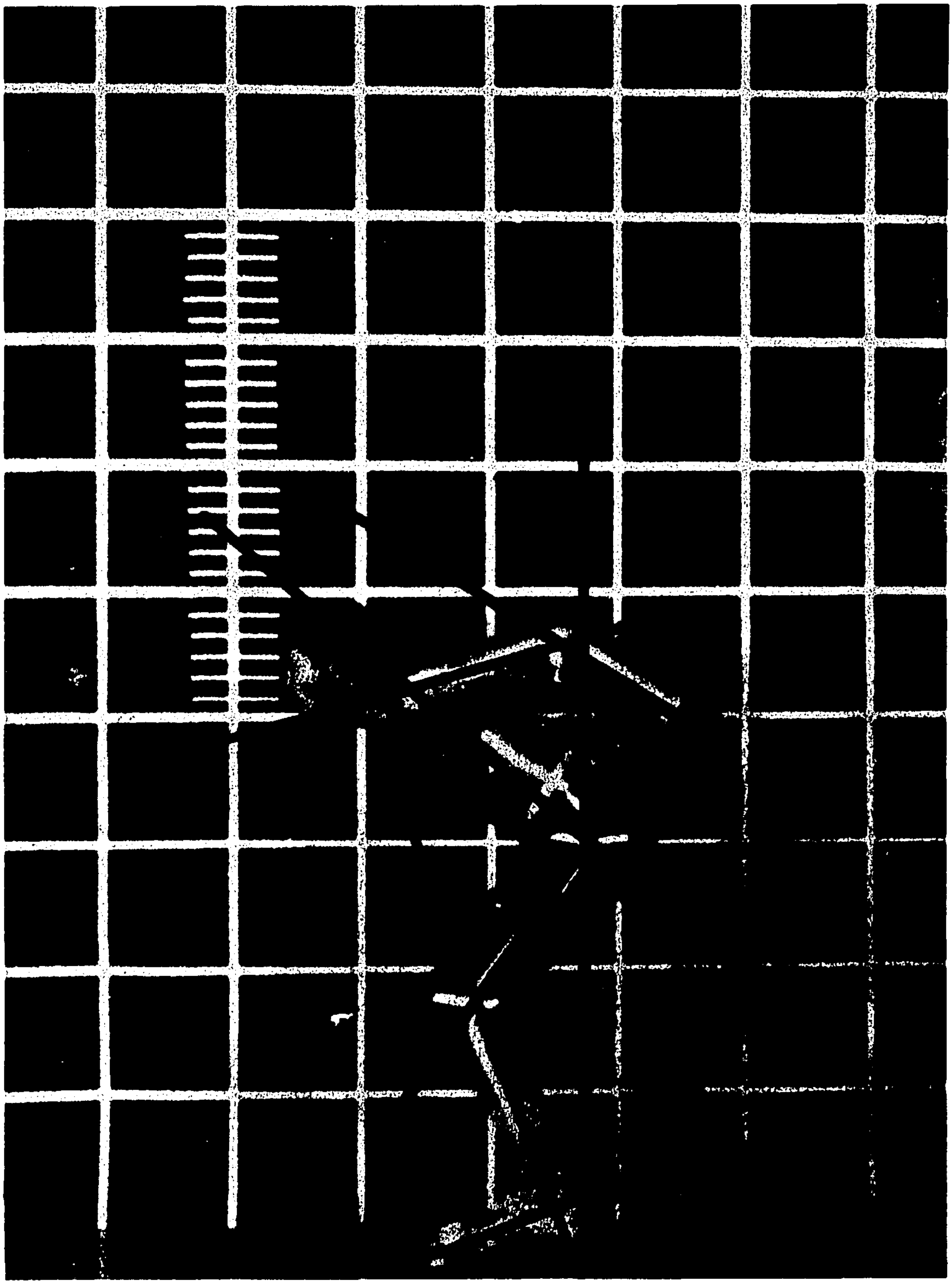


Figure 4

Body Angles Used in Measurements

Then by subtracting the difference between the angles from the two sets of prints the distance or range of movement, in degrees, was determined for each joint movement. The formula $V = \frac{D}{t}$ was used to calculate the actual velocity.

V = Degrees per second

D = Distance in degrees

t = time per frame

Sequential Analysis

In order to gain a more complete and orderly understanding of the movement pattern of body parts during the vertical jump a sequential analysis of the position, velocity, and acceleration of the body parts was made from point A, the preparatory position, to point E, the point of take-off. To facilitate this analysis the film was re-run through the movieola viewer until all details were noted and then a sequential description of the action that took place was made for each subject comparing his best and poorest jumps.

CHAPTER IV

ANALYSIS OF DATA

Through the use of cinematography each subject's best and poorest jumps, from a series of seven performances, were selected, analyzed, and compared on an individual basis. The data for the selected jumps of each individual subject were divided into the following three categories and are presented in the following order.

1. The angular measurements of the elbow, shoulder, hip, knee, ankle, and body lean at selected points throughout the jump.

2. The velocity calculations for the arm movement, hip extension, knee extension, and plantar flexion at selected points during the jump.

3. The sequential order of the position, velocity, and acceleration of body parts during the selected jumps.

Finally, similar mechanical factors which may have contributed to the subject's poorest jumping performance were identified.

SUBJECT ONE

Table I shows the actual height attained for the seven trial jumps performed by subject one. Trials 3 and 5 were selected as the best and poorest jumps. The difference between these two jumps was 1 1/2 inches.

TABLE I

MAXIMUM HEIGHT REACHED IN THE SEVEN TRIAL JUMPS
(Subject One)

Trials	Maximum Height Reached
1	72 inches
2	72
3*	72.5
4	72
5**	71
6	72
7	72

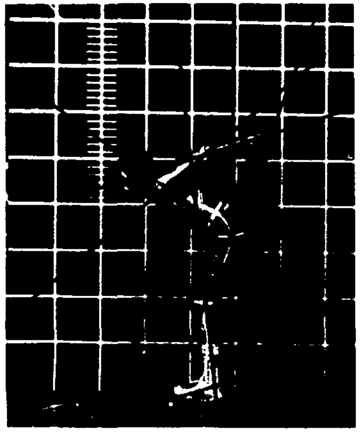
* Best Jump
** Poorest Jump

Angular Measurements

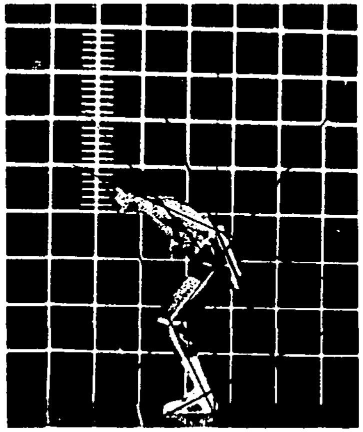
Figures 5 and 6 illustrate the selected points that were analyzed and compared. Table II presents the angles as they were measured from the positive prints represented in Figures 5 and 6.

Elbow Joint. Flexion in the elbow joint was greater in the poorest jump at all points except point F, the apex of the jump. This means that the arms were bent more at the elbow during the downward phase and were not as straight during the upward phase through the point of take-off. The difference was greatest, 14 degrees, at points A and B after which the differences gradually decreased to 2 degrees at point E. Point F was the only point at which elbow flexion was less for the poorest jump. At that point the elbow angle measured 3 degrees more (less flexion) during the poorest jump. In both jumps the flexion of the elbow increased steadily from point A to point D after which elbow flexion decreased gradually (arms straightened).

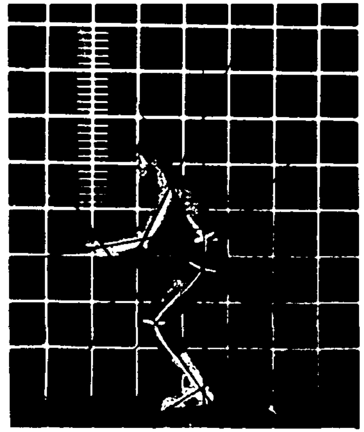
Shoulder Joint. The shoulder joint during the poorest jump was .5 degree less than during the best jump at point A, the preparatory stance. This represents slightly lower hyperextension of the shoulder joint at the starting point for the downward flight of the arms. The angle at the shoulder joint continued to measure less at point B by 1.5 degrees. At point C, the greatest difference between the two jumps was noted. The poorest jump measured 22 degrees less, 48.5 degrees as compared to 26.5 degrees. The arms for the poorest jump, at the point of deepest knee flexion, were not elevated nearly as



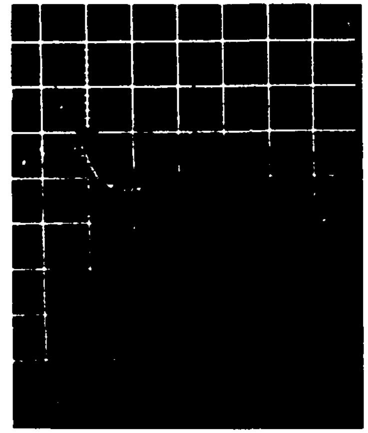
Point A



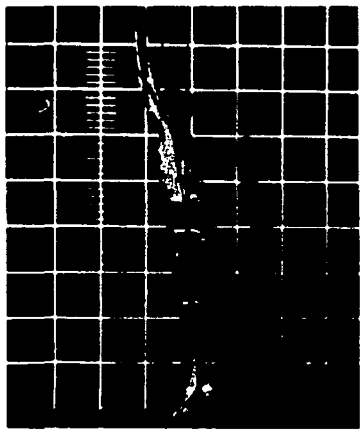
Point B



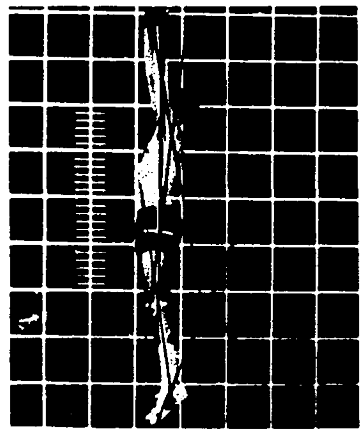
Point C



Point D



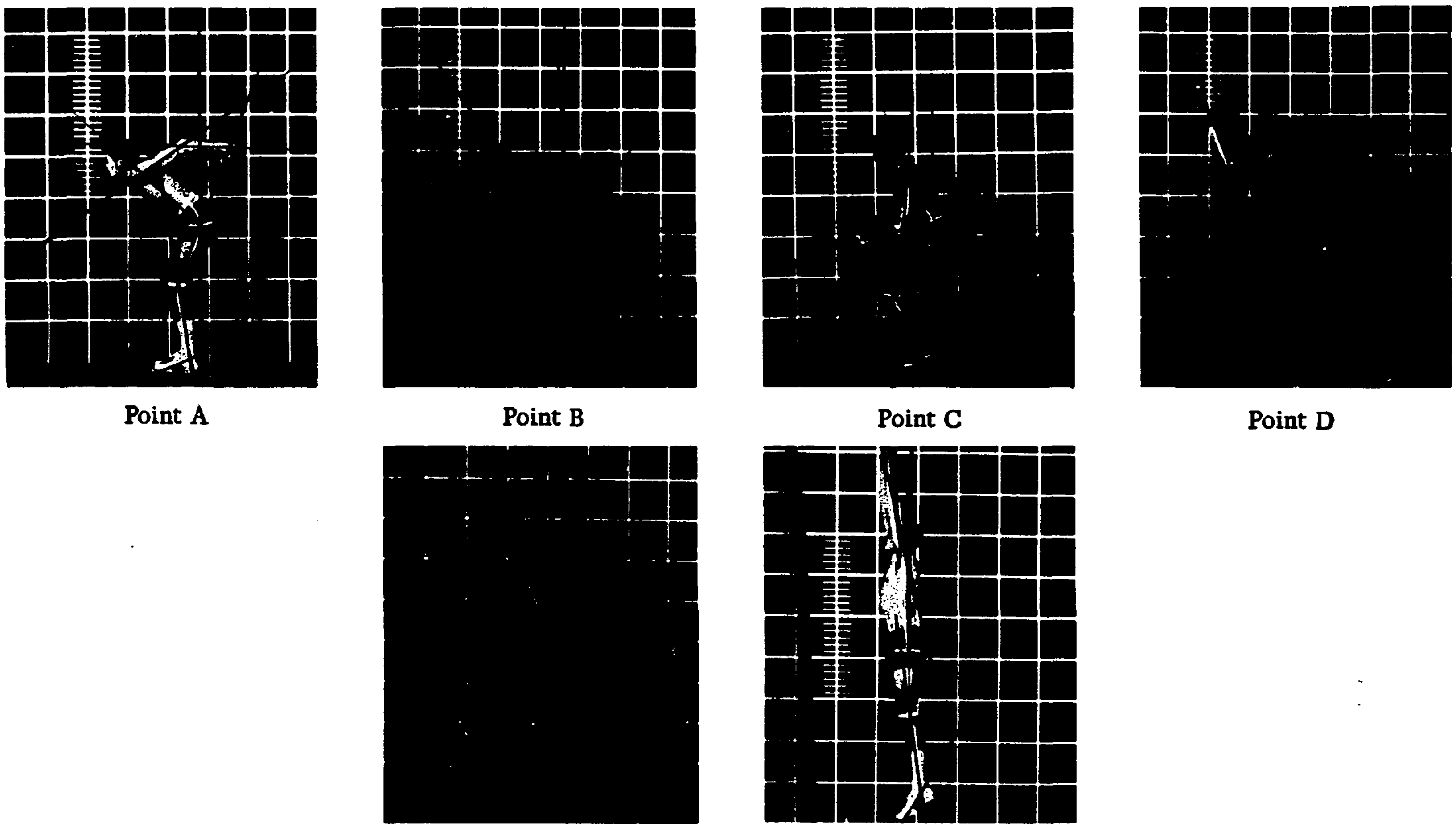
Point E



Point F

Figure 5

Subject One: Sequences in Best Jump



Point A Point B Point C Point D

Point E Point F

Figure 6

Subject One: Sequences in Poorest Jump

TABLE II

ANGULAR MEASUREMENTS OF BODY PARTS
AT SELECTED POINTS
(Subject One)

Body Parts	A	B	C	D	E	F
	Selected Reference Points					
Elbow						
Best	158	138	127	112.5	160.5	171
Poorest	144	124	117	105.5	158.5	174
Shoulder						
Best	76	25	48.5	101.5	160	163.5
Poorest	75.5	23.5	26.5	97.5	159	162.5
Hip						
Best	106	102.5	118.5	129.5	175.5	186
Poorest	110.5	108	119.5	133	171	181
Knee						
Best	152.5	117	105	112.5	180	171
Poorest	149.5	111.5	103	119	180	171
Ankle						
Best	100.5	91.5	87	85	140.5	147.5
Poorest	103.5	82	83	87.5	140.5	140
Body Lean						
Best	54	41	21.5	17	7	7
Poorest	48.5	36	20.5	18	12	1

much as in the best jump. The difference diminished at point D but the subject's arms during the poorest jump still was less by 4 degrees. At the point of take-off, point E, shoulder flexion was less by 5 degrees in the poorest jump. Again, at point F, the apex of the jump, the arms for the poorest jump were still slightly lower. Range of motion for the arms was less during the poorest jump by 1.5 degrees (239.5 degrees to 238 degrees).

Hip Joint. Hip flexion was less for the poorest jump at points A through D. The reverse was true at point E, the point of take-off. There was 4.5 degrees greater flexion in the hip joint for the poorest jump at this point. This indicated that the body was not as straight in the poorest jump at take-off. At point F, the apex of the jump, the hips were hyperextended in both jumps. However, during the poorest jump the hip joint was hyperextended 5 degrees less than in the best jump. During both jumps, hip flexion increased from point A to point B after which it decreased as the body straightened.

Knee Joint. Knee flexion was greater for the poorest jump at points A through C. At point C, the point of deepest knee flexion, the poorest jump displayed 2 degrees greater flexion (103 degrees to 105 degrees). However, at point D, less flexion was evident during the poorest jump. At point E, the point of take-off, the knees were extended to 180 degrees in both jumps, indicating that the legs were perfectly straight at take-off. At point F, the apex of the jump, the knee angle for both jumps was identical at 174 degrees. The knees, then, changed from a straight line at take-off to a slight degree of flexion at the highest point during the jump.

Ankle Joint. The ankle joint evidenced a great deal of inconsistency throughout the poorest jump for subject one. During that jump the ankle joint was flexed 3 degrees less at point A. At point B the reverse was true by 9.5 degrees. The ankle joint remained flexed more in the poorest jump at point C but at point D this changed and once again the ankle joint, during the poorest jump, displayed less flexion. At the point of take-off the ankles, in both jumps, showed flexion of 140.5 degrees. At point F, the apex of the jump, greater ankle flexion again occurred during the poorest jump. In the poorest jump the ankle joint decreased in degrees, indicating increased flexion from point A to B. This was followed by decreasing flexion (increased plantar flexion) until point E. Then, once again, flexion increased by .5 degree at point F. Steadily increasing ankle flexion was displayed, in the best jump, from points A to D and then decreasing flexion (increased plantar flexion) for points E and F.

Body Lean. Body lean, in the poorest jump, was less or the body was more erect at points A through C. The difference was greatest (54 degrees to 48.5 degrees) at the preparatory position, point A. This difference gradually decreased to point C where a difference of only 1 degree existed (21.5 degrees to 20.5 degrees). Body lean, at points D and E, was greater in the poorest jump, 1 degree at point D and 5 degrees at point E, the point of take-off. This means that the body at take-off was less erect in the poorest jump than in the best. In both jumps posterior body lean was evident at point F, the apex of the jump. However, the lean displayed during the poorest jump at this point was 6 degrees less than that of the best jump. There was a steady decrease in degrees of body lean throughout both the jumps.

Velocity Calculations

Points B, C, D, and E in plates 1 and 2 illustrate the selected points that were analyzed and compared. Table II presents the velocities as they were calculated from the positive prints represented in plates 1 and 2.

Arm Velocity. A slower rate of velocity for the arms at points B through D was observed during the poorest jump. The difference was greatest at point D by 233.59 degrees per second. Only at point E, the point of take-off, did the jumper produce greater arm velocity during the poorest jump. After showing an increase in velocity or acceleration from point B to C during the poorest jump the arms experienced negative acceleration from point C to E. In comparison, an increase in arm velocity (acceleration) from point B through D was noted during the best jump with negative acceleration occurring only from point D to E.

Hip Extension. Faster hip extension was experienced during the poorest jump at both measured points D and E. The rate of acceleration was also greater in the poorest jump from point D to E by 46.72 degrees per second. In both jumps there was an increasing rate of acceleration at take-off.

Knee Extension. Like hip extension, faster knee extension was observed

TABLE III

VELOCITY CALCULATIONS OF BODY PARTS
AT SELECTED POINTS
(Subject One)

Body Parts	Selected Reference Points B	C	D	E
Arm				
Best	467.18	825.34	934.35	596.33
Poorest	389.31	763.05	700.76	654.05
Hip Extension*				
Best	......	......	171.30	389.31
Poorest	......	......	218.02	482.75
Knee Extension*				
Best	......	......	155.73	700.76
Poorest	......	......	295.88	716.34
Plantar Flexion*				
Best	......	......	100.00	545.04
Poorest	......	......	93.44	700.76

*No measurements taken at points B and C

during the poorest jump at points D and E. However, while the poorest jump demonstrated a faster velocity for knee extension at both points the rate of acceleration between the two points of the best jump was greater by 124.57 degrees per second.

Plantar Flexion. A slower initial velocity for plantar flexion or ankle extension was experienced at point D of the poorest jump. However, at the point of take-off, point E, the reverse was true. Plantar flexion was faster, in both jumps, at point E than in point D. However, the rate of acceleration was greater for the poorest jump by 249.16 degrees per second.

Sequential Analysis

The sequential analysis involved a study of the arm position and velocity in relation to other body parts and their velocities from point A, the preparatory position, to point E, the point of take-off. Figures 5 and 6 illustrate the position of body parts throughout the preparation for both jumps, the best and poorest. In Table III are presented the velocities as they were calculated.

Point A to Point B. The initial downward movement during both jumps was started with increased flexion of the hips, knees, and ankles followed in close succession by the initial downward movement of the arms. However, the arm movement, during the poorest jump, occurred slightly later than during the best jump. The arms were moving downward and were ahead during the poorest jump between these two points but they were traveling at a slower rate of speed. The fact that the arms were elevated less and started later during the poorest jump may be the reason for this discrepancy. During both jumps the hips had obtained maximum flexion at or shortly after point B while the knees were still continuing to show increasingly greater flexion. This would appear to indicate that the body was continuing to be lowered by greater knee flexion after the hips had reached their maximum flexion as the arms were moving downward. Body lean was starting to decrease at point B during both jumps.

Point B to Point C. The arms, between these two points, continued to pick up speed and at point C were moving in an upward direction. It was between these two points that initial hip extension was inaugurated. The initial upward movement of the arms, during the best jump, occurred prior to the initial hip extension while during the poorest jump the upward flight of the arms occurred after or simultaneously with hip extension. The arms were elevated less but reached the point of maximum velocity at point C during the poorest jump. This means that during the poorest jump the arms had reached their maximum rate of velocity and acceleration at a lower elevation and prior to or at the same time that knee extension was being initiated. The ankles, during the poorest jump, showed slight extension between these two points while during the best jump ankle flexion was still continuing.

Point C to Point D. The arm elevation was less between these two points and the arms were experiencing negative acceleration as they approached point D during the poorest jump while they were still increasing in speed and reached their greatest rate of velocity at point D during the best jump. Knee extension was being initiated between these two points during both jumps. Plantar flexion was also initiated between these two points during the poorest jump while it had not yet begun during the best jump. The above would indicate that during the best jump the arms were elevated higher at the point of greatest arm velocity and the point of greatest arm velocity occurred after hip and knee extension had begun but prior to the time plantar flexion had been initiated. During the poorest jump the arms had already begun to slow down as knee extension and plantar flexion were being initiated.

Point D to Point E. The arms between these two points were demonstrating negative acceleration during both jumps. However, the arms were traveling faster at point E, the point of take-off, during the poorest jump even though they were not elevated as much throughout. As the arm velocity was decreasing, hip extension, knee extension, and plantar flexion were all experiencing positive acceleration for both jumps between these two points. All reached their maximum velocity at or just prior to point E, the point of take-off. This means that during the last phases of preparation for take-off the arms were experiencing negative acceleration at the point of greatest knee and hip extension and plantar flexion during both jumps.

SUBJECT TWO

Table IV shows the actual height attained for the seven trial jumps performed by subject two. Trials 3 and 4 which differed 2 3/4 inches were selected as the best and poorest jumps.

Angular Measurements

Figures 7 and 8 illustrate the selected points that were analyzed and compared. Table V presents the angles of the body parts as they were measured from the positive prints represented in Figures 7 and 8.

Elbow Joint. The elbow joint was flexed 2 degrees more in the poorest jump at point A, the preparatory position. At points B and C, the elbow, in the poorest jump, was flexed less by 7 degrees and 3 degrees respectfully. During the final downward flight (point B) and initial upward flight (point C) the arms were straighter at the elbow during the poorest jump. However, at point D the elbow was flexed more by 5.5 degrees during the poorest jump. As the arms continued their upward flight, from point C to point D, they were being flexed during the poorest jump while during the best jump they were being straightened. At the point of take-off (point E) there was no difference in the elbow flexion of the two jumps. At the apex of the jump (point F) the arms were again flexed more during the poorest jump.

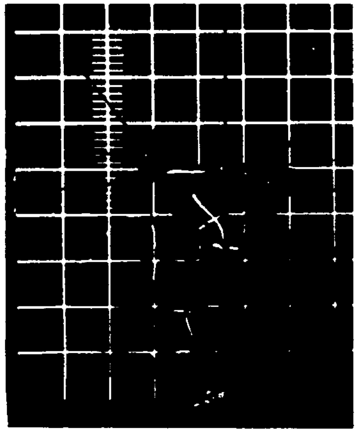
Shoulder Joint. The angle of the shoulder joint during the poorest jump measured 3.5 degrees less at point A, the preparatory stance. This represents

TABLE IV

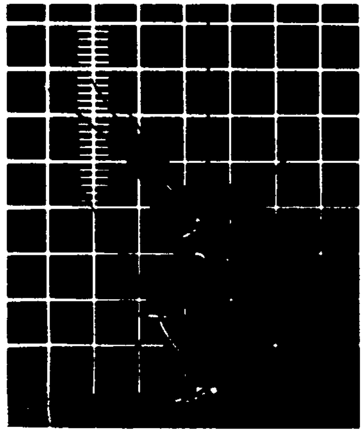
MAXIMUM HEIGHT REACHED IN THE SEVEN TRIAL JUMPS
(Subject Two)

Trials	Maximum Height Reached
1	77 inches
2	76
3**	75.75
4*	78
5	76
6	77
7	77

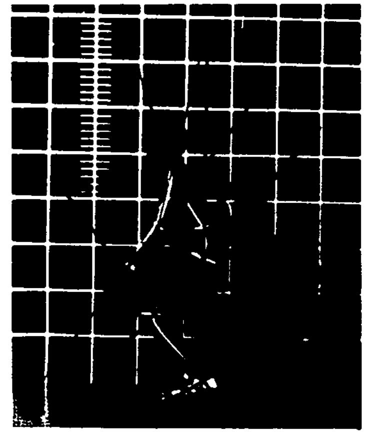
* Best Jump
** Poorest Jump



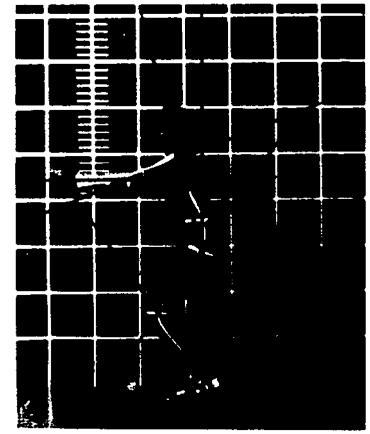
Point A



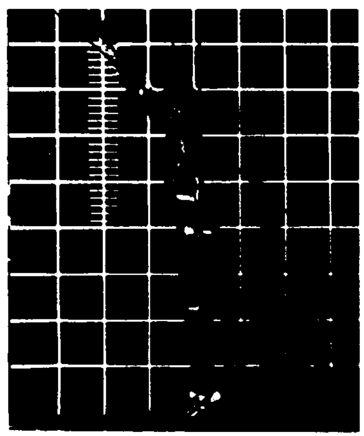
Point B



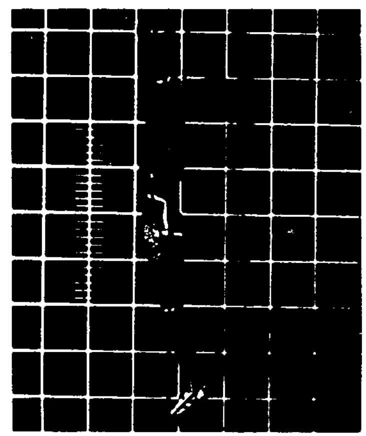
Point C



Point D



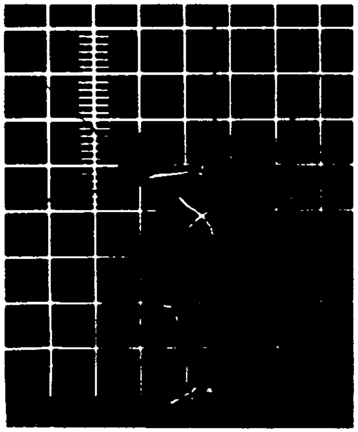
Point E



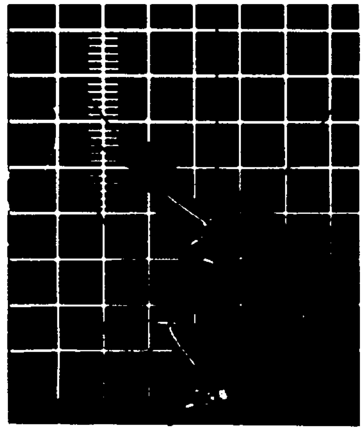
Point F

Figure 7

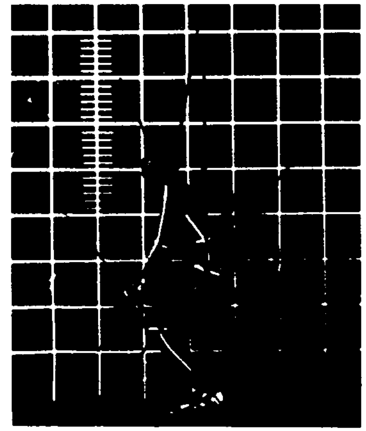
Subject Two: Sequences in Best Jump



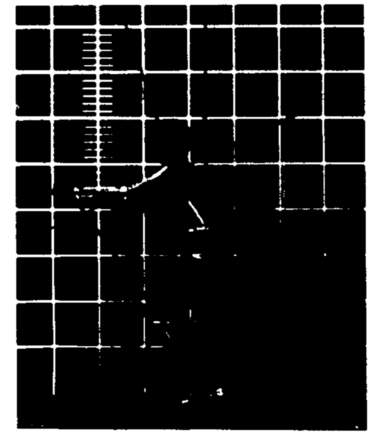
Point A



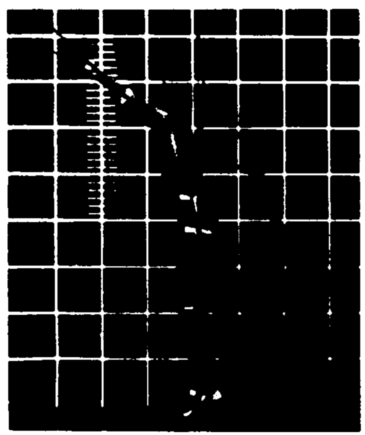
Point B



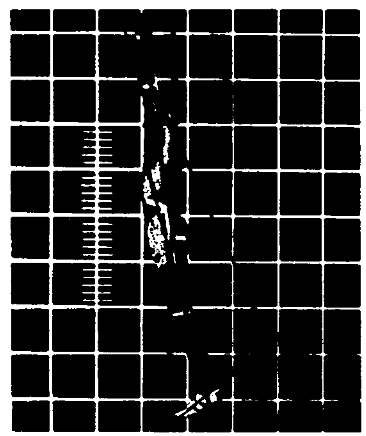
Point C



Point D



Point E



Point F

Figure 8

Subject Two: Sequences in Poorest Jump

TABLE V

ANGULAR MEASUREMENTS OF BODY PARTS
AT SELECTED POINTS
(Subject Two)

Body Parts	Selected Reference Points A	B	C	D	E	F
Elbow						
Best	165	163	157	160	169	180
Poorest	163	172	160	154.5	169	167
Shoulder						
Best	57	16	33	82	140	164
Poorest	53.5	17.5	34	84	135	154
Hip						
Best	109	108.5	120	131	176	187
Poorest	101	105	118	127.5	165	190
Knee						
Best	128	109	101.5	108.5	178	173
Poorest	130	109.5	102	110	169	175
Ankle						
Best	95	85	83	85	129.5	123.5
Poorest	102.5	93.5	81	83	129	115
Body Lean						
Best	39	33.5	20	13.5	8	4
Poorest	46.5	38	23.5	19	13	1

lower hyperextension of the shoulder joint at the starting point for the downward flight of the arms. The shoulder joint then measured slightly more at points B, C, and D, indicating that the arms were slightly ahead on the downward flight during the poorest jump. At point C, the point of deepest knee flexion, and also at point D the arms were elevated slightly higher resulting in greater shoulder flexion on the upward flight of the arms during the poorest jump. However, at point E, the point of take-off, shoulder flexion was less during the poorest jump. Again at point F, the apex of the jump, the arms for the poorest jump were still lower. The range of motion for the arms was less during the poorest jump by 13.5 degrees (221 degrees to 207.5 degrees).

Hip Joint. Hip flexion was greater for the poorest jump at points A through E. The greatest differences occurred at point A, the preparatory position (8 degrees) and point E, the point of take-off (11 degrees). At point F, the apex of the jump, the hips were hyperextended in both jumps. However, during the poorest jump the hip joint was hyperextended 3 degrees more. Hip flexion steadily decreased from point A to point F during the poorest jump. During the best jump hip flexion increased from point A to B and then steadily decreased from point B to F.

Knee Joint. Knee flexion was slightly less during the poorest jump at points A through D. At point A, the preparatory position, 2 degrees difference existed between jumps while at point C, the point of deepest knee flexion, .5 degrees difference was displayed. At point E, the point of take-off, the knees were flexed 9 degrees more during the poorest jump. At the point of take-off the knee joint was extended less during the poorest jump, while at the apex of the jump, there was evidence of greater extension.

Ankle Joint. The ankle joint was flexed less during the poorest jump at points A (7.5 degrees) and B (8.5 degrees). However the reverse was experienced at points C through F during the poorest jump, with the greatest difference (8.5 degrees) occurring at point F, the apex of the jump. During both jumps the ankle joint decreased in degrees, indicating increased flexion, from points A to B with decreasing flexion (increased plantar flexion) from points B to E.

Body Lean. Body lean during the poorest jump was greater at points A through E. This means that the body was less erect at these points. The difference was greatest at the initial position, point A, by 6.5 degrees (39 degrees to 46.5 degrees). The difference gradually decreased to point C where a difference of only 3.5 degrees existed (20 degrees to 23.5 degrees). This increased to a difference of 5.5 degrees at point D. At point E, the point of take-off the body was less erect during the poorest jump by 5 degrees. In both jumps posterior body lean was evident at point F, the apex of the jump. However, the lean displayed in the poorest jump was 3 degrees less than that of the best jump. There was a steady decrease in degrees of body lean throughout both jumps.

Velocity Calculations

Points B, C, D, and E in Figures 7 and 8 illustrate the selected points that were analyzed and compared. Table VI presents the velocities as they were calculated from the positive prints represented in Figures 7 and 8.

Arm Velocity. A greater rate of velocity for the arms at points B, C and E was observed during the poorest jump. Only at point D did the jumper produce less arm velocity during the poorest jump. The difference was also greatest at this point by 295.88 degrees per second. After showing an increase in acceleration from point B to C during the poorest jump, the arms experienced zero acceleration from point C to D and negative acceleration from point D to E, the point of take-off. In comparison, zero acceleration of the arms was noted from point B to C during the best jump with positive acceleration occurring from point C to D. Then, as in the poorest jump, negative acceleration occurred from point D to E.

Hip Extension. Slower hip extension was experienced during the poorest jump at both the measured points D and E. However, the rate of acceleration was greater during the poorest jump from point D to E by 31.14 degrees per second. In both jumps there was an increasing rate of acceleration for hip extension at E, the point of take-off.

Knee Extension. Slower knee extension was experienced during the poorest jump at point D and an identical rate of knee extension was displayed at point E, the point of take-off during both jumps. However, the rate of knee

TABLE VI

VELOCITY CALCULATIONS OF BODY PARTS
AT SELECTED POINTS
(Subject Two)

Body Parts	Selected Reference Points B	C	D	E
Arm				
Best	591.76	591.76	934.35	404.86
Poorest	638.47	685.19	638.47	529.47
Hip Extension*				
Best	......	......	233.59	560.61
Poorest	......	......	155.73	513.89
Knee Extension*				
Best	......	......	233.59	840.92
Poorest	......	......	186.87	840.92
Plantar Flexion*				
Best	......	......	93.44	451.60
Poorest	......	......	31.15	716.34

*No measurements taken at points B and C

extension was faster by 78.72 degrees per second during the poorest jump.

Plantar Flexion. A slower initial velocity for plantar flexion or ankle extension was experienced at point D during the poorest jump. However, at the point of take-off, point E, the reverse was true. Plantar flexion was faster, in both jumps, at point E than at point D. However, the rate of acceleration during the poorest jump was greater by 327.03 degrees per second.

Sequential Analysis

Figures 7 and 8 illustrate the sequence of the movement of body parts throughout the jumps (best and poorest). The velocities, as they were calculated throughout the preparation for the jump, are presented in Table VI.

Point A to Point B. During the poorest jump the initial movement was initiated by increasing knee flexion simultaneously with downward movement of the arms. During the best jump the movement was initiated first by increased hip and knee flexion and then in close succession downward movement of the arms. During both jumps the hips obtained maximum flexion at or shortly after point B while the knees were still continuing to show greater flexion. This means that as the arms were moving downward the body was continuing to be lowered by greater knee flexion after the hips had reached their maximum flexion. Body lean was beginning to decrease at point B during both jumps.

Point B to Point C. The arms, between these two points, continued to accelerate during the poorest jump while during the best jump the rate of arm velocity remained the same. It was between these two points that hip extension was started. The initial upward movement of the arms during both jumps occurred prior to hip extension. The arms were elevated slightly more at point C during the poorest jump but reached their maximum rate of velocity at this point. This means that, during the poorest jump, the arms reached their maximum rate of velocity at a lower elevation than during the best jump and prior to or at the same time that knee extension and plantar flexion was being initiated.

Point C to Point D. The arms showed greater shoulder flexion but because of greater body lean were not elevated as much between these two points during the poorest jump. They were experiencing negative acceleration as they approached point D during the poorest jump while the arms were still increasing in speed and reached their maximum rate of velocity at point D during the best jump. Knee extension and plantar flexion were being initiated between these two points during both jumps. Knee extension and plantar flexion were faster during the best jump. The above would indicate that during the best jump the point of greatest arm velocity occurred after knee extension and plantar flexion had begun while during the poorest jump the arms had already begun to slow down during the early stages of knee extension and plantar flexion.

Point D to Point E. The arms were demonstrating negative acceleration during both jumps between these two points. However, the arms were traveling faster at point E, the point of take-off, during the poorest jump although they were not elevated as much. As the arms were decreasing in velocity, hip extension, knee extension, and plantar flexion were all experiencing positive acceleration for both jumps between these two points. All reached their maximum velocity at or just prior to point E. This means that during the last phases of preparation for take-off the arms were experiencing negative acceleration at the point of greatest hip and knee extension and plantar flexion during both jumps.

SUBJECT THREE

The actual height attained for each of the seven trial jumps performed by subject three is presented in Table VII. On the basis of these data trials 1 and 7 were selected as the poorest and best jumps respectively. It should be noted that the best jump was 3 inches higher than the poorest.

Angular Measurements

Figures 9 and 10 illustrate the selected points that were analyzed and compared. Table VIII presents the angles as they were measured from the positive prints represented in Figures 9 and 10.

Elbow Joint. The elbow joint was flexed more, by 10 degrees, during the poorest jump at point A, the preparatory position. At point B, the elbow angle was identical for both jumps while at points C, D, and E the elbow was flexed less, resulting in the arms being straighter during the poorest jump. Thus, during the initial downward flight the arms were bent the same in both jumps but on the upward flight the arms were being straightened more at the

TABLE VII

MAXIMUM HEIGHT REACHED IN THE SEVEN TRIAL JUMPS
(Subject Three)

Trials	Maximum Height Reached
1**	68 inches
2	68
3	69
4	69
5	70
6	70
7*	71

* Best Jump
** Poorest Jump

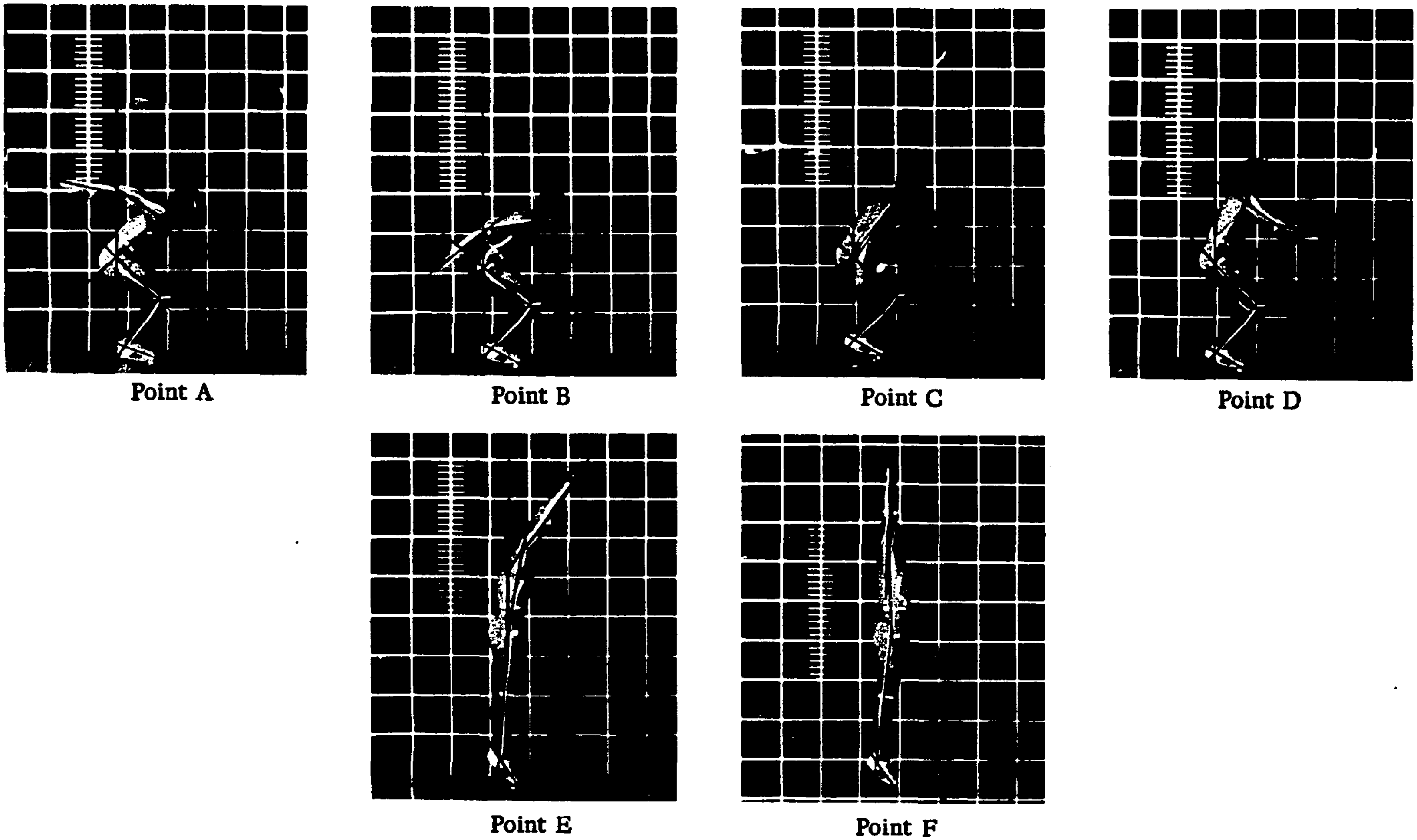
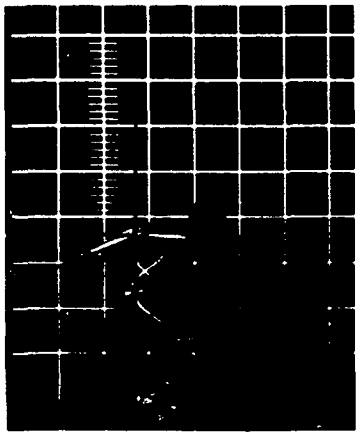
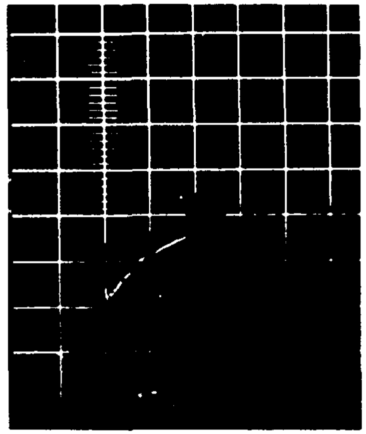


Figure 9

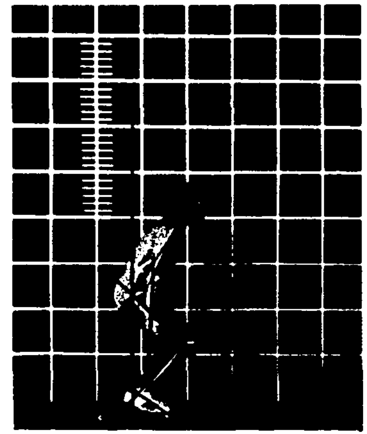
Subject Three: Sequences in Best Jump



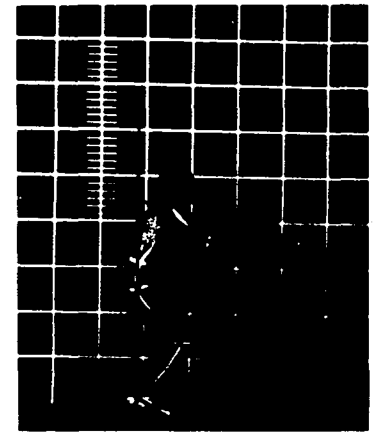
Point A



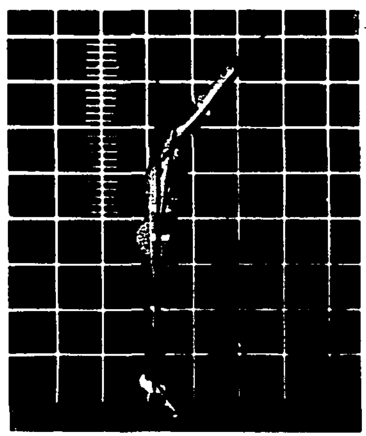
Point B



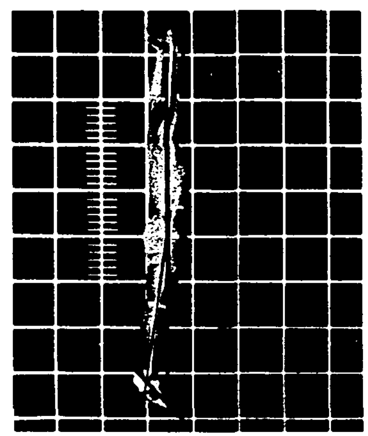
Point C



Point D



Point E



Point F

Figure 10

Subject Three: Sequences in Poorest Jump

TABLE VIII

ANGULAR MEASUREMENTS OF BODY PARTS
AT SELECTED POINTS
(Subject Three)

Body Parts	Selected Reference Points A	B	C	D	E	F
Elbow						
Best	159	153	153	153	175	180
Poorest	149	153	158	162.5	178	178
Shoulder						
Best	75	35	2.5	80	150	179
Poorest	55	24	9	79.5	145	177
Hip						
Best	85	84.5	94	111	176.5	188
Poorest	89	93	103.5	121	174	189
Knee						
Best	98	89	88	97	180	180
Poorest	98	95	92.5	105	180	180
Ankle						
Best	81.5	77.5	82	83	148	138
Poorest	84	81	81	90	140	137
Body Lean						
Best	47.5	47	38	27	8	2
Poorest	45	41	31	21	8	0

elbow, up through point E, the point of take-off, during the poorest jump. The greatest difference, 9.5 degrees, was noted at point D. However, at point F, the apex of the jump, the arms were again flexed more during the poorest jump. This represents less straightening of the arms during the poorest jump at the highest point during the jump.

Shoulder Joint. The angle of the shoulder joint during the poorest jump measured 22 degrees less at point A, the preparatory position. This represents lower hyperextension of the shoulder joint at the starting point for the downward flight of the arms. The shoulder joint continued to show lower hyperextension at point B during the poorest jump. Thus the arms during the poorest jump were ahead of the arms during the best jump on the downward flight. At point C, the point of deepest knee flexion, there was less shoulder flexion during the poorest jump and there continued to be less throughout the remainder of the jump, points D through F. The greatest difference in shoulder flexion was noted at point E, the point of take-off. The range of motion for the arms was less during the poorest jump by 22 degrees (254 degrees to 232 degrees).

Hip Joint. Hip flexion was less during the poorest jump at points A through D. The reverse was true at point E, the point of take-off. The hip joint for the poorest jump measured 2.5 degrees greater flexion at this point. This means that the body was not as straight during the poorest jump at take-off. At point F, the apex of the jump, the hips were hyperextended in both jumps. However, during the poorest jump the hip joint was hyperextended 1 degree more than in the best jump. In both jumps hip flexion increased from point A to B after which it decreased steadily.

Knee Joint. Knee flexion was identical at point A during both jumps. At points B through D knee flexion was less during the poorest jump. At the point of deepest knee flexion, point C, there was 4.5 degrees less flexion displayed during the poorest jump. The greatest difference was noted at point D where the poorest jump displayed 8 degrees less knee flexion, 105 degrees for the best to 97 degrees for the poorest. As a result the legs were straighter at these points during the poorest jump. At point E, the point of take-off, the knees were extended to 180 degrees during both jumps. This means that the legs were perfectly straight at take-off. They remained straight through point F, the apex of the jump.

Ankle Joint. The ankle joint was flexed slightly less during the poorest jump at both point A and at point B. However, the reverse, greater flexion, was true at point C. Again at point D the ankle displayed less flexion or more extension. At point E, the point of take-off, the ankle was again flexed more during the poorest jump. At the point of take-off this subject had less plantar flexion during the poorest jump. At the apex of the jump, point F, the ankle remained flexed slightly more during the poorest jump. During both jumps the ankle joint evidenced a decrease in plantar flexion from point A to B followed by an increase from point B to E.

Body Lean. Body lean was less during the poorest jump at points A through D. As a result the body was more erect at these points during the poorest jump. The difference in body lean was greatest between the two jumps at point C, the point of deepest knee flexion. At point E, the point of take-off, an identical body lean of 8 degrees was noted. At point F, the apex of the jump, zero body lean was exhibited during the poorest jump while the best jump showed a posterior body lean of 2 degrees. A steady decrease in degrees of body lean was displayed throughout both jumps.

Velocity Calculations

Points B, C, D, and E in Figures 9 and 10 illustrate the selected points that were analyzed and compared. Table IX presents the velocities as they were calculated from the positive prints represented in Figures 9 and 10.

Arm Velocity. A slower rate of velocity for the arms was observed during the poorest jumps at points B through D. The difference was greatest at point B by 233.59 degrees per second. Only at point E, the point of take-off, did the jumper produce greater arm velocity during the poorest jump. Both jumps showed an increase in acceleration from point B to D and then negative acceleration from point D to E. However, the greatest rate of acceleration during the poorest jump was observed from point B to C while the greatest rate of acceleration during the best jump was observed from points C to D.

Hip Extension. Faster hip extension was observed at point D during the poorest jump while the reverse was true at point E or at take-off. In both

TABLE IX

VELOCITY CALCULATIONS OF BODY PARTS
AT SELECTED POINTS
(Subject Three)

Body Parts	Selected Reference Points B	C	D	E
Arm				
Best	685.19	825.34	1058.93	280.31
Poorest	451.60	747.48	918.78	467.18
Hip Extension*				
Best	......	......	93.44	482.75
Poorest	......	......	124.58	311.45
Knee Extension*				
Best	......	......	140.16	825.34
Poorest	......	......	155.73	654.05
Plantar Flexion*				
Best	......	......	0	934.35
Poorest	......	......	124.58	622.90

*No measurements taken at points B and C

jumps there was an increase in velocity from point D to E. However, the rate of acceleration was less during the poorest jump by 202.44 degrees per second.

Knee Extension. Faster knee extension was observed at point D during the poorest jump while the reverse was true at point E or at take-off. Both jumps gave evidence of an increase in velocity from point D to E. However, the rate of acceleration was less during the poorest jump by 186.86 degrees per second.

Plantar Flexion. A faster initial velocity for plantar flexion or ankle extension was experienced at point D during the poorest jump while at point E, the point of take-off, the reverse was true. Plantar flexion was faster during both jumps at point E than at point D. However, the rate of acceleration was slower during the poorest jump by 498.32 degrees per second.

Sequential Analysis

Figures 9 and 10 illustrate the position of body parts throughout the best and poorest jumps for subject three. In Table IX are the calculated velocities for the various body parts.

Point A to Point B. The arms initiated the movement downward during the poorest jump followed in close succession by greater knee and ankle flexion. During the best jump movement was initiated first by greater hip, knee and ankle flexion and then followed in close succession by a downward movement of the arms. Greatest hip flexion was observed between these two points during the best jump. However, as the arms started their movement downward the hips started to extend, also, body lean started to decrease. The arms were moving downward between these two points and were ahead during the poorest jump when compared to the best jump. However, the arms were traveling at a slower rate of speed.

Point B to Point C. The arms were moving downward throughout the distance between these two points and continued to accelerate during both jumps. Also the knees were continuing to experience greater flexion over the same distance. The ankles, however, were beginning to extend between these two points during the best jump but remained flexed in an identical position between these two points during the poorest jump. As the arms were continuing on their downward flight body lean continued to decrease. This indicates that the body was becoming more erect as the arms were moving downward and as the knees were approaching their greatest flexion.

Point C to Point D. The arms were beginning their upward flight between these two points. They were still accelerating and at point D reached their greatest rate of velocity. Also it was between these two points that knee extension and plantar flexion were being initiated. Hip extension, knee extension and plantar flexion were faster between these two points during the poorest jump. The above would indicate that during both jumps knee extension and plantar flexion were initiated before the arms had reached their point of greatest velocity. During the best jump the arms were elevated higher as knee extension and plantar flexion were being initiated. Between these two points body lean continued to decrease, during both jumps, at about the same rate.

Point D to Point E. The arms between these two points were beginning to experience negative acceleration during both jumps. As the arms were decreasing in velocity, hip and knee extension and plantar flexion were all experiencing positive acceleration during both jumps and reached their maximum rate of velocity at or just prior to point E. This showed that during the last phase of preparation for take-off, the arms were experiencing negative acceleration during both jumps at the point of greatest hip and knee extension and plantar flexion. Body lean decreased more rapidly during the best jump between these two points. This means that the body was brought into an erect position more rapidly at the point of take-off during the best jump, as the arms were reaching upward.

SUBJECT FOUR

In Table X are presented data for the actual height attained on each of the seven trial jumps performed by subject four. Trials 2 and 6 were selected as the best and poorest jumps. The difference between the two was 2 inches.

Angular Measurements

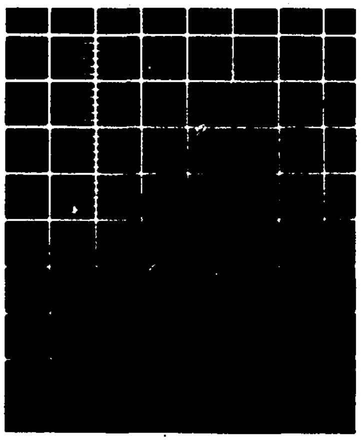
Figures 11 and 12 illustrate the selected points that were analyzed and compared. Table XI presents the data based upon body angles as they were derived from the positive prints represented in Figures 11 and 12.

TABLE X

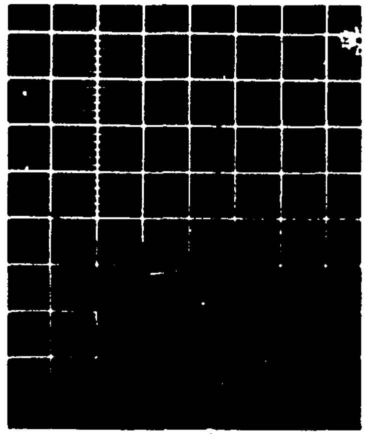
MAXIMUM HEIGHT REACHED IN THE SEVEN TRIAL JUMPS
(Subject Four)

Trials	Maximum Height Reached
1	75 inches
2*	74.5
3	73
4	74
5	73
6**	72.5
7	74

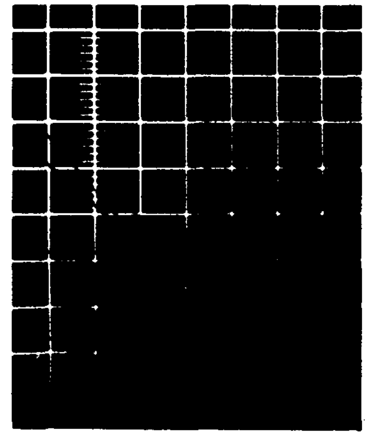
* Best Jump
** Poorest Jump



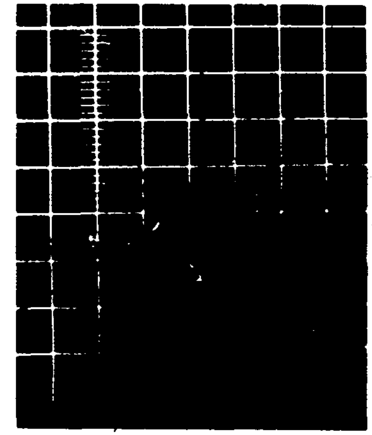
Point A



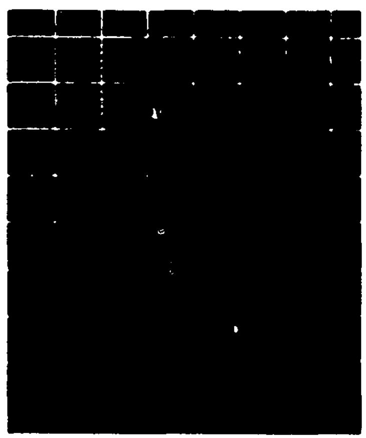
Point B



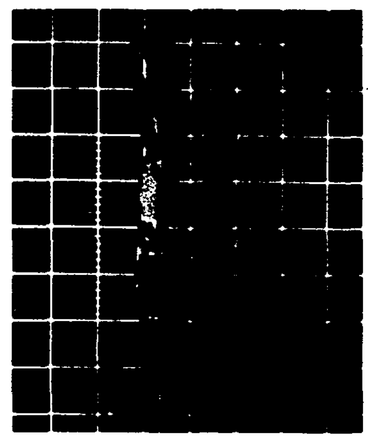
Point C



Point D



Point E



Point F

Figure 11

Subject Four: Sequences in Best Jump

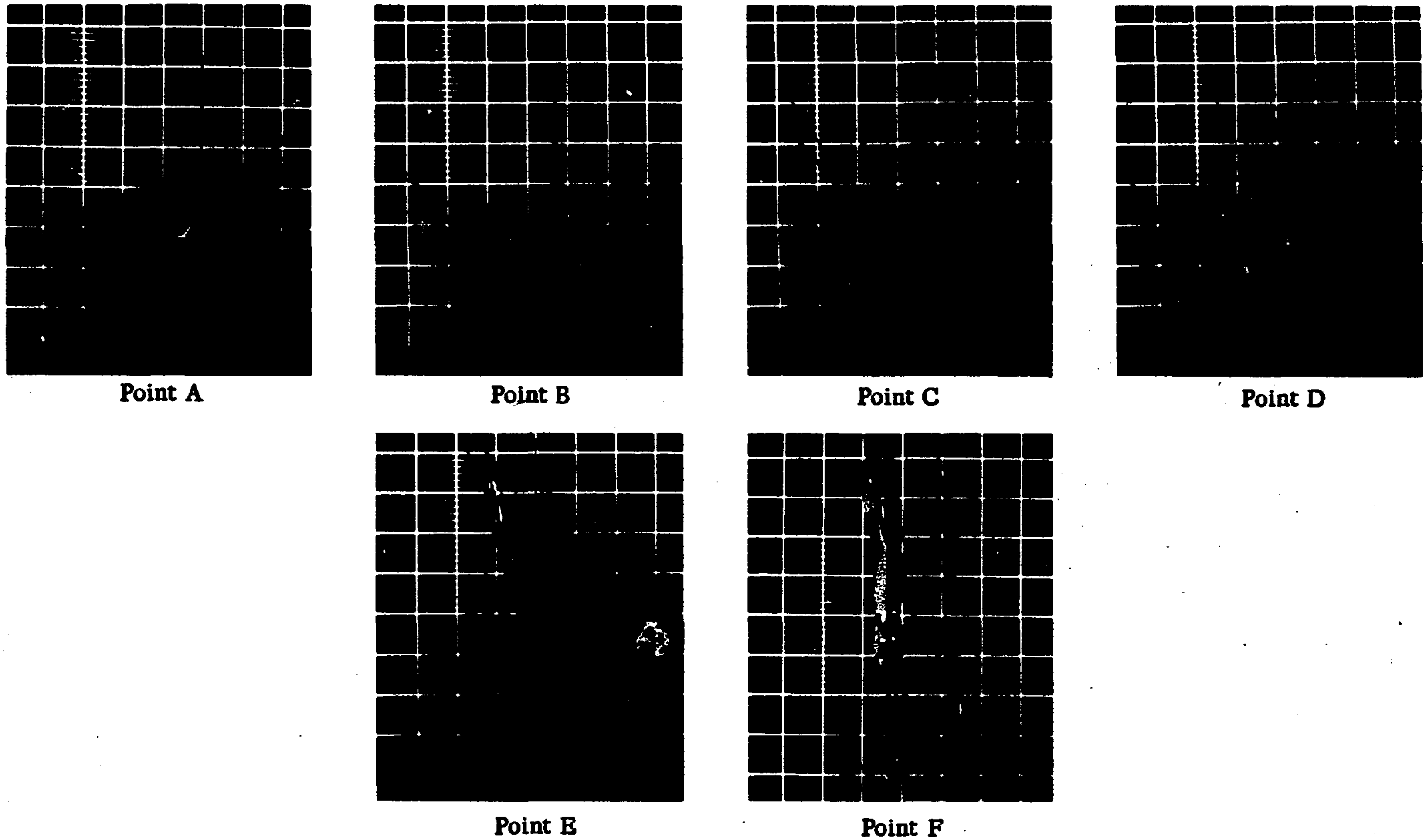


Figure 12

Subject Four: Sequences in Poorest Jump

TABLE XI

ANGULAR MEASUREMENTS OF BODY PARTS
AT SELECTED POINTS
(Subject Four)

	Selected Reference Points					
Body Parts	A	B	C	D	E	F
Elbow						
Best	166	160	149	146	176	176
Poorest	169	171.5	163	142	167	172
Shoulder						
Best	71	40	8	85.5	173	165
Poorest	42	18	9	85	169	156
Hip						
Best	60	66.5	83.5	111	180	188
Poorest	67.5	68	83	109	175	190
Knee						
Best	115	82	76	86	185	180
Poorest	130	87	78.5	86	185	180
Ankle						
Best	88	67.5	67	71	145	145
Poorest	92	69	71	70	143	144
Body Lean						
Best	74	58	41	24	9	3
Poorest	76	58	42	24	13	3

Elbow Joint. The elbow joint was flexed less during the poorest jump resulting in the arms being straighter at points A, B, and C. Greater flexion of the elbow was then displayed at points D, E, and F. The greatest difference, one of 14 degrees, occurred at point C. This means that on the downward flight and initial upward flight (points A, B, C) the arms were straighter while on the upward flight they were flexed more during the poorest jump.

Shoulder Joint. The angle of the shoulder joint measured 29 degrees less at point A, the preparatory position, during the poorest jump. This represented lower hyperextension of the arms at the starting point for the downward flight of the arms. The shoulder joint continued to show lower hyperextension at point B during the poorest jump. This means that the arms were ahead on the downward flight of the arms during the poorest jump. At point C, the point of deepest knee flexion, the shoulder joint showed slightly, only 1 degree, more shoulder flexion during the poorest jump. As a result the arms were higher. However, the arms were lower throughout the remainder of the poorest jump, points D through F, than in the best jump. The range of motion for the arms was less during the poorest jump by 38 degrees, 236 degrees to 198 degrees.

Hip Joint. Hip flexion was less (the body was straighter) during the poorest jump at point A, the preparatory position, and remained less at point B. However, at points C, D, and E the body was flexed more during the poorest jump. At point F, the apex of the jump, the hips were hyperextended in both jumps. However, during the poorest jump the hip joint was hyperextended 2 degrees more than in the best jump. During both jumps, hip flexion decreased steadily throughout the jump.

Knee Joint. Knee flexion was less during the poorest jump at points A, B, and C. The greatest difference, one of 15 degrees, occurred at point A, the preparatory position. At point C, the point of deepest knee flexion, the difference had diminished to 2.5 degrees. Knee flexion was identical at points D, E, and F or throughout the points where diminishing knee flexion (knee extension) was occurring.

Ankle Joint. The ankle joint was flexed less during the poorest jump at points A, B, and C. However, the reverse or greater flexion was evident at points D, E, and F. During both jumps the ankle joint decreased in degrees, resulting in increased flexion, from points A to B. Decreasing flexion was found from points C to E, the point of take-off. At point F, the apex of the jump, slightly greater, 1 degree, ankle flexion was displayed during the poorest jump.

Body Lean. Body lean during the poorest jump was greater at point A, the preparatory position, point C, the point of deepest knee flexion, and at point E, the point of take-off. The greatest difference occurred at point E, the point of take-off. At all other points the angle of body lean was identical for both jumps. In both jumps body lean steadily decreased throughout the jump.

Velocity Calculations

Points B, C, D, and E in Figures 11 and 12 illustrate the selected points that were analyzed and compared. Table XII presents the velocities as they were calculated from the positive prints represented in Figures 11 and 12.

Arm Velocity. A slower rate of velocity for the arms was observed during the poorest jump at points B through D. The difference was greatest at point D where it was found to be 327.02 degrees per second. Only at point E, the point of take-off, did the jumper produce greater arm velocity during the poorest jump. An increase in arm velocity acceleration was displayed during both jumps from points B to D and then negative acceleration was experienced from points D to E. The greatest rate of acceleration during the poorest jump was observed from points B to C while the greatest rate of acceleration during the best jump was observed from points C to D, which could be described as the beginning of the upward flight of the arms.

Hip Extension. Slower hip extension was experienced during the poorest jump at both measured points D and E. In both jumps there was an increasing rate of acceleration for hip extension at the point of take-off but the rate of acceleration was greater during the poorest jump from point D to point E by 91.14 degrees per second.

Knee Extension. Slower knee extension was also experienced during the poorest jump at both measured points D and E. As in the case of hip

TABLE XII

VELOCITY CALCULATIONS OF BODY PARTS
AT SELECTED POINTS
(Subject Four)

	Selected Reference Points			
Body Parts	B	C	D	E
Arm				
Best	498.32	685.19	1105.65	186.87
Poorest	373.74	591.76	778.63	219.02
Hip Extension*				
Best	......	......	249.16	716.34
Poorest	......	......	126.87	685.19
Knee Extension*				
Best	......	......	218.02	1152.37
Poorest	......	......	155.73	1136.79
Plantar Flexion*				
Best	......	......	31.15	1308.09
Poorest	......	......	0	1214.66

*No measurements taken at points B and C

extension the rate of acceleration was greater during the poorest jump from point D to E. This difference was greater by 46.71 degrees per second. In both jumps there was an increasing rate of acceleration for knee extension at the point of take-off.

Plantar Flexion. A slower rate of plantar flexion was displayed during the poorest jump at both measured points D and E. Also the rate of acceleration was slower during the poorest jump by 63.28 degrees per second. In both jumps there was an increasing rate of acceleration for plantar flexion at the point of take-off (point E).

Sequential Analysis

Figures 11 and 12 illustrate the sequence of the movement of body parts throughout the best and poorest jump for subject four. The data in Table XII presents the velocities as they were calculated throughout the preparation for the jump.

Point A to Point B. The initial downward movement during both jumps was started by increased flexion of the hips, knees, and ankles followed in close succession by downward movement of the arms. As the arms started their downward flight hip extension was initiated during both jumps. However, knee and ankle flexion continued throughout this phase. The arms were slightly ahead on the downward flight between these two points during the poorest jump; however, the arms were traveling at a slower rate of speed.

Point B to Point C. The arms were moving downward throughout the distance between these two points and continued to accelerate during both jumps. The knees also were continuing to experience greater flexion over the same distance. The ankles continued to flex during the best jump while the ankles were beginning to extend during the poorest jump. As the arms continued their downward flight, body lean continued to decrease during both jumps. Thus the body was becoming more erect as the arms were moving downward and the knees were approaching their point of greatest flexion.

Point C to Point D. During both jumps the arms were completing their downward flight just past point C and then started their upward flight between these two points. Simultaneously with the upward flight of the arms knee extension and plantar flexion were being initiated. This means initial knee extension and plantar flexion were occurring while the arms were still experiencing acceleration. At point D the arms had achieved their point of greatest velocity. This occurred during both jumps as knee extension and plantar flexion and hip extension were still accelerating. The above indicates that, during both jumps, knee extension was initiated before the arms had reached their point of greatest velocity.

Point D to Point E. The arms between these two points were beginning to experience negative acceleration during both jumps. As the arms were decreasing in velocity, hip and knee extension and plantar flexion were all experiencing positive acceleration during both jumps between these two points.

and reached their maximum velocity at or just prior to point E. Thus during the last phase of preparation for take-off the arms were experiencing negative acceleration during both jumps at the same time the hip, knee extension and plantar flexion were experiencing positive acceleration. Body lean was decreasing more rapidly during the best jump between these two points. This would indicate that the body was brought into an erect position more rapidly at the point of take-off while the arms were beginning to move slower and the rate of hip, knee extension and plantar flexion were the greatest.

INTERPRETATION OF DATA

Angular Measurements

The measurements of body angles revealed that considerable range of motion was employed at the shoulder joint for all the jumps. However, all four subjects displayed a smaller range of motion during the poorest jumps from point A, the preparatory position, to point F, the apex of the jump. Also there was smaller range of motion from the preparatory position to the point of take-off. All subjects showed lower hyperextension of the arms during the preparatory position and lower elevation of the arms at both the point of take-off and at the apex of the jump. This means that during the poorest jumps the arms were raised less behind the body in preparation for moving downward as well as lower elevation of the arms at take-off and at the apex of the jump.

Writers have stated that the more vertical all forces are applied at take-off the greater will be the effective force for the jump. This analysis revealed the arms to be elevated less at the point of take-off during the poorest jump of all four subjects. This analysis also revealed the angle of body lean was equal or greater at the point of take-off during the poorest jumps of all four subjects. All four subjects displayed a less or equally erect trunk and lower elevation of the arms at the point of take-off during their poorest jumps. These data would indicate that all forces were not applied in as nearly a vertical direction during the poorest jumps as during the best jumps.

For the four subjects used in this study there was not a common pattern among the measurements of the hip, knee and ankle that would distinguish the poorest jumps from the best jumps except at point E, the point of take-off. At this point all four subjects displayed equal or less extension of the hips, knees, and ankles during the poorest jumps. Failure to have the knees, hips, and ankles as fully extended as possible would indicate that less force was being exerted against the floor at take-off during the poorest jumps. To obtain the greatest maximum force at take-off the hips, knees, and ankles should be fully extended so that the applied force may pass as close to the hips, knees, and ankles as possible. Also by having lower elevation of the arms and less extension of the hips, knees, and ankles during the poorest jump the body's center of gravity is not projected from as great a height at take-off during the poorest jump. Also by having greater body lean the force, exerted by the feet against the floor, does not pass as close to the body's center of gravity. Because of the above the force will not be in a vertical direction and the body will be projected upward at an angle.

Velocity Calculations. A similar pattern of arm velocity for all four subjects was experienced only at point D and point E. The rate of velocity was slower at point D while at point E a greater rate of velocity was displayed during the poorest jumps for all four subjects. There was less negative acceleration during the poorest jumps of all four subjects between these same two points indicating that less momentum was being transferred from the arms to the body. These data would further indicate that greater arm momentum was still being experienced at a point of lower shoulder flexion and less elevation of the arms at the point of take-off during these jumps. Because the arms were lower and were traveling at a faster rate of velocity, greater momentum in a horizontal direction would be experienced immediately after take-off during the poorest jumps. Any movement in a horizontal direction after take-off would be considered detrimental to attaining maximum height during the vertical jump.

The greatest rate of hip and knee extension and plantar flexion was experienced during all the jumps (best and poorest) at or just prior to point E, the point of take-off. However, no pattern was established that would distinguish the poorest jumps from the best jumps with regard to velocity in hip, knee, or ankle.

Sequential Timing of Body Parts. Writers have stated that if the arms are timed properly with knee and hip extension and plantar flexion prior to take-off greater force will be added to the jump. They further stated that the upward movement of the arms should coincide with extension of the hips, knees, and ankles. This analysis showed that during all jumps (best and poorest) hip extension started with the downward movement of the arms as body lean (trunk rotation) decreased. This analysis also revealed varying degrees of shoulder flexion prior to knee extension which would indicate that upward movement of the arms occurred prior to or simultaneously with knee extension during both jumps of all four subjects. However, less shoulder flexion was evident during the poorest jump as the knees were extending. The sequence of body movement prior to take-off according to this analysis was hip extension due to trunk rotation and then upward movement of the arms prior to or simultaneously with extension of the knees.

During the upward flight of the arms at point D a slower rate of arm velocity was being experienced during the poorest jump of all four subjects. This would mean less momentum was being generated on the upward flight of the arms during the poorest jump. As the arms were increasing their rate of velocity the knees started to extend. This would mean that during the poorest jump the arms were traveling slower and were elevated less as the knees were beginning to extend. After the arms reached their point of greatest velocity (point D) on the upward flight they experienced a less rapid decrease in acceleration and were moving more rapidly during the poorest jumps at take-off. The above would indicate the arms were experiencing less negative acceleration and were traveling at a greater rate of velocity during the poorest jump as the hips, knees and ankles were attaining their point of greatest velocity of extension, while during the best jump the arms were decreasing at a faster rate of and were traveling at a slower rate of velocity as the knees, hips, and ankles were experiencing their greatest rate of extension.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

The purpose of this investigation was to study, through cinematography, selected mechanical factors that contribute to vertical jumping performance and to identify common factors which may have contributed to the subjects' poorest jumping performance.

Three professional basketball players from the Carolina Cougars and one member of the University of North Carolina at Greensboro varsity basketball team served as subjects for the study. Each subject's best and poorest jump, from a series of seven trial jumps were selected, analyzed, and compared on an individual basis. Using white adhesive tape the elbow, shoulder, hip, knee, and ankle on the lateral side of the body facing the camera were marked prior to filming.

The filming for this investigation took place in Rosenthal gymnasium on the campus of the University of North Carolina at Greensboro. A grid, constructed for use as a background, made it possible to determine the actual height attained for each jump. Tape was placed on the floor in front of the grid to serve as a starting position.

A 16 MM Bolex movie camera equipped with a 25 mm viewfinder lens was used for the filming. The camera was set to run at 64 frames per second. It was placed at a 90 degree angle to and 48 feet from the center of the grid. The camera was set on a tripod adjusted so that there was a distance of 5 feet 6 inches from the floor to the bottom of the lens. The film used was Kodak plus X negative 16 mm type 7231. Two Smith Victor 650 watt Quartz flood lights were placed on either side of the grid to insure adequate lighting.

The camera remained fixed and focused on the grid. The subjects were instructed to jump in their normal style and to reach as great a height as possible while extending both arms upward as in reaching for a rebounding basketball. Each subject performed seven trial jumps. To insure consistency in the speed of the camera it was tightly wound after each jump.

A shot was dropped 3 times prior to filming and again 3 times at the conclusion of the filming in order to calculate the actual speed of the camera. The actual speed of the camera was calculated to be 62.29 frames per second and the time per frame was calculated to be .016 seconds. These calculations were made in accordance with the method described by Cureton. (15)

When developed the film was viewed on a 16 mm movieola viewer. Each subject's best and poorest jumps were selected for analysis. From the selected jumps (best and poorest) six individual positions or reference points were selected for specific analysis and comparison.

Positive prints were developed of the selected points used for comparison. The anatomical landmarks were located, marked, and then connected with a straight line. The angles formed at the elbow, shoulder, hip, knee, ankle and body lean were measured with a protractor. Angular velocity was calculated for the arms, hip and knee extension, and plantar flexion at the selected points. A sequential description of the movement pattern of body parts prior to take-off was made of each subject comparing his best and poorest jump. Finally, similar mechanical factors which may have contributed to the subjects' poorest performance were identified.

As a result of those analyses the following factors were found to be similar during the poorest jumps of all four subjects.

Angular Measurement

All subjects showed lower hyperextension of the arms during the poorest jump at the preparatory position. Less shoulder flexion at both the point of take-off and at the apex of the jump was also evident.

The knees, hips, and ankles displayed equal or less extension at the point of take-off while the angle of body lean was equal to or greater at this same point.

Velocity Calculations

With respect to velocity a slower rate of arm velocity was displayed at point D during the poorest jumps. On the other hand the rate of arm velocity was faster at the point of take-off.

Sequential Analysis

The arms had less elevation and a slower rate of velocity during the beginning phases of knee extension in the poorest jumps. This was at point D.

Lower elevation combined with a faster rate of arm velocity was experienced at the point of the greatest rate of knee and hip extension and plantar flexion. This occurred at the point of take-off.

CONCLUSIONS

Within the limitations of this investigation and from the analysis of data included in this study the following conclusions seem appropriate.

1. The point of take-off is the point where the greatest number of similar mechanical factors not conducive to maximum jumping performance occur. These are:

   a. lower elevation of the arms

   b. greater body lean

   c. less extension of the hips, the knees, and the ankles

   d. a faster rate of arm velocity.

2. Failure of the arm position, velocity, and acceleration of hip and knee extension to function together seems to be important to performance of the vertical jump.

3. Increasing the range of arm motion would appear to be conducive to attaining maximum height during the jump.

RECOMMENDATIONS

It is recommended that further studies be made emphasizing different degrees of arm hyperextension during the preparatory position. Also it is suggested that further investigation consider flexion of the elbow throughout the jump in order to clarify the relationships of the arm (lever) length to success when performing the vertical jump.

BIBLIOGRAPHY

BIBLIOGRAPHY

A. BOOKS

1. American Association for Health, Physical Education, and Recreation. Research Methods in Health, Physical Education and Recreation. Edited by Gladys Scott and Thomas Cureton. Washington, D. C.: American Association for Health, Physical Education and Recreation, 1952.

2. American Association for Health, Physical Education, and Recreation. Research Methods in Health, Physical Education and Recreation. Edited by Gladys Scott. Washington, D. C.: American Association for Health, Physical Education and Recreation, 1959.

3. Broer, Marion. Efficiency of Human Movement. Philadelphia: W. B. Saunders Company, 1966.

4. Bunn, John. Scientific Principles of Coaching. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1955.

5. Clarke, David H. and H. Harrison Clarke. Research Processes in Physical Education, Recreation, and Health. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1970.

6. Dyson, Geoffrey. The Mechanics of Athletics. London: University of London Press, 1964.

7. Gilbreth, Frank B. Motion Study. New York: The McMillian Company, 1911.

8. Gilbreth, Frank B. and Lillian M. Gilbreth. Applied Motion Study. New York: Stugis and Walton Company, 1930.

9. Godfrey, Barbara B. and Newell C. Kephart. Movement Patterns and Motor Education. New York: Appleton-Century-Crofts, 1969.

10. Logan, Gene A. and Wayne C. McKinney. Kinesiology. Dubuque: Wm. C. Brown Company, 1970.

11. Morehouse, Laurence E. and John Cooper. Kinesiology. St. Louis: C. V. Mosby Company, 1950.

12. Muybridge, Edweard. Animal Locomotion Prospectus and Catalogue of Plates. Philadelphia: The University of Pennsylvania Press, 1887.

13. Scott, Gladys. Analysis of Human Motion. New York: Appleton-Century-Crofts, 1963.

14. Wickstrom, Ralph L. Fundamental Motor Patterns. Philadelphia: Lea and Febiger, 1970.

B. PERIODICALS

15. Cureton, Thomas K. "Elementary Principles and Techniques of Cinematographic Analysis," The Research Quarterly, 10:3-24, May, 1939.

16. Doolittle, T. L. "Errors in Linear Measurements with Cinematographical Analysis," Kinesiology Review, 1971, pp. 32-38.

17. Eckert, Helen. "Angular Velocity and Range of Motion in the Vertical and Standing Broad Jumps," The Research Quarterly, 39:937-942, December, 1968.

18. __________. "The Effects of Added Weights on the Joint Actions in the Vertical Jump," The Research Quarterly, 39:943-947, December, 1968.

19. Martin, M. and A. Stull. "Effects of Various Knee Angles and Foot Spacing Combinations on Performance in the Vertical Jump," The Research Quarterly, 40:324-331, May, 1969.

20. VanDalen, Deobold. "New Studies in the Sargent Jump," The Research Quarterly, 11:112-115, May, 1940.

C. UNPUBLISHED MATERIALS

21. Barth, Dorothy A. "A Cinematographical Analysis of the Badminton Backhand Stroke," Unpublished Master's thesis, University of Illinois, Urbana, 1961.

22. Burdan, Paul. "A Cinematographical Analysis of Three Basic Kicks Used in Soccer," Unpublished Master's thesis, The Pennsylvania State University, University Park, 1965.

23. Conrad, Ruth. "A Cinematographical Analysis of the Major Sequential Movement Patterns of Skilled, Semi-Skilled, and Non-Skilled Baseball Batters," Unpublished Doctoral dissertation, Temple University, Philadelphia, 1965.

24. Couper, Margaret. "An Analysis of the Transfer of Horizontal Momentum to the Vertical Jump," Unpublished Master's thesis, Smith College, Northampton, 1965.

25. Haldeman, Neil D. "A Cinematographical Analysis of the Standing High Jump as Related to the Basketball Jump Ball Situation," Unpublished Master's thesis, The Pennsylvania State University, University Park, 1965.

26. Heess, Richard. "Effects of Arm Position and Knee Flexion on Vertical Jumping Performance," Unpublished Master's thesis, The Pennsylvania State University, University Park, 1964.

27. Henry, Charles. "A Mechanical Analysis of the Initial Velocity in the Sargent Jump and in the Standing Broad Jump," Unpublished Master's thesis, The University of Iowa, Iowa City, 1948.

28. Hill, Henry L. "A Cinematographical Comparison of Selected Mechanical Factors Associated with Vertical Jumping Height," Unpublished Master's thesis, The University of North Carolina at Greensboro, 1970.

29. Lewis, Barbara. "The Relationship of Selected Factors to the Vertical Jump," Unpublished Master's thesis, The University of Iowa, Iowa City, 1959.

30. Lyons, William R. "A Cinematographical Analysis of the Overhand Baseball Throw," Unpublished Master's thesis, The University of Wisconsin, Madison, 1961.

31. Quandt, Harlan H. "A Cinematographical Analysis of the Palm Ball Pitch Compared to the Fast Ball Pitch in Baseball," Unpublished Master's thesis, The University of Wisconsin, Madison, 1964.

32. Rozzi, Louise. "A Cinematographical Analysis of the Lacrosse Carry," Unpublished Master's thesis, The University of North Carolina at Greensboro, 1969.

33. Sarver, Robert E. "A Cinematographical Analysis of the Double Leg Circle on the Side Horse," Washington State University, Pullman, 1962.

34. Smith, Robert L. "A Cinematographical Analysis of the Triple Jump," University of Kansas, Lawrence, 1967.

35. Victors, Evelyn E. "A Cinematographical Analysis of Catching Behavior of a Selected Group of Seven and Nine year old Boys," Unpublished Doctoral Dissertation, The University of Wisconsin, Madison, 1961.

36. Wilson, Kent. "The Relative Effects of Various Foot Spacings on Performance in the Vertical Jump," Unpublished Master's thesis, The Pennsylvania State University, University Park, 1965.

37. Wilson, Marjorie. "Development of Jumping Skill in Children," Unpublished Doctoral dissertation, The University of Iowa, Iowa City, 1945.

38. Wrigglesworth, Frank L. "A Cinematographical Analysis of the Short Chip Shot in Golf," Unpublished Master's thesis, The University of Wisconsin, Madison, 1964.