A CINEMATOGRAPHIC ANALYSIS OF THE TAKE-OFF PHASE AND PATH OF CENTER OF GRAVITY IN THE RUN, LEAP FOR HEIGHT, AND LEAP FOR DISTANCE

by

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A Thesis Submitted to the Faculty of the

DEPARTMENT OF PHYSICAL EDUCATION FOR WOMEN

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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ACKNOWLEDGMENTS

Many persons have been influential during the course of my education, however, time and space only permit one big "thanks" to all concerned.

Very special thanks goes to Dr. Anne E. Atwater, my advisor, for her patience and help during this endeavor. I would also like to acknowledge Gloria Kosowski and the Orchesis Club members for their cooperation and help as subjects.

Last but not least I would like to thank Miss Ruth Wynn for all the moral support, encouragement, and help throughout the year.

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ABSTRACT

The purpose of this study was to analyze, through cinematography, the path of the center of gravity during the flight phase, and the supporting leg joint actions during the support phase of the run, leap for height, and leap for distance. Five skilled female dancers served as subjects.

The center of gravity of the body in the run was projected in a lower arc than for either of the leaps. The leap for height had the highest angle of projection and highest arc in the center of gravity path. In the leap for distance, the angle of projection and the height of the arc in the center of gravity path were intermediate between those for the run and the leap for height.

The sequence of supporting leg joint actions in the support phase of the three skills was similar. There were differences in duration of the support phases for each skill with the run having a shorter support phase than the leaps. The range of angular motion in the supporting leg joints was greater in the leaps than in the run.

There were sufficient differences between the three skills to warrant the recommendation that each leap be taught separately, and not as a variation of the run.

CHAPTER I

NATURE AND SCOPE OF THE STUDY

Introduction to the Problem

The run and the leap are considered as basic locomotor patterns in much of the published material on dance technique and rhythms. The reader usually finds the run and the leap being compared by vague descriptions, commonly, the goal or end result of the skill being the only distinction. The leap is generally considered to have two possible end results, either height or distance, while the goal or end result of the run is usually speed.

Locomotor patterns in dance do not exist in isolation. The run, leap for height and leap for distance are basic to many other forms of dance techniques. There appears to be a need for more detailed descriptions of the run, leap for height, and leap for distance in order to distinguish them as separate but basic locomotor skills. More specifically, information regarding the force producing phase of the run, leap for height and leap for distance, as well as the location and path of the center of gravity during these three skills should serve to clarify the distinctions between these locomotor skills.

Cinematography provides a useful means of studying both basic locomotor patterns and abstract movement qualities in dance. Through the use of cinematography, motion can be slowed down or studied frame-by-frame for a more detailed analysis of the action. Therefore, cinematography was the technique selected as most appropriate in the study of selected kinematic aspects of the run, leap for height and leap for distance.

Statement of the Problem

The purpose of this study was to analyze and describe, through cinematographical analysis, the path of the center of gravity and the joint actions of the take-off leg during the force producing phase in three locomotor skills performed by skilled female dancers. The locomotor skills selected for study were the run, leap for height, and leap for distance. Comparisons were made among the three skills performed by each subject and among all subjects performing each skill.

Questions to be Investigated

The following questions were formulated to serve as guidelines for the investigation:

1. What is the path of the center of gravity during the flight phase of the run, the leap for height, and the leap for distance?

a. Are there similarities among subjects in the angle of projection and the initial velocity for each skill?

b. Are there differences in the angle of projection and the initial velocity among the run, leap for height and leap for distance?

c. Where is the center of gravity located in relation to the supporting foot at take-off?

2. During the support phase, what are the joint actions of the take-off leg?

a. What is the angular displacement of joint actions occurring at the ankle and knee of the supporting leg, and of the segmental inclination of the thigh during each skill?

b. Are there differences among the skills in range, sequence, or time involved for joint actions?

c. Is there a relationship between the horizontal velocity of the center of gravity over the supporting foot and the initial velocity of each projection?

Scope of the Study

The subjects in this study were limited to highly skilled dancers who were members of the modern dance club or had completed an advanced level dance class. The study also was confined to an investigation of the support phase and the path of the center of gravity during the non-support phase of three basic locomotor skills: the run, leap for height, and leap for distance. The only aspect of the support phase investigated was the action of the take-off leg. The actions of the arms, lead leg, and trunk were not analyzed in detail. All the subjects used the left leg as take-off leg and the right leg as lead or landing leg in the portion of film analyzed for each of the three skills. Therefore, only one-half of the normally described running cycle and a leap from only one leg were studied. The subjects were instructed to perform basic straight leg leaps although some small variations may have occurred in the style of each individual dancer.

Probable Value of the Study

The existing literature on dance technique contains, for the most part, descriptions of the joint actions and final outcomes for the run, leap for height, and leap for distance. This study might provide a more detailed description of the path of the center of gravity for each skill and some specific evidence regarding the range and sequence of actions of the take-off leg. Such information may give both the teachers and the students of dance a better idea of the final outcome desired and the actions necessary to produce and to differentiate among the run, leap for height, and leap for distance.

Definition of Terms

Center of Gravity: The center of gravity is the point around which the weight is equal on all opposite sides (Jensen, 1970).

Leap for Distance: The leap for distance is a transfer of weight from one foot to the other, similar to the run, but involving more space covered by each step and requiring more energy for its performance (Hayes, 1964).

Leap for Height: The leap for height is a transfer of weight from one foot to the other, similar to the run and the leap for distance, except the force must be applied in an upward arc (Hayes, 1964).

Run: The run is a transfer of weight from one foot to the other with brief loss of contact with the ground during transfer.

Support Phase: The support phase is the period of time between the point at which the supporting foot touches the floor until it leaves the floor again as the body is projected into the air.

Take-off Foot: The take-off foot is the supporting foot, that is, the foot last in contact with the ground prior to the flight phase of each skill.

CHAPTER II

REVIEW OF THE LITERATURE

The review of literature is concerned primarily with the descriptions of three basic locomotor skills, the run, leap for height, and the leap for distance. However, a brief review of cinematographic techniques and basic principles related to locomotion and body projection is also included.

Cinematographic Techniques

With the use of cinematography, motor skills can now be studied in terms of recognizable scientific principles instead of empirical guesses. Thomas Cureton (1939), one of the pioneers in cinematographic analysis of athletics, stated that angular measurements can be taken directly from the film without the use of a correction factor and linear measurements can be made if there is a known dimension in the film. Additional techniques of cinematographic analysis have been described recently by Plagenhoef (1971), and include detailed directions for using composite tracings to follow the path of certain body parts and the path of the center of gravity of the body.

Fenn (1931), in his early work with cinematography and locomotion, combined what was seen in film with the physiology of muscle action to investigate the limiting factors in running. He marked certain points on the body in order to follow them on film. The subjects ran behind a horizontal and vertical lattice work which served as film reference markers. The film speed was calculated by photographing a dropping ball. A more recent cinematographic study on the running pattern established criteria for accuracy of film measurement and verified any inconsistancy by remeasuring (Teeple, 1968).

Basic Principles Related to Locomotion and Body Projection

This study is concerned with body projection skills, and the actions of the body during any body projection skill follow the basic principles of physics. One such principle deals with the location of the center of gravity of an object. The location of the center of gravity of the body is where all the mass of the object is assumed to be concentrated, and therefore, that point can be used to represent the mass as a whole (Dyson, 1970).

To locate the center of gravity of the body, Plagenhoef (1966) explained that the position of the proximal and distal ends of the hand, forearm, upperarm, foot, shank, thigh, and trunk should be located and then the center of gravity can be computed for each segment. The sum of the products of the proportionate weight of each body segment and the position of the center of gravity of the separate segments determines the position of the center of gravity of the whole body. In cinematographic analyses of motion this segmental method of locating of the center of gravity often is used (Cureton 1939, Fenn 1930, Teeple 1968).

In locomotion skills the center of gravity can be considered a projectile. Assuming that air resistance is negligible, the laws of physics describe the path of a projectile as a parabola (Bunn, 1955). The movements of the performer while in the air cannot change the path of the center of gravity of the body, therefore, this path is determined at take-off (Dyson, 1970). The angle and the velocity at which the body is projected determine the height it reaches (Jensen, 1970). Therefore it might be expected that the leap for height would require a different angle and velocity of projection than would the leap for distance, and that the run would require an angle and velocity of projection different from that of the leaps.

The force of gravity on a body must be considered as well. As soon as a performer breaks contact with the ground, the force of gravity acts to decelerate the upward movement of the body center of gravity and accelerate its downward movement. Therefore, greater range or horizontal distance can be covered when there is an upward as well as a forward component to the projection, permitting the performer to stay in the air longer and go farther before returning to the ground (Dyson, 1970).

The Run, Leap for Height, and Leap for Distance

The literature in the field of dance was limited. That is not to say the quantity was limited, but rather the topics covered were limited. Much of what was written in the field of dance pertained to critique of style and choreography work of an individual. Another area of dance literature included the techniques and the teaching of dance. In most dance education books the run and the leap are considered as basic locomotor patterns (Hayes, 1964). However, there was never a detailed description of the execution of the basic locomotor patterns. No one text supplied enough information about execution of the skills to actually distinguish between them.

The Run

The run is not only a locomotor skill used in dance, but a fundamental skill in most athletics. Therefore, research on the run is more extensive. The analysis of sprint running by Deshon and Nelson (1964) was typical of current studies on running. Their study was conducted to investigate intercorrelations between the speed of running and the angle of knee lift, length of the stride, and the angle of touchdown of the supporting leg. However, their investigation was concerned primarily with the free, non-supporting leg. They found that running speed correlates significantly with high knee lift, long stride length, and the placement of the foot as closely as possible beneath the center of gravity of the runner.

In the run, the body weight is received on the forward or supporting foot and a coordinated flexion of the three leg joints follows, as if giving on impact to keep the body from jarring (Godfrey, 1969). Then, extension of that take-off leg at the hip, knee, and ankle propels the body forward and upward into the non-support phase (Wickstrom, 1970). Cooperand Glassow (1972) described the joint actions of the supporting limb of an Olympic runner to illustrate what happens during the .075 sec. support phase. The ankle flexed due to the forward momentum of the body and, after .03 sec., ankle extension began, which continued until take-off. The knee flexed at contact and, during the last .045 sec., extended carrying the entire body, except the supporting leg, forward. The hip joint also flexed momentarily, then began to extend.

The flexion of the three joints serves a dual purpose; first, as a reaction to impact and secondly, to increase the range of motion through which the joints extend (Wickstrom 1970, Dyson 1964). Because the center of gravity of the body is moving rapidly over the forward foot in the run, the propulsive phase can begin almost immediately after the take-off foot contacts the surface.(Jensen, 1970).

At the end of the propulsive or take-off phase the push is with the toes as the ankle and knee fully extend in order that the full force of the push back can be converted in forward movement of the body (Bunn, 1955). In a slower run the supporting foot lands forward of the center of gravity and the leg is not as fully extended at take-off.

Most sources agreed that the up and down motion of the body is very slight in a sprint run (Fenn 1930, Godfrey 1969, Wickstrom 1970). In fact, according to Fenn (1930), the actual path of the center of gravity of the body reached its highest point at take-off and subsequently fell. The up and down action of the body is increased during a slow run (Wickstrom, 1970).

Leap for Height and Leap for Distance

The mechanics of the run have been quite well analyzed probably because of the important role of running in athletics. This was not true of the leap. Mention of the leap was made in reference to the run. According to Schlueter (1933), the leap is an elongated step during running, increasing either the distance or the height of the step. Miller and Whitcomb (1957) used similar terms in stating that the leap is a run where there is more elevation and space covered by each step and where the body is suspended in the air for a longer period of time.

Some dance education literature, however, considered the leap as a separate category of locomotion, similar to a run, and tried to make some distinction between the two locomotor skills. Although no one source provided enough distinction between the skills, examples of some descriptions of the leap appearing in dance or fundamental movement literature are presented here.

A leap is slower than a run and is characterized by more energy expenditure than a run (Lockhart, 1951). The push-off into the air rather than the landing distinguishes the leap from the run. The push-off should strive for height and distance in the leaps (Hayes, 1964). In preparation for the leap the hips, knees and ankles flex to stretch the extensor muscles (Broer, 1966). The main propulsive force comes from the supporting leg, beginning with hip extension followed by knee extension, ankle extension, and toe flexion (Jensen, 1970). Little mention was made of the position of the center of gravity of the body during a leap but Cooper and Glassow (1972) stated that the center of gravity of the body was in front of the last contact point at the time of take-off.

Most often the only distinction identified between the leap for height and the leap for distance was in terms of the goal or end result. Only a few mechanical differences were discussed. When height is desired in the leap the center of gravity of the body is shifted back over the support foot for take-off (Broer, 1966). Along with this change, Schlueter (1933) described the preceding running steps before a leap for height as short, with the lead knee being raised during the leap. The only description of the leap for distance other than "strive for distance" was by Hayes (1964) who stated that, during the leap for distance, it is necessary to extend both the lead leg and the take-off leg as completely as possible. The reach of one leg and push with the other occur simultaneously.

Summary

Cinematography has proved to be an effective technique for the analysis of movement patterns, because specific observable aspects of motion can be isolated. Locomotion and body projection skills which are governed by the laws of physics related to object projection, can be effectively studied with cinematography.

The run and the leap are considered as basic locomotor patterns (Hayes, 1964). However, quite often the leap is considered as an extension of the run rather than as a separate skill. Much of the literature on running dealt with the actions of the free or recovery leg rather than with the support or take-off phase. The greatest distinction established between the run and the leap was that the performer expends more energy and strives for additional height or distance in the leap (Hayes, 1964). A more detailed comparison of the three locomotor skills may help to clarify the distinctions between them and the specific similarities among them.

CHAPTER III

DESIGN OF THE STUDY AND PROCEDURES USED

The purpose of this chapter is to present the procedures that were used in the cinematographical analysis of the run, leap for height, and leap for distance. The selection and preparation of the subjects, a description of the filming procedures, and the processes by which data were obtained from the film are included.

Selection of the Subjects

The subjects for this study were five skilled dancers. They were selected from an advanced modern dance class and from Orchesis (the Modern Dance Club) at The University of Arizona. Originally six women were identified by Gloria Kosowski, a modern dance instructor and the Orchesis advisor, and by the investigator as having the best ability to perform the leap. The criteria for selection were that the subject should be well skilled, the subject should have no highly noticeable individual style and the subject should have consistant form throughout repeated performances.

After viewing the films, it was evident that one subject had a style noticeably different from that of the other five subjects. There was sufficient rotation in the hip joint of the take-off leg to distort the side view picture of the knee and ankle joint actions. Valid angular displacement data could not be collected from the film of this subject. For these reasons this subject was dropped from the study and the investigation was conducted using the remaining five subjects.

Preparation of and Instructions to the Subjects

The subjects were instructed to wear light colored leotards and tights which provided good visibility of all body segments. The following points on the body were marked with dark tape to indicate the joints of the body: 1) right and left ankle; 2) right and left knee; 3) greater trochanter of the left hip; 4) right and left elbow; and 5) right and left shoulder. Figure 1 shows the placement of these markings. The tape marks were used as guidelines for identifying and measuring joint and segment positions from the film.

During the filming, each subject was asked to execute a series of straight leg leaps for height leading each time with the right leg and taking off with the left leg, which was the leg nearest the camera. The subject was instructed to take a step between each leap so that every leap was performed using the same take-off leg. The series of step-leaps was preceded by a run which took the subject along a designated floor line toward the area viewed by the camera. Approximately two step-leaps were

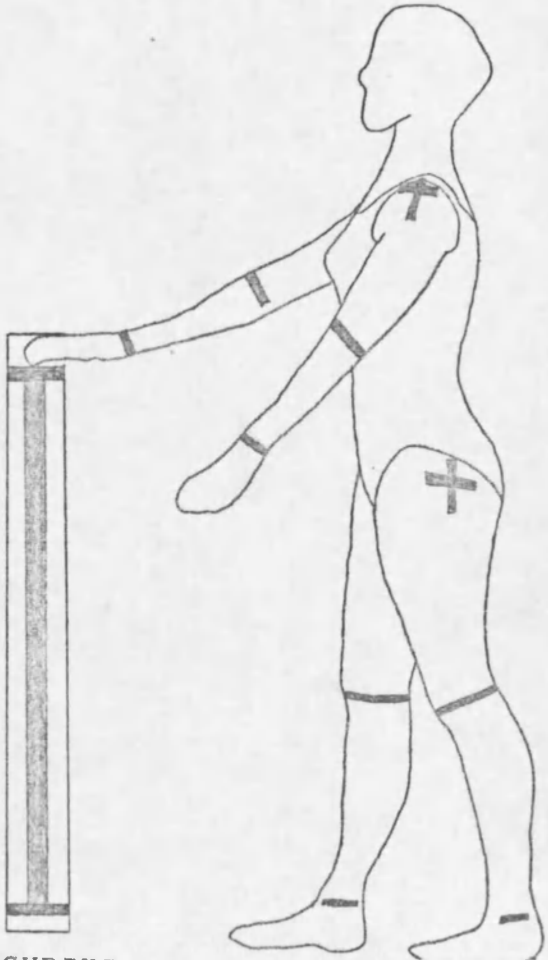


Figure 1. Joint Markings and Measurement Frame

performed within the camera field of view, and the subject then continued this pattern for a distance of at least ten feet beyond the filming area to ensure consistant performance throughout the entire camera field of view.

In the first series of step-leaps the subjects were told to stress height rather than distance or style on each leap. On the second series of step-leaps the subjects were instructed to perform straight leg leaps with an emphasis on the horizontal distance covered during each leap. Finally, each subject was asked to run as fast as possible along the designated floor line which was perpendicular to the optical axis of the camera. The subjects were allowed to approach the filming area over a distance of at least 100 feet in order to attain maximum running speed within the filming area. Each subject was told to neglect any dance form or style and to run with the emphasis on speed. Verbal encouragement was given for the run.

For each skill a practice trial was given and then the subject was filmed. After each trial was filmed, the subject was asked to evaluate her own performance. If the subject or the investigator was dissatisfied with the performance, another trial was filmed, and the better trial was used for analysis.

Filming

All the equipment necessary for filming was set up prior to the filming session. Figure 2 shows the

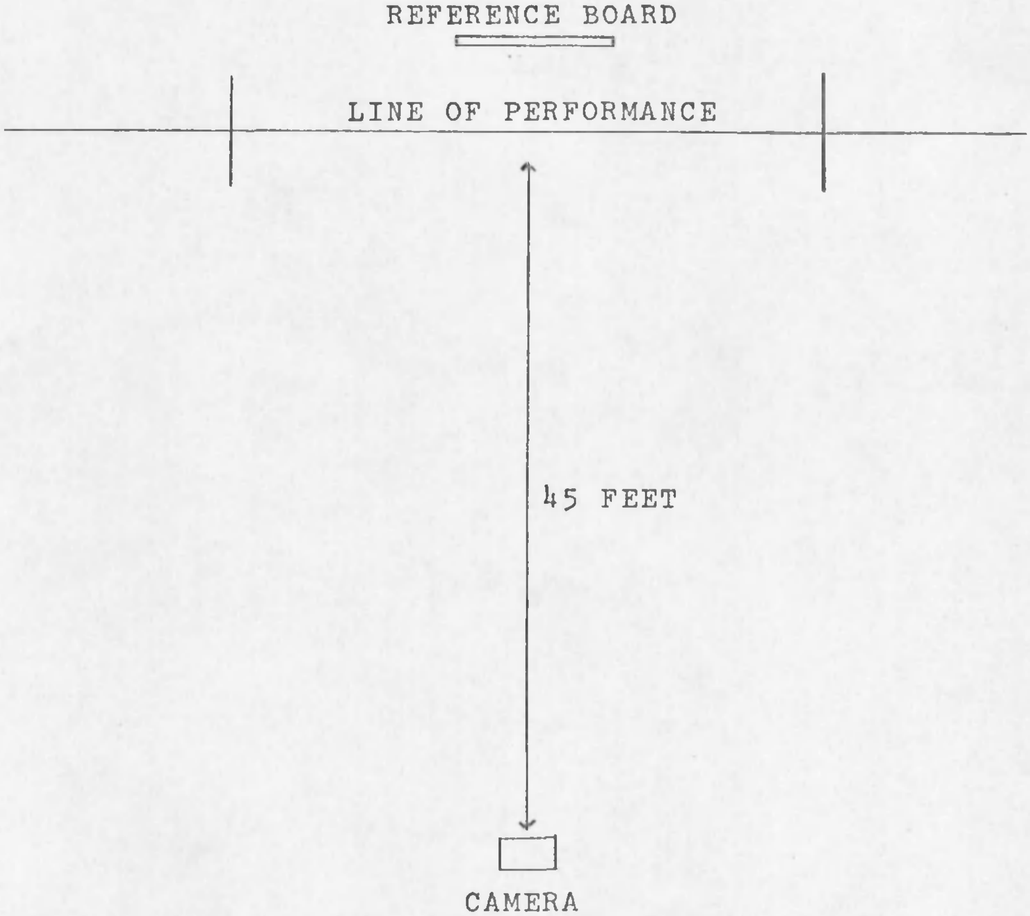


Figure 2. Overhead Perspective of the Filming Area

arrangement of equipment in the filming area. All filming was done from the side view of the subjects. The actions studied occurred primarily in the sagittal plane, and the side view of the subjects was most appropriate to capture this movement.

A 16 mm Pathé motion picture camera with a 25 mm lens was placed at a distance of 45 feet from the performance area. It was set on a tripod to ensure a level and steady picture. Kodak black and white 4X film with double perforations was used. The camera was set to operate at 64 frames per second with the shutter wide open (equivalent to a 180 degree shutter). Thus, the exposure time of a single frame was 1/128 sec. and the f stop was 1.8.

A line was marked on the floor along which the subjects were to perform the three locomotor skills. This line was perpendicular to the optical axis of the camera. The width of the field of view for the camera was marked along the line of performance. These lines were drawn to ensure that each subject would always be performing at the same distance from the camera and within the camera field of view.

Behind the performance line a chalk board was placed to serve as a reference for horizontal and vertical constants. The corners of the board were measured at 90 degrees each. The board was also used to record the subject number, trial number, date, and the activity to be performed.

To provide a distance conversion factor, each subject was filmed holding a measuring board with tape marks placed exactly three feet apart. (See Figure 1, p. 16.) The actual camera speed was recorded by filming a three second-sweep stop watch for one to two seconds for each subject.

The filming of all six subjects was done on the same day, with the same camera and film speed. Each subject completed all three skills before the next subject was filmed. The order of events for each subject was as follows:

1. Practice trial, leap for height
2. Film the leap for height
3. Film the 3-second stop watch
4. Practice trial, leap for distance
5. Film the leap for distance
6. Practice trial for the run
7. Film the run
8. Film the subject on the performance line holding the measuring board.

If a second trial was filmed for any skill it was done immediately following the first filming of that trial.

Data Collection from the Film

A Recordak microfilm reader (Model P-40) was used to project the film images frame-by-frame onto tracing paper. All measurements were taken from tracings or by superimposing each frame onto graph paper. To assure correct spatial alignment of each frame the horizontal and vertical reference lines were drawn on each tracing. Figure 3 is a sample tracing which shows the reference lines.

Time Conversion Factor

The frame time, or time elapsed between any two adjacent frames, was calculated from the three-second-sweep stop watch. The number of frames in one second of time was counted during two different time periods for each subject. Each of the one-second time periods considered had 69 or 70 frames per second. The frame time was calculated using the average of these two or 69.5 frames per second. The frame time for the films of all subjects was, therefore, 1 sec ÷ 69.5 or .0144 sec. per frame interval.

Distance Conversion Factor

Each subject was filmed while holding a board on which a three foot distance had been marked. (See Figure 1, p. 16.) Film measures of this three foot distance were taken in 50ths of an inch and the actual distance represented by 1/50th inch was calculated. These measures were made on two separate frames for each subject. All measures indicated that 136/50ths of an inch equalled three feet, therefore, the distance conversion factor for all subjects was 3 feet ÷ 136, or 1/50th inch = .02206 feet.

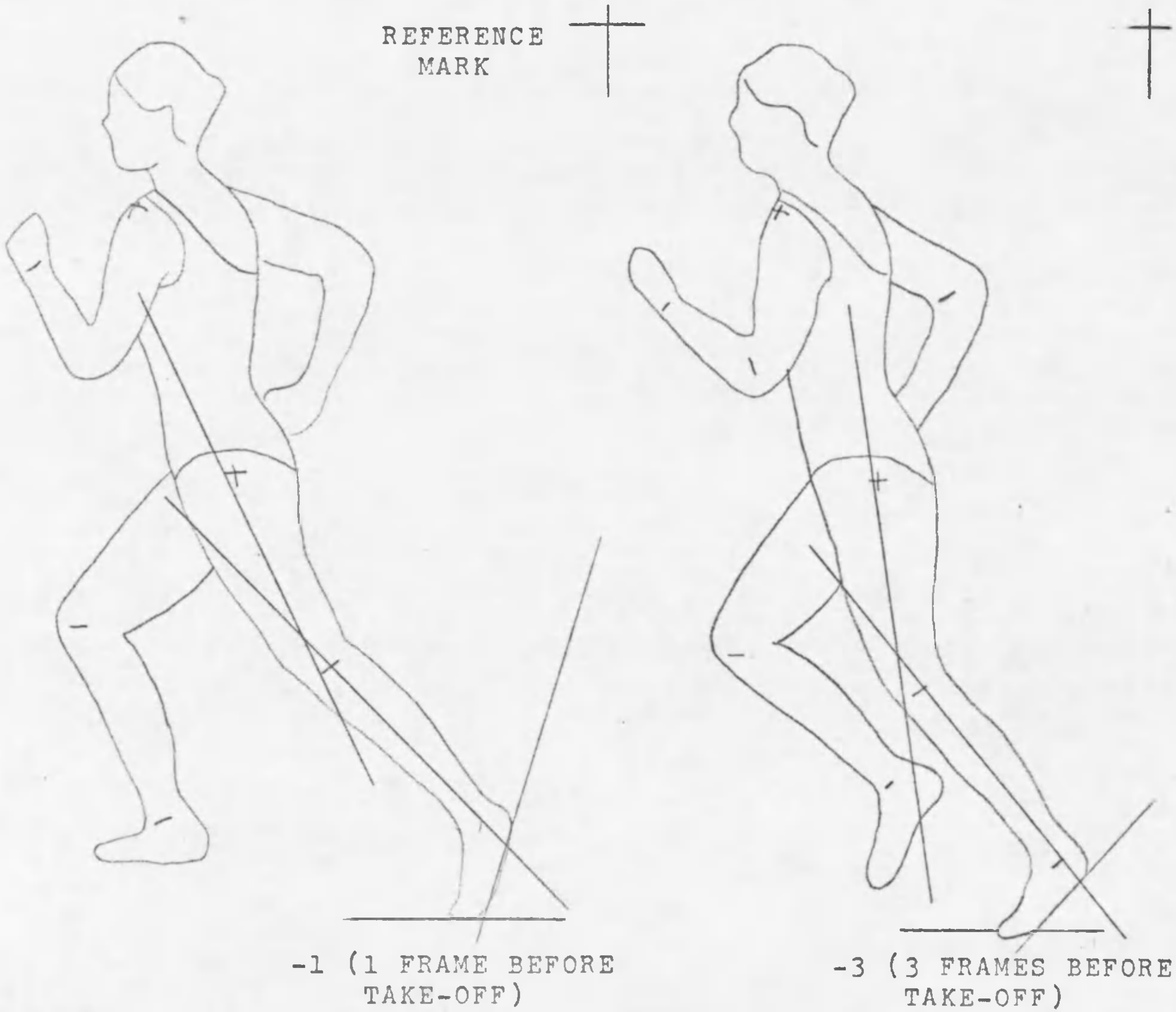


Figure 3. Sample Tracing

Path of Center of Gravity

The path of the center of gravity for each subject in each locomotor skill was determined through the use of a computer program. This program was a modified version of the center of gravity program developed at Purdue University. (See Appendix C.) The program used the x and y coordinates of fifteen specific segment end points on the body of the subject to determine the location of the center of gravity. These coordinates were measured from film tracings of the body. Figure 4 illustrates the 15 points that were measured. Based on the location of the center of gravity of the body at take-off and at four selected frames during flight, the program determined a theoretical path of the center of gravity. Every fourth frame from the take-off to the high point during flight was plotted for the leaps, and every second frame to the high point was plotted for the run. The angle of projection and the initial velocity of the center of gravity were computed by averaging those values obtained for each individual frame. The angle of projection was measured with reference to the horizontal, as shown in Figure 5. If the range in the angles of projection for the several frames of any given trial was greater than five degrees, the velocity and angle of projection data for that trial were rejected and the tracings and measurements were repeated.

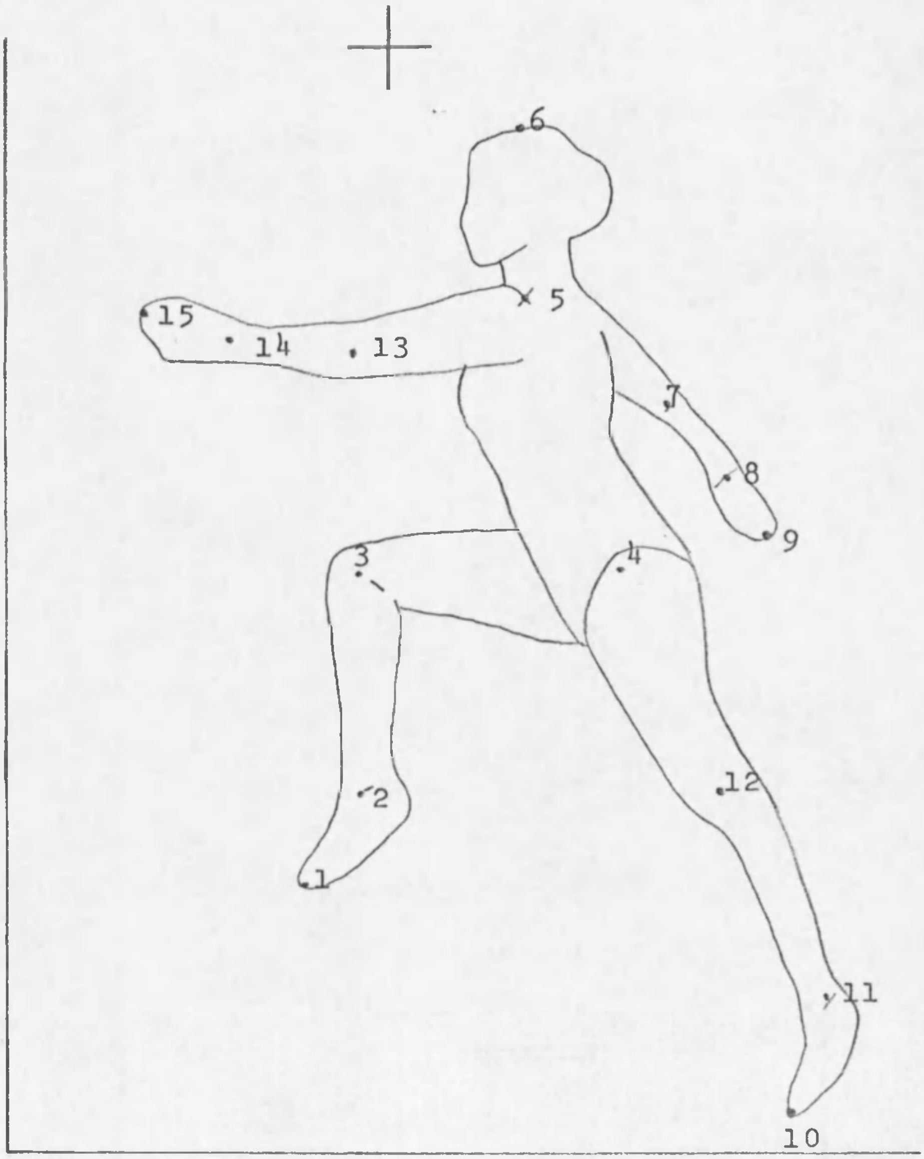


Figure 4. Segment Endpoints of the Body Used to Calculate the Center of Gravity

KEY: 1 - Angle of Lean
2 - Angle of Projection

A - Last Point of Contact
B - Center of Gravity

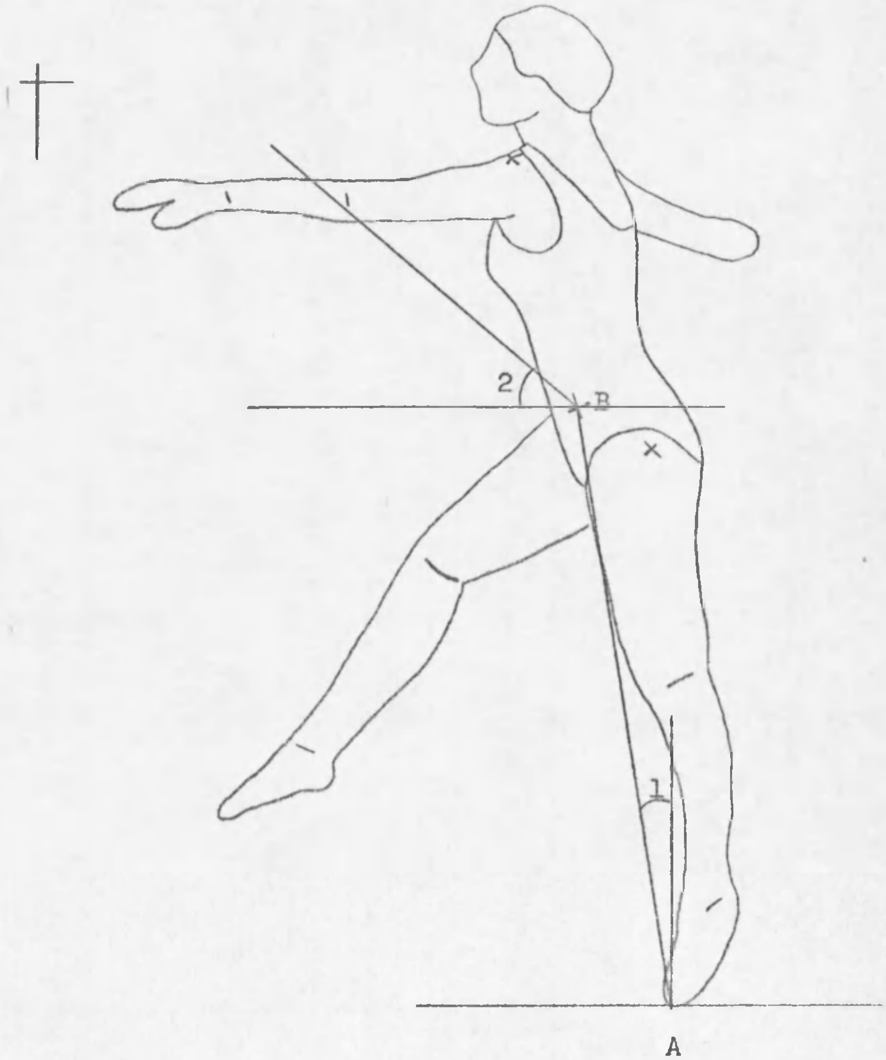


Figure 5. The Angle of Projection and the Angle of Lean

The location of the center of gravity at plant of the supporting foot was also computed using the computer program. A comparison of the position of the center of gravity at plant of foot and at take-off provided the data for calculating the horizontal velocity of the center of gravity over the supporting foot.

Angle of Lean

The angle of lean was determined by drawing a line from the center of gravity of the body at take-off to the position of the toes of the take-off foot. The angle formed between this line and the vertical was measured for each skill as indicated in Figure 5, page 25.

Angular Displacement

The joint actions of the take-off leg were determined by means of angular measurement of the angle at the ankle and the knee and the inclination of the thigh in relation to the horizontal. The angles measured are illustrated in Figure 6. In the graphic presentations of these angles, any point or angle which was discrepant by more than five degrees from the line of best fit was retraced and remeasured. This was done to ensure that the angular displacement curves would be accurate to within five degrees at any point in time.

KEY: 1. Thigh Inclination
2. Knee Joint
3. Ankle Joint

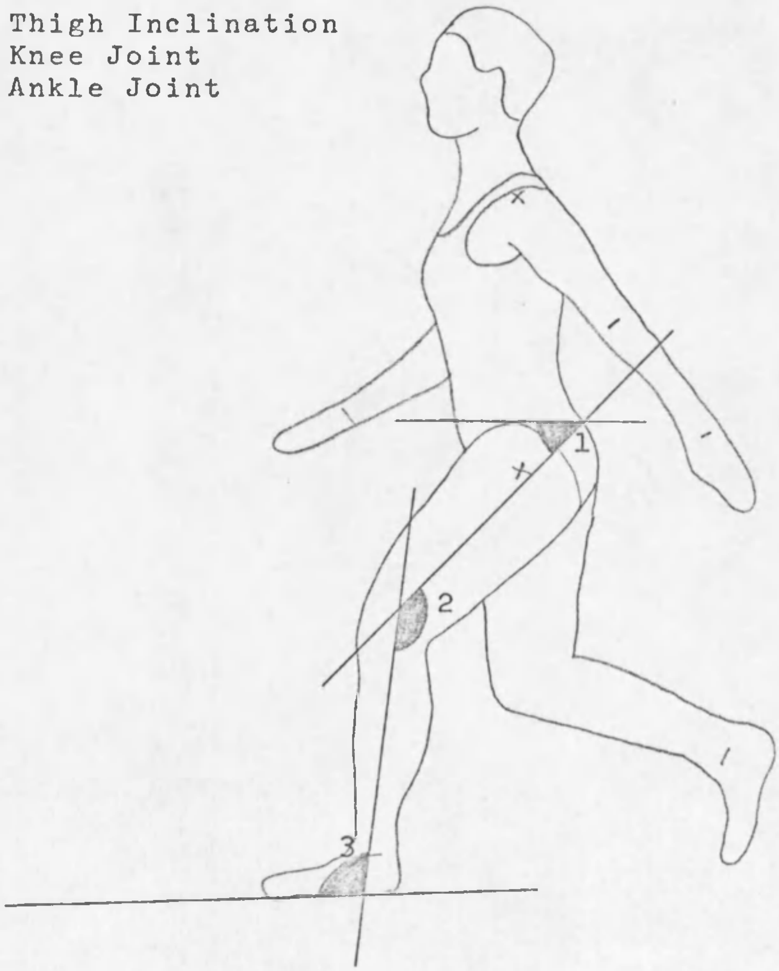


Figure 6. Joint Angle and Segmental Inclination Measurements in the Take-off Leg

Summary

The techniques of film analysis were used in this study. Motion pictures were taken of each subject performing a leap for height, a leap for distance, and a run. The film was then studied frame-by-frame. Measurements of time, distance, center of gravity, trajectory, angle of lean and joint angular displacement were taken from the film frames and tracings to obtain the data necessary for comparison of the skills.

CHAPTER IV

ANALYSIS OF THE DATA AND PRESENTATION OF THE FINDINGS

The purpose of this chapter is to present the results of the study. The chapter is divided in two major parts; the first, dealing with the path of the center of gravity of the body during the flight phase of the run, the leap for height, and leap for distance, and the second, concerned with the actions of the supporting leg during the support phase of the three skills. Graphs, charts and tracings are presented to illustrate and further clarify the discussion of the data.

The Path of the Center of Gravity

The first section of this chapter focuses on the path of the center of gravity during the flight phase of the run, leap for height, and leap for distance. The questions of interest to be answered in this section are: a) Are there similarities among subjects in the angle of projection and initial velocity for each skill?, b) What are the differences, if any, in the angle of projection and the initial velocity among the three locomotor skills?, c) Where is the center of gravity located in relation to the supporting foot at take-off in each skill?

Angle of Projection and Initial Velocity among Subjects for Each Skill

It was first necessary to determine whether any similarities in angle of projection and initial velocity existed among subjects for each skill, because if there were no similarities among subjects, it would not be possible to detect distinct differences among the three separate skills. Thus, for each skill, the measure used to express the degree of variability among the five subjects was the range, or difference between high and low values of initial velocity and angle of projection.

The angle of projection in the run was similar for all subjects, ranging from 2.57° to 5.74° with an average angle of projection of 3.95° Table I and Figure 7 present the angle of projection and the initial velocity for each skill, and the average and range for each measure. In the leap for height and the leap for distance there was somewhat greater variability among subjects. Excluding subject 5, the average angle of projection for the leap for height was 40.66° with a range of 10.38°. The leap for distance had an average angle of projection for subject 1 through 4 of 25.28° and a range of 5.44°.

In comparison with the other subjects, the leap for height performed by subject 5 might be considered unsuccessful, mainly because of the low 28.54° angle of projection. Likewise the leap for distance for subject 5 had a comparatively low angle of projection (14.01°) in

Table I. Angle of Projection and Initial Velocity In the Run, Leap for Height, and Leap for Distance

Subject	Run		Leap for Height		Leap for Distance	
	Angle[a]	Velocity[b]	Angle[a]	Velocity[b]	Angle[a]	Velocity[b]
1	5.74	21.9	42.75	9.67	28.24	13.57
2	4.38	20.42	34.16	11.99	22.8	13.05
3	2.57	19.36	41.2	9.84	23.43	11.85
4	4.42	21.52	44.54	10.34	26.32	12.29
5	2.62	20.19	28.54	9.81	14.01	12.49
Average	3.95	20.68	38.24	10.33	22.96	12.65
Range	3.14	2.54	16	2.32	14.23	1.72

[a] all angles are measured in degrees

[b] velocity is expressed in feet per second

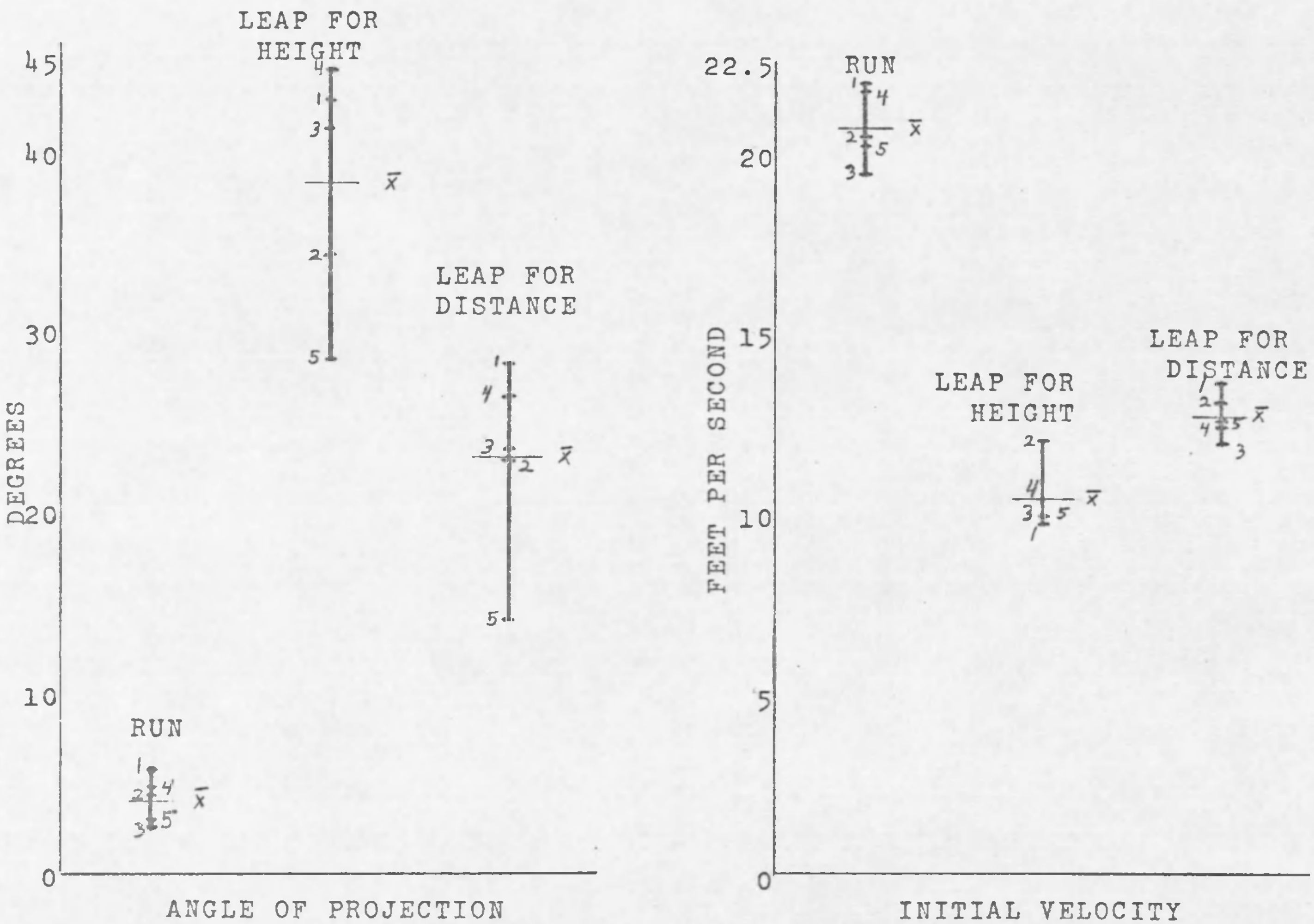


Figure 7. The Range and Mean in the Angle of Projection and Initial Velocity for Each Skill

relation to the other subjects. The average angle of projection for the leap for height when all five subjects were included was 38.24° with a range of 16°. In the leap for distance, the average angle of projection based on five subjects was 22.96° with a range of 14.23°.

Thus, the greatest variation in the angle of projection among subjects occurred in the leap for height, which was the skill that required the highest angle of projection. The leap for distance, which required a somewhat lower angle of projection, had the next smallest variation among subjects on this measure. (See Figure 7, p. 32.)

A comparison of the initial velocity of projection among subjects for each skill showed more consistancy than did the measures of projection angle among subjects. (See Figure 7, p. 32 and Table I, p. 31.) The range in initial velocity among subjects was never greater than 2.54 feet per second, which was the range found for the run. The skill having the least variability in initial velocity among subjects was the leap for distance, which had a range of 1.72 feet per second. The range in initial velocity for the leap for height was 2.32 feet per second.

It was not the intent of this study, nor were there enough subjects, to determine the most desirable angle of projection and initial velocity for each skill. However, the angles and velocities produced by these subjects were similar enough for each skill to provide a basis for the identification of differences in the determinants of the path of the center of gravity for each of the three locomotor skills.

Angles of Projection and Initial Velocity among Skills

Comparison of the angles of projection and initial velocities for the run, leap for height, and leap for distance revealed distinct differences in the determinants of the flight phase path of the center of gravity for each skill. (See Table I, p. 31.) In all five subjects, the angle of projection in the run was considerably lower than that for either the leap for height or the leap for distance. Therefore, the upward motion of the center of gravity during the flight phase in the run was slight in comparison to the upward motion in the leaps. The leap for height had a larger angle of projection than did the leap for distance. Figure 8 shows that each of the three skills had a distinctly different angle of projection, the mean for the five subjects being 38.24° in the leap for height, 22.96° in the leap for distance, and 3.95° in the run. The range in angle of projection among subjects for each of the three skills is shown in Figure 7, page 32.

The initial velocity of projection of the center of gravity also is recorded in Table I and Figure 7, pages 31 and 32. For all five subjects, the run had the greatest initial velocity of any of the three skills ($\overline{X}$ = 10.33 ft./sec.). Both the leap for height ($\overline{X}$ = 10.33

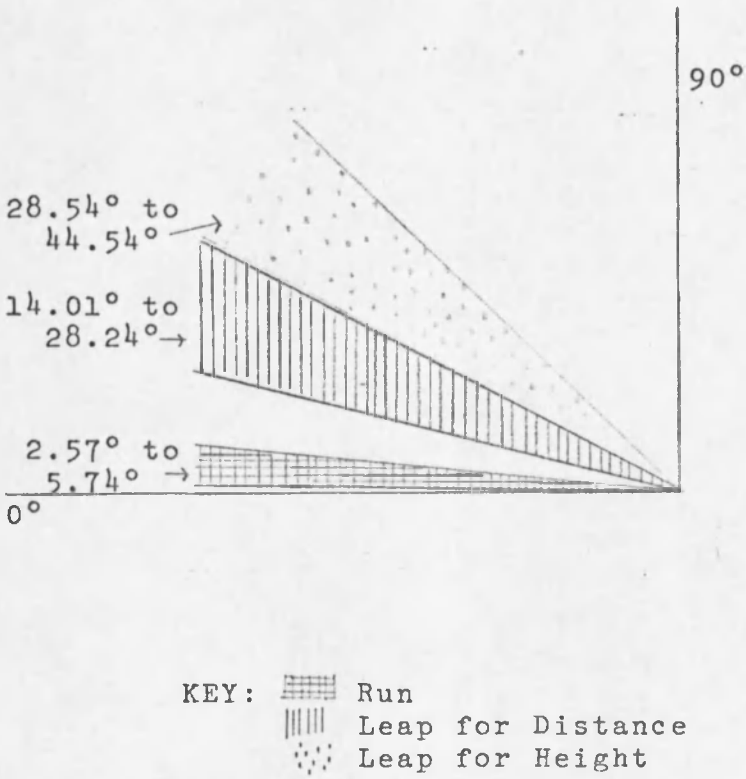


Figure 8. Angle of Projection in the Run, Leap for Height, and Leap for Distance

ft./sec.) and the leap for distance ($\overline{X}$ = 12.65 ft./sec.) had much slower initial velocities. The leap for distance had an initial velocity of two to three feet per second greater than the leap for height. Even if the angles of projection for the two leaps had been the same, the greater initial velocity in the leap for distance would have caused the center of gravity of the body to travel farther during flight than in the leap for height.

<u>Actual Path of the Center of Gravity</u>

Although the angle of projection and the initial velocity determine the actual path of the center of gravity of the body, a comparison of the actual height and distance achieved in each skill may illustrate more vividly the differences among the three skills. Table II presents the maximum horizontal and vertical distances attained by the center of gravity during each of the skills. For all subjects, the center of gravity was projected to a greater height above starting level ($\overline{X}$ = .637 ft.) in the leap for height than in the other two locomotor skills. Figures 9 through 13 illustrate the path of the center of gravity for the three skills of each subject. In the leap for distance the center of gravity followed a lower arc (average height = .397 ft.) than it did in the leap for height in all subjects. The center of gravity followed a very flat arc during the run (average height = .037 ft.) in each subject.

Table II. Maximum Horizontal and Vertical Distance* Covered in the Leap for Height, Leap for Distance, and Run

Subject	Leap for Height		Leap for Distance		Run	
	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
1	.669	2.839	.641	4.664	.074	2.833
2	.705	4.069	.397	3.728	.038	1.832
3	.653	2.962	.345	3.153	.0116	.9671
4	.818	3.318	.461	3.745	.043	2.145
5	.341	2.5	.142	2.182	.013	1.009
Average	.6372	3.138	.3972	3.494	.037	1.757
Range	.477	1.569	.499	2.482	.062	1.866

* Measured in feet

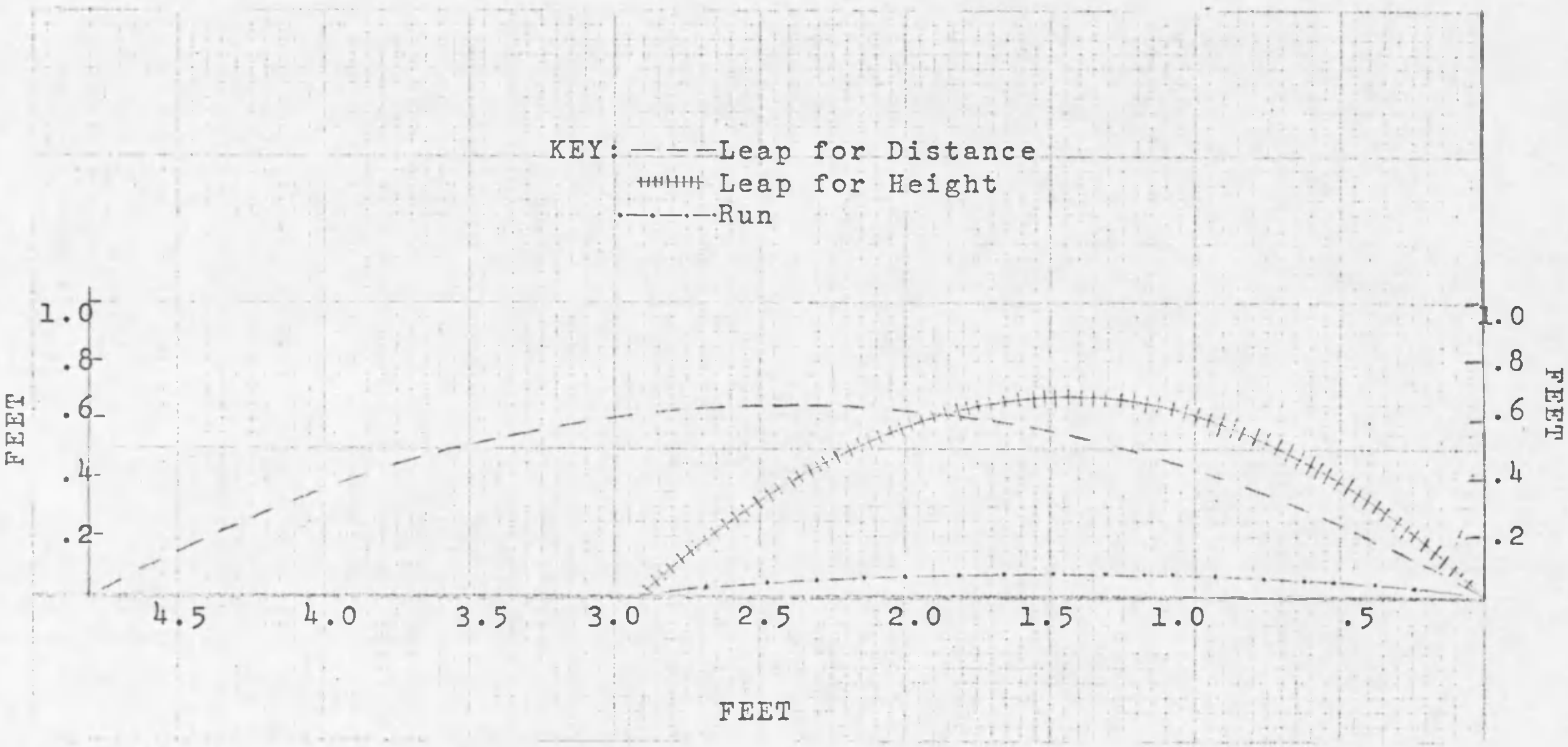


Figure 9. Path of the Center of Gravity for Subject 1

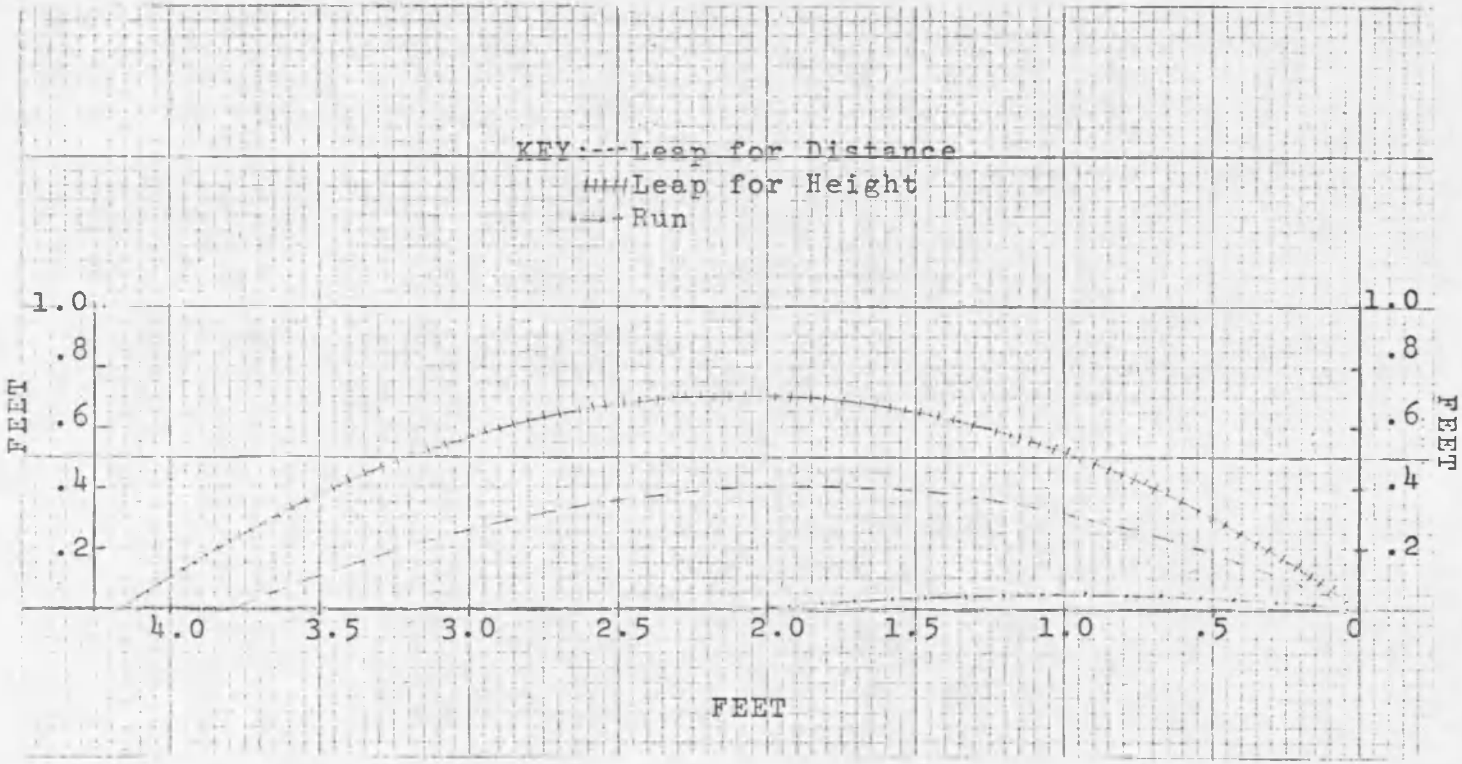


Figure 10. Path of the Center of Gravity for Subject 2

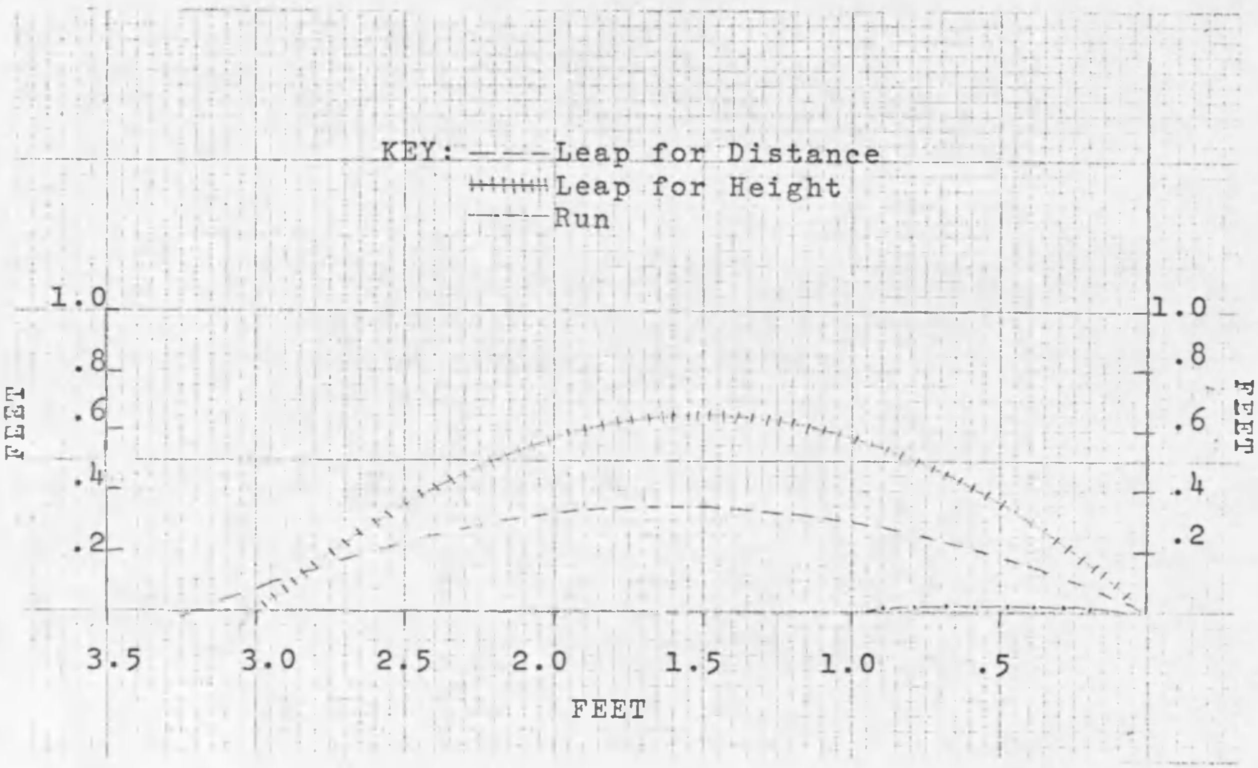


Figure 11. Path of the Center of Gravity for Subject 3

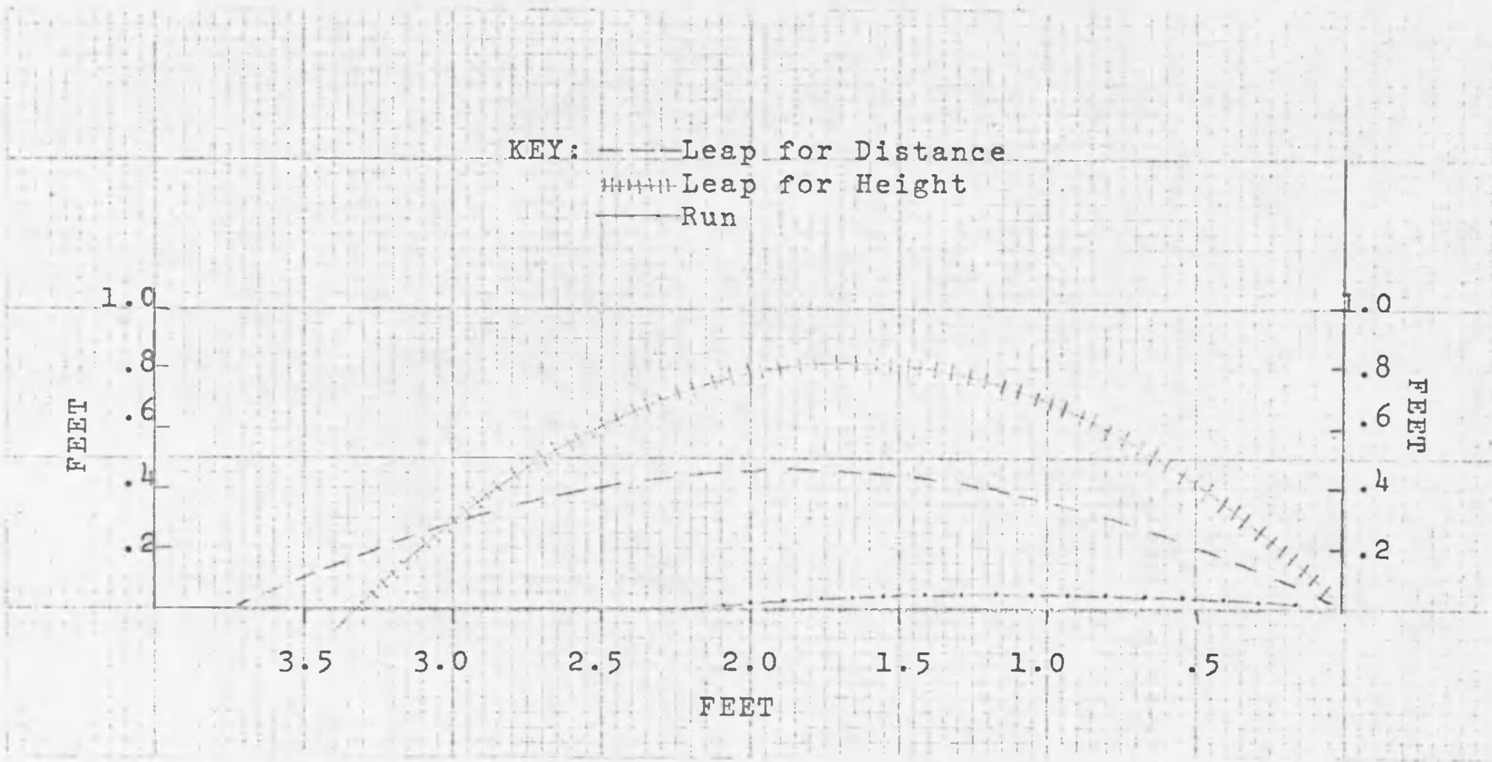


Figure 12. Path of the Center of Gravity for Subject 4

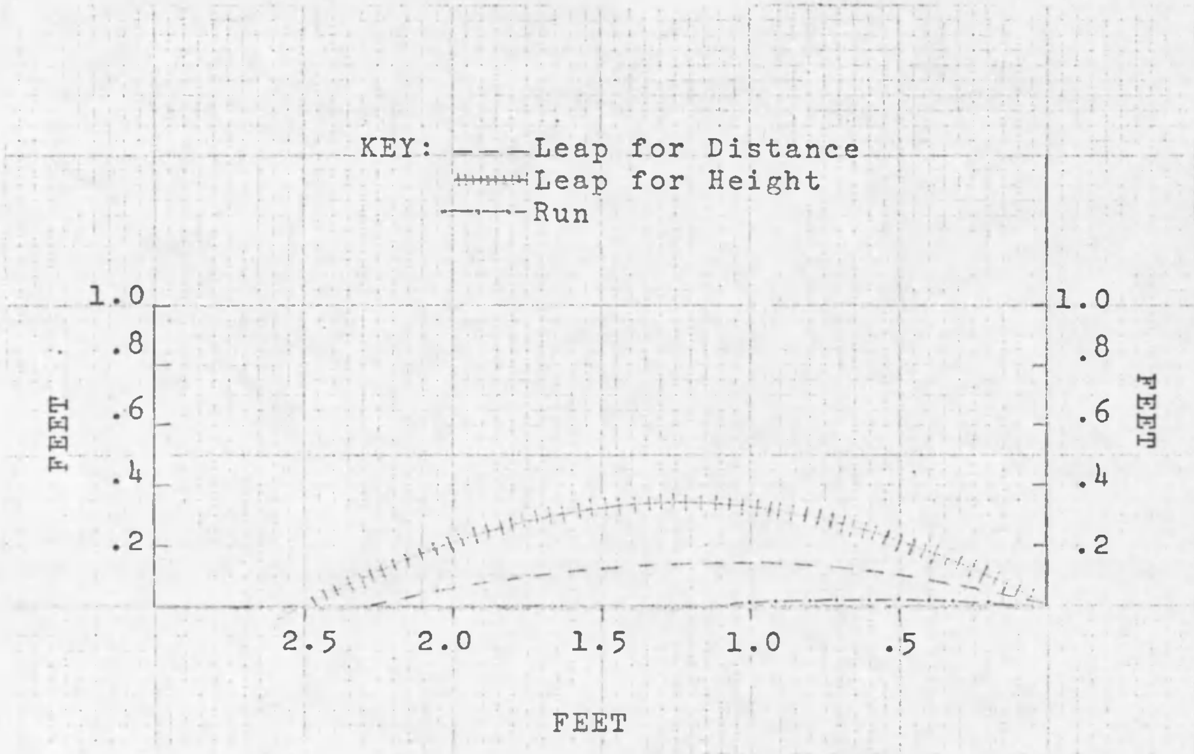


Figure 13. Path of the Center of Gravity for Subject 5

Only the horizontal distance covered by the center of gravity from take-off to the point where it returned to its starting level was measured. It should be noted that this distance was not a direct measure of the total horizontal distance traveled by the center of gravity from take-off to landing in each skill but was usually somewhat shorter than the total distance. Generally the greatest horizontal distance covered by the center of gravity occurred during the leap for distance ($\overline{X}$ = 3.494 ft.). The average horizontal distance covered by the leap for height ($\overline{X}$ = 3.128 ft.) was slightly less than that for the leap for distance. The horizontal distance covered by the center of gravity during the run ($\overline{X}$ = 1.757 ft.) was shorter than for either of the leaps.

Although the average horizontal distance for each skill differed, actual horizontal distances covered in the leap for height and leap for distance overlapped in some cases. For two of the five subjects the leap for height covered greater horizontal distance than did the leap for distance. A possible reason why there was much overlap in the greatest horizontal distances covered in the leap for height and the leap for distance might have been due to the fact that the distance the center of gravity travels is a function of both the angle of projection and the initial velocity of projection for each skill.

A comparison of the data in Table I, page 31, and Table II, page 37, showed that the one leap with the greatest height also had the largest angle of projection. The one leap for distance which covered the largest horizontal distance had the greatest initial velocity and the largest angle of projection of all of the leaps for distance. The run which covered the greatest horizontal distance of all of the runs also covered the greatest vertical distance and had the greatest angle of projection and initial velocity of all of the runs.

Center of Gravity in Relation to the Take-off Foot

The angle of lean from the vertical was used to illustrate the position of the center of gravity of the body in relation to the supporting foot at take-off. When the angle of lean was large the center of gravity was farther ahead of the take-off foot than when the angle of lean was small. (Figure 14 illustrates the angle of lean at take-off for each skill.)

The angles of lean associated with each skill were quite consistant among the five subjects. The angle of lean in the leap for height ranged from 8.5° to 16.5° with an average of 13.5°. In the leap for distance the range in the angle of lean was 19.5° to 32° with an average of 19.6°. The angle of lean for the run was most consistant among the subjects with a range of 31° to 37° and the average of 33.7°. (See Figure 15 and Table III.)

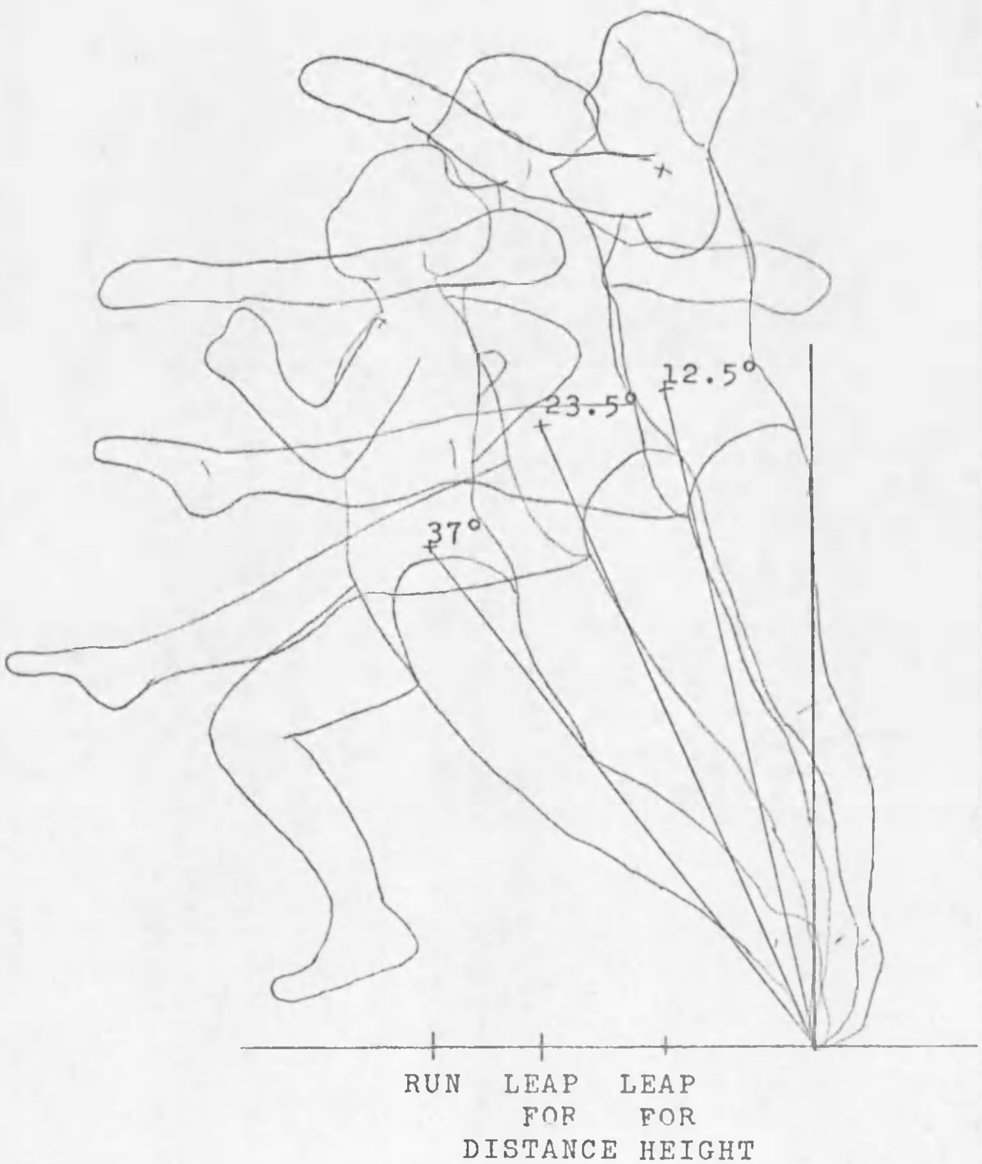


Figure 14. Angle of Lean in the Run, Leap for Height, and Leap for Distance (Subject 4)

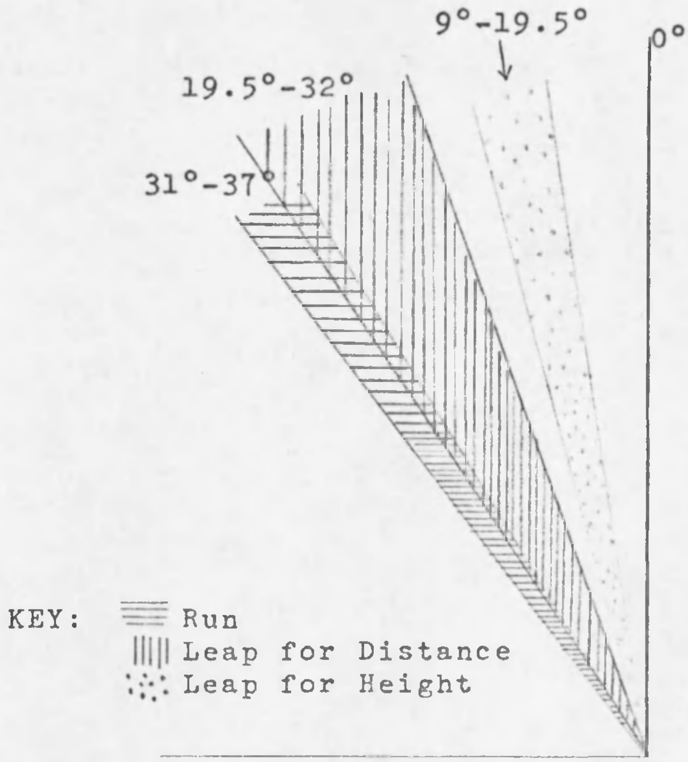


Figure 15. Range in the Angle of Lean from the Vertical

Table III. Angle of Lean and Angle of Projection in the Run, Leap for Height, and Leap for Distance

Subject	Run		Leap for Height		Leap for Distance	
	Angle of Lean	Angle of Projection	Lean	Projection	Lean	Projection
1	35.5°	5.74°	15°	42.75°	20°	28.24°
2	31.0°	4.38°	16.5°	34.16°	19.5°	22.8°
3	31.5°	2.57°	9°	41.2°	24.0°	23.43°
4	37°	4.42°	12.5°	44.54°	23.5°	26.32°
5	33.5°	2.67°	15°	28.54°	32°	14.01°
Average*	33.7°	3.95°	13.5°	N = 5 38.24° N = 4 40.66°	19.6°	N = 5 22.96° N = 4 25.28°
Range*	6°	3.17°	8°	N = 5 16° N = 4 10.38°	12.5°	N = 5 14.23° N = 4 15.44°

* N = 5 in all cases except where otherwise indicated

In each subject, the smallest angle of lean was associated with the leap for height. Figure 16 illustrates a comparison among subjects of the angle of lean. The somewhat larger angle of lean associated with the leap for distance placed the center of gravity farther ahead of the supporting foot than it was for the two leaps. Thus, at take-off the position of the center of gravity in relation to the supporting foot clearly distinguished among the three skills. (See Figure 14, p. 45.)

A comparison of the angle of lean and the angle of projection for the three skills showed an inverse relationship between two measures. (See Table III, p. 47.) That is, when the angle of lean was large, the angle of projection of the center of gravity tended to be small. The leap for height was characterized by the smallestangle of lean and the largest angle of projection of any of the skills. For each subject, both the angle of lean and the angle of projection in the leap for distance were intermediate values between those for the leap for height and the run. In each case the run had the greatest angle of lean and the smallest angle of projection for the three skills. Figure 17 presents a comparison between the angle of projection measured from the horizontal and the angle of lean measured from the vertical for each of the three skills.

For any given skill, however, the subject having the greatest angle of lean did not necessarily have the

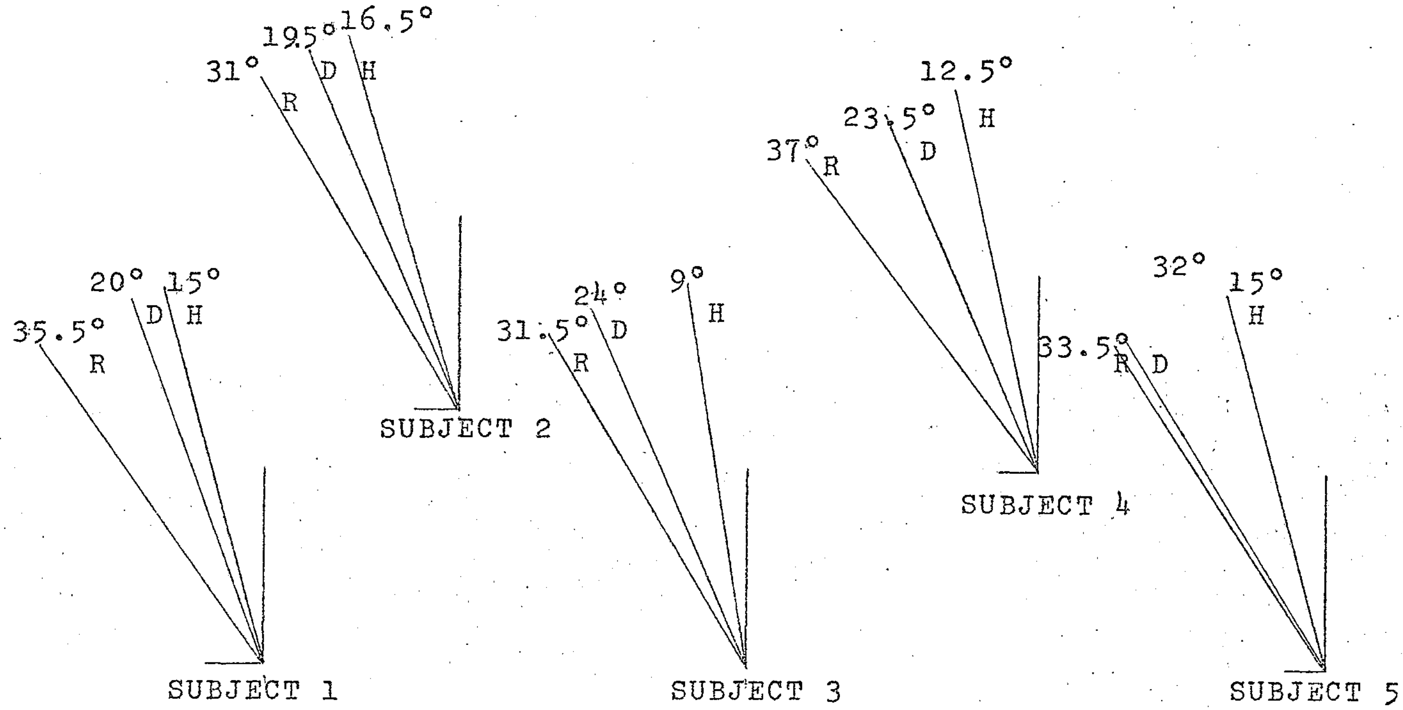


Figure 16. Comparison of the Angles of Lean in the Run, Leap for Height, and Leap for Distance

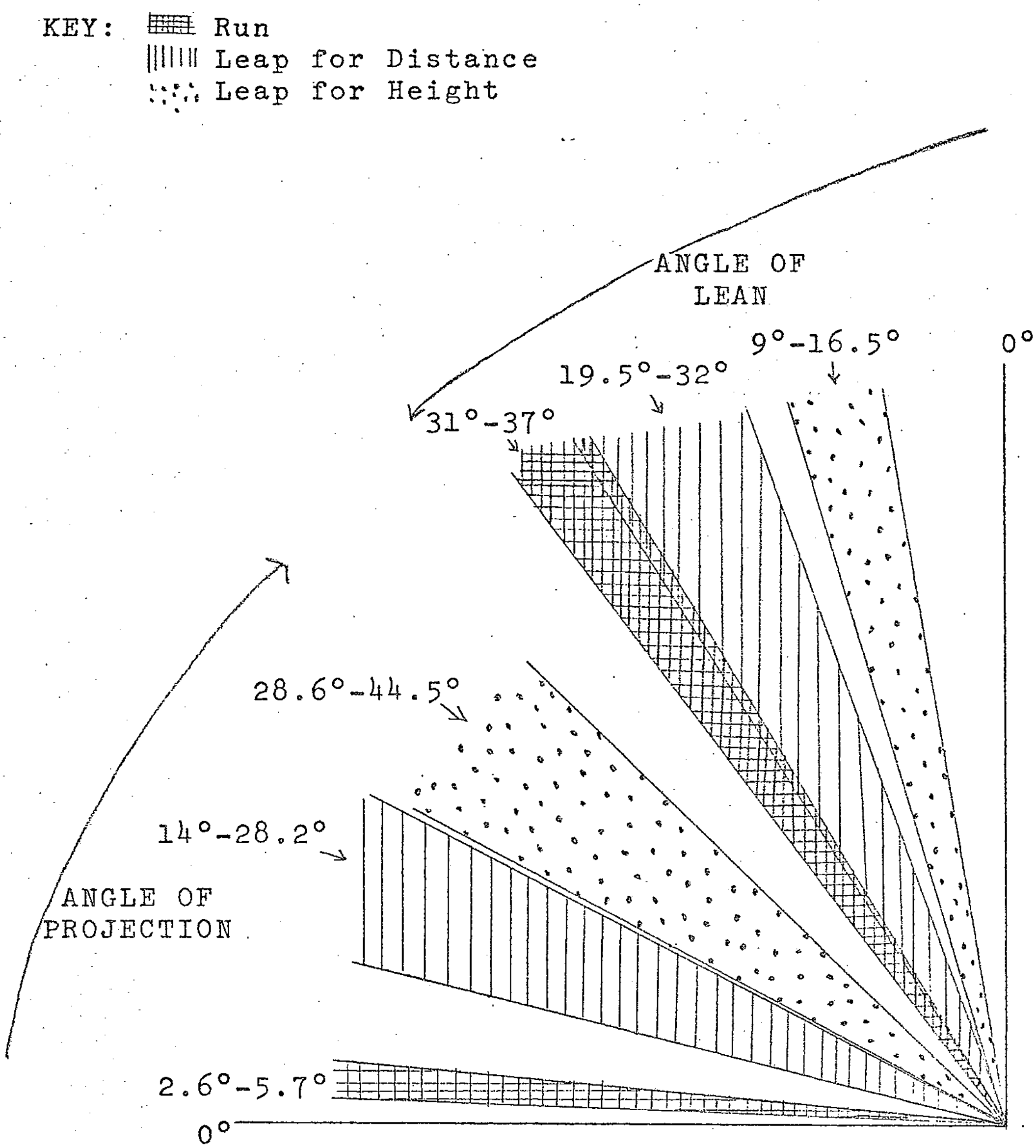


Figure 17. A Comparison of the Angle of Projection and the Angle of Lean

smallest angle of projection, nor did the subject with the smallest angle of projection necessarily have the greatest angle of lean. (See Table III, p. 47.) Furthermore, if the angle of lean had been measured in relation to the horizontal rather than to the vertical, this angle would have been larger, in every instance, than the angle of projection for that skill. Thus, it should be pointed out that the angle of lean was not the same as the angle of projection. Figure 17 illustrates that there is no overlap between the angle of projection and the angle of lean for each skill.

Actions of the Take-off Leg

The second section of this chapter deals with the actions of the supporting leg prior to take-off in the run, the leap for height, and the leap for distance. The questions of interest to be answered in this section are: a) What are the actions of the take-off leg in each of the three skills?, b) Are there differences among the three skills in the range, sequence, or time involved for joint actions?, and c) Is there a relationship between the velocity of the center of gravity over the supporting foot and the initial velocity of projection in each skill?

Angular Change in the Joints of the Supporting Leg

The joint actions of the take-off or supporting leg are described in terms of angular change at the ankle joint, angular change at the knee joint, and the change in the inclination of the thigh relative to the horizontal in front of the body. It should be noted that the thigh inclination is a measure of only one of the segments which make up the hip joint, therefore, the full action of the hip joint is not represented. However, the movement of the thigh in relation to the horizontal is indicitive of the action of the hip joint since the trunk segment changed its inclination only slightly throughout the support phase and the flight phase of the three skills. (See Appendices A and B.)

The Run. The joint actions for the run are graphed in Figures 18-22. An increasing value of angular change in all three of the measures indicates extension at that joint. Each graph starts as the support foot touches the floor and continues until take-off. The point at which the hip is over the supporting foot is indicated in each graph.

The support phase of the run was short in comparison to this phase for either of the leaps. In all but subject 3, the take-off foot touched the floor 9 or 10 frames (.1295 to .1439 sec.) before take-off. Subject 3 touched the floor to begin the support phase at the 11th frame (.1583 sec.) before take-off. (See Figures 18-22.)

Ankle: The ankle in each subject flexed upon contact and continued to flex until the point of greatest flexion occurred between 5 and 6 frames (.072 to .0863 sec.) before take-off. The point of greatest flexion

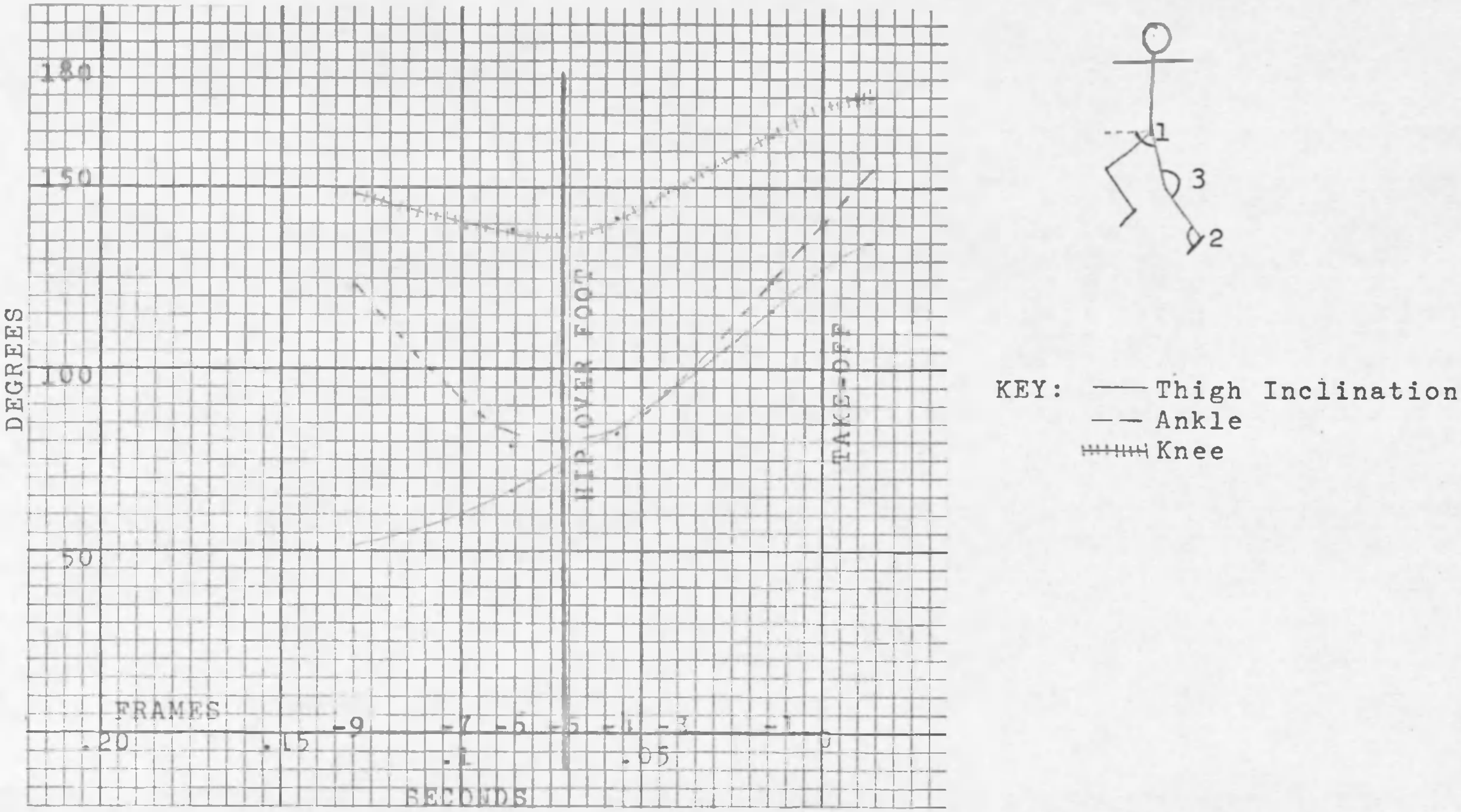


Figure 18. Angular Displacement of Knee and Ankle Joints and Thigh Inclination in the Run, Subject 1

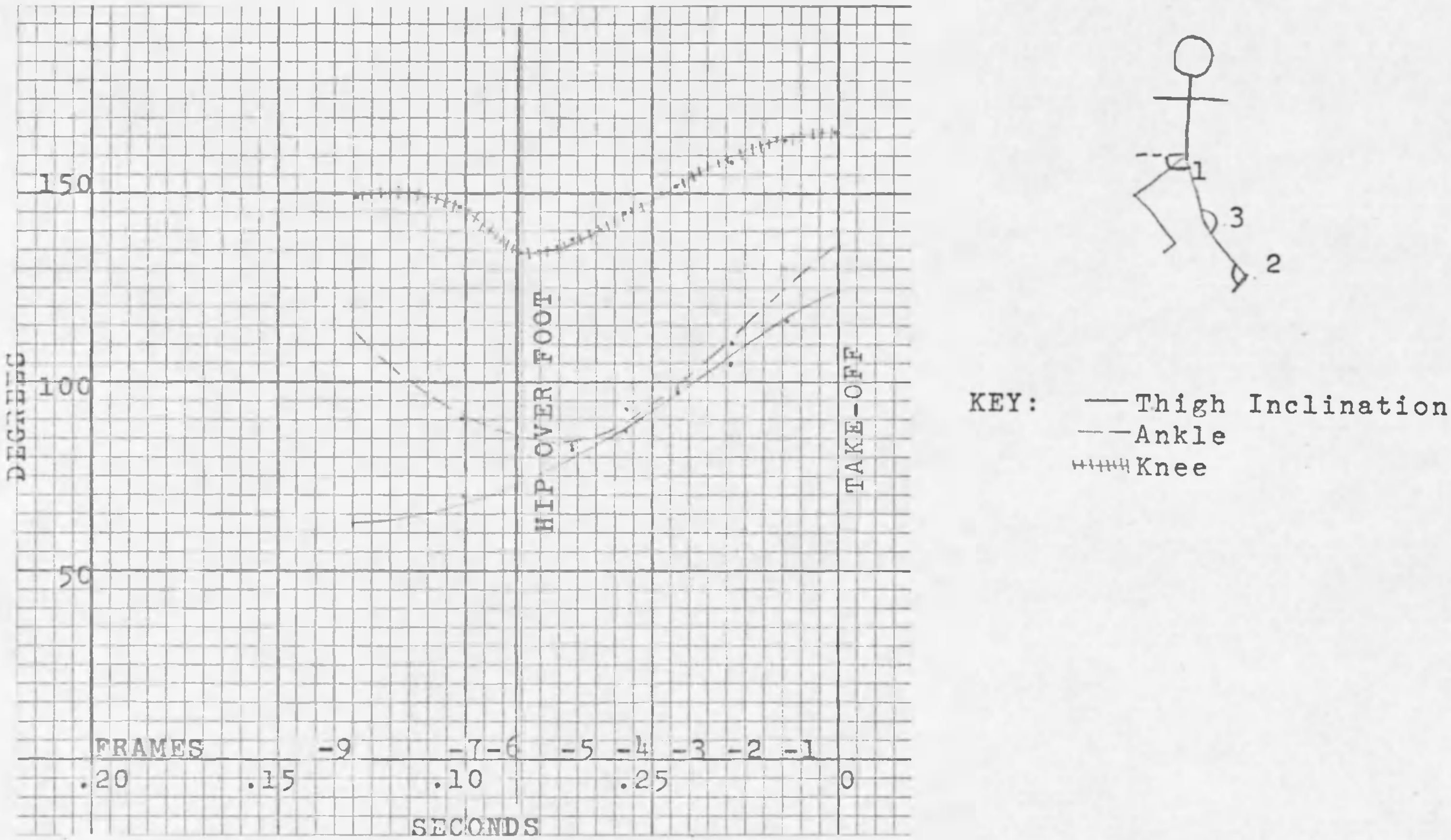


Figure 19. Angular Displacement of Knee and Ankle Joints and Thigh Inclination in the Run, Subject 2

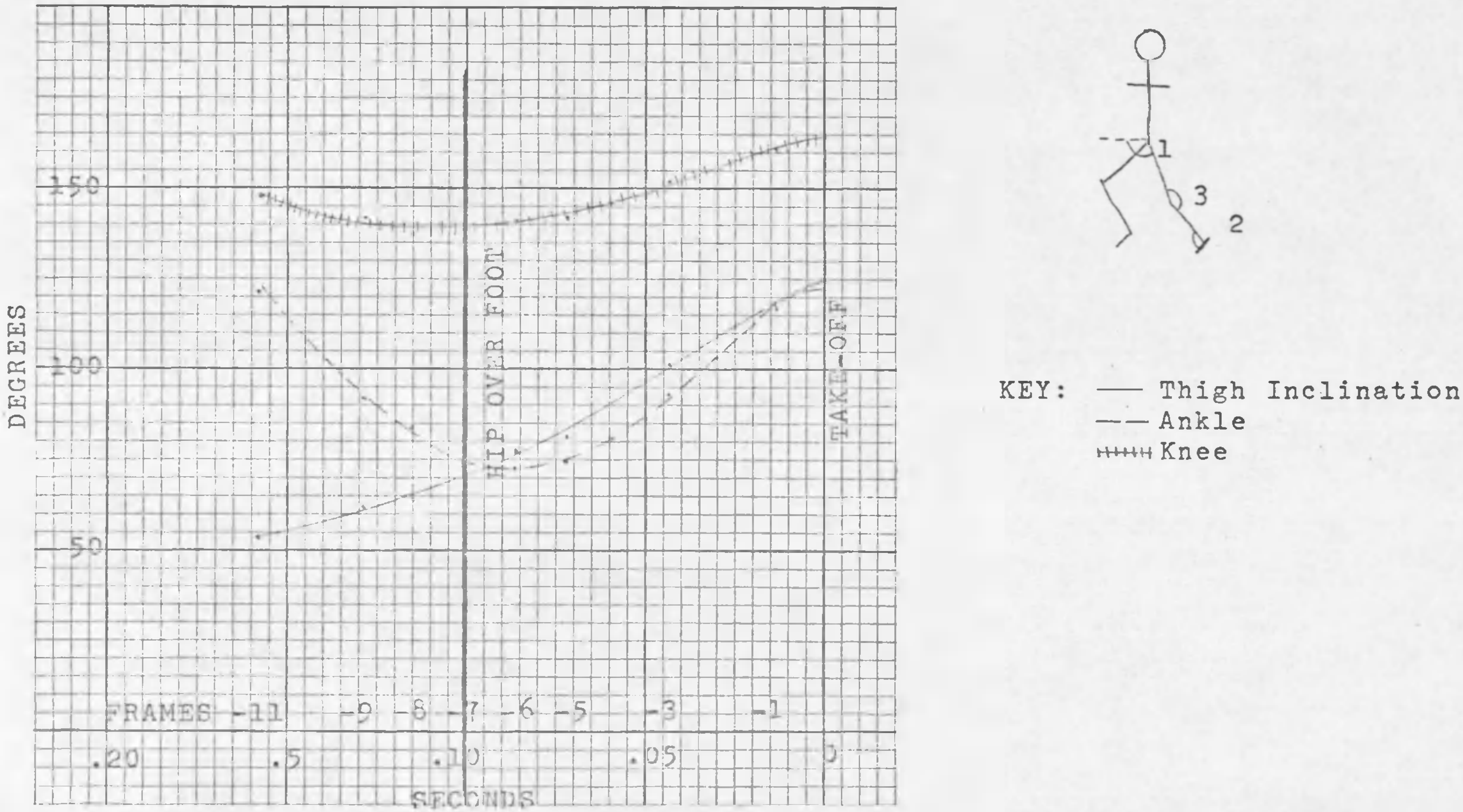


Figure 20. Angular Displacement of Knee and Ankle Joints and Thigh Inclination in the Run, Subject 3

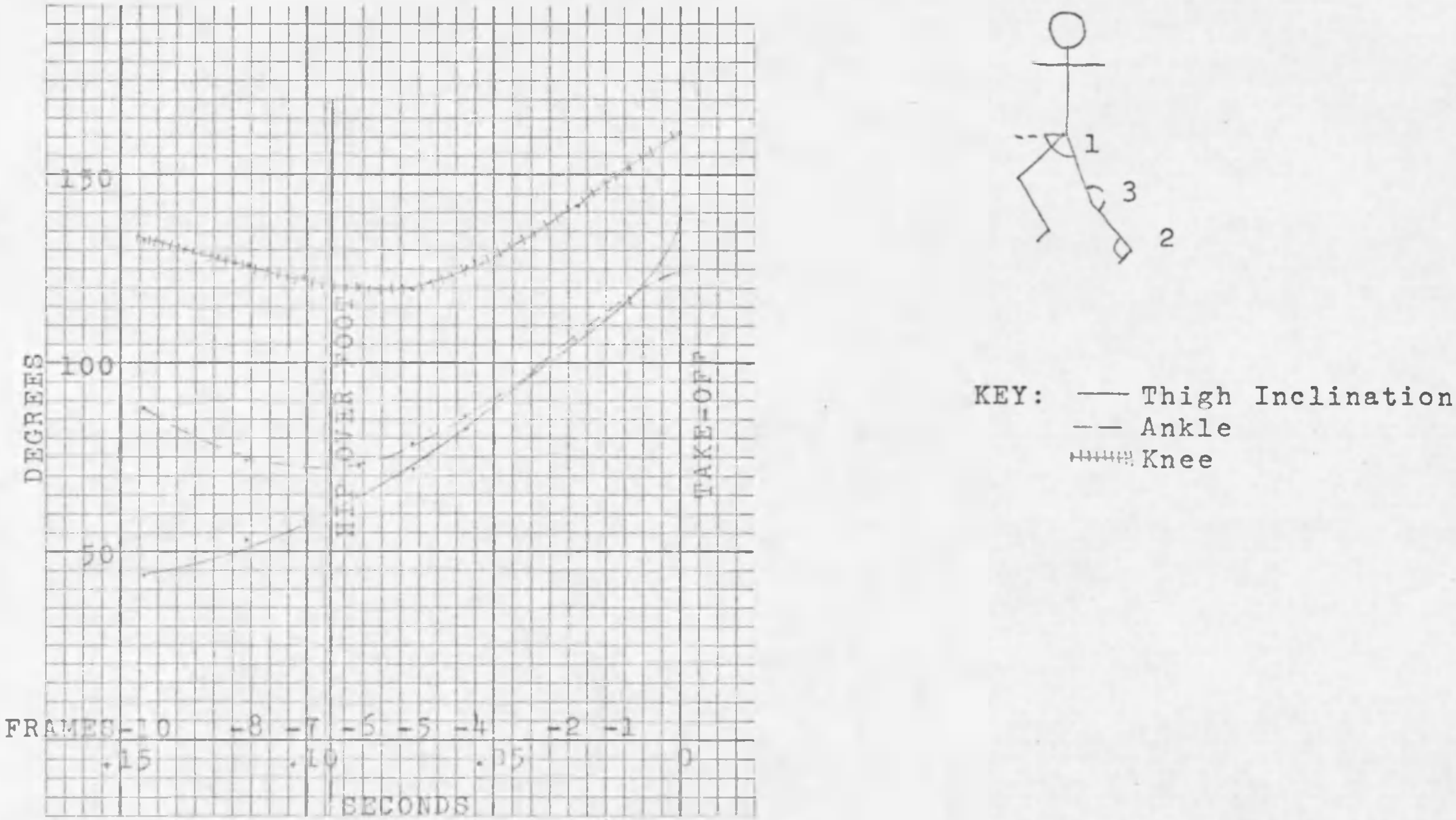
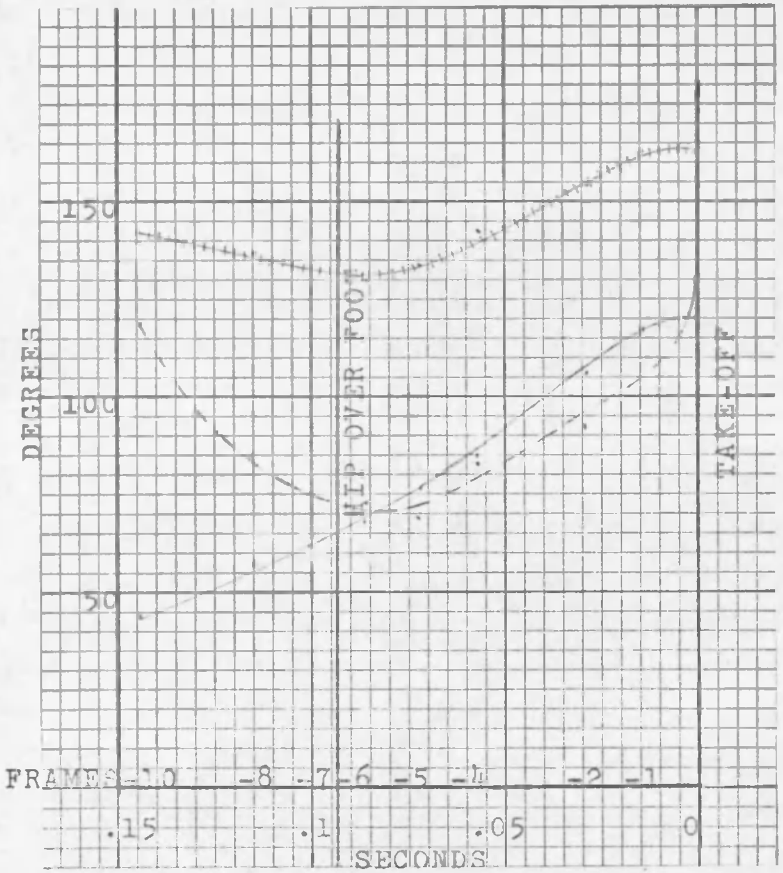
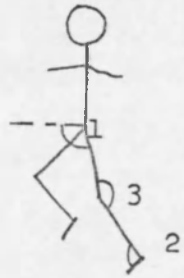


Figure 21. Angular Displacement of Knee and Ankle Joints and Thigh Inclination in the Run, Subject 4





KEY: —— Thigh Inclination
— — Ankle
+++++ Knee

Figure 22. Angular Displacement of Knee and Ankle Joints and Thigh Inclination in the Run, Subject 5

for subject 5 occurred a little earlier in the support phase or .1007 sec. before take-off. The average degree of greatest flexion for the ankle was 75.6°, after which rapid extension of the ankle joint occurred. (See Table IV, p. 79, for the range of angular motion in each joint.) The extension of the ankle took place at a steady rate after the point of greatest flexion. At take-off the average angle at the ankle was 133.4°.

Knee: The knee flexed gradually as the support foot contacted the floor, and reached the point of greatest flexion, an angle averaging 132° for the five subjects, just before the point of greatest flexion in the ankle. An exception to this was found in subject 4 for whom the knee continued slight flexion after the ankle had started extending. The knee then extended at a steady rate until take-off, at which time the average angle was 165.8°.

Thigh inclination: The angle of inclination of the thigh to the horizontal changed very little for the first two frames (.0288 seconds) after floor contact of the support foot. Then, the angle began to increase as the hip was extended. This increase in thigh inclination continued up until take-off, at which time the average angle was 124.2° from the horizontal. This angle was greater at take-off in the run than in either of the leaps, indicating that the thigh was inclined farther forward at take-off than in the other two skills.

Sequence of joint actions: The sequence of joint actions during the take-off phase of the run began with flexion of the knee and ankle upon foot contact with the floor, while the thigh inclination increased slightly. Then, a sequence of hip extension, knee extension and ankle extension followed the flexion. The point of greatest flexion in the knee and the ankle occurred between .072 and .0863 sec. before take-off, while the entire support phase lasted only .1294 to .1439 sec. This indicated that the extension phase of the joint actions took well over half of the total time for the support phase. The frame during which the hip was directly over the supporting foot occurred just prior to or during the period of greatest flexion in the ankle and the knee. (See Figure 18-22, pp. 53-57.) The rate of hip extension, as illustrated by the change in slope of the thigh inclination graph line, increased slightly for all subjects after the hip passed over the supporting foot.

Leap for Height. The joint actions for the leap for height are graphed in Figures 23-27. An increasing value of angular change in all three of the measures indicates extension at that joint. Each graph starts

Figure 23. Angular Displacement of Knee and Ankle Joints and Thigh Inclination in the Leap for Height, Subject 1

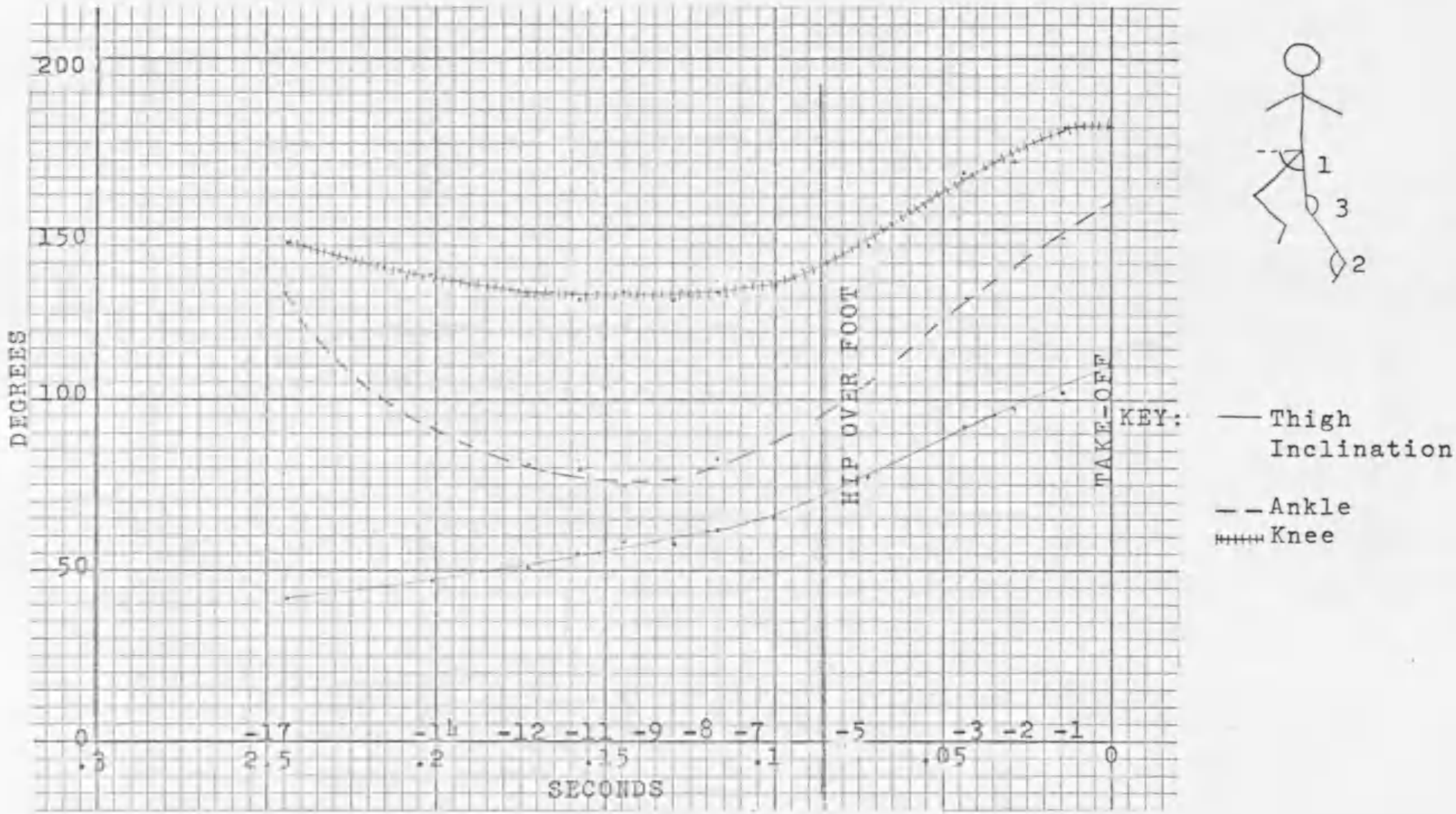


Figure 24. Angular Displacement of Knee and Ankle Joints and Thigh Inclination in the Leap for Height, Subject 2

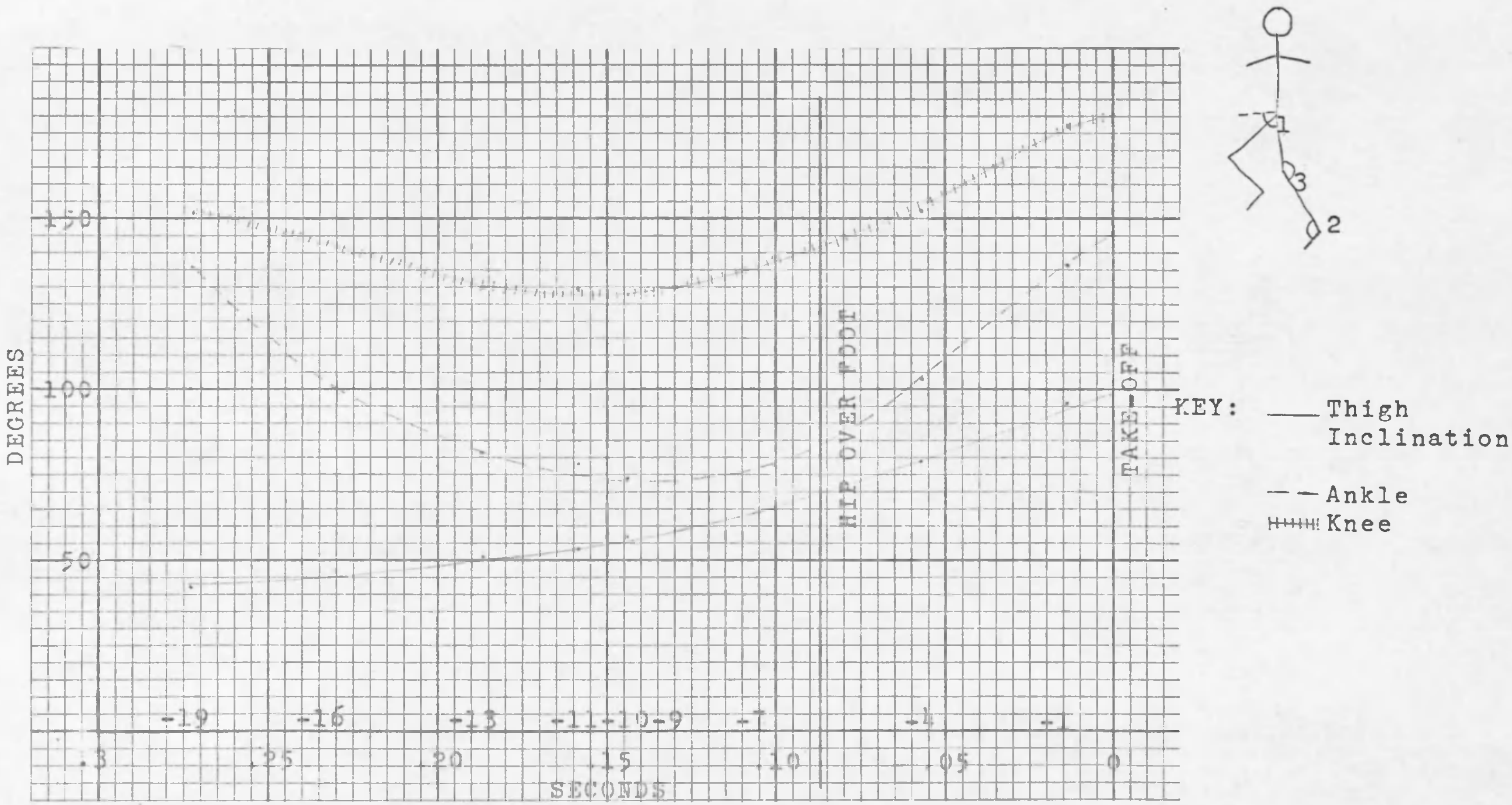


Figure 25. Angular Displacement of Knee and Ankle Joints and Thigh Inclination in the Leap for Height, Subject 3

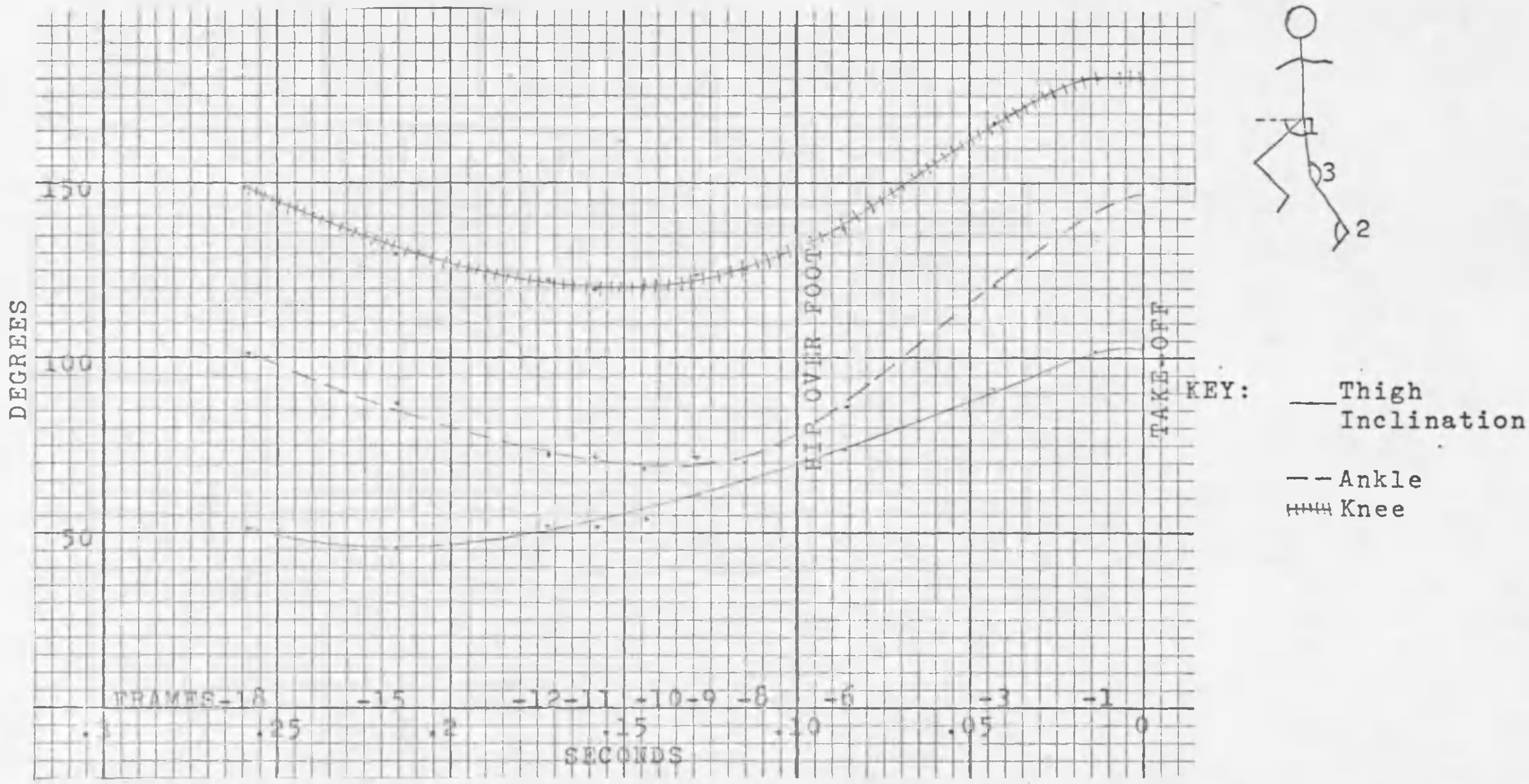


Figure 26. Angular Displacement of Knee and Ankle Joints and Thigh Inclination in the Leap for Height, Subject 4

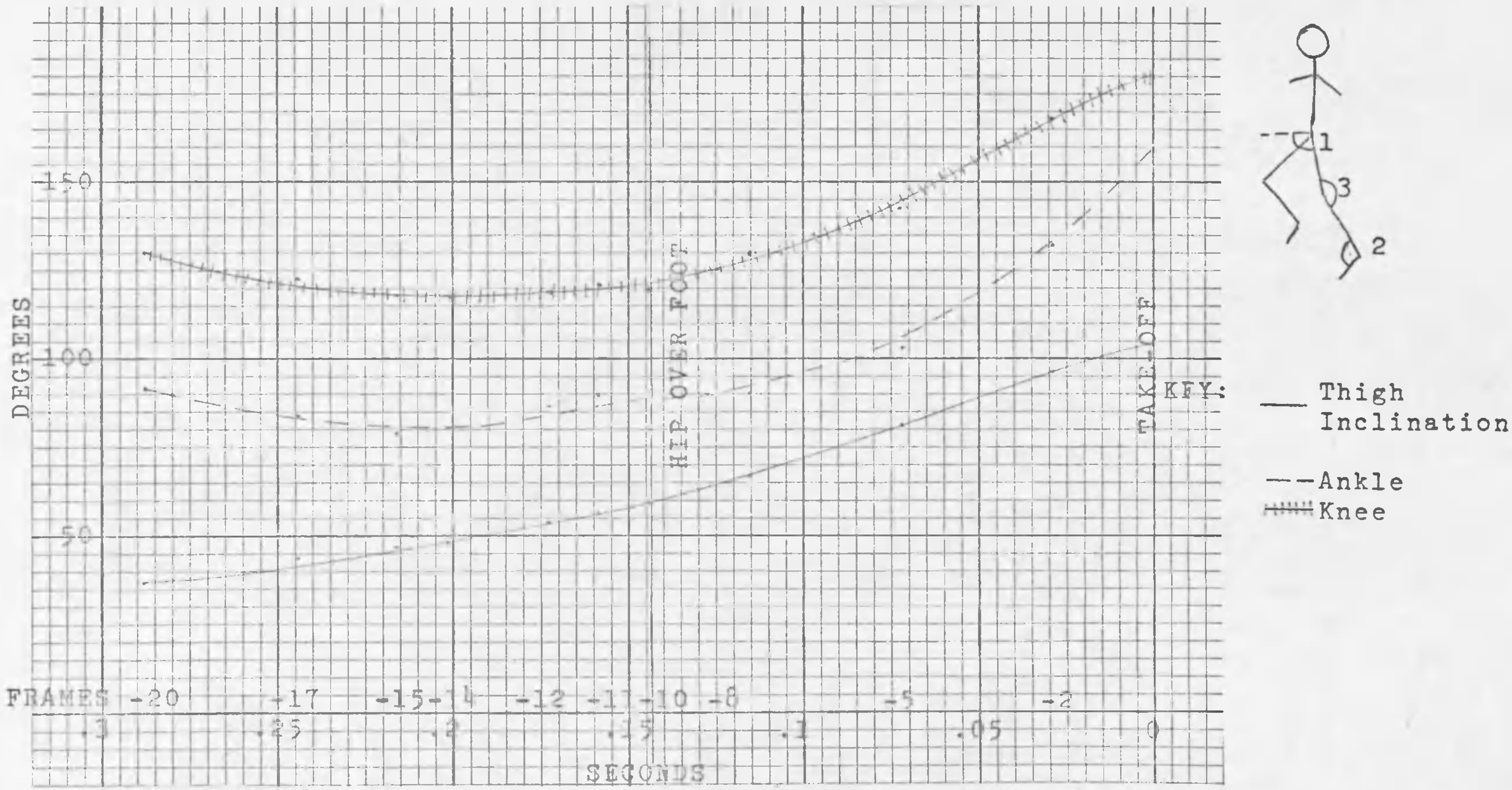


Figure 27. Angular Displacement of Knee and Ankle Joints and Thigh Inclination in the Leap for Height, Subject 5

as the support foot touches the floor and continues until take-off. The support phase of the leap for height lasted an average of 18 frames (.259 sec.) which was almost twice as long as the support phase of the run. (See Figures 23-27.)

Ankle: The ankle flexed upon contact of the support foot with the floor. The point of greatest flexion occurred between the 9th and 10th frames (.1295 and .1439 sec.) before take-off. This was approximately midway through the take-off phase. The average range of motion in the ankle during the latter part of the support phase in the leap for height was 79°, or from 72° at the point of greatest flexion to 151° at take-off.

Knee: Flexion occurred at the knee joint after contact of the supporting foot with the floor. The knee flexion took place gradually in comparison with the action of the ankle joint, and the point of greatest flexion in the knee was reached before the point of greatest flexion in the ankle in all but subject 2 and subject 5, where the knee and ankle reached the point of greatest flexion at approximately the same time. Once the angle of greatest flexion occurred, the angle at the knee joint did not change more than three to four degrees during the next three to four frames, or for approximately .0432 sec. Then, the knee joint began to extend at a steady rate until take-off. The angular range of motion for the knee averaged from 124° at the point of greatest flexion to 180° at take-off.

Thigh inclination: Generally, for the first five frames after the supporting foot touched the floor, there was only a very slight increase in the angle of inclination of the thigh indicating hip extension. In fact, there was a slight decrease in the angle of inclination of the thigh during the first three frames of the support phase for subject 4, which indicated that some hip flexion occurred in this subject upon contact of the support foot with the floor. The velocity of angular change or extension at the thigh increased somewhat (as shown by the increased slope of the angular displacement graphs) as the knee reached the point of greatest flexion, and the hip continued to extend through take-off. The average angular range of motion for thigh inclination during the leap for height was 60.4°, or 42.6° at the beginning of the support phase to 103° at take-off. This angle of thigh inclination at take-off was smaller than in the run or leap for distance, indicating that the thigh was closer to a vertical position at take-off than in the other two skills.

Sequence of joint actions: The sequence of take-off leg joint actions during the leap for height was similar to that of the run. During initial foot contact with the floor the ankle flexed, while the angle of inclination of the thigh remained almost unchanged with very slight extension of the thigh at the hip. The sequence of propulsion was hip extension, knee extension and then ankle extension.

One noticeable difference between the leap for height and the run was that, in the leap, the change in knee angle occurred more slowly as the point of greatest flexion was approached. There was a period of time (approximately .0432 sec.) before extension of the knee in which there was almost no change in the angle at the knee. Also, in the case of the leap for height, knee and ankle extension started close to the midpoint in time of the support phase, whereas in the run, knee and ankle extension started before the midpoint in time of the support phase.

It was also noted that the hip joint did not pass over the supporting foot until after the hip, knee and ankle had begun to extend. (See Figures 23-27, pp. 60-64.) The point when the hip was over the supporting foot occurred much later in the support phase or closer to the actual take-off in the leap for height than it did in the run. The leap for height of subject 5 did not follow this sequence exhibited by the other subjects. In subject 5 the knee and ankle reached the point of greatest flexion at about the same time, and the hip was over the supporting foot about midway in the support phase. However, it was noted earlier that the leap for height of subject 5 more closely resembled the leap for distance performed by the other four subjects. (See Figure 27, p. 64.)

Leap for Distance. The graphs of the angular displacement of the take-off leg joints during the leap for distance are found in Figures 28-32. Each graph starts at the touch of the support foot to the floor and continues until take-off with increasing values of angular chance indicating extension of a joint. The total time taken by each subject during the support phase of the leap for distance was varied, ranging from 13 frames (.1871 sec.) to 19 frames (.2734 sec.). Even with the wide variety of times, the length of time for the support phase of the leap for distance was similar to that of the leap for height.

Ankle: The ankle joint flexed at touch down of the supporting foot just as it did in the leap for height and the run. The ankle reached its point of greatest flexion prior to the midpoint in time of the support phase and then began to extend. The average range of motion for the ankle joint was 6.92°, or from 72.8° at the point of greatest flexion to 142° at take-off.

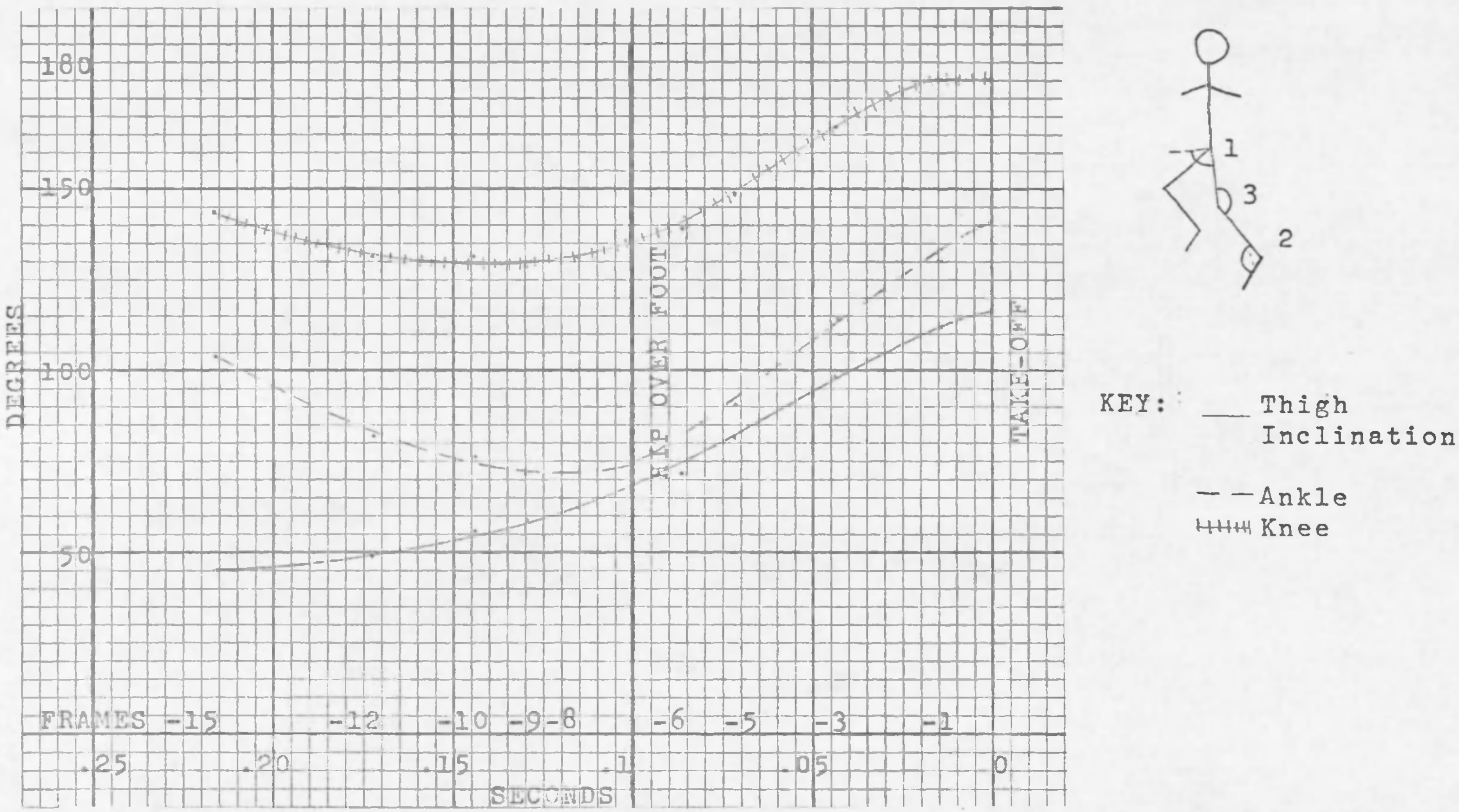


Figure 28. Angular Displacement of Knee and Ankle Joints and Thigh Inclination in the Leap for Distance, Subject 1

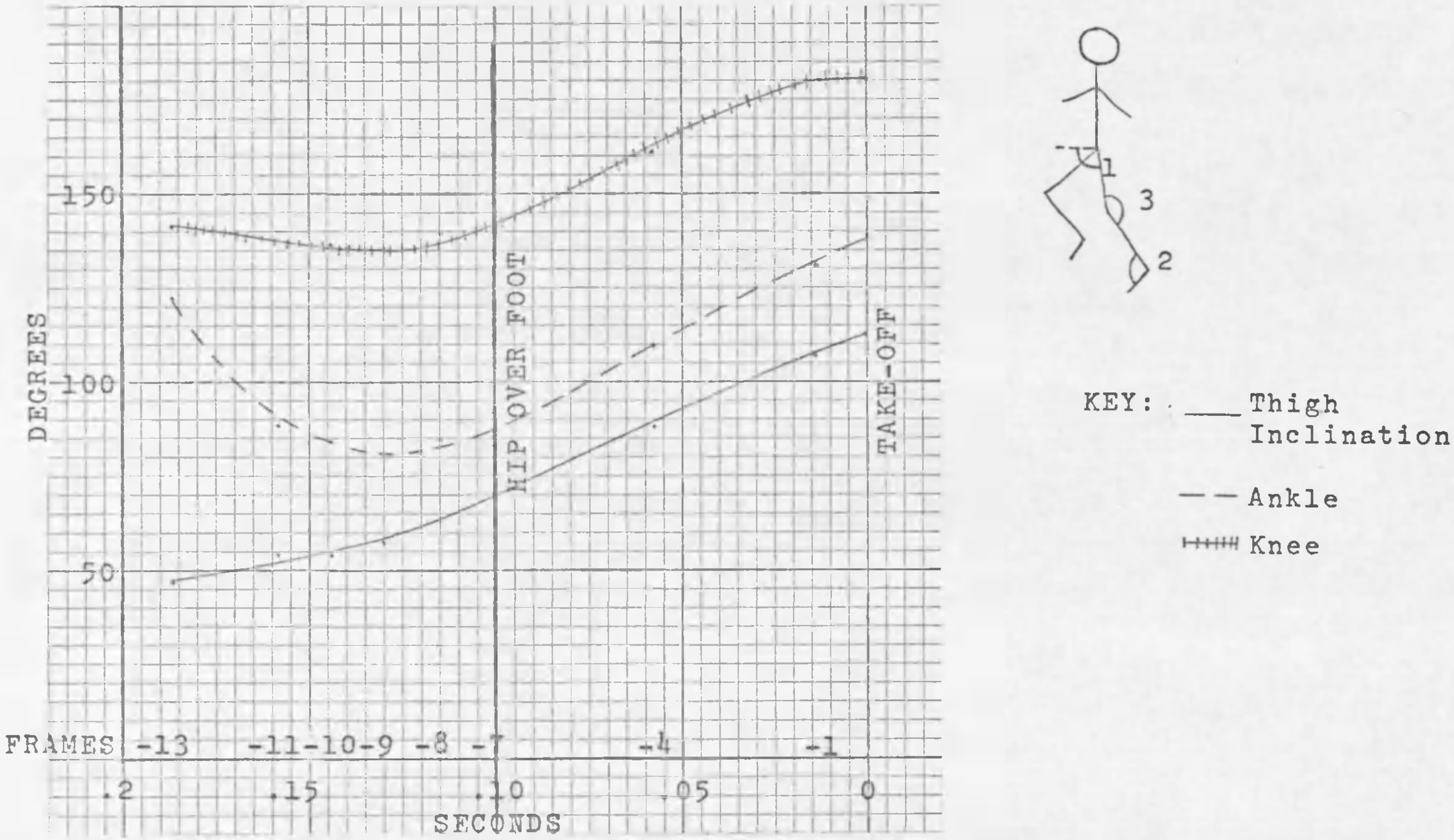


Figure 29. Angular Displacement of Knee and Ankle Joints and Thigh Inclination in the Leap for Distance, Subject 2

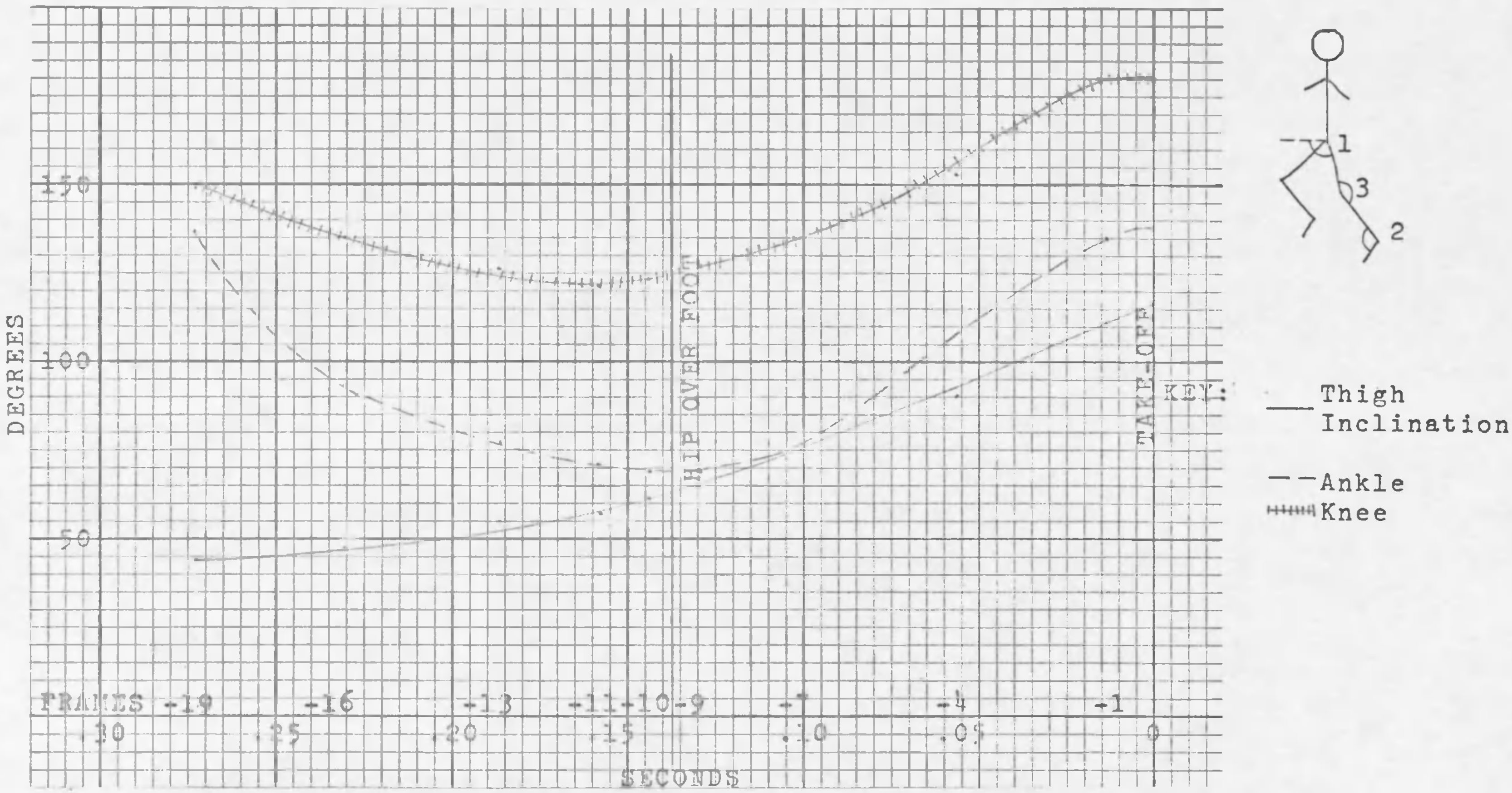


Figure 30. Angular Displacement of Knee and Ankle Joints and Thigh Inclination in the Leap for Distance, Subject 3

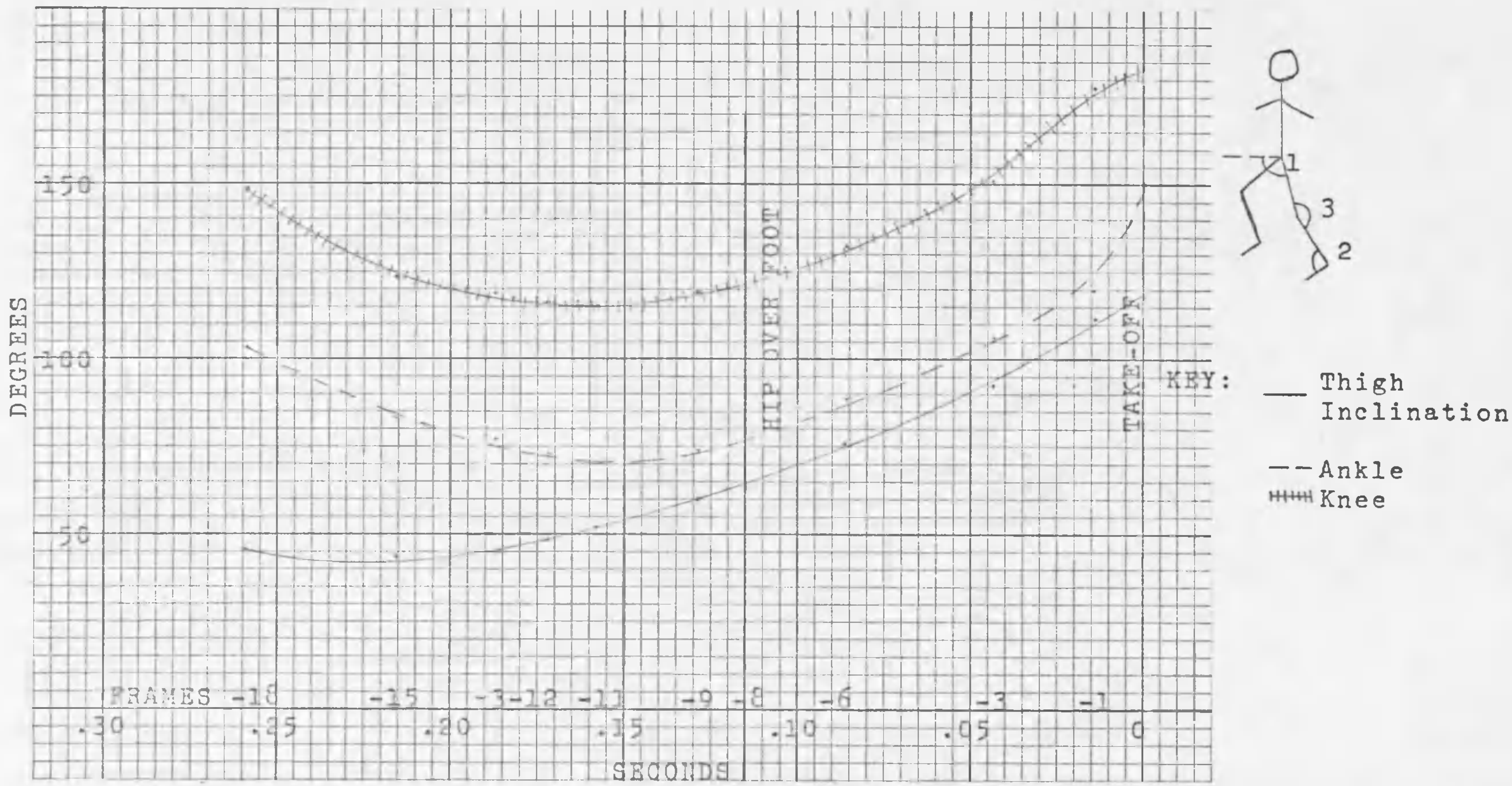


Figure 31. Angular Displacement of Knee and Ankle Joints and Thigh Inclination in the Leap for Distance, Subject 4

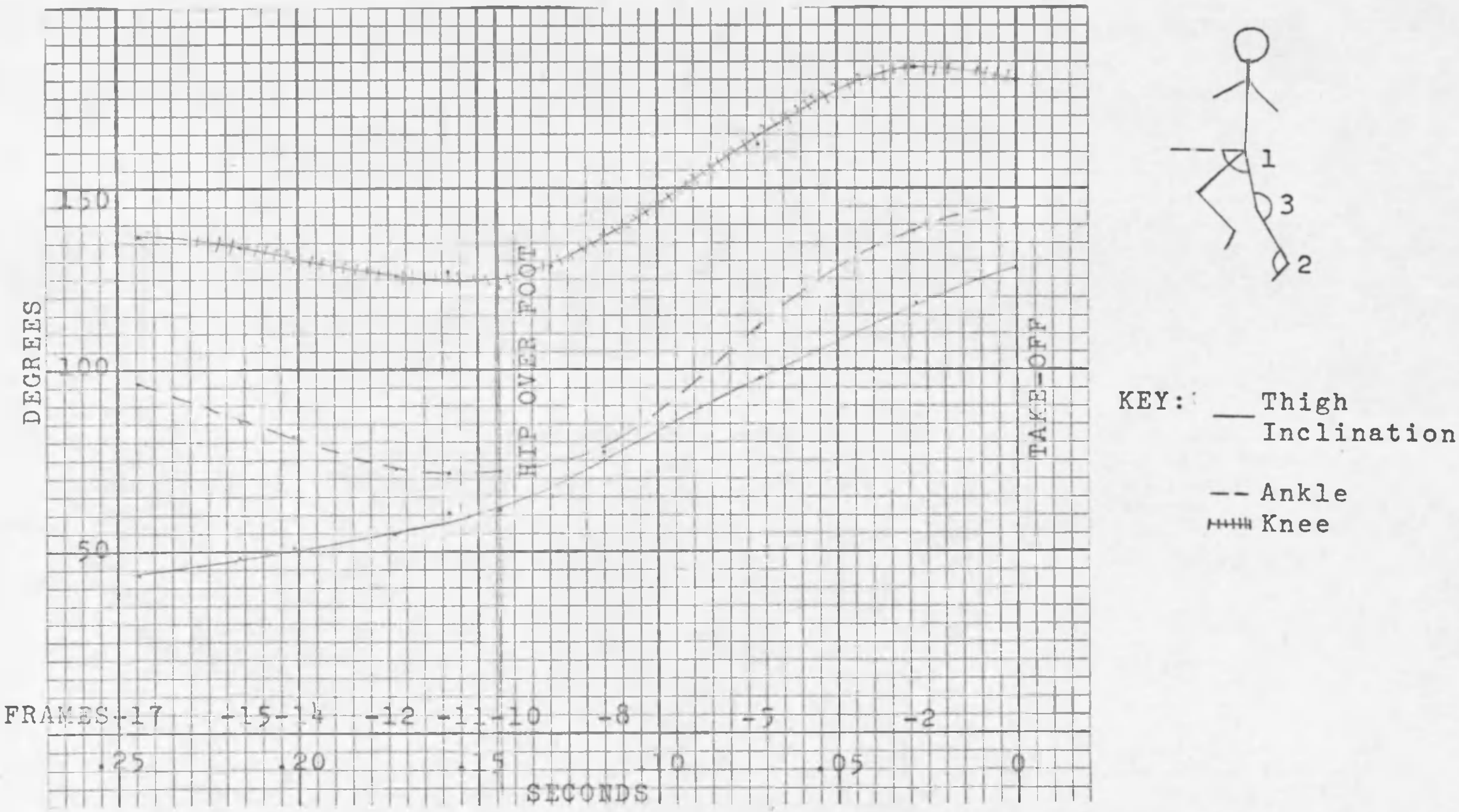


Figure 32. Angular Displacement of Knee and Ankle Joints and Thigh Inclination in the Leap for Distance, Subject 5

Knee: The knee flexed after the supporting foot contacted the ground, just as it did in the run and the leap for height. The knee reached the angle of greatest flexion, an average of 125°, before the ankle reached this point. The flexion was followed by a brief period of very little angular change in the knee joint, and then by knee extension to a position of 180° at take-off. There was a period of very slight angular change (.0432 sec.) as the knee approached greatest flexion, just as there was in the leap for height.

Thigh inclination: The action of the hip joint, as illustrated by the change in the angle of thigh inclination, was similar in the leap for distance and in the leap for height. For the first few frames after foot contact, the angular change in the thigh inclination was very slight, but gradually increased, except in subject 4 who showed slight hip flexion during the first three frames of support just as she did in the leap for height. (See Figure 31, p. 72.) The point of greatest flexion for most subjects was at the beginning of the support phase with an average of 44.4°. The angular velocity of the hip extension increased, as shown by the greater slope of the thigh inclination line in Figures 28-32, pages 69-73, when the ankle and the knee began to extend.

The average angle of thigh inclination at take-off during the leap for distance was 118°, which was an angle intermediate in value between that in the run and the leap for height.

Sequence of joint actions: The sequence of the supporting leg joint actions at the start of the support phase in the leap for distance was similar to the sequence of joint actions in the run and leap for height. Flexion occurred at the ankle and knee while the hip was slowly extending. This was followed by continued hip extension, then knee extension and ankle extension.

The frame in which the hip joint was directly over the supporting foot was usually close to the midpoint in the time for the entire support phase in the leap for distance. In the run, the hip was in front of the supporting foot for the majority (63%) of the support phase, and in the leap for height, the hip was behind the supporting foot for the majority (64%) of the support phase. The point of greatest flexion in the ankle and the knee was reached just prior to or at the frame in which the hip was over the supporting foot. This differed from the leap for height in which the ankle and the knee were already extending by the time the hip was over the foot.

Comparisons of the Run, Leap for Height, and Leap for Distance

The sequence of joint actions in the supporting leg prior to take-off was similar for each of the three skills. In each skill the actions were described as flexion at the ankle and knee joints just after the supporting foot touched the ground. The thigh inclination measure indicated that the hip showed very slight extension for most subjects immediately after the supporting foot touched the ground in each skill. This seemed to be due to the movement of the body over the supporting foot. After the point of the greatest flexion in the knee, hip extension increased, and was followed by knee extension and then ankle extension which continued through take-off. The only real difference in sequence of joint actions was found in the action of the knee in the run and in the leap. Knee extension directly followed the point of greatest flexion of the knee in the running skill. However, in the leaps, angular change at the knee just about ceased after reaching the point of greatest flexion, and the knee did not begin extension until from .0288 sec. to .0576 sec. later.

The total duration of time for the support phase differed for each skill. Figure 33 shows the time for the support phase of each skill. The support phase of the run ranged from .1295 to .1439 sec. in the five subjects. In the leap for height the support phase ranged

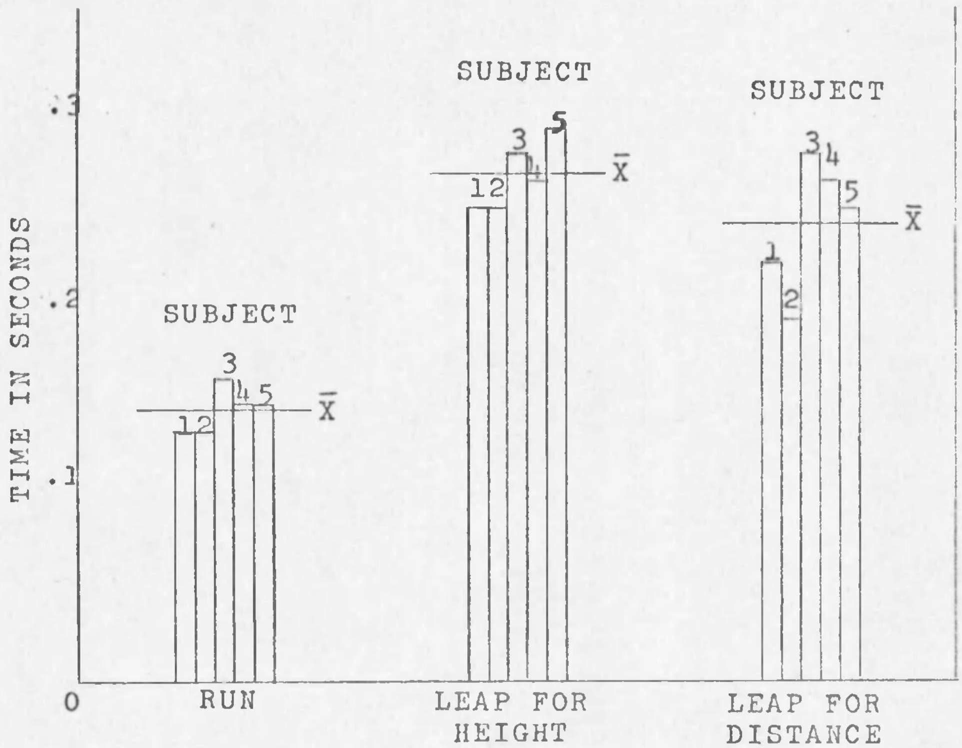


Figure 33. Duration of the Support Phase

from .2446 to .2878 sec. which was twice as long as the time for the run. The support phase for the leap for distance lasted from .1871 to .2734 sec., which was a longer time than that in the run, but just slightly shorter than the support phase in the leap for height. The proportion of the time during the support phase that was spent in flexion of the knee and ankle as opposed to extension of these joints varied for each of the skills. In the run, approximately 60% of the time for the support phase was used for supporting leg extension while in the leaps the extension of the joints in the supporting leg started about midpoint in time during the take-off phase.

Range of Motion in Take-Off Leg Joint Actions

The range in angular change of the ankle joint, knee joint and thigh inclination represents the difference between the angle of greatest flexion and the angle of greatest extension. The range for each joint in each skill for all five subjects is presented in Table IV. The average angle of greatest flexion in the ankle was similar in the run, leap for height and leap for distance. However, the ankle reached a greater degree of extension in the two leaps than it did in the run. Thus, the average angular range in the ankle was greater in the leaps than it was in the run. Figure 34 presents the average angular range in the ankle joint, knee joint, and thigh inclination of the supporting leg for each skill.

Table IV. The Range of Motion in the Ankle, Knee, and the Thigh Inclination of the Take-off Leg During Support Phase

Subject		Run	Leap for Height	Leap for Distance
	Ankle	80° - 140°	72° - 153°	72° - 141°
1	Knee	136° - 173°	125° - 182°	129° - 180°
	Thigh Inclination	51° - 128°	45° - 102°	45° - 116°
	Ankle	83° - 136°	75° - 158°	81° - 138°
2	Knee	134° - 167°	130° - 180°	135° - 180°
	Thigh Inclination	62° - 124°	42° - 110°	47° - 112°
	Ankle	73° - 122°	73° - 146°	69° - 138°
3	Knee	139° - 165°	128° - 180°	122° - 180°
	Thigh Inclination	54° - 125°	43° - 99°	44° - 116°
	Ankle	71° - 138°	68° - 147°	70° - 150°
4	Knee	120° - 161°	120° - 180°	115° - 182°
	Thigh Inclination	44° - 124°	46° - 103°	42° - 118°
	Ankle	71° - 131°	79° - 159°	72° - 149°
5	Knee	131° - 163°	118° - 180°	124° - 183°
	Thigh Inclination	44° - 120°	37° - 104°	49° - 128°
	Average Range	75.6°-133.4° (57.8°)	73.4°-152.6° (79.2°)	72.8-142.2° (69.4°)
		132°-165.8° (33.8°)	124.2°-180° (55.8°)	125°-181° (56°)
		51°-124.2° (73.2°)	42.6°-107.6° (65°)	44.4°-118° (73.6°)

Key: 1st Value angle of greatest flexion
2nd Value angle at take-off

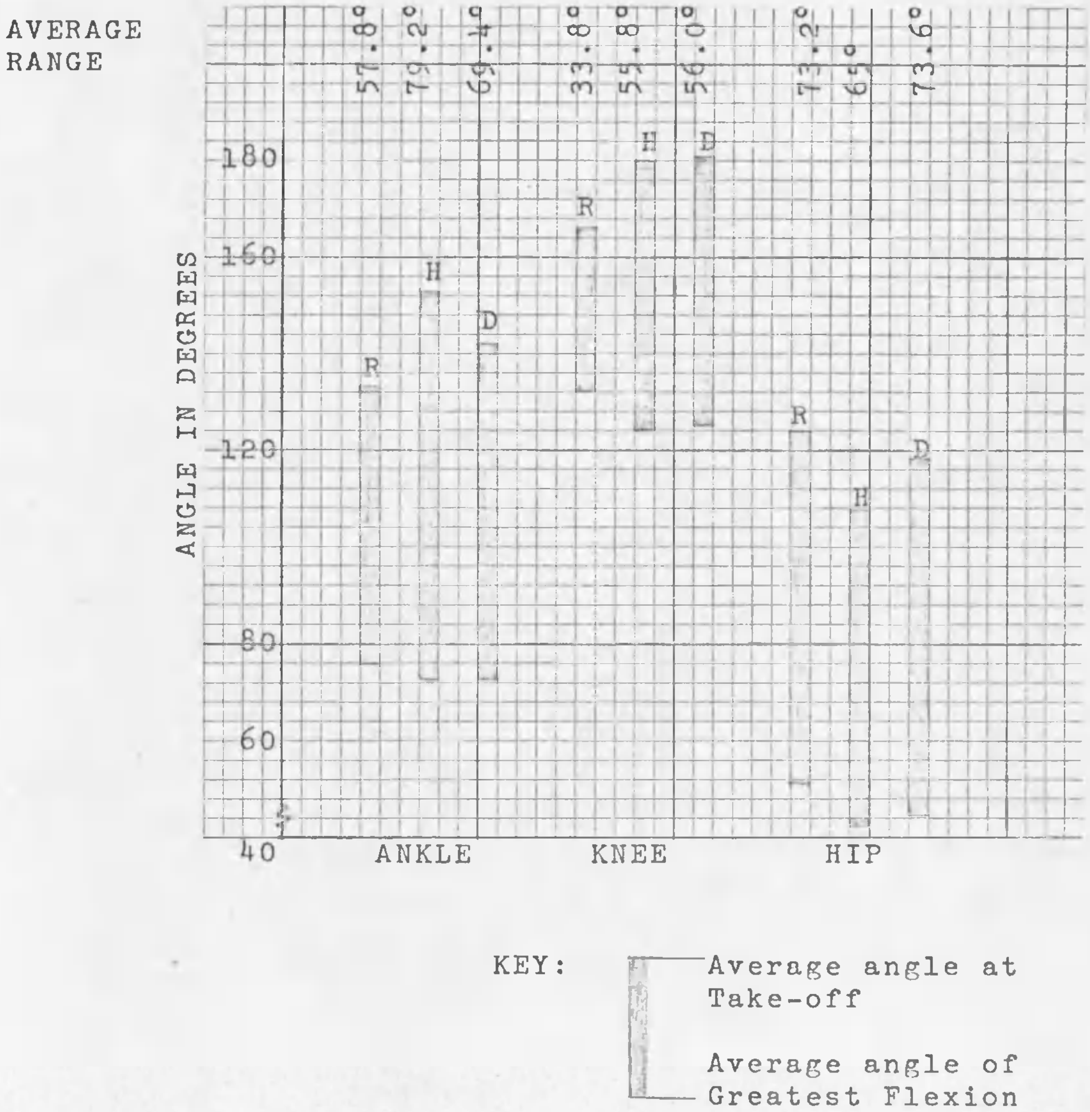


Figure 34. Average Range of Motion in the Joints of the Supporting Leg

The knee joint was more fully extended at take-off in both leaps than it was in the run. The angle of greatest knee flexion was smaller in the leaps than it was for the run. Therefore, the average range of knee extension was greater during the two leaps than in the run. (See Table IV, p. 79 and Figure 34 p. 80.)

The average range of motion at the hip joint, as indicated by the change in the inclination of the thigh to the horizontal, was largest for the leap for distance (73.6°), but was very similar to the thigh inclination average range for the run (73.2°). The leap for distance had a smaller average range of thigh inclination (65°). However, there was a smaller angle of thigh inclination for the leaps than for the run at the beginning of the support phase. In the leaps, this smaller angle of thigh inclination reflected the fact that the supporting foot was farther in front of the hip at the beginning of the support phase. Figure 35 illustrates the position of the supporting foot at the beginning of the support phase. Likewise, the angle of thigh inclination from the horizontal was greater at take-off in the run than in the leaps. This indicated that the hip joint was farther ahead of the supporting foot at take-off in the run than in the leaps. Figure 36 presents an example of the take-off position for each skill. The leap for height had the smallest average angle of thigh inclination from

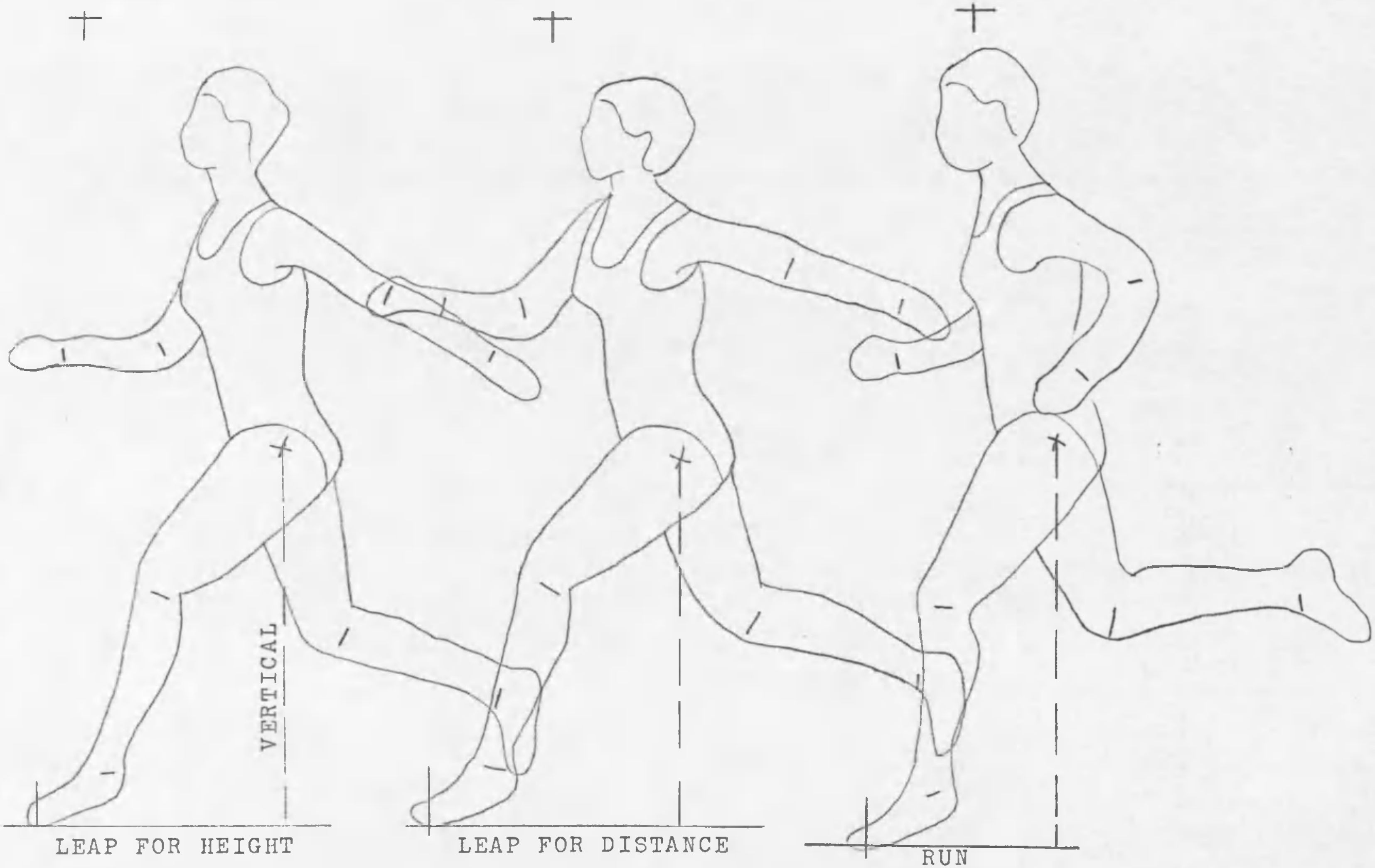


Figure 35. Position of the Supporting Foot in Relation to the Hip Joint at Touch Down (Subject 4)

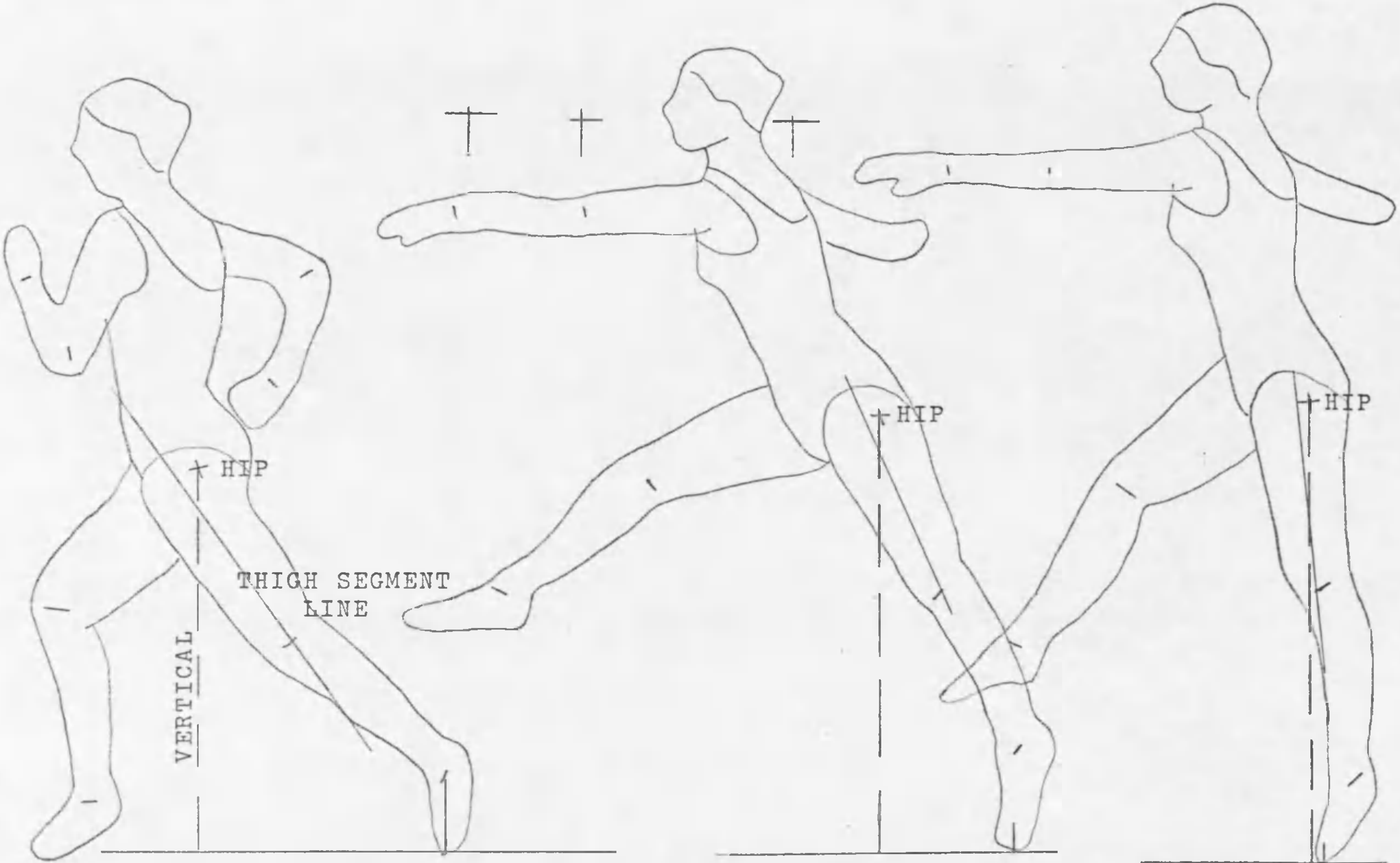


Figure 36. Position of the Supporting Leg in Relation to the Hip Joint at Take-off (Subject 4)

the horizontal at take-off (197.6°) which meant that the thigh was closer to being vertical in this skill at take-off than in the run and leap for distance.

Velocity of the Center of Gravity Over the Supporting Foot

The position of the center of gravity of the body as the supporting foot first touched the floor and the position of the center of gravity at take-off were used to calculate the average horizontal velocity of the center of gravity during the support phase. Table V presents the horizontal velocity of the center of gravity over the supporting foot in comparison with the initial velocity of projection of the center of gravity.

There was a direct relationship between the horizontal velocity of the center of gravity over the supporting foot and the initial velocity of projection of the center of gravity. In the run for each subject, these velocities were greater than for either of the leaps. Both velocities for the run were very similar in value. The maximum difference between the two velocities for the run was 1.4 feet per second. The leap for distance had the next highest velocities, with the initial velocity of projection being slightly greater than the horizontal velocity of the center of gravity over the supporting foot. The maximum difference between the two velocities in the leap for distance was 1.04 feet per second. Both the velocity values were the smallest in the leap for height,

Table V. Horizontal Velocity of the Center of Gravity Over Supporting Foot

Subject		Time Over Foot (second)	Horizontal Velocity (feet per second)	Initial Velocity of Projection (feet per second)
	Run	.1295	21.7	21.9
1	Height	.2446	8.54	9.67
	Distance	.2159	12.53	13.57
	Run	.1295	20.0	20.4
2	Height	.2446	11.38	11.99
	Distance	.1871	12.63	13.05
	Run	.1583	19.18	19.36
3	Height	.2734	8.08	9.84
	Distance	.2734	10.83	11.85
	Run	.1439	22.72	21.52
4	Height	.2590	8.8	10.34
	Distance	.259	12.32	12.29
	Run	.1439	18.79	20.19
5	Height	.2878	7.51	9.81
	Distance	.2446	12.67	12.49

and again the initial velocity was greater than the horizontal velocity over the supporting foot. The maximum difference in the two velocities in the leap for height was greater than the other two skills at 2.3 feet per second. (See Table V, p. 85.)

Summary and Discussion of the Results

The first section of this chapter included a discussion of the path of the center of gravity of the body during the flight phase of the run, leap for height, and leap for distance. There were distinct differences found in the path of the center of gravity for the run, the leap for height, and leap for distance. In all subjects, the angle of projection for the run was lower and the initial velocity for the run was greater than for either of the leaps. The leap for distance had an angle of projection greater than that for the run but less than that for the leap for height. The initial velocity of the leap for distance was less than the initial velocity for the run but greater than the initial velocity for the leap for height. The angle of projection for the leap for height was always greater in each subject than it was for either the leap for distance or the run. There were similarities in the angles of projection between subjects for each skill and similarities between subjects in the initial velocity for each skill. (See Table I, p. 31.)

This indicated that there was a similar angle of projection and initial velocity for each skill, which differed from the angle and initial velocity of the other two skills.

The angle of lean, or position of the center of gravity of the body in relation to the take-off foot, differed for each skill. In the run, the center of gravity was well ahead of the supporting foot at take-off. In the leap for height, the center of gravity at take-off was closer to being over the take-off foot. In the leap for distance the center of gravity at take-off was in front of the take-off foot but not as far as in the run, nor as close to the take-off foot as in the leap for height.

The second section of this chapter included a discussion of the sequence, range, and duration of joint actions of the supporting leg, and the horizontal velocity of the center of gravity during the support phase.

The sequence of joint actions in the supporting leg prior to the take-off was similar for each of the three skills. After the point of greatest flexion in the knee, hip extension was followed by knee extension and then ankle extension which all continued through take-off. The only difference in the sequence of joint actions was found in the actions of the knee in the run and the two leaps. In the leaps, angular change at the knee just about ceased after reaching greatest flexion, and this joint did not begin to extend until from .0288 sec. to .0576 sec. later, while in the run, knee extension directly followed the point of greatest flexion at the knee.

The range of angular motion of the ankle, knee and thigh during the support phase was generally greater in the leaps than for the run. The thigh of the supporting leg was inclined farther behind a vertical line drawn through the supporting foot at the beginning of the support phase in the leaps than it was in the run. However, the thigh was inclined farther in front of this vertical line at take-off in the run than in the leaps.

The time during the support phase when the hip passed over the supporting foot differed in each skill. In the run, the hip was in front of the supporting foot for 63% of the total time of the support phase. In the leap for height the hip was behind the supporting foot for 64% of the total support phase. The hip passed over the supporting foot close to the midpoint in time of the support phase for the leap for distance.

The total duration of time for the support phase of the run averaged .141 sec. The support phase of the leaps was longer than in the run with an average time of .2619 sec. for the leap for height and .236 sec. for the leap for distance. In the run approximately 60% of the time for the support phase was used for supporting leg extension while in the leaps the supporting leg extension started about midpoint in the time of support.

The horizontal velocity of the center of gravity of the body was directly related to the initial velocity of projection of the center of gravity in all three skills. Both these velocities were highest in the run, next highest in the leap for distance and lowest for the leap for height. Generally, the initial velocity of projection was the larger of two measures.

CHAPTER V

SUMMARY, MAJOR FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS FOR FURTHER STUDY

Summary

The purpose of this study was to analyze and describe through cinematographical analysis, the path of the center of gravity of the body during the flight phase, and the joint actions of the supporting leg during the support phase of the run, leap for height, and leap for distance. The three locomotor patterns were performed by five skilled dancers from the Orchesis Club at The University of Arizona.

A review of the related literature concerning the run, leap for height, and leap for distance was conducted. Most of the literature on the run was concerned with the free swinging or recovery leg, while the literature dealing with the leap for height and the leap for distance stated only that the leap was an extended run but failed to clearly distinguish the similarities and differences between the two leaps.

Data concerning the angle of projection of the center of gravity of the body, the initial velocity of projection, the angle of lean, angular displacement in the supporting leg at the ankle and knee joints, and of the thigh segment inclination to the horizontal, and the velocity of the center of gravity over the supporting foot were obtained from a frame-by-frame analysis of the films. A computer program was used to compute the initial velocity, angle and path of the center of gravity of the body during flight. Comparisons of these measures were made among subjects and among skills.

Major Findings

The following questions were formulated to guide this study and are presented here accompanied by the related findings.

1. What is the path of the center of gravity during the flight phase of the run, the leap for height, and the leap for distance?

The path of the center of gravity during the flight phase of the run followed a very flat arc, lower than the arc for either of the leaps. The center of gravity was projected to a greater height above starting level during the leap for height than for the leap for distance or the run. In the leap for distance the center of gravity followed an arc lower than in the leap for height but higher than in the run.

a. Are there similarities among subjects in the angle of projection and the initial velocity for each skill?

Using the range in angle and initial velocity of projection as a measure of variability, each skill was found to have a characteristic angle of projection and initial velocity distinct from those of the other skills. The range in angle of projection among subjects for the leap for height was 16 degrees ($\overline{X}$ = 38.24°). In the leap for distance the range was 14.23 degrees ($\overline{X}$ = 22.96°) while in the run it was 3.17 degrees ($\overline{X}$ = 3.95°). The initial velocity of projection was more consistant among subjects for each skill than was the angle of projection. The range in initial velocity for each skill never exceeded 2.54 feet per second. Therefore, the similarities in the determinants of the path of the center of gravity among subjects for each skill were great enough to provide a basis for distinguishing differences among the three skills.

b. Are there differences in the angle of projection and the initial velocity among the run, leap for height and the leap for distance?

In all subjects, the angle of projection for the run was lower than for the leaps and the initial velocity of the run was greater than for the leaps. The initial velocity of the leap for height was less than either the run or the leap for distance, however, the angle of projection for the leap for height was always greater than that for the run or leap for distance. The angle of projection in the leap for distance was intermediate between the run and leap for height, while the initial velocity in the leap for distance was greater than for the leap for height.

c. Where was the center of gravity located in relation to the supporting foot at take-off?

In the run, the center of gravity was well ahead of the take-off foot as reflected by a large angle of lean. In the leap for height the center of gravity was close to being over the take-off foot as reflected by a small angle of lean. The leap for distance had an intermediate value for the angle of lean, so the center of gravity was in front of the take-off foot farther than in the leap for height but closer to the foot than in the run.

2. During the support phase, what are the joint actions of the take-off or supporting leg?

The ankle and knee joints of the supporting leg flexed and then extended during the support phase. The hip extended during the support phase as reflected by the increasing angle of thigh segment inclination to the horizontal.

a. What is the angular displacement of joint actions occurring at the ankle and knee of the supporting leg, and of the segmental inclination of the thigh during each skill?

In the run, the ankle reached the point of greatest flexion at an average of 75.6° and extended to 133.4° at take-off. The knee reached an angle of 132° at the point of greatest flexion and extended to 165.8° at take-off. The thigh inclination was 51° at the touch of the supporting foot and 124.2° at take-off.

In the leap for height the point of greatest flexion at the ankle was 73.4° and at take-off it was 152.6° on the average. The knee had an average angle of 124.2° at greatest flexion and 180° at take-off. The thigh inclination was 42.6° as the supporting foot landed and 107.6° at take-off.

In the leap for distance the ankle reached the point of greatest flexion at an average angle of 72.8° and it extended to 142.2° at take-off. The knee joint had an average angle of 125° at greatest flexion and extended to 180° at take-off. The thigh inclination was 44.4° at the landing of the supporting foot and 118° at take-off.

b. Are there differences among the skills in range, sequence, or time involved for joint actions?

The sequence of joint actions in the supporting leg during the support phase was similar for the run, the leap for height and the leap for distance. After the point of greatest flexion in the knee, hip extension was followed by knee extension and ankle extension, all of which continued through take-off for each skill. However, only in the leaps did the knee remain close to the angle of greatest flexion for approximately .0432 seconds before beginning extension. In the run, the knee started extension immediately after the point of greatest flexion was reached. The duration of the support phase of the run was approximately half as long as the support phase for the leaps for height and for distance. Also, the point during the total time of the support phase when the hip passed directly over the supporting foot differed for each skill. In the run, this point occurred before the midpoint in time, while in the leap for distance it occurred at approximately the midpoint in time, and in the leap for height it occurred closer to the take-off than in the other two skills.

c. Is there a relationship between the horizontal velocity of the center of gravity over the supporting foot and the initial velocity of each projection?

There was a direct relationship between the horizontal velocity of the center of gravity over the supporting foot and the initial velocity of the projection of the center of gravity. These two values differed from each other by no more than 2.3 feet per second with the initial velocity usually being the greater of the two values.

Conclusion

The run, leap for height, and leap for distance are three distinctly different skills. The performance of each leap should be taught separately and not as a variation of the run or as a variation of the other leap.

Recommendations for Further Study

Further study in the area of locomotor patterns should take into consideration the following recommendations:

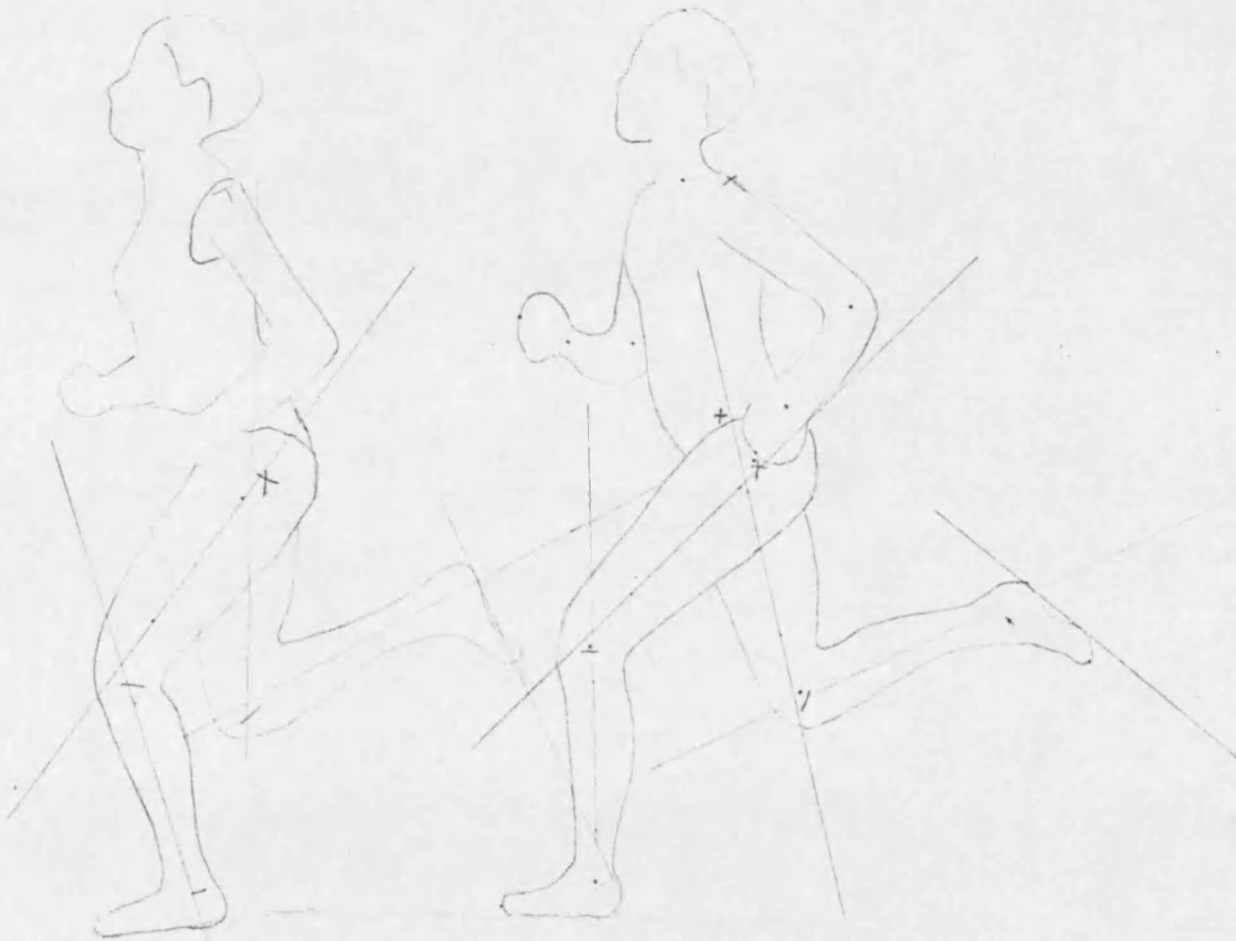
1. More subjects should be used to determine if there is an optimum angle of projection and/or initial velocity for the run, the leap for height and the leap for distance.
2. Investigate the effects of the use of the right as compared to the left leg as take-off leg.

3. Investigate the actions of the arms and the lead leg in the run and the leaps, and their effect, if any, on the projections of the center of gravity.

4. Investigate whether the position of the center of gravity changes within the body during the flight phase of various styles of leaps as the positions of the arms and legs change.

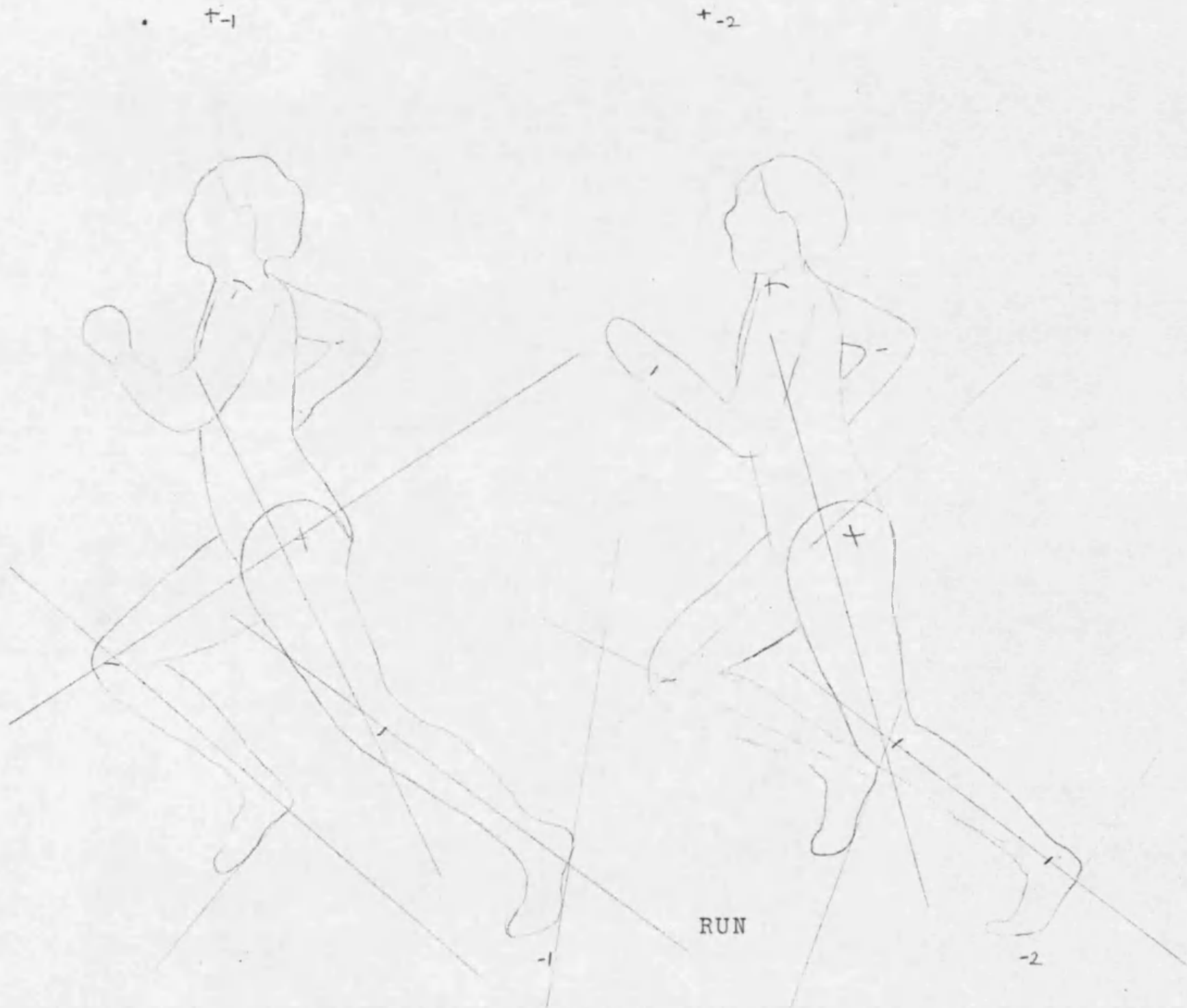
APPENDIX A

EXAMPLES OF TRACINGS OF SUPPORT PHASE (SUBJECT 4)

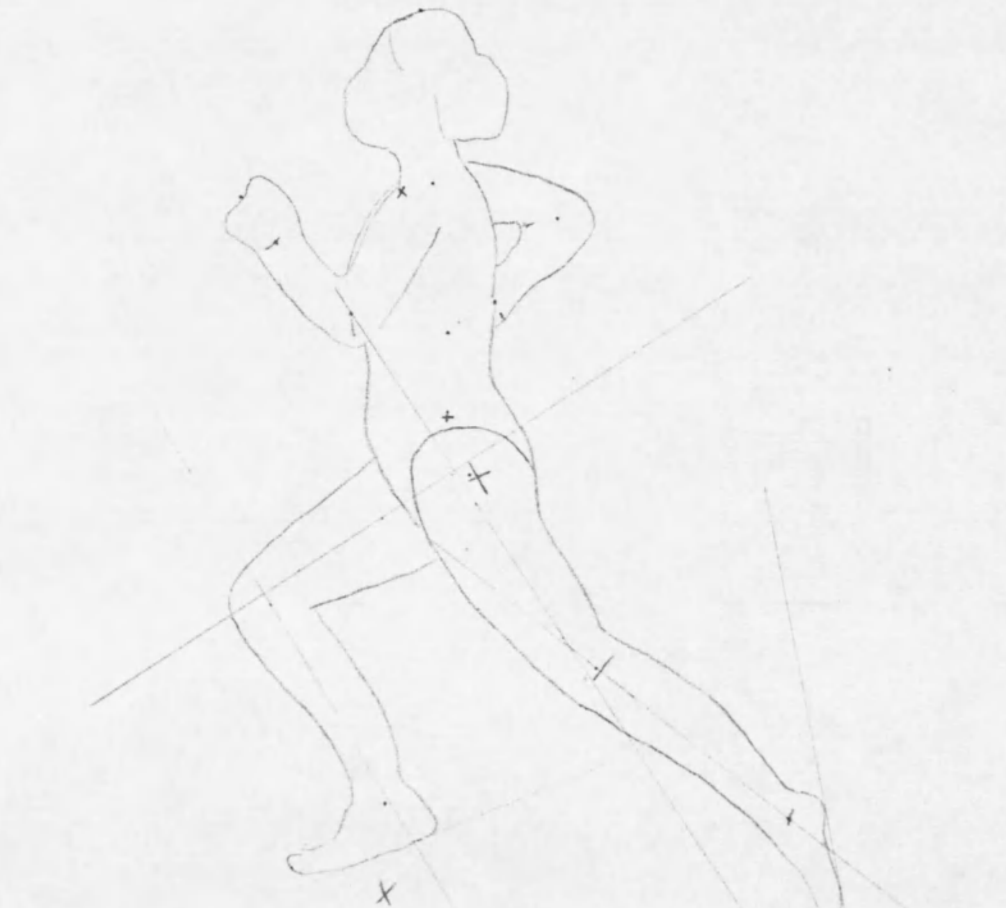


-8 RUN -10

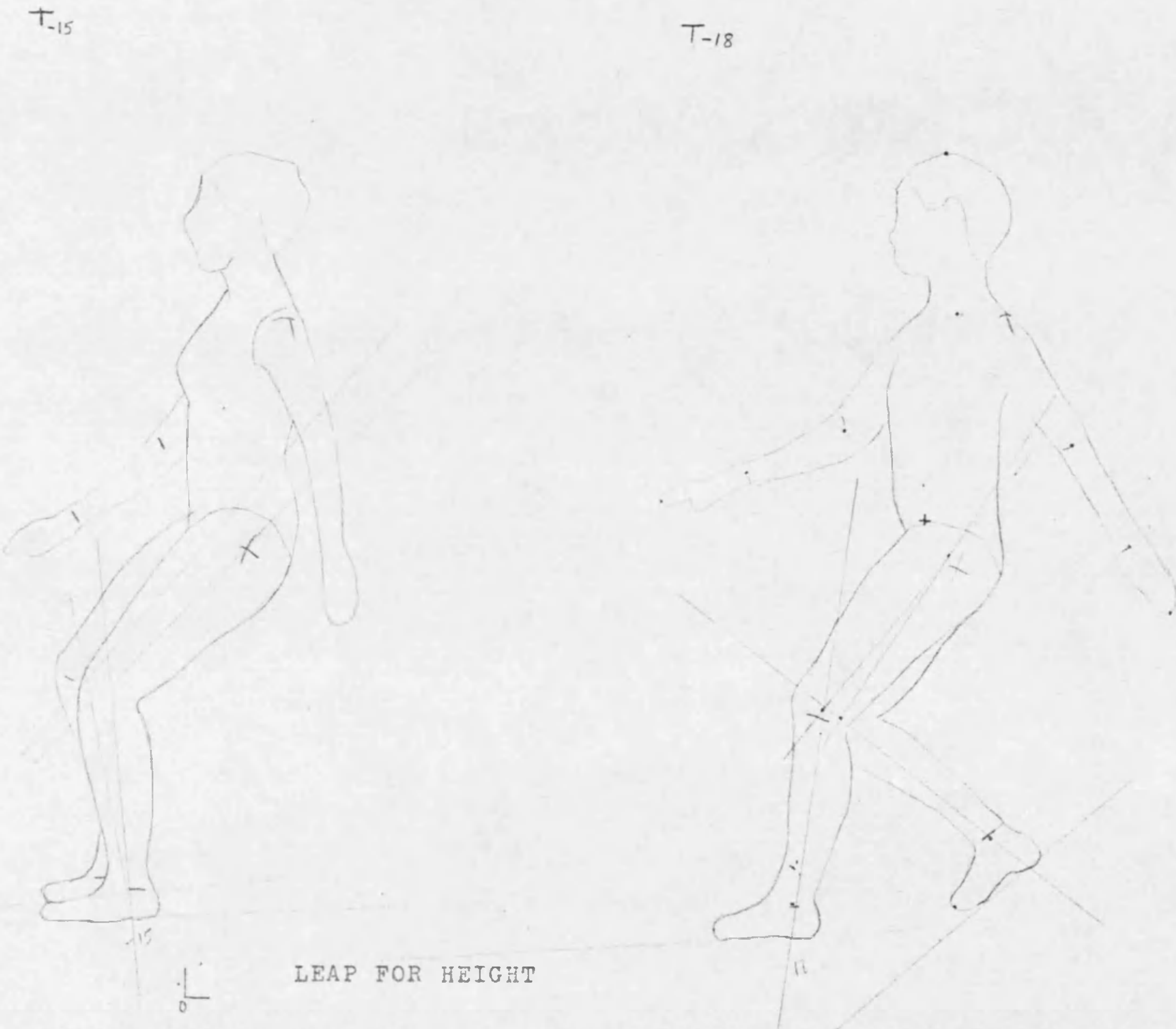
RUN



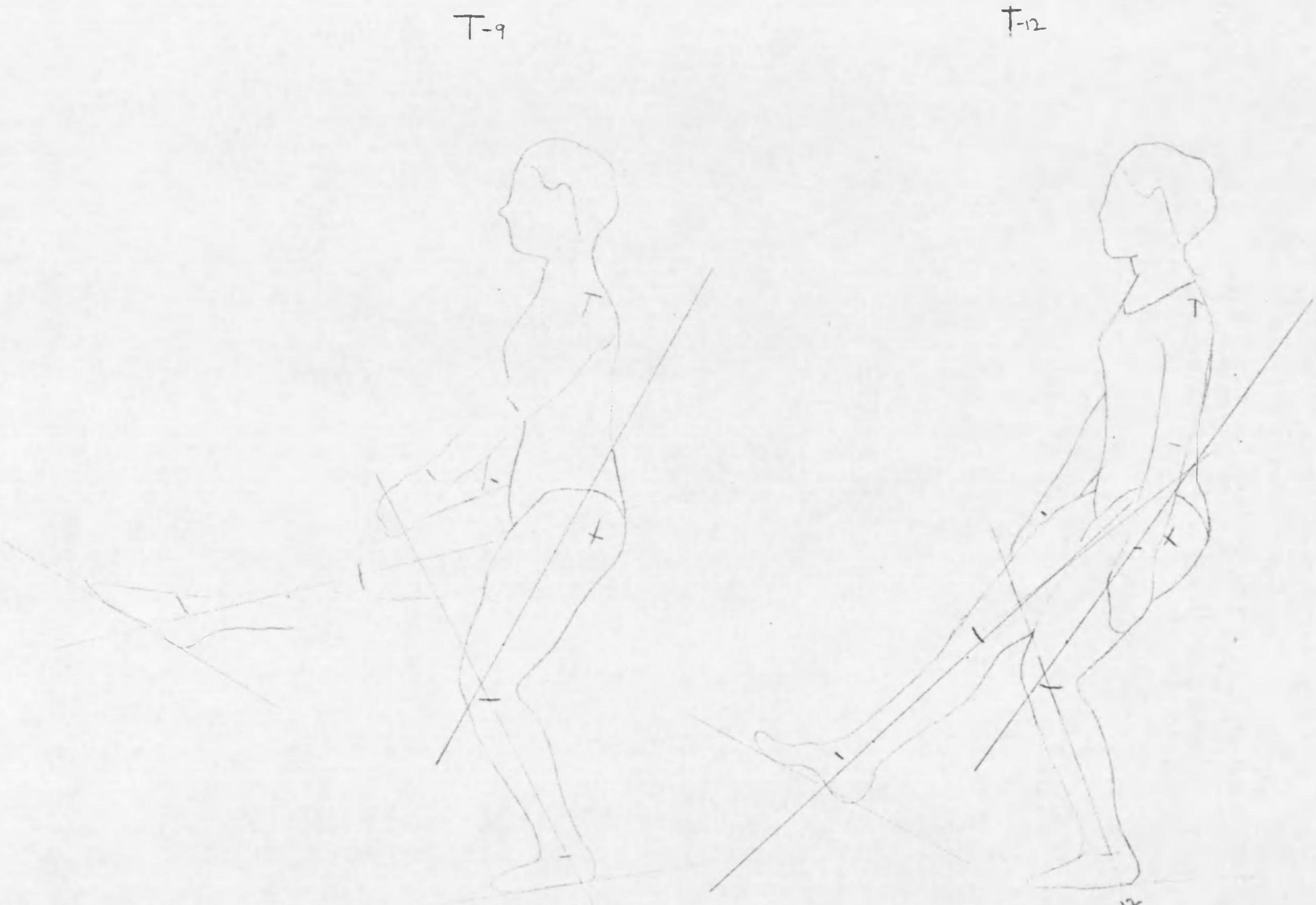
RUN



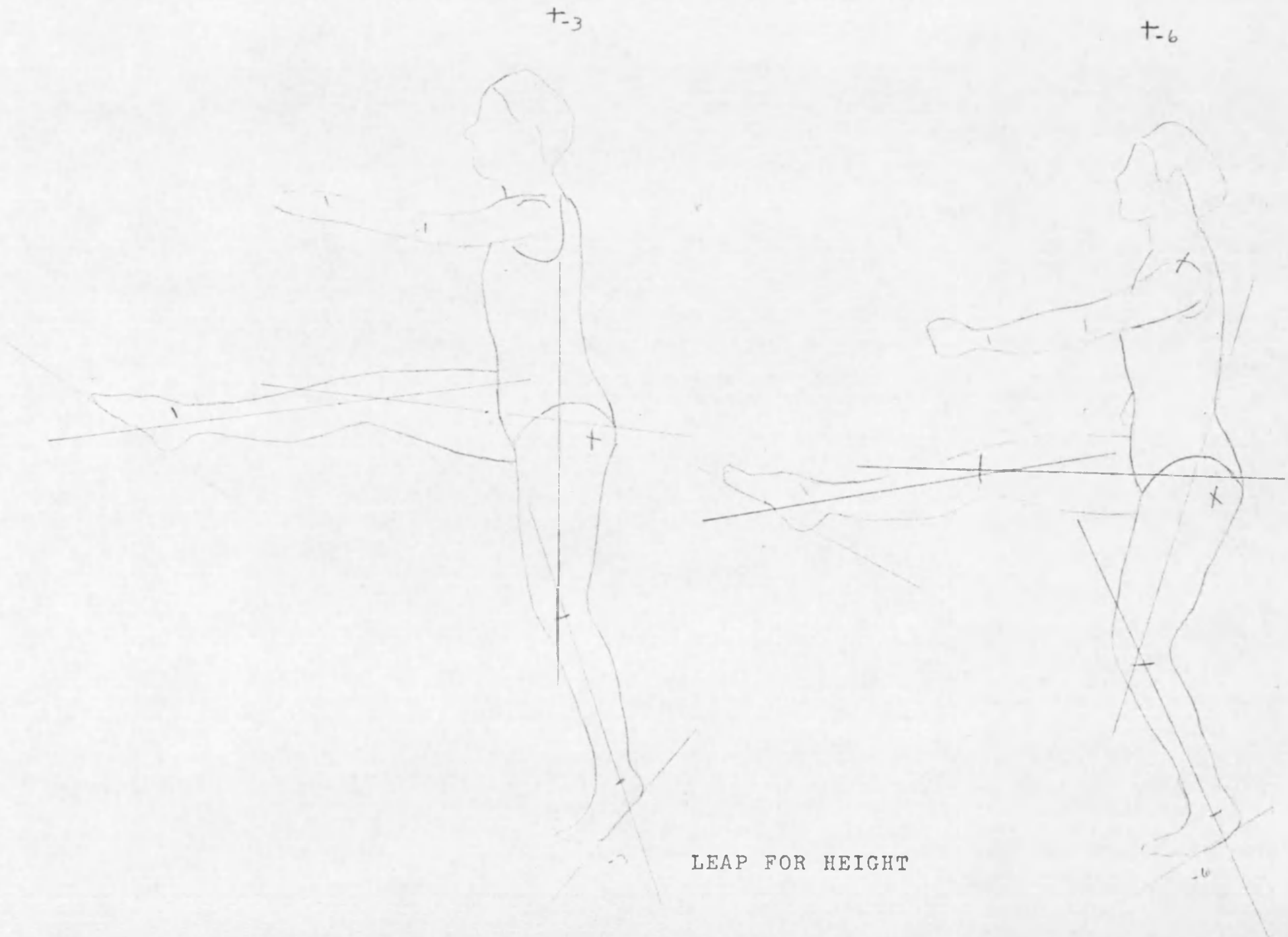
TAKE-OFF FRAME, RUN



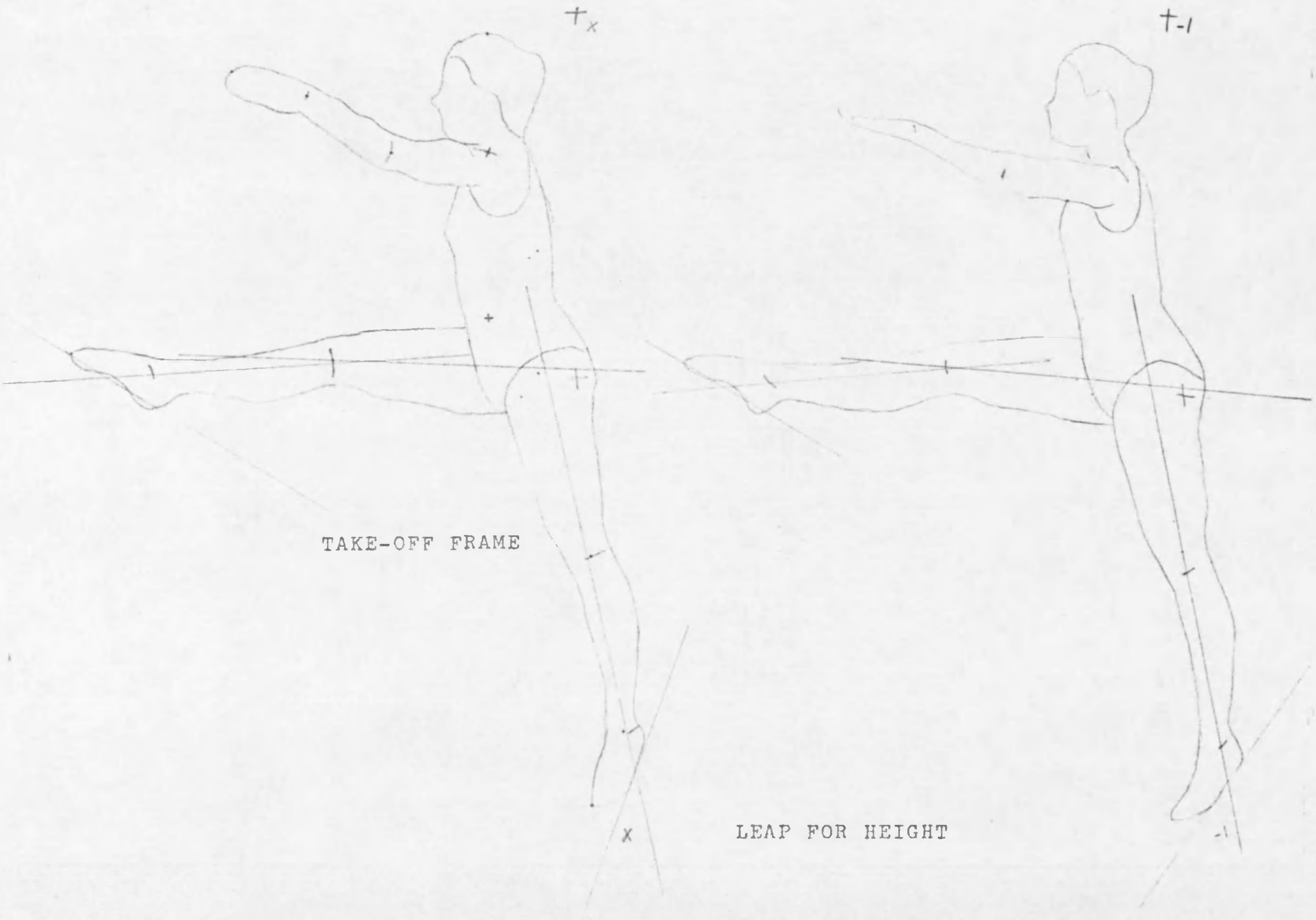
LEAP FOR HEIGHT



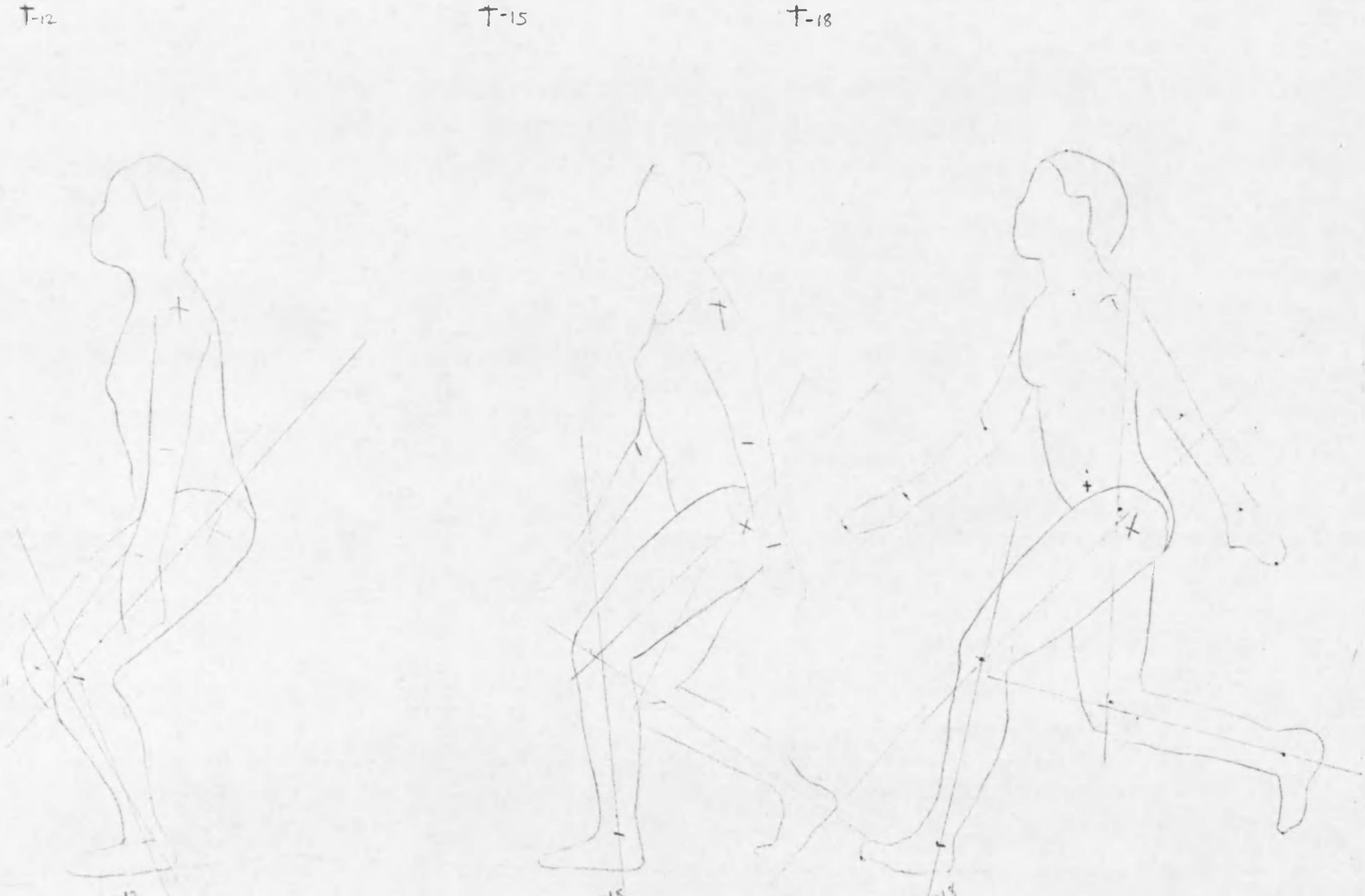
LEAP FOR HEIGHT



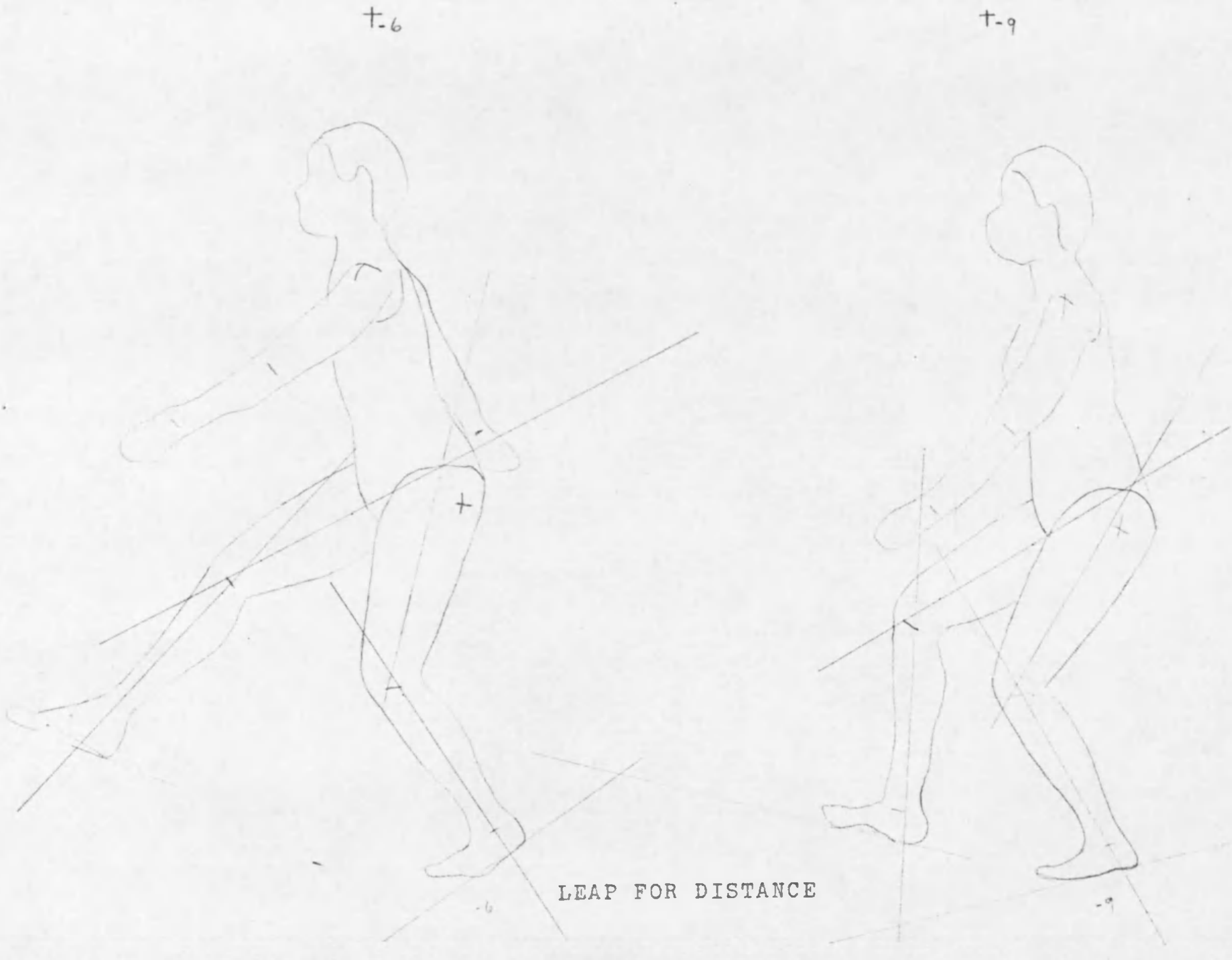
LEAP FOR HEIGHT



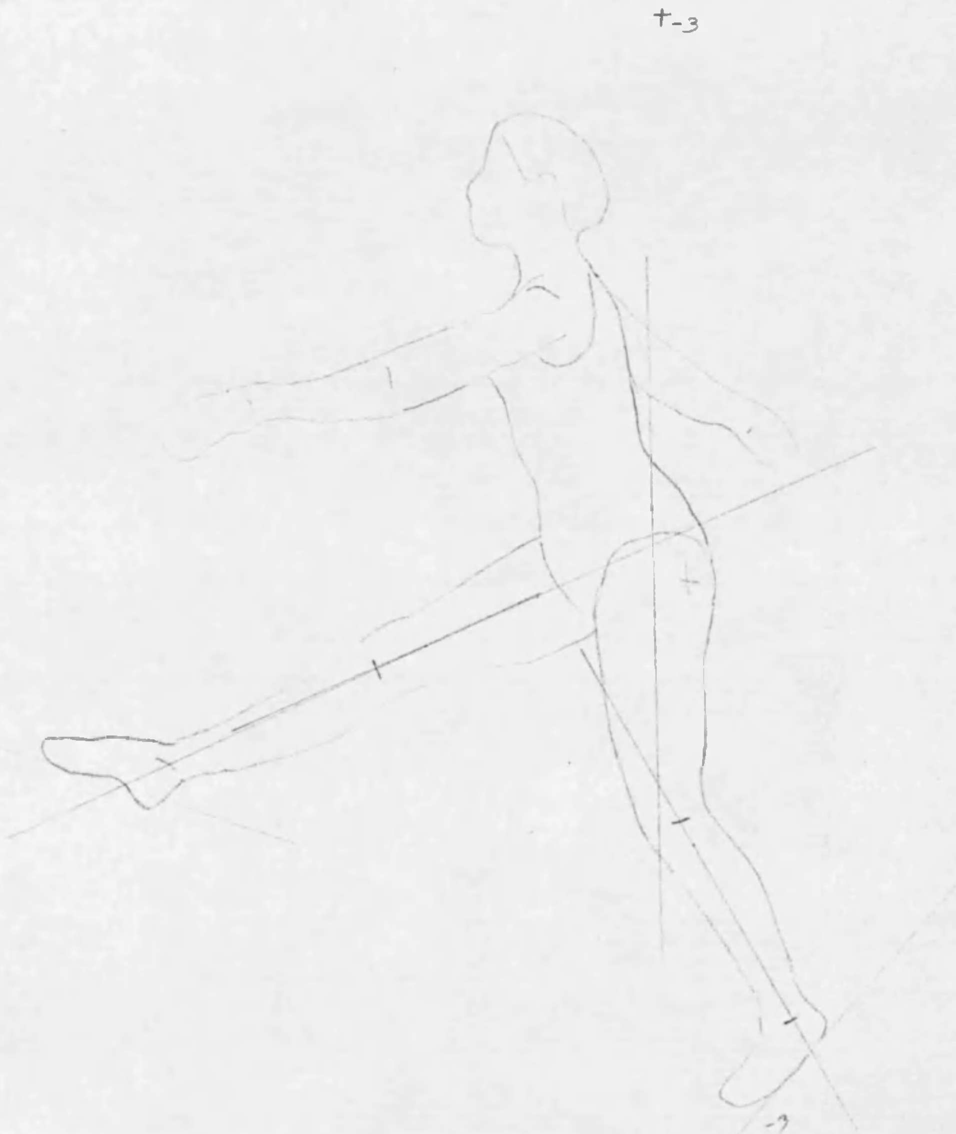
LEAP FOR HEIGHT



LEAP FOR DISTANCE

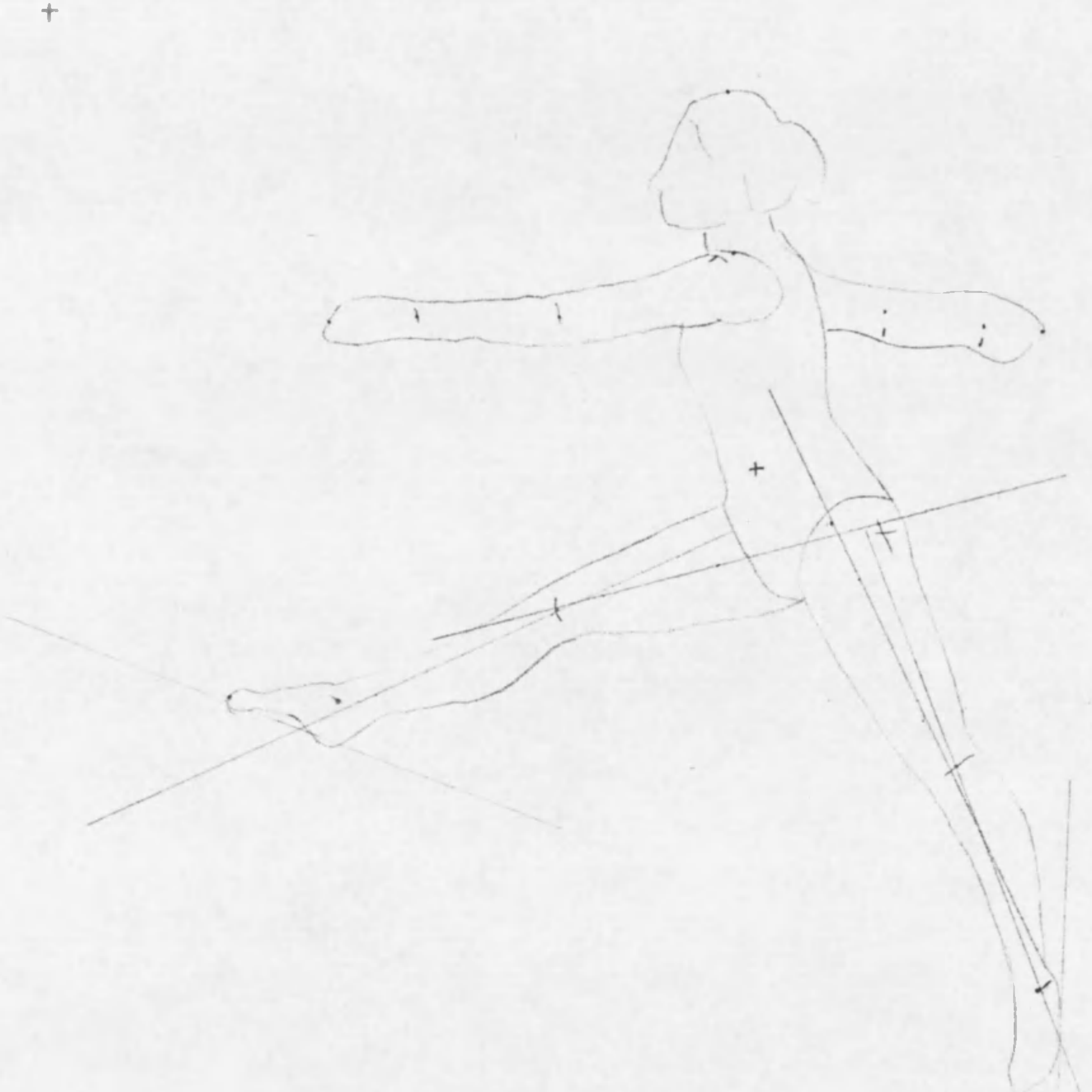


LEAP FOR DISTANCE



LEAP FOR DISTANCE

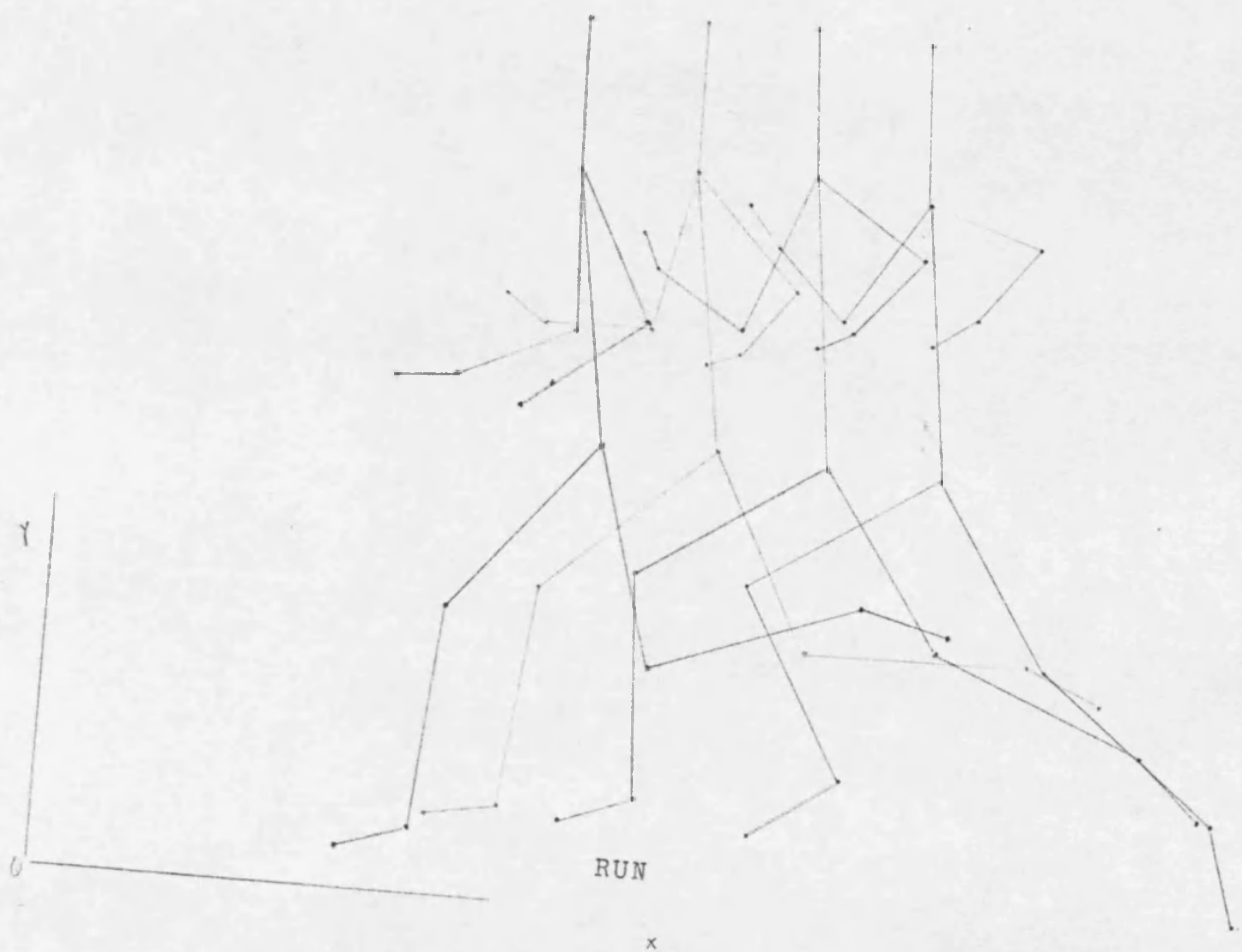
LEAP FOR DISTANCE

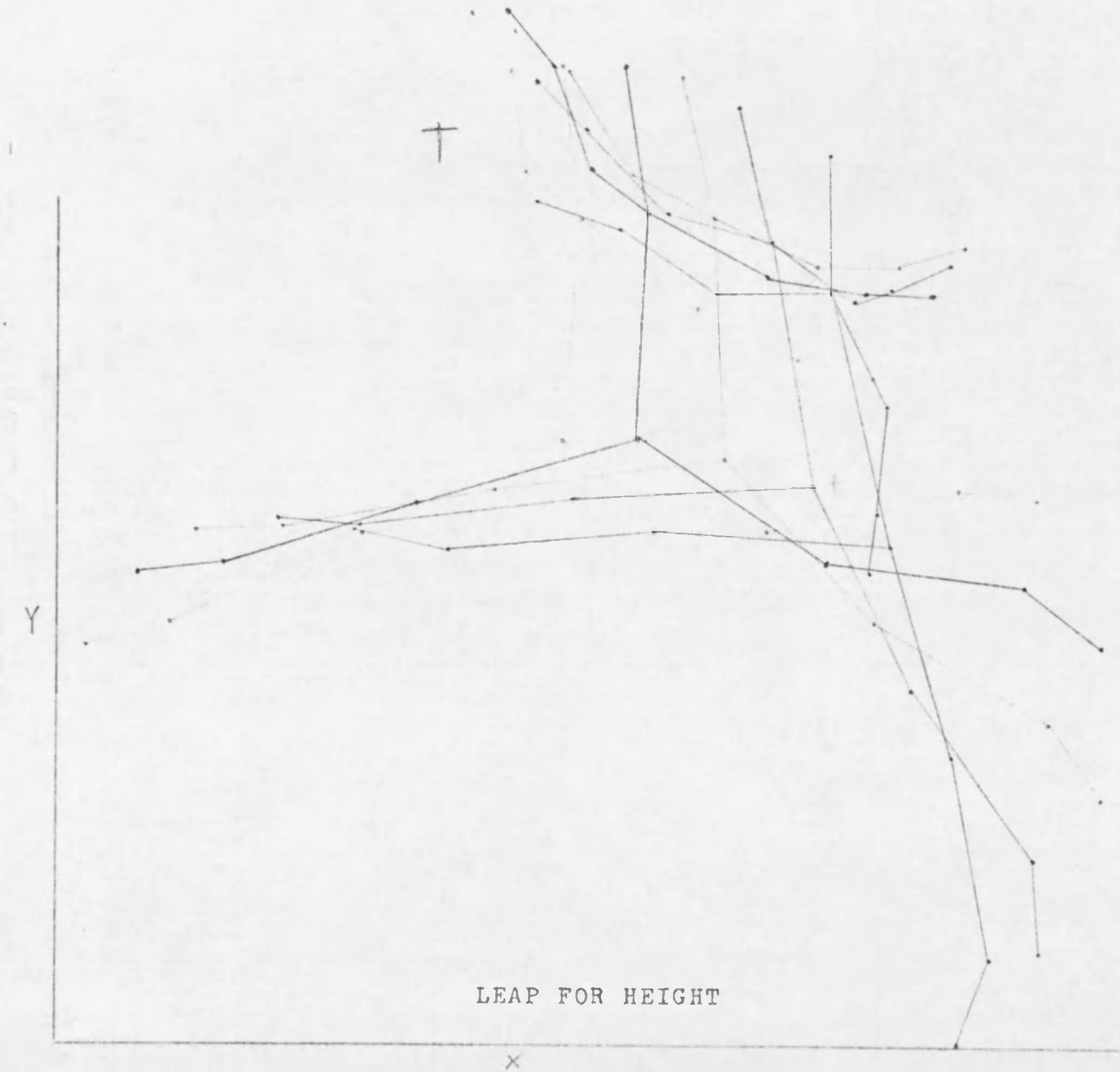


TAKE -OFF FRAME, LEAP FOR DISTANCE

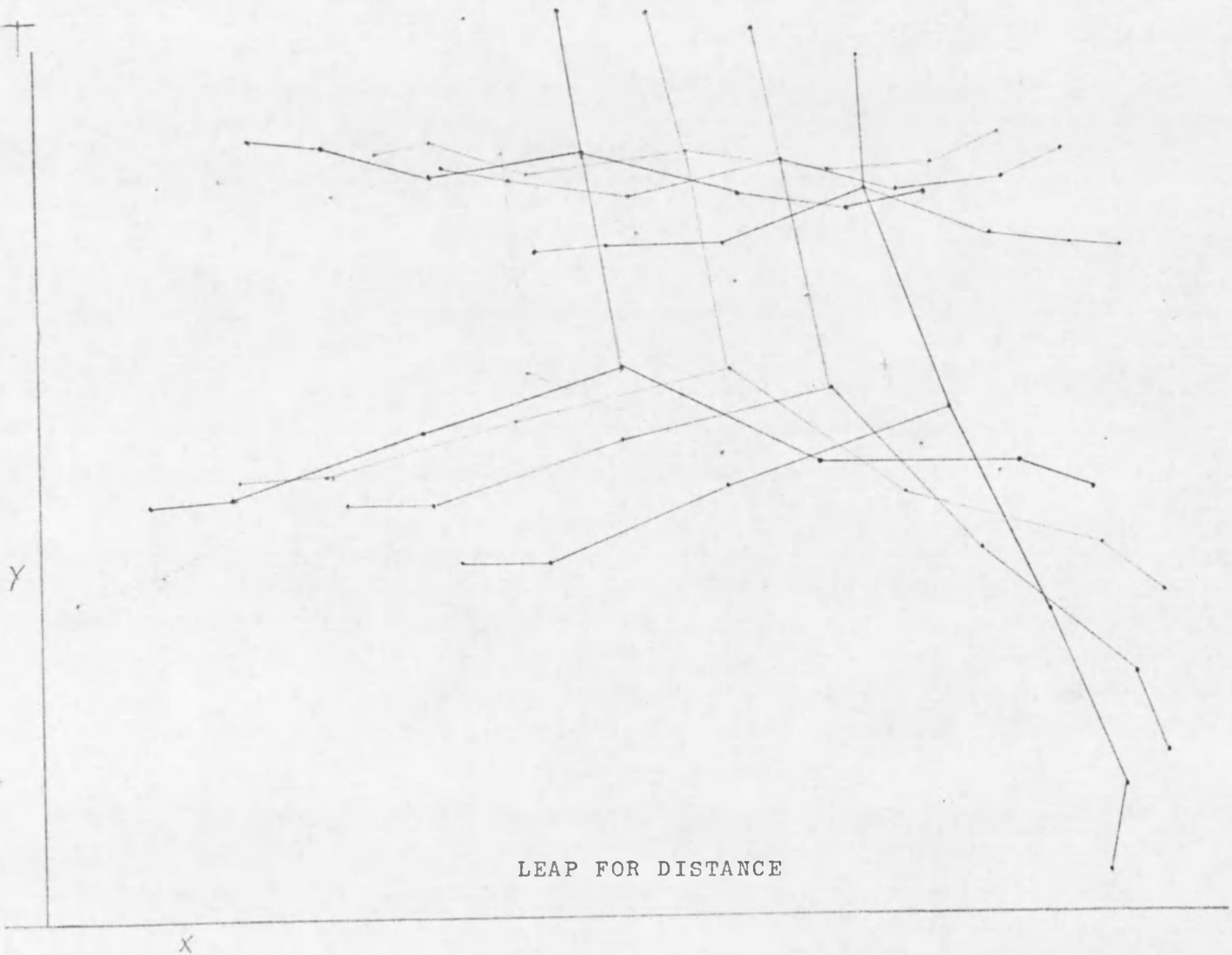
APPENDIX B

EXAMPLES OF STICK FIGURE TRACINGS USED TO CALCULATE PATH OF CENTER OF GRAVITY DURING FLIGHT (SUBJECT 4)


Y
0
RUN
x



LEAP FOR HEIGHT



LEAP FOR DISTANCE

APPENDIX C

COMPUTER PROGRAM FOR LOCATION OF THE CENTER OF GRAVITY

For a clearer copy of this program, apply at the office of the thesis advisor, Department of Physical Education for Women.

```
                PROGRAM BIOM (INPUT,OUTPUT,TAPE 1 = INPUT, TAPE 2 = OUTPUT)
          C  CORRECTED RUN - AUGUST 31,1972
          C  THIS PROGRAM IS DESIGNED TO CALCULATE THE SEGMENTAL AND OVERALL CENTERS OF
          C  GRAVITY BY READING IN THE JOINT LOCATIONS IN RECTANGULAR COORDINATE FORM
          C  NOTE - MUST READ IN 15 COORDINATES FROM TOE TO HEAD TO FINGER TIPS
          C  THIS PROGRAM WILL ALSO CALCULATE THE TRAJECTORY CHARACTERISTICS OF THE BODY
          C  CENTER OF GRAVITY BY AVERAGING THE INITIAL VELOCITY AND ANGLE OF PROJECTION
          C  OF ALL FRAMES INVESTIGATED.  NOTE - TAKEOFF FRAME MUST BE FIRST
          C  UNIVERSITY OF ARIZONA, DEPARTMENT OF PHYSICAL EDUCATION FOR WOMEN -
          C  MODIFIED FOR USE IN BIOMECHANICAL KINESIOLOGY - PURDUE PROGRAM
000003          DIMENSION CGX(20,50),CGY(20,50),CGW(20),XM(50),YM(50)
000003          DIMENSION CGXU(20),CGYU(20)
000003          DIMENSION X(500),Y(500),VX(500),VY(500),VTOTAL(500)
000003          DIMENSION XTRAJ(100),YTRAJ(100),JFRAME(100),T(100)
000003          DIMENSION GX1(50),GX2(50),GX3(50),GX4(50),GX5(50),GX6(50),GX7(50),
               1GX8(50),GX9(50),GX10(50),GX11(50),GX12(50),GX13(50),GX14(50)
000003          DIMENSION GY1(50),GY2(50),GY3(50),GY4(50),GY5(50),GY6(50),GY7(50),
               1GY8(50),GY9(50),GY10(50),GY11(50),GY12(50),GY13(50),GY14(50)
000003          DIMENSION XNUM(100),YNUM(100)
000003          SGAMA = 0.0
000004          SVEL = 0.0
          C  READ IN THE NUMBER OF FRAMES TO BE ANALYZED -  (K)
          C  READ IN THE TOTAL NUMBER OF ANALYZED FRAMES TO HIGH POINT, IHP, (IF THERE
          C  IS NO FREE FLIGHT, THEN LEAVE BLANK AND THE TRAJECTORY PHASE WILL
          C  BE OMITTED)
000005          READ (1,20) K,IHP
000014       20 FORMAT (2I10)
          C  READ IN TIME INCREMENT DESIRED, AND DURATION OF FLIGHT DESIRED
000014          READ(1,104) DELTI,TT
000024      104 FORMAT(2F10.0)
000024          SUMGAM = 0.0
000025          SUMVEL = 0.0
000026          TIME = 0.0
000027          PI = 3.1415927
000030          DO 100 J=1,K
000032          WRITE(2,1)
000035        1 FORMAT(1H1)
000035          WRITE (2,8)
000041        8 FORMAT(///45X,40HLOCATION OF SEGMENTAL CENTERS OF GRAVITY/)
000041          WRITE (2,9)
000045        9 FORMAT(48X,34HAND OVERALL BODY CENTER OF GRAVITY/)
000045          WRITE (2,10)
000051       10 FORMAT(42X,47HBY THE USE OF RECTANGULAR CARTESIAN COORDINATES///)
000051          SUMXM = 0.0
000052          SUMYM = 0.0
          C  READ IN THE COORDINATES
000053          READ (1,22)JFRAME(J)
000060       22 FORMAT (I6)
000060          READ(1,21)X1,Y1,X2,Y2,X3,Y3,X4,Y4,X5,Y5,X6,Y6,X7,Y7,X8,Y8,X9,Y9,
              1  X10,Y10,X11,Y11,X12,Y12,X13,Y13,X14,Y14,X15,Y15,T(J),CALFAC
000164       21 FORMAT (8F10.0)
000164          G = 32.1725/CALFAC
          C   CALCULATE THE SEGMENTAL CENTERS OF GRAVITY COORDINATES, X AND Y
          C   SUBSCRIPTS (1) AND (9) REPRESENT THE RIGHT AND LEFT FEET
          C   SUBSCRIPTS (2) AND (10) REPRESENT THE RIGHT AND LEFT LEGS
          C   SUBSCRIPTS (3) AND (11) REPRESENT THE RIGHT AND LEFT THIGHS
          C   SUBSCRIPT (4) REPRESENTS THE TRUNK
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            C    SUBSCRIPT (5) REPRESENTS THE HEAD AND NECK
            C    SUBSCRIPTS (6) AND (12) REPRESENT THE RIGHT AND LEFT UPPER ARMS
            C    SUBSCRIPTS (7) AND (13) REPRESENT THE RIGHT AND LEFT FOREARMS
            C    SUBSCRIPTS (8) AND (14) REPRESENT THE RIGHT AND LEFT HANDS
  000166           CGX(1,J) = (.625*(X2-X1)+X1)
  000175           CGX(2,J) = (.567*(X3-X2)+X2)
  000203           CGX(3,J) = (.567*(X4-X3)+X3)
  000211           CGX(4,J) = (.451*(X5-X4)+X4)
  000217           CGX(5,J) = (.590*(X6-X5)+X5)
  000225           CGX(6,J) = (.436*(X7-X5)+X5)
  000233           CGX(7,J) = (.430*(X8-X7)+X7)
  000241           CGX(8,J) = (.429*(X9-X8)+X8)
  000247           CGX(9,J) = (.625*(X11-X10)+X10)
  000255           CGX(10,J) = (.567*(X12-X11)+X11)
  000263           CGX(11,J) = (.567*(X4-X12)+X12)
  000271           CGX(12,J) = (.436*(X13-X5)+X5)
  000277           CGX(13,J) = (.430*(X14-X13)+X13)
  000305           CGX(14,J) = (.429*(X15-X14)+X14)
  000314           CGY(1,J) = (.625*(Y2-Y1)+Y1)
  000322           CGY(2,J) = (.567*(Y3-Y2)+Y2)
  000330           CGY(3,J) = (.567*(Y4-Y3)+Y3)
  000336           CGY(4,J) = (.451*(Y5-Y4)+Y4)
  000344           CGY(5,J) = (.590*(Y6-Y5)+Y5)
  000352           CGY(6,J) = (.436*(Y7-Y5)+Y5)
  000360           CGY(7,J) = (.430*(Y8-Y7)+Y7)
  000366           CGY(8,J) = (.429*(Y9-Y8)+Y8)
  000375           CGY(9,J) = (.625*(Y11-Y10)+Y10)
  000403           CGY(10,J) = (.567*(Y12-Y11)+Y11)
  000411           CGY(11,J) = (.567*(Y4-Y12)+Y12)
  000417           CGY(12,J) = (.436*(Y13-Y5)+Y5)
  000425           CGY(13,J) = (.430*(Y14-Y13)+Y13)
  000433           CGY(14,J) = (.429*(Y15-Y14)+Y14)
            C  WRITE IN THE SEGMENTAL WEIGHT DISTRIBUTION
  000441           CGW(1) = .02120
  000443           CGW(2) = .04940
  000444           CGW(3) = .11580
  000446           CGW(4) = .42700
  000447           CGW(5) = .07060
  000451           CGW(6) = .03360
  000452           CGW(7) =.02496
  000454           CGW(8) = .00624
  000455           CGW(9) = .02120
  000457           CGW(10) = .04940
  000460           CGW(11) = .11580
  000462           CGW(12) = .03360
  000463           CGW(13) = .02496
  000465           CGW(14) = .00624
  000466           DO 98 I=1,14
            C  CALCULATE X MOMENTS AND SUM THEM
  000470           XM (I) = CGW(I)*CGX(I,J)
  000474           SUMXM = SUMXM + XM(I)
            C  CALCULATE Y MOMENTS AND SUM THEM
  000476           YM(I) = CGW(I)*CGY(I,J)
  000502           CGXU(I) = CGX(I,J)*CALFAC
  000506           CGYU(I) = CGY(I,J)*CALFAC
  000511        98 SUMYM = SUMYM + YM(I)
  000514           WRITE(2,14) (I,CGXU(I),CGX(I,J),I,CGYU(I),CGY(I,J), I = 1,14)
  000543        14 FORMAT (10X,4HCGX(I2,3H) =F10.5,11H FEET    (ORF10.5, 7H UNITS),
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```
                   1        10X,4HCGY(I2,3H) =F10.5,11H FEET    (ORF10.5, 7H UNITS))
000543                SUMXMU = SUMXM*CALFAC
000545                WRITE (2,15) JFRAME(J), SUMXMU, SUMXM
000557             15 FORMAT(/9X,61HTHE  X  COORDINATE OF THE BODY CENTER OF GRAVITY IN
                  1FRAME NO. I5,  2X, 2HISF10.5,11H FEET    (ORF10.5, 7H UNITS)/)
000557                SUMYMU = SUMYM*CALFAC
000561                WRITE (2,16) JFRAME(J), SUMYMU, SUMYM
000573             16 FORMAT (/9X,61HTHE  Y  COORDINATE OF THE BODY CENTER OF GRAVITY IN
                  1FRAME NO. I5,  2X, 2HISF10.5,11H FEET    (ORF10.5, 7H UNITS)/)
000573                IF(J.GT.1) GO TO 17
000577                XTRANS = -SUMXM
000600                YTRANS = -SUMYM
000601                GO TO 99
000602             17 XTRAJ(J) = SUMXM + XTRANS
000605                YTRAJ(J) = SUMYM + YTRANS
000610                XNUM(J) = XTRAJ(J)*CALFAC
000612                YNUM(J) = YTRAJ(J)*CALFAC
000613                IF(J.LE.INP) GO TO 125
000615                WRITE(2,126)
000621            126 FORMAT (/////)
000621                GO TO 120
000622            125 SGAM = ATAN((YTRAJ(J) +0.5*G*T(J)**2)/XTRAJ(J))
000633                SVEL = XNUM(J)/(T(J)*COS(SGAM))
000640                SUMGAM = SUMGAM + SGAM
000642                SUMVEL = SUMVEL + SVEL
000644                SGAMA = SGAM*180./PI
              C  WRITE OUT INFORMATION READ INTO PROGRAM FOR EACH FRAME
000646             99 WRITE (2,18)
000652             18 FORMAT (////30X, 26HBASED ON THIS POSITION ONLY.)
000652                WRITE (2,101) SGAMA,SVEL
000662            101 FORMAT (33X, 21HANGLE OF PROJECTION =F7.2, 8H DEGREES/
                  133X, 21HINITIAL VELOCITY     =F7.2, 9H FEET/SEC///)
000662            120 CONTINUE
000662                WRITE(2,19)CALFAC,X1,Y1,X2,Y2,X3,Y3,X4,Y4,X5,Y5,X6,Y6,X7,Y7,X8,Y8,
                  1  X9,Y9,X10,Y10,X11,Y11,X12,Y12,X13,Y13,X14,Y14,X15,Y15,T(J)
000756             19 FORMAT(10X,52HTHE GEOMETRY OF THE BODY FOLLOWS  (SCALE IS 1 UNIT =
                  1F6.3, 6H FEET)//
                  127X,12HX COORDINATE, 3X, 12HY COORDINATE/
                  113X, 8HPOINT  1,2F15.2/
                  113X, 8HPOINT  2,2F15.2/
                  113X, 8HPOINT  3,2F15.2/
                  113X, 8HPOINT  4,2F15.2/
                  113X, 8HPOINT  5,2F15.2/
                  113X, 8HPOINT  6,2F15.2/
                  113X, 8HPOINT  7,2F15.2/
                  113X, 8HPOINT  8,2F15.2/
                  113X, 8HPOINT  9,2F15.2/
                  113X, 8HPOINT 10,2F15.2/
                  113X, 8HPOINT 11,2F15.2/
                  113X, 8HPOINT 12,2F15.2/
                  113X, 8HPOINT 13,2F15.2/
                  113X, 8HPOINT 14,2F15.2/
                  113X, 8HPOINT 15,2F15.2/
                  1//10X,36HTIME TO THIS POSITION FROM TAKEOFF =F9.4)
000766                GX3(J) = CGX(3,J) + XTRANS
000773                GY3(J) = CGY(3,J) + YTRANS
000777                GX4(J) = CGX(4,J) + XTRANS
001003                GY4(J) = CGY(4,J) + YTRANS
```

```
001007          GX8(J) = CGX(8,J) + XTRANS
001013          GY8(J) = CGY(8,J) + YTRANS
001017      100 CONTINUE
        C  WRITE OUT THE BODY C.G. COORDINATES AS COMPUTED FROM THE FILM AND WITH
        C  THE ORIGIN TRANSFORMED TO THE TAKEOFF BODY C.G.
001021          WRITE (2,1)
001024          WRITE (2,121)
001030      121 FORMAT(///40X,37HCOORDINATES OF BODY CENTER OF GRAVITY/
               146X,21HAS COMPUTED FROM FILM//
               143X,37H(ORIGIN TRANSFORMED TO TAKE-OFF C.G.)//////
               162X,10HHORIZONTAL,11X,8HVERTICAL/
               127X, 5HFRAME,13X,4HTIME,13X,10HCOORDINATE ,10X,10HCOORDINATE/
               126X, 6HNUMBER,10X,9H(SECONDS),13X,6H(FEET),14X,6H(FEET)//)
001030          DO 123 J=1,K
001032          XNUM(1) = 0.0
001033          YNUM(1) = 0.0
001034      123 WRITE(2,122) JFRAME(J),T(J),XNUM(J),YNUM(J)
001052      122 FORMAT (I30,3F20.4)
        C  THE TRAJECTORY PHASE OF THE PROGRAM STARTS HERE
001052          IF(IHP.EQ.0) GO TO 201
001053          FLK = IHP
001054          GAMMAR = SUMGAM/(FLK-1.)
001057          VZERO = SUMVEL/(FLK-1.)
001061          GAMMA = GAMMAR*180./PI
001065          WRITE (2,1)
001067          WRITE (2,107)
001073      107 FORMAT (45X,11HTHEORETICAL/ 40X,22HMOTION CHARACTERISTICS/
               131X,  39HOF THE BODY CENTER OF GRAVITY IN FLIGHT///)
001073          WRITE(2,102)GAMMA,VZERO
001103      102 FORMAT(33X,21HANGLE OF PROJECTION =F7.2, 8H DEGREES/
               133X,21HINITIAL VELOCITY    =F7.2, 9H FEET/SEC///)
        C  WRITE OUT THE HEADINGS FOR TRAJECTORY RESULTS
001103          WRITE(2,106)
001107      106 FORMAT(32X,10HHORIZONTAL, 6X,8HVERTICAL,6X,10HHORIZONTAL,
               16X,8HVERTICAL,6X,5HTOTAL/
               120X,4HTIME,9X,8HDISTANCE,7X,8HDISTANCE,7X,8HVELOCITY,
               17X, 8HVELOCITY,7X,8HVELOCITY/
               17X,5HINDEX,5X,9H(SECONDS),8X,6H(FEET),9X,6H(FEET),
               17X,10H(FEET/SEC),5X,10H(FEET/SEC),5X,10H(FEET/SEC)//)
        C  CALCULATE INITIAL VALUES
001107          OVX = VZERO*COS(GAMMAR)
001113          OVY = VZERO*SIN(GAMMAR)
001116          WRITE(2,103)OVX,OVY,VZERO
001127      103 FORMAT(9X,1H0,9X,6H0.0000,9X,6H0.0000,9X,6H0.0000,3F15.4)
        C  CALCULATE SUBSEQUENT POINTS ON THE TRAJECTORY
001127          INCNUM = TT/DELTI
001132          DO 200 I=1,INCNUM
001133          TIME = TIME + DELTI
001135          G = 32.1725
001137          X(I) = VZERO*TIME*COS(GAMMAR)
001144          Y(I) = VZERO*TIME*SIN(GAMMAR)-0.5*G*TIME**2
001154          VX(I) = VZERO*COS(GAMMAR)
001161          VY(I) = VZERO*SIN(GAMMAR)-G*TIME
001167          VTOTAL(I) = SQRT(VX(I)**2+VY(I)**2)
001175          WRITE (2,105)I,TIME,X(I),Y(I),VX(I),VY(I),VTOTAL(I)
```

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001217      105 FORMAT (I10,6F15.4)
001217      200 CONTINUE
001222      201 STOP
001224          END
```

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