THE EFFECTS OF SPECIFICITY IN PLYOMETRIC TRAINING FOR THE DISCUS THROW

by

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ABSTRACT

The purpose of this study was to describe the mechanical components of the discus throw; and more specifically, to investigate the altering effects of plyometric training within the discus ring. A comparison of the movement patterns of a selected female discus thrower at the University of Kansas was made before, during, and after plyometric training. The method of investigation was computer-aided cinematography. The subject was filmed throwing the discus six times in a session before, midway, and after specific plyometric training.

Major findings of the study were: (1) longer throws occurred with longer stride length; (2) stride length of the first step diminished, while time elapsed remained constant; (3) time elapsed for the entire throw shortened in the second session as the distance the discus was thrown increased; (4) time elapsed during the second step was too great; (5) linear velocity of the right hip did not increase prior to release, and velocities of the right ankle and knee did not decrease after release; (6) the subject's center of gravity was lowest while pivoting over the left foot, but the discus was inconsistent in rising as the subject stepped to the middle of the circle; (8) the trunk was erect at the back of the circle and over the right foot in the middle of the circle; (9) the angle of the right knee was shortened while traveling to the middle of the circle; (10) angles of the right arm and discus at release insured optimal rotary momentum; (11) the release point was slightly higher than

shoulder level.

Within the stated scope and limitations of the study the following conclusions were drawn: (1) plyometric training inhibited the drive of the left leg stepping to the center of the circle; (2) elapsed time for the entire throw decreased after plyometric training; (3) a proper throwing base was not established to provide the sequential transfer of energy from the right ankle to the right hand; (4) the subject's angle of release was low considering the low velocity of release.

DEDICATION

To my wife, Mary French Calder, without whose love, support, and technical assistance I could never have undertaken or completed this study; and to my parents, Mr. and Mrs. William E. Calder, who have always fully supported and encouraged my academic and athletic endeavors.

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CHAPTER I

INTRODUCTION

One of the major concerns in the evaluation of an athletic performance has been the physical mechanics as they apply to the structure and function of the body's movement; or, in the case of an athlete, the biomecahnical principles governing the athlete during the performance of an athletic feat. These biomechanical principles stem from Newton's Laws of Motion, which have dictated how various universal phenomena have affected every individual on earth.

By using the knowledge of the physicist, a technique may be developed that will capitalize on mechanical advantages. These advantages may then be implemented through biomechanical principles. It is also necessary to avoid certain aspects of each of the principles which will hinder the performance of the athlete. This analysis of both the laws of physics and of the desired effects of the athletic competition is one of the central purposes of biomechanics.

Once the biomechanics of an athletic event have been analyzed the performer must use power to implement the principles. The Russians developed plyometrics as a new training technique to develop power to be used in conjunction with biomechanical priniciples (42). In plyometric training the athlete jumps down from a prescribed height to force contraction in his legs. The athlete then immediately performs a vertical rebound jump to train the leg muscles for explosive power. With plyometric training the athlete can develop the

power necessary to utilize the biomechanical principles of the event to their optimal level.

Methods of artificially manipulating the athlete's body into an ideal technique for competition in the discus event in track and field has not been established through research studies. Although McLaughlin (38), Zanon (30), Moynihan (45), Woicik (81), Gambetta (20), and Wilt (80) stated that by using plyometrics, their athletes did obtain better throwing patterns than by using traditional training methods, their training methods have not been tested through critical research. McLaughlin (38) used a platform four inches to six inches in height at the back of the circle to have his athletes land in an exaggerated bent-leg position prior to the drive off the power leg. Zanon (30) and Gambetta (20) had their athletes land in the center of the circle from a 30 to 40 centimeter elevated position and then perform a normal delivery. Wilt (80) established 12 to 18 inches as his elevation for throwers to use with five repetitions of six to eight sets.

Since an athlete first threw the discus 200 feet in 1962, the world record has improved over 35 feet in 20 years. The major reasons for the increase in distance are the larger competitors utilizing a technique which emphasized using the lower body to generate power into the implement. It has not been determined as to whether using an alternative training method, specifically plyometrics, would aid the athlete in realizing the ideal technique in the discus throw by developing power in the lower body.

Statement of Purpose

The purpose of this study was to describe the mechanical components of the discus throw. More specifically, the study was designed to investigate the altering effects of plyometric training within the discus ring, and then to compare the movement patterns of a female discus thrower at the University of Kansas before, during, and after plyometric training.

The components of the discus throw that were examined were the following:

1. The stride length of each step taken within the discus circle.
2. The time factors of various components of the throw.
3. Linear velocity resultants of selected body segments during the entire throw.
4. The center of gravity at selected points of the throw.
5. Path of the discus throughout the throw.
6. Angle of the trunk inclination to the horizontal in the last frame in which both feet were on the ground at the back of the circle and in the frame in which the right foot was placed down in the center of the circle.
7. Angle of the right knee in the frame in which the knee was at its greatest height stepping to the center of the circle.
8. Angle from the vertical axis (midline of the trunk) of the right arm at the point of release of the discus.

9. Angle of release of the discus.
10. Height of the discus at the moment of release.
11. Velocity of the discus at the release point.

The farthest throw from each session was selected for a more in-depth computer study.

Scope of the Study

The study involved the analysis of a female discus thrower before, at the mid-point, and after eight weeks of plyometric training. A computer-aided analysis was conducted. Measurement of six successive trials by the subject at each filming session provided the researcher with the means of reliability for each technique.

The subject selected for the study was Rebecca McGranahan. Becky was a senior at the University of Kansas and a member of the women's track and field team. Becky was five feet, eight inches tall and weighed one hundred and fifty-five pounds. The subject was born February 20, 1961. Becky's best throw through her junior year in college was 159'7".

The training of the subject took place on the campus of the University of Kansas in Lawrence, Kansas. Two discus circles were used for the study. One of the circles was located outside of the northeast corner of Memorial Stadium where all of the varsity competition in the event took place. The other circle was located on the third level of the northeast corner of Allen Fieldhouse where the implement was thrown into a net during inclement weather.

The training instrument was a wooden platform located at the back of the discus circle. The platform was five inches high and sloped at a seven degree angle down toward the center of the circle (Appendix A). The training session lasted from September 22, 1982, to November 22, 1982. Plyometrics were used twice a week throughout this period. The subject was filmed with a high speed camera; the filming sessions took place on September 22, 1982, October 22, 1982, and November 19, 1982. Throws from all filming sessions were digitized for information to be programmed and tabulated by a computer for descriptive purposes.

Assumptions

It was assumed that the subject selected for the study could alter her technique through plyometric training. It was also assumed that the investigator could communicate his knowledge of plyometric training principles to the subject to aid her improvement. And finally, it was assumed that the case study would provide pertinent data as predictors for discus throwers in general.

Limitations

One limitation cited was the degree to which the athlete's control over her body's movements in the discus circles would be altered due to strength and power gains from maturation and weight training. Another limitation cited was the use of only one camera being implemented to film a rotational movement.

Significance of the Study

The use of plyometric training is still in its infancy in the United States. There are no recorded data which exist on the effectiveness of specific plyometric training on an athletic event. Plyometric training has been used, but not with scientific investigation of its effects (20, 30, 38, 45, 80, 81). This study was significant as an investigation of the effectiveness of utilizing plyometrics within the remaining schedule of a discus thrower at the University of Kansas in relation to change prior to the training period.

The findings of this study were of significance to the author in his attempt to better understand the discus throw and plyometrics. By developing a better understanding of the techniques, the author can relate his ideas to other coaches and athletes in hopes of improving discus performances at all levels of competition.

The study may be of similar use to track and field coaches as an instructional tool and as a source of technical knowledge of the discus throw in the analysis of athletes' performances. To the discus thrower, the study would also provide a source of technical knowledge and self-assessment guidelines. The study design in computer analysis may be helpful to kinesiologists in future skill analysis of various sports.

Definitions

Acceleration - Change in the velocity of a moving body per unit time.

Agonist - The primary muscle that causes a motion.

Angle of Release - The angle at which a body or object is projected at release or takeoff, measured from the horizontal (36).

Angular Momentum - The product of a body's rotational inertia and angular velocity.

Antagonist - A muscle that can cause the joint movement opposite to the movement being done by the agonist.

Axis of Rotation - The imaginary line or point about which a body or segment rotates.

Back of Discus Ring - The portion of the ring farthest from the discus field and where the initial action of the throw takes place.

Center of Gravity - The theoretical point in a body around which its weight is evenly distributed or balanced.

Centrifugal Force - The force directed radially outward that is exerted by a rotating body on a structure or mass.

Concentric Tension - The contraction of a muscle during which the muscle shortens and causes movement of one or more attached segments.

Dynamics - The study of mechanical factors associated with systems in motion (36).

Eccentric Tension - A contraction of a muscle during which the muscle lengthens and resists segmental motion (36).

Front of Discus Ring - The portion of the ring closest to the throwing field and where the release of the discus takes place.

Impulse - The product of the magnitude of a force or torque and its time of application.

Inertia - The resistance to change in motion.

Momentum - The product of mass and velocity.

Plyometrics - Performing a vertical jump immediately following a downward jump from a given height which has forced eccentric contraction of the muscles (64).

Power - The product of an applied force and the speed with which it is applied; the quantity of work done per unit time.

Strength - The ability of a muscle or group of muscles to exert force against a resistance.

Technique - The coordination of the movement structure when compared with the time and the structure of power application to the implement (40).

Torque - A turning or rotary force.

Velocity - The speed in a given direction of a body; the amount of displacement per given unit of time.

CHAPTER II

RELATED LITERATURE

Introduction

The most efficient use of the athlete's body and its use of power has been studied by athletes, coaches, and biomechanists for many years. The major contributing studies have dealt with the discus technique and power development separately. Therefore, the purpose of this study was to describe the mechanical components of the discus throw. More specifically, the study was designed to investigate the altering effects of plyometric training within the discus ring, and then to compare the movement patterns of a selected discus thrower at the University of Kansas before, during, and after plyometric training.

The review of literature covers the following: parameters of discus throwing technique, factors which lead to a successful throw, review of accepted discus throwing technique and similar studies, and plyometric training.

Regulations of Discus Throwing

There are certain requirements in throwing the discus encompassed in the rules of the sport and in techniques for attaining the greatest distance. The discus throw must take place from a circle eight feet two and one-half inches in diameter. To be valid, all

throws must fall within the inner edges of lines marking a sector of approximately forty degrees extended from the center of the circle and marked on the ground. The discus throw must be started from a stationary position to be considered legal. It would be a foul throw and would not be measured if the thrower touched the ground outside of the circle, the circle itself, left the circle in the front half or did not throw an implement which conformed to legal requirements. The measurement of a legal throw must be from the nearest edge of the first point of contact made by the discus to the inside edge of the circle nearest such a mark along an extended radius of the circle (47).

Factors Leading to a Successful Throw

The three most essential elements to obtaining the greatest distance possible from the discus circle are the thrower's physical size (strength, flexibility and the length of the throwing arm), speed (linearly and rotationally) through the circle, and technique (27). These elements contribute to the one major facet which would enable the superior athlete to throw farther, that is, power derived from the speed and strength applied with the correct technique. Also, the larger the mass of the thrower, the greater the extension that can be obtained in releasing the discus, because the thrower will not be as severely subjected to Newton's third Law of Motion. The thrower's larger mass will have a lesser reaction to the action of the discus being applied with a maximal amount of energy. Hence, a greater extension may be reached by the thrower.

Speed of Release

The sum of all of the above elements becomes the most critical component of the throw, which is the speed of release. The speed of release is determined by the magnitude and direction of the forces applied to the discus and by the distance and time over which these forces act (26). Ward (73) found that a good discus throw would be released at 80-85 feet per second. Virgas (69) stated that the release would occur when the discus reached its highest rate of velocity. According to Morris (44) this could be accomplished by keeping the discus as far from its longitudinal axis as possible to insure optimal rotary momentum.

There are four basic factors which affect the speed of release. The first factor is that the longer the radius between the discus and the axis of rotation, the greater the speed of the release will be.

The second and third factors deal with the fact that maximum force is applied to the discus at right angles. Hence, the second factor is that the release should be at shoulder height to accommodate the 90^{o} angle between the thrower's body and throwing arm. The third factor is that the discus should be released from the index finger and the center of mass of the discus creating a right angle between the hand and the discus.

The fourth factor which contributes to the speed of release of the discus is the physical law which states that the best way in which the discus can be accelerated is when both feet are on the ground. The right foot begins to drive the body forward from the

middle of the circle. These foot placements should occur nearly simultaneously, indicating the importance of quick foot movement within the discus circle.

Circle Speed

Writers on the subject of improved distances of modern throwers attribute the accomplishments to the improved linear and rotary speed across the discus circle. Ganslen (21) stated that the throwers now employ more efficient torque effects through perfecting a quicker turn throughout the circle. Thompson (67) agreed with Ganslen and added that this efficient turn was probably the most difficult phase of any field event to learn. The athlete must maintain balance while continually developing greater speed and force.

Ward and Ward (75) asserted that still more improvements upon distance would be realized if methods of throwing and training that free the mind of interference from unwanted tension could be discovered. Metsur (40) stated that good distances were achieved when muscle groups involved in the throw perform with maximum strength in a minimal amount of time. Paish (52) concluded that the fundamental component of all athletic activity would be controlled speed. Speed would be produced by the action of the levers and muscles of the body.

Laws of Physics

Morris (44) observed that the thrower is subject to several irreputable laws of physics handed down by Sir Issac Newton which govern movements within the discus circle.

Law of Inertia. One segment of the first law, or the Law of

Inertia, is the angular analogue, which is defined as a body's resistance to change and motion. The discus thrower is sometimes able to decrease the moment of inertia. When the thrower reduces the radius of rotation of the non-throwing arm upon releasing the discus, there is an increase in the entire upper body's rotary velocity. The reduction in the radius of rotation allows the thrower to apply additional force to the discus because of the decrease resistance to change in motion.

Law of Linear Momentum. Another aspect of the first law which applies to the discus is linear momentum. This momentum must be developed maximally from the back of the circle to the front of the circle.

Law of Center of Gravity. Newton's second law deals with the movement of the center of gravity. The direction of the center of gravity's movement determines how efficient the athlete is in dissolving the various forces about that center of gravity as he goes through the motions of the throw.

Ward and Ward (75) summarized these laws of physics as they apply to the discus by stating that through proper acceleration and deceleration of body segments, greater performances would occur. Ward (74) further stated that various forces of the body execute in a specific sequence, and with proper timing bring about a gradual acceleration of the discus. Simonyi (61) found that when these laws are applied to a well-performed turn, they contribute to the velocity of the release, get the discus on the proper plane, enhance the lower segment lead, lengthen the radius of the throwing arm, while

maintaining proper balance and rhythm.

Law of Rotary Momentum. Other physics laws are concerned with the effect of a wide and a narrow radius about the vertical axis. The thrower develops greater rotary momentum by keeping the arms and the right leg as far away from the vertical axis as possible at the beginning of the throw. As the thrower moves to the center of the ring, the arms and the free leg move closer to the center of the axis, creating a very fast movement through the center of the axis. Rotational velocity is increased in proportion to the shortening of the radius.

Law of Action-Reaction. The third Newtonian law states that for every action there is an equal and opposite reaction. The discus thrower experiences a transfer of energy because of laws the thrower uses when his or her left leg blocks the linear acceleration and the thrower's left arm blocks the shoulder rotation during the final effort of the throw. Because of the deceleration of the left side of the body, acceleration of the right side will come about. When rotary momentum is checked at one point of the body (the left foot) it will shift to the point (the right hand) farthest removed from the first point, thus conserving the rotational motion.

Link System: Summation of Joint Forces. Virgas (69) observed that when these physical principles are practiced upon release of the discus that a summation of joint forces occurs. This would be when all of the joints of the body that can contribute to projecting the discus; they must be engaged when the final phase of the throw is initiated. The sequence of this continuity of joint forces must

begin with the larger, slower, and stronger segments of the body and progress until the small, quicker segments are put to use.

Ariel (2) applied these principles to the human body and established it as a link system. He stated that the proper sequence began at the foot and then progressed through the shank, thigh, trunk, shoulders, upper arm, forearm, and terminated with the hand. Each of these segments had three forces acting upon it. Gravity pulled each segment away from its axis of rotation. Tangential and rotational forces pulled each segment perpendicularly down from its longitudinal axis with gravitational energy. The entire body must counter these forces as it travels through the ring. Ecker (15) stated that the body must apply horizontal force to travel across the ring. Also vertical force must be applied to the body upon delivery of the discus upward. Kerssenbrock (34) added rotational force as being needed to turn the body in the ring.

Polhemus (53) found that when opposing these joint forces, rotary velocity was more important than linear speed or vertical lift. Ward (73) agreed that rotary velocity was the predominate concern when countering these joint forces. His research indicated that linear velocity amounted to only seven to eight percent of the release velocity.

Law of Angle of Release. The critical phase of the throw in which all of the body parts must be summoned together to propel the discus is the final body position after the left foot has been placed down and prior to the release of the discus: the power position. A key factor in this phase is the angle of release of the discus.

Dyson (14) suggested that the angle of release should be between 35^{o} and 40^{o}. World class performers strive to release at a 32^{o} angle, while less-skilled throwers should raise their angle, but never above 45^{o}. Webb (77) stated that the proper angle should be 39^{o} plus or minus a few degrees. Ecker's (15) statements agree with Dyson's. Ecker's range was 34^{o} to 40^{o} with the qualification that the greater the speed of release means the lower the angle of release should be. Terauds' (66) research permitted a larger range of 25^{o} to 40^{o} with 36^{o} as the optimum angle for world class performers. Jarver (29) took into consideration an opposing wind when he recommended lowering the angle of release to be between the range of 30^{o} to 35^{o}. All of these studies (14, 15, 29, 66, and 77) made similar recommendations to lower the angle of release when throwing into an opposing wind.

Terauds (66) studied the competitors of the discus throw at the 1974 USA-USSR dual meet, the 1976 U.S. Olympic Trials competition, and the Montreal Olympic Games of 1976. He found that the distance of the flight was determined by numerous variables immediately prior and during the release.

Terauds measured the velocity of the discus by determining the change of position of the discus' center of gravity as it left the thrower's hand. The angle of release was the acute angle between the path of the discus' center of gravity and the horizontal. The angle of attack was the angle between the long axis of the discus and the path of the discus' center of gravity. The angle should be between 5^{o} and 15^{o}, or whatever is comfortable to the thrower.

The height of release was the vertical distance from the discus to the ground at the moment when the discus leaves the hand. The height of release should be what is natural for the thrower. The rotation of the discus was the rotation about the discus' short axis. This rotation should come naturally off the index finger of the thrower (66).

Ecker (16) summed up Terauds' study by stating that the thrower applies both translational and rotational kinetic energy to the discus. The translational energy is applied for horizontal distance and the rotational energy is applied for the stabilizing spin.

Summary. Ward (73) asserted that the training objectives for a discus thrower would be to bring about the three most essential elements to obtaining the greatest distance possible from the discus circle. The thrower should strive toward the development of size and strength along with the mastery of technique. This would give the athlete superiority over his competition according to Hay (26). If all else is equal, a tall muscularly developed thrower who would release the discus from an erect position with his legs and trunk fully extended would have an advantage over other throwers who were shorter or who released the discus with their bodies in a less effective position.

Technical Analysis of a Discus Throw

The discus is considered by many track and field aficionados the most classic of all of the throwing events. Since the ancient Greek athletes threw the implement from a standing position on a

pedestal, the event has evolved to a one and three quarter turn using the same classic athletic type. Frazier (19) referred to the event as an amalgan of strength, agility, coordination, balance, rhythmn and timing. The athlete must be able to combine speed with the ability to precisely summate the forces for delivery. Modern throwers are extremely conscious of a faster turn with greater torque.

Bush (7) warned any athlete attempting to compete in the event, that it is theoretically simple to learn the technique of the spin, yet it is difficult to adapt the body to it. The speed of the athlete and discus must be gradually increased throughout the discus circle, until an explosive force is reached at the end.

Paish (52) defined "a fundamental of technique as something which ALL good athletes exhibit in the execution of their event and one which is based on sound biomechanical principles."

Biomechanical Principles

Introduction. The discus thrower begins his one and three quarter revolution movement by standing at the back of the circle facing opposite the throwing area. The right-handed thrower turns to his left constantly striving to keep his lower body ahead of his upper body throughout the spin. He also tries to keep the discus trailing his body and fully extended from his body's midline. After the thrower has turned to his left, he steps to the middle of the circle with his right foot and to the front of the circle with his left foot. From this stance the thrower attempts to throw the discus as far as possible into the designated throwing area (Appendix B).

Principles. Several biomechanical principles must be maintained through the turn of the throw:

1. The thrower must bear his/her weight on his/her toes. This implies that the thrower's center of gravity is properly balanced and enables an increase in the speed of the feet turning (7).
2. The lower legs must be tensed prior to the actual delivery of the discus. This diminishes the tendency for the thrower to settle his/her center of gravity and to shift the hips prior to the actual release (28).
3. The heels should remain as close to the ground as possible so that complete range of motion of the plantar flexion may be realized (28). Consistency in this will aid in eliminating all pauses, dips, and hesitations (62).
4. The feet must turn. When they turn, the hips may turn, and then the upper body will follow. Paish (49) maintained that "the speed with which the right leg activates the right hip should be the prime consideration" of the entire throw. The hips should be kept active; this can only be achieved by keeping the right leg active, which in turn is only possible if the right foot has landed in the correct position with speed.
5. The shoulders must be parallel to the surface of the ring (79). This aids in keeping the eyes on the same level plane which is necessary in keeping the head on the same level or at a right angle to the shoulders (7). By

keeping the shoulders parallel to the discus ring, it is also easier to keep the discus arm straight and away from the thrower's body (15). In this position the discus will always trail the body's lead (7).

6. Movements must be used which will stretch the large muscle groups. They are then able to contract automatically with great power (70). An example of this principle is when the thrower relaxes his upper body to trail the lower body until the release of the discus occurs. This relaxation is necessary so that nothing is forced to the point of creating tension (63).
7. The discus must be lifted up gradually throughout the throw and not just upon release (71).

While these principles must be followed when complying to the fundamentals of technique, each athlete may use a unique style. Paish (52) defined style as "the way the individual interprets the fundamentals of technique."

Throughout the history of the event there was one thrower whose style was emulated by the rest of the competition. Gemer (22) observed that five of the eight finalists at the Munich Olympic Games of 1972 used a style very similar to that of Jay Silvester. Today, the most popular style among all of the throwers is that of Mac Wilkins who has made only a few alterations to the style of Silvester.

The analysis that follows will deal with the style of Mac Wilkins with a few alternative variations at different phases of the throw which are equally popular. The phases of the throw will be the

following: the starting position, the transition of the center of gravity to over the left foot, the turn to the center of the ring, the drive foot landing in the center of the ring, the power position, the leg and hip drive, the free side block, and the release of the discus.

Starting Position

The first concern of the thrower is the grip of the discus. Jarver (29) stated that the aim of the grip is to provide a hold on the discus for an efficient delivery and to create clockwise rotation to stabilize the flight. The fingers should be held as close together as possible so that the most pressure applied to the discus will come from the last two fingers. Light pressure will also come from the thumb pressing down for balance and stability of the discus. The heel of the hand will rest over the center of the discus, but the discus should not touch the palm of the hand. The discus will rest midway between the first joint and the end of the fingers.

The next concern is where the thrower stands in the back of the ring. He/she should stand balanced upon the balls of his/her feet which are slightly wider than shoulder width apart and facing the opposite direction to the throwing field. Powell (56) recommended that the thrower straddle an imaginary line which bisects the throwing field. Silvester (60) recommended that the ball of the left foot be placed on the bisecting line. Gemer (22) observed that by using Silvester's style, the length of the turn is extended, creating better utilization of the circle. Scoles (58) warned that beginning

throwers should be gradually moved from the straddle position over to placing the ball of the left foot upon the bisecting line.

The final concern of the starting position is the warm-up swings. The center of gravity should remain high between both feet during the extreme points of the wind up. This will allow the discus to be taken back a maximum distance (72). Movements should be slow and under control at this time. The knees should be flexed acutely. At the completion of each swing the discus should be caught with the left hand at shoulder height which keeps the shoulders and chest relaxed. The warm-up swings should initiate acceleration and seek to obtain torque between the shoulder and the hips. This torque is accomplished by taking the discus as far back as possible, under control, and on the last swing giving the thrower's body its maximum range of motion.

The Transition of the Center of Gravity to Over the Left Foot

Frazier (19) asserted the importance of a well-coordinated weight shift at the back of the ring. "Most throwing errors originate with the initial move at the back of the circle." The cause of the errors is the difficulty encountered by the thrower having to move his body across the circle and simultaneously cause it to spin. Strong concentration is needed to apply speed with control and balance. To insure the proper motion, always have the head balanced with the eyes moving the left arm. Wilkins (79) emphasized the importance of the head being balanced because the most important element in the weight shift is to have the entire body balanced. Another aid in

having balance at the back of the ring is to have an erect trunk and flexed knees with both feet pivoting. To insure having the center of gravity go over the left foot, Carr (8) stated that the thrower should sit to the left. This movement should be done laterally and not circularly. This can be accomplished if the thrower will project the left hip strongly as the right foot is swept outside of the ring as wide as possible. Ward (72) stated that the right arm should drop with the body lean to shorten the radius of rotation. The wide right foot and right arm actually take the thrower's weight outside of the left foot's base. The coordination of these movements will insure the thrower's center of gravity being properly placed over the left foot as the drive toward the center of the ring begins.

The Turn to the Center of the Ring

According to Jarver (29) the aim of the turn is to gather horizontal and angular velocity and to land in an efficient throwing position. Silvester (60) stated that the timing of the left leg drive to the center of the ring is very crucial to the throw. The timing begins as soon as the right foot is picked up (which is delayed as long as possible). The left leg must now begin to drive forward, not upward, from its flexed state. The right leg will continue to swing wide, staying ahead of the right shoulder, and eventually causing the right hip to be closer to the center of the ring than the left hip. This will come about because the knee of the right leg is gradually brought up into a sprinting position.

Foreman (18) suggested that whenever possible, gravity should

be used to overcome the force of inertia during the drive. The larger massed muscles comprising the body's center of gravity (the thighs and the torso) should be used by the thrower so that he/she leaves the back of the ring slower and under greater control. Gordon (24) referred to this as the "fall" around the circle. Morris (44) acknowledged that if the hips were allowed to fall out toward the center of the circle the thrower could gain incredible linear momentum across the circle without excess motion out of the back of the ring.

The control over this large mass of center of gravity aids in maintaining the balance necessary before the drive can be efficient. The upper body is vertical with a slight tilt for balance. If the left shoulder is allowed to drop, the hips will catch up. The chin remains in the same vertical plane as the sternum. When the chin and sternum are pointing toward the direction of the throw, the legs and hips should be leaned toward the center of the ring in an attempt to lead the rest of the body out of the back of the ring to later produce torque. Ward and Ward (75) recommend picking a spot on the horizon prior to the throw to initiate the lean toward the center and then to keep the eyes on the object to gain torque. Simultaneously to this action to the middle of the ring, Ward (72) suggested lifting the discus to increase the radius of rotation. Pagani (48) recommended that by lifting and turning the left heel, the left knee can be leaned into the center of the ring more efficiently.

The left leg is now in a flexed, sprinting position and ready to make a linear drive across the ring. The thighs are now fairly

close together which decreases the moment of inertia and increases the angular velocity of the legs. The shoulders should be level, with the discus held away from the axis of rotation, increasing the moment of inertia of the upper body and decreasing the angular velocity. As the legs and hips lead the movement, the left arm is brought in across the body to keep the shoulders back, which causes the lower body to get further ahead of the upper body.

Ward (72) stated that the left leg extends as the right leg is flexed at the knee for an approximate angle of 135^{o}. The drive to the center is then made as close to the ring's surface as possible and as quickly as possible. The right foot steps to the center of the ring, but never in an attempt to have both feet on the ground while coming out of the back of the ring. Ward (72) recommended the step be approximately 56 inches in length for elite men and end as the turned right foot lands and begins to pivot. Doherty (12) stated 54 inches as the proper length of the first step.

The Drive Foot Landing in the Center of the Ring

The thrower should land on the ball of his foot after the foot has completed a 270^{o} to 360^{o} rotation from when it was picked up in the back of the ring. Morris (44) observed that a straight line drawn from the right shoulder through the right hip should go through the ball of the right foot. Ward (72) stated that a trunk inclination of 36^{o} from the vertical in the opposite direction of the throw would enable the thrower to land in this position. The force of the landing should create a slight settling of the entire body, which

Gemer (22) found vital to achieving torque because of the eccentrical contraction which takes place.

Upon landing on the right foot, immediate rotation on the ball of the foot should take place. This will enable the hips to be pushed through due to the violent thrust of the right leg.

The Power Position

The thrower should keep the relaxed discus arm as high and as far back as possible in the power position. The discus should now be at its highest point of the entire throw. The upper body should be relatively inactive as the lower body continues its counterclockwise twist toward a torqued position. Steben (63) referred to this movement as retention of torque.

The left foot should be placed down as quickly as possible. Powell (56) recommended attempting to place both the right foot in the center of the ring and the left foot in the front of the ring at the same time to establish a good base from which to throw. But, the center of gravity of the thrower must remain over the right foot. This is best accomplished by bringing the flexed (45^{o} angle) left knee in very close to the right knee and the heel up very high and as close to the buttocks as possible. This will also conserve the rotary momentum.

The left leg should be slightly bent as it touches down on either the toe or upon a flat foot which is extended on the toe. The toe of the left foot should be just left of the imaginary line bisecting the throwing area. If the feet were both flat-footed, there

would be a heel-toe relationship between the two. This allows proper weight shift and ability to use the entire range of motion of the hips. Also, to assure a gradual acceleration the thrower should place the left leg a comfortable distance from the flexed power leg. Ward (72) suggested 44 inches for the length of the step. The left knee should remain slightly bent as the left foot turns in the direction of the throw.

The Leg and Hip Drive

Jarver (29) described the aim of the leg and hip drive as arriving at a position "to exploit the horizontal and angular velocity achieved during the turn and to accelerate the discus further by applying forces of the body over the greatest range at the optimum release angle." The first of these forces is created by allowing the left arm to travel out wide from the axis of rotation. This will aid the entire body's balance and it will allow the lower body to travel faster than the upper body. The wider the left arm travels, the greater the potential rotary momentum that can be built up in the shoulders. The left arm's orbit angle should approximate the desired angle of release.

The weight of the thrower should be over the right foot so that the center of gravity will be in line with the left foot, which is a critical position during the throw. The body can now move in a straight line in the direction of the center of gravity. Connolly (10) stated that the thrower must feel this shift in weight; there is no manner of doing it.

The sequence of the body unwinding to assume the proper leg and hip drive position is to allow the unwinding of the hips, trunk, chest, and shoulders. The left hip leads the discus from the center of the ring. The right hip should be thrown forward, upward, and forward like a punch which adds power to the throw. Powell (56) referred to this as "scaling" to the front of the ring.

The hips precede the shoulders as the chest is thrust upward and forward. The discus should be as far away from the axis of rotation as possible and accelerating due to the rotation of the body during the unwinding movement. The arm should not begin to make its forward movement until the left foot has been placed down. All of these forces should bring the thrower over his left leg.

Free Side Block

A solid left foot plant is very important to the throw. The foot must be placed down as quickly as possible with a bent knee so that the force and power may be driven. The quicker the left foot can be placed down, the less likely the center of gravity will be raised prematurely. This plant braces against the right leg drive of linear force which will create a whip effect. The speed of the discus will be increased because the halting motion of the left foot has transferred all of the energy to the fast moving discus as the torque of the body is explosively released. The left heel is free to rotate in a counterclockwise direction, which aids in holding the block for as long a period as possible.

The bent left arm should be brought in close to the side of

the thrower. This will stop the shoulder rotation and give the right arm a block to work against. Even though because of hip rotation, the right leg is never fully extended, the left leg must be straightened. By combining the speed of the body with the opposing force of the blocking left leg, the lifting forces on the discus become the optimal sum of forces for the release.

The Release of the Discus

The speed of the release comes from power generated from the right leg as the right arm unwinds and follows the release of tension from the well-stretched abdominal muscles. The explosive check of the left side of the body lifts the thrower as the right side continues to rotate.

This movement can best take place when both hips are between the area marked by the feet which provides the proper weight shift. This means that the head must be erect over the shoulders and it should be tilted slightly back. The weight shift should come as the thrower attempts to squeeze his right and left knees together as both legs drive into the direction of the throw.

Dyson (14) stated that the Russians now accept two methods of releasing the discus: with or without ground contact. The throwers with the stronger upper bodies and weaker lower bodies should release the discus with both feet in contact with the discus ring. Throwers who possess a high speed-strength quality will naturally (from a position where the legs are somewhat closer together) jump, releasing the discus with both feet off the ground. Ecker (15) asserted that

"since the throwing arm contributes very little to the length of the throw during the final delivery, and since almost all the forces against the ground have been applied prior to release, it now appears that taking the time to hold the foot down during release decreases the velocity of the release a little more than the loss from having both feet off the ground."

The upper body merely guides the discus through its proper plane. The discus is pulled around the body's vertical axis with a slight lifting motion. The release occurs when the head is looking into the throwing area and the discus is at shoulder level. The torque and linear acceleration should be at their optimal levels at the moment the discus comes off the index finger from an extended wrist. The upper edge of the discus drops away from the wrist and all the force is applied through the fingers at the discus' center of gravity. Tellez (65) described the feeling as squeezing a slippery bar. The thrower completes the release by watching the discus until it reaches the highest point in its flight.

Hay (26) cited Ganslen's studies on Aerodynamic Factors Which Influence Discus Flight. The findings were that the poorer thrower will benefit from a head wind more because the percent increase is greater for him than for a thrower who is already attaining a high speed of release. Also, there is no optimal wind velocity for a maximum distance thrown.

The Reverse

The reverse is the action immediately following the release

of the discus in which the thrower lowers his center of gravity away from the discus. Jarver described the aim of the reverse as being to maintain balance and to prevent fouling. The reverse should not take place until after the discus has been released from the thrower's hand. The right arm should then pass in front of the thrower's face. The left leg presses hard to delay the reverse by keeping a wide base of support to lower the center of gravity for better body control.

Bullard (6) described three styles of reverse. The first method is for the thrower to replace his left foot with the right foot. The legs should be flexed with a bend at the waist to lower the center of gravity. The second method is to have no reverse at all. The right toe is dragged to halt any forward momentum. The third method is for the thrower to make a 360^{o} rotation in the air and land on flexed knees with the feet wide apart.

Plyometrics

There are three main physiological principles which are the basis of all throwing movements, according to Zanon as cited by Jarver (29). The first principle is initial strength. The second one is the optimal path of acceleration. The final principle is the coordination of the part impulses. The thrower is constantly attempting to improve the relationship between the maximum strength and the explosive power by coordinating these principles perfectly. One particular training activity which aims to link maximum (gross) strength with elastic (power) strength is plyometrics. Plyometrics may be used for any athletic event requiring power, speed, and acceleration.

Plyometrics were developed in Russia for jumpers, sprinters, throwers, and steeplechasers. Other names for plyometrics are depth jumping, reactive-ability training, imitative power training, and elastic energy transfer (31).

Plyometric training involves jumping down from a height and immediately performing a rebound jump vertically upwards. Miller and Power (42) explained the scientific basis of this action. "A concentric (shortening) contraction is much stronger if it immediately follows an eccentric (lengthening) contraction of the same muscle. An eccentric contraction occurs when a muscle is loaded sufficiently to lengthen it, even though at the same time it is trying to shorten. The faster the transition can occur, the greater the tension in the concentric contraction." Ariel (3) explained that in any movement of any part of the body, there is an initial burst of muscular activity as the agonist muscle contracts and the antagonist muscle relaxes thus causing acceleration of the limb.

Plyometric exercises are based on the principle of a prestretching of the muscles to use the kinetic energy developed in this phase in the immediately-following contraction.

Goals of Plyometric Exercise

The first goal of the plyometric exercises is to overload specific muscle groups at similar speeds of contraction in order to improve the neuromuscular responses within the white muscle fibers. The second goal is for coordination to be improved through the athlete's ability to time the rotary actions of the shoulders, hips, and

the actions (not truly rotary) of the ankles, knees, wrists, and elbows so they take place in the optimal sequence for maximum thrust (1).

The third goal of the exercises is to condition the body to adapt to the stress of the ballistic movement derived from the muscle being placed in its stretched condition. Mann (39) stated that this is the storage of elastic energy, or the ability of muscles to contract more completely when they have been forcibly stretched in their contracted state.

A fourth goal of the plyometric exercises is to develop explosive power by altering the stimulatory pathways which reciprocally reduce inhibitory actions. The myotatic reflex, or stretch reflex, is used when the muscle suddenly stretches. The reflex almost instantaneously contracts to resist the stretch. However, the plyometric technique trains the alpha motor nerve to pick up the muscle spindle signal at the spinal column. This is a much quicker and efficient means of transmitting the stimuli for explosive power.

Principles of Plyometric Training

Anderson (1) recommended four basic principles when establishing plyometric exercises in the athlete's training. The first principle is that maximum tension is produced when the muscle is stretched rapidly. The faster the muscle is lengthened, the greater its tension. Another principle is that the rate of stretch is more important than the magnitude of the stretch. Finally, the exercise should be the same basic pattern of movement which the athlete is trying to imitate for competition.

The athlete must have good strength before he/she can apply these principles to improve his/her athletic power performance. Once the strength training has been completed, the greatest intensity of the plyometrics should occur. This should assure that the training methods correspond to the contraction format of the muscles in competitive performance to develop the required motor capacities and to make specific morphological, physiological, and biomechanical adjustments (57).

Plyometric Training

These adjustments can best be made if the coach develops a variety of plyometric drills for the athlete to perform. The drills should become a link between the weight training sessions and the throwing sessions in an effort to develop speed and power. Positive training with the plyometric drills will only take place when they fully resemble the total throw in all of its qualities.

Strong (64) described this adjustment with plyometrics as an effort to create an overload for the athlete, to set up a progression, and to gain specificity in the athlete's training. The overload is the effort required to perform a task which is greater than the effort to which the athlete is accustomed. An increase in strength, speed, or endurance should result from the overload. Progression is when the total work done by a group of muscles over a given time is increased gradually. Specificity is when improvements in performance are specifically proportional to the way the athlete trains. The drills should replicate the movement pattern used in competition in

terms of body position, range of motion, speed, duration, and muscle recruitment.

Paish (50) stated that throwers should take part in plyometrics because of the need for the athlete to stop the weight of his/her body suddenly. The body must then change its direction of movement in a way that is similar to the throwing event itself. When the jumper descends from a height, he/she must immediately drive himself up just as a discus thrower must immediately drive up from the power position.

Johnson (32) specified that short jumps should be used to improve acceleration and stride length. Longer jumps would improve maximal speed and speed endurance. Varhoshanskiy (68) recommended heights of two feet, five and one-half inches for the short jumps and three feet, seven and one-quarter inches for the longer jumps. The seasonal training of the athlete should begin with long jumps and progress to shorter ones. But, during the same practice session do all shorter jumps first. Short jumps should be done before throwing while longer ones should be done after the throwing session has been complete.

Gambetta (20) stated that East German research recommended eight to ten repetitions of jumps should be done with six to ten sets of various exercises. Endemann (17) explained that if only one exercise was done repeatedly disadvantages of phsical adaptation for the nerve-muscle coordination would occur. Also the monotony would inevitably lead to slackness and staleness.

The East Germans also recommended that ten to fifteen minute

active rest and relaxation period should take place between the exercises. A complete rest day from the plyometrics should be taken after a workout.

Jessee (31) researched Russian experiments which revealed that the plyometric exercises were of no benefit to the very young or the very old athlete. This is due to a primary principle of plyometrics: ample muscular strength must precede plyometric power training. Also, no plyometric exercise should be done ten to fourteen days prior to competition.

The plyometric training should be introduced gradually and on an individual basis because of the demands they place on the body. The less-prepared athlete should only have one training session per week, with 20 to 30 repetitions per session. The prepared athlete may have two sessions per week with no more than 40 exercises per session in the early stages of development. The repetitions should be split into sets of ten repetitions.

The athlete should jump down from a height and land on pre-stretched (bent) legs on the balls of the feet. The pelvis should be tilted upwards to keep the long head of the rectus femoris muscle stretched. This is the correct posture for all explosive events. The athlete should then explode quickly with a fast, active take-off after the landing to get full extension from the legs.

General Training Sessions

Strong (64) divided the yearly training schedule into five stages. During the first stage the athlete performs 60 jumps twice a

week. During the second stage the athlete performs 80 jumps three times a week. The third stage is 100 jumps three times a week. The fourth stage is 120-150 jumps three times a week. And the fifth stage is 150 jumps three times a week.

Mann (39) suggested that advanced athletes should do plyometrics two to three times a week with 20 to 40 repetitions in each session. Johnson (32) discovered that Pat Matzdorf, a former world record holder in the high jump, did four to five sets of five to ten repetitions once a week during the pre-season and season. During conditioning periods Matzdorf did the same number of sets and repetitions two to three times a week. Johnson (32) also found that middle distance runners run 400 meters up a five to fifteen degree gradient for their plyometric training.

Thrower's Training Sessions

Miller and Miller (41) stated that throwers needed more than linear plane work. They also needed a rotational element involved. The researchers suggested twisting plyometric exercises. Dunn (13) trained his throwers to jump down a 30-inch box, and then make a half twist jumping up to an 18-inch box. The throwers also made the half twist coming off an 18-inch box and then immediately bounded backwards onto a 30-inch box. The throwers also jumped backwards from a 40-inch box, and upon landing, jumped with a half twist onto an 18-inch box. Endemann (17) used a training system identical to this for his throwers.

Jarvis (30) observed that Zanon trained his shot putters by

having them glide from a box of 30 to 40 centimeters and land on the shot put ring to perform their normal delivery. The throwers did this exercise with five to eight repetitions of six to ten sets.

McLaughlin (38) had his shot putters use a platform of four to six inches in height to glide from. He stated that by landing in an exaggerated bent-leg position, the thrower would be forced to drive off his power leg in a more explosive and strenuous manner.

Gambetta (20) had both his shot putters and discus throwers jump from a 30 to 40 centimeter platform to work on their drive leg. Wilt (80) trained his discus throwers to turn from a 12 to 18 inch box, to land in a throwing position, and to execute their delivery. This exercise was done with five repetitions in six to eight sets.

Summary of Related Literature

The regulations of the discus throw are governed by the rules which apply to the track and field event. The performer must strive to obtain the best technique within the regulations established by the rules of the sport.

The factors which lend to a successful discus throw are the performer's physical dimensions, linear and rotational speed, and technique (27). The Laws of Physics govern these factors, thus they affect the athlete's performance. The stronger, faster thrower can cope with the Laws of Physics better than the weaker or slower thrower. This concept becomes important when the performer is applying the biomechanical principles of physics which must be observed within the discus circle. The culmination of this effort is the most critical

component of the throw, the speed of release (70).

Strength, agility, coordination, balance, rhythm, and timing must be considered in the technical analysis of the discus throw (19). The thrower seeks an efficiency of movement which will allow him/her to position the mechanical levers of the body in the proper place, at the proper time, in the proper sequence in order to produce the optimal results (74).

The use of plyometrics enables the athlete to improve the relationship between the maximum strength and the explosive power through coordination of body movement (42). By forcing extreme contraction and extension the athlete improves power, speed, and acceleration (32).

CHAPTER III

PROCEDURE

Research Design

The purpose of this study was to describe the mechanical components of the discus throw. More specifically, the study was designed to investigate the altering effects of plyometric training within the discus ring, and then to compare the movement patterns of a female discus thrower at the University of Kansas before, during, and after plyometric training.

The components of the discus throw that were examined were the following:

1. Stride length.
    a. Stride length of the first step towards the center of the circle.
    b. Stride length of the second step from the center of the circle to the front.
2. Time factors.
    a. Time taken for the first step.
    b. Time taken for the second step.
    c. Time taken from the feet being positioned on the second step to the release of the discus.
    d. Time taken for the entire throw.
3. Linear velocity resultants of selected body segments during the entire throw.

4. The center of gravity at selected points of the throw.
5. Path of the discus throughout the throw.
6. Angle of the trunk inclination to the horizontal in the last frame in which both feet were on the ground at the back of the circle and in the frame in which the right foot was placed down in the center of the circle.
7. Angle of the right knee in the frame in which the knee was at its greatest height stepping to the center of the circle.
8. Angle from the vertical axis (midline of the trunk) of the right arm at the point of release of the discus.
9. Angle of release of the discus.
10. Height of the discus at the moment of release.
11. Velocity of the discus at the release point.

A female discus thrower was analyzed using a cinematographical procedure. A plyometric training program was then designed for the discus thrower. Upon completion of the plyometric training, a post-program cinematographical analysis of the discus thrower's technique was evaluated.

The subject selected for the study was a senior female discus thrower for the University of Kansas' women's track team. The subject had training sessions with the researcher five days a week from September 22, 1982, through November 22, 1982. During this period the subject participated in a weight training program Monday through

Friday. Monday's and Wednesday's sessions were also used for aerobic conditioning and a prescribed discus throwing practice. A weekly workout (Appendix C) was followed throughout the eight week training period.

The throwing portion of the practice consisted of the subject throwing two sets of ten repetitions from a plyometric platform within a discus circle (Appendix A). The wooden platform was constructed to raise the thrower five inches above the center of the circle's height, at the back of the circle. The platform sloped downward at a seven degree angle to permit proper body movement throughout the circle. A third set of ten repetitions was thrown from a conventional circle. The subject received immediate subjective analytical feedback from the researcher after each of her throws.

The study was conducted at the University of Kansas. The subject was analyzed through cinematographical analysis by digitizing the film and processing the data with a computer. The computer programs used were able to provide kinematic data on the selected linear velocities. Other measures were directly taken from the film. A comparison was made between cinematographic sessions which occurred before the plyometric training began, at the mid-point of the training, and after the training was completed. This comparison was used as the descriptive basis of the study.

Selection of the Subject

The subject was selected by the researcher because of her involvement with the University of Kansas' women's track and field

team. The researcher was the coach whose responsibility it was to train the subject.

The subject selected was Rebecca McGranahan. Becky was a 21 year old senior at the University of Kansas. Becky had graduated in 1979 from St. Mary High School in Kansas where she was a state high school champion in the discus and held the national high school record in that event for her age group. Becky had been a captain for the University of Kansas' track team since her sophomore year (1980-1981) when she placed fourth in the Big Eight Conference Meet and qualified (157'9") to attend the AIAW National Meet. During her junior year (1981-1982) Becky placed fifth in the Big Eight Meet and qualified (157'7") to attend the NCAA National Meet. Becky had a career best throw of 159'7".

Data Collected Before Filming

Prior to filming, the subject was asked to read and sign a consent form (Appendix D). The discus was weighed to the nearest gram; this weight was recorded, along with the wind velocity (Appendix E), for each throw. All NCAA Women's Track and Field rules pertaining to the discus were observed.

Measurements of the filming procedure were recorded. Also, the shutter speed of the camera and F-stop of the camera were recorded (Appendix E). Each throw was marked with field markers. At the conclusion of the six throw series, the distance of each throw was measured to the nearest centimeter.

Personnel Used

Dr. Carole Zebas, Director of the Kinesiology Laboratory at the University of Kansas, operated the 16mm camera used to collect the data in the study. She also oversaw the collection of data. Others who assisted in the filming procedure were Diana Beebe, Clint Johnson, and Keith Noland.

Equipment Used

Plyometric Platform

One inclined platform which measure five inches at its greatest height with a seven degree slope was placed at the back of the discus circle during training sessions (Appendix A).

Cinematographic Equipment

A 16mm LOCAM camera was used in the filming of the discus throws. The activity was filmed at 200 frames per second on Kodak Plus-x reversal 7276 black and white film. A Luna 6 light meter was used to determine a lens aperture setting. A 25mm lens was used. A Recordak Film Analyzer magnified 40x was used to view the film for frame selection and to trace the performances onto graph paper.

Clock

A large electric one-second sweep-hand clock was used and positioned so that it was visible to the camera during the filming. The clock was designed for cinematographic studies of this type; sectors of .02 were divided on the face of the clock. It served as an

aid in the analysis of data.

Meterstick

A meterstick was photographed by the camera in order to be used as a scaling device.

Discus

A one kilo discus was used by the subject throughout the investigation.

Markers

Six markers were used to mark each throw during each throwing session.

Tape Measure

A 300 foot/90 meter steel tape measure was used to measure the distances of the throws.

Wind Gauge

A Precision Digital Anemometer Model 3815 was used to determine the average wind velocity for five seconds during the throw. The velocity was recorded in units of meters per second.

Generator

A Lincoln Electric Welanpower 150 A.C. Power Generator and A.C. Arc Welder was used to provide power for the 16mm camera and one-second sweep-hand clock.

Forklift

A Hyster Model XA-60 Lift Truck was used to elevate the 16mm camera onto the same horizontal plane as the discus circle.

Level

A carpenter's level was used to level the platform of the forklift on which the camera's tripod rested.

Digitizer

A Numonics Model 1224 electronic digitizer was used to locate the X and Y coordinates for all of the joint centers from the film tracings.

Computer

An Applied Digitial Data Systems Incompany Viewpoint/3A Plus unit was used to file the data compiled by digitizing the film. The file was then programmed into the University of Kansas' central processor, Honeywell DPS 3E.

The computer was programmed to determine body and segmental centers of gravity, angle of trunk inclination, linear velocities of selected segments, and various time factors.

Filming Procedures

The filming was done on the University of Kansas' varsity throwing field east of Memorial Stadium. The pre-training filming session took place September 22, 1982. The mid-point training session took place October 22, 1982. The post-training filming session

took place November 19, 1982. The filming of the throws commenced at approximately one o'clock p.m. The subject was allowed to go through a warm-up period prior to the filming. This was to simulate the thrower performing at a track meet site and to instill the psychological desire to throw the discus as well as she possibly could.

The 16mm LOCAM camera was placed on a tripod elevated on a forklift 40 feet from the circle at a 90-degree angle from where the thrower would release the discus. The height of the camera from the ground was five feet, eight inches. This height was necessary because the area 40 feet from the circle was approximately one meter lower than the ground surrounding the discus circle. At this position the entire movement of the thrower could be observed through the view-finder. A meterstick was held by the subject and recorded on the film to calibrate the dimensions of the subject in the film. A large clock was placed five feet in front of the circle so that it could be observed in the lower left-hand corner of the camera's view. A generator was used to provide electricity for the camera and the clock.

Filming the Discus Throw

The filming procedure began with a verbal signal by the subject and continued until the subject completed her throw and movement to the rear of the circle had begun. At each of the three filming sessions, the subject was given six trials. Each of the throws were marked with six different stakes so that the distance measurements could be done after all six throws had been accomplished. The

distance of each mark was measured with a steel tape measure in accordance with track and field federation laws (47). Each throw was also judged and recorded as to whether it was a fair or illegal throw.

A wind gauge was placed with its directional table placed parallel to and beside the right sector line, four feet above the ground and 75 feet from the circle. The average wind velocity for five seconds during the throw was recorded in units of meter per second for each throw. All 18 trials taken at the three six-throw filming sessions were used for analysis.

Photographic Data

The camera was loaded with balck and white double perforated, reversible, Kodak Plus-x 7276 film. The camera was set at 200 frames per second for filming. The F-stop value of the three sessions varied due to light conditions: the six trials before the training began needed an F-stop setting of 4.0; the F-stop value for the six trials during the training was 4.0; the F-stop value for the six trials after the training was 2.8. The shutter speed of the camera was set at 1/3 for all three filming sessions.

Analysis of Data

All 18 trials were used in the analysis. None of the film was analyzed until all 18 throws were completed.

The frames from which data was collected were:

1. The end of the final backswing.

2. The last frame in which both feet were on the ground at the back of the circle.
3. The frame in which the right knee was at its height stepping to the center of the circle.
4. The frame at which the right foot landed in the center of the circle.
5. The frame in which the left foot landed at the front of the circle.
6. Three frames prior to the release of the discus.
7. The frame in which the left side of the body has completed its block.
8. The frame in which the discus was released.
9. Three frames after the discus was released.

Using these nine frames the body's center of gravity was determined by the "Old COG" computer program. Other factors were determined from the film tracings of the nine frames. This analysis was used for 15 of the 18 throws, with the farthest throw of each session excluded. These three throws were selected for a more in-depth computer program analysis. The "FILMDAT" computer program analyzed the same nine frames as the "Old COG" program, plus each of the five frames prior to and following the release of the discus. The "FILMDAT" program determined the body and segmental centers of gravity, angle of trunk inclination, linear velocities of selected segments, and various time factors.

Additional information was analyzed directly from the 18 film

tracings described above. Data obtained included:

1. Stride length of the first step (frames 3-4).
2. Stride length of the second step (frame 6).
3. Angle of the right knee at its highest point (frame 3).
4. Angle of the right arm at the release point (frame 3).
5. Angle of release of the discus (frame 13).
6. Velocity of the discus at the release point (frames 10 and 13).

Method of Tracing

Each tracing was done on a piece of 8½ x 11 inch graph paper in which the lines were 1 millimeter apart. The paper was considered Quadrant I of the Cartesian coordinate system. This allowed all values. To insure accuracy, all frames were referenced by the clock which was set in the exact same position for both filming sessions, and did not move during the sessions.

The tracings were then digitized to determine the subject's body placement on X and Y axes by locating the following segmental endpoints: top of head, tragus of ear, sternal notch, crotch, elbows, shoulders (acromion process), wrists, hands, hips (trochanters), ankles (malleolus), knees, feet, object, and reference point. The forms in Appendix F and G were used for the Old COG and FILMDAT programs, respectively. The cursor was placed on each pair of these segmental endpoints to determine the X and Y coordinates. If a body marker was not visible, the coordinate was estimated and the resulting output considered accordingly.

Prior to these readings the digitizer was calibrated. This was done to insure that the data provided were properly placed on the X and Y coordinates. The first step in calibration was to press the $^{D}_{DP}$ character key to place the instrument into the proper mode. The cursor was then placed on the origin of the source document. The ^{O}/RES key was pressed to zero the X and Y coordinates on the origin. The scale was then established for an inch on the chart to equal 25.4 centimeters on the source document. This was accomplished by pressing the following character keys on the digitizer in succession: ^{S}/M, 2, 5, ^{D}/DP, 4, En.

The meterstick held by the athlete was also calibrated for its use as a reference. The meterstick was measured from the film in millimeters. This number was recorded so that it could be used as a conversion factor to change millimeters to meters in the computer program. The conversion factor was found by taking the measurement of the meterstick in millimeters on the film and dividing this into the standard length (1 meter) to give the answer in meters.

Running FILMDAT

Once the X and Y coordinates were determined information for running, FILMDAT was placed in the file in the following order:

1. Smoothing factor.
2. Number of frames (minimum of 10, maximum of 25).
3. Number of digitizations of the film. The program can average the coordinates of up to five digitizations of the film.

4. A one or zero designating whether or not the shift option was desired. The shift option allowed the user to shift the coordinate data on the axes by a given amount in each direction. A one indicated that this option was desired.
5. The title for the analysis consisting of up to 60 alpha/numeric characters.
6. The times between each frame analyzed.
7. The subject's weight in kilograms.
8. The object's weight in kilograms.
9. The subject's height in meters.
10. The actual length of the reference measure used in the film in millimeters.
11. The length of the reference measure used in the film coordinates in millimeters.
12. The distance for X-shift and Y-shift if desired.
13. A number 1, 2, 3, or 4 indicated a selection of one of the following sets of anthropometric data:
    1) Dempster
    2) Berstein - male
    3) Average of Dempster, Harless, Braune, and Fischer
    4) Berstein - female
14. The subject's body segment lengths in the following order: hand, forearm, upper arm, foot, shank, thigh, trunk, and combination of head and trunk.
15. The forces imposed on a force plate in each frame in

order of X and Y from frame 1, X and Y from frame 2, etc. In frames where no forces were involved, zeros must be entered. Note that the directions of the forces correspond to those in the film and are not as defined by the force plate manufacturer.

16. The X and Y coordinates of the body markers.

After the file containing these data had been created it was printed and checked for errors before running the program. FILMDAT was then run with the following command:

```
ftn/filmdat -io -nogo -form l=ims/ims18.la
go 01/data 02/output 08/endpts 09/cogplts
```

Output

FILMDAT created an output file which remained intact until the next time the program was run. It was then printed as needed.

Running Old COG

Once the X and Y coordinates were determined, information for running Old COG was placed in the computer in the following order:

Command: *OLD XTRU

*BRN

1. The number of frames to be analyzed.
2. The scale correction factor.
3. The units to be processed in meters.
4. The X and Y coordinates of the segmental endpoints.

The Old COG program then displayed the body's center of gravity in X and Y coordinates in graph units and in meters. These procedures of measurement were used for the pre-plyometric training film session, the mid-point training film session, and the post-plyometric training film session.

Stride Lengths

The stride length of the first step towards the center of the circle was measured using the film tracings from frames 3 and 4. The stride length was defined as the distance between the endpoint of the left foot in frame 3 to the endpoint of the right foot in frame 4. This measurement was made in millimeters and divided by the scale factor which converted the measurement to life-size simensions.

Similarly, the stride length of the second step from the center of the circle to the front was measured using the film tracing from frames 4 and 6. The stride length was defined as the distance between the endpoint of the right foot in frame 4 to the endpoint of the left foot in frame 6. This measurement was made in millimeters and divided by the scale factor which converted the measurement to life-size dimensions. The above data analyses were performed on all throws of each session.

Time Factors

The time taken for the first step was defined as the difference between the time measure of frame 4 and frame 3. This information was obtained from the FILMDAT computer printout for the farthest

throws of each session and from the film tracing of the remaining throws.

Secondly, the time taken for the second step was defined as the difference between the time measure of frames 6 and 4. This information was obtained from the FILMDAT computer printout for the farthest throws of each session and from the film tracings of the remaining throws.

Thirdly the time taken from the feet being positioned on the second step to the release of the discus was defined as the difference between the time measure of frames 13 and 6 of the FILMDAT program. This information was obtained only for the farthest throws of each session from the FILMDAT printout. The corresponding frames (8 and 6) of the film tracings of the Old COG program were used for each of the remaining throws.

Finally, the time taken for the entire throw was obtained from the time measure of frame 13 of the FILMDAT computer printout. The corresponding frame of the Old COG program, 8, was used for each of the remaining throws.

Linear Velocity Resultants

The linear velocity resultants of the right ankle, right hip, right knee, and right hand were obtained from the FILMDAT computer printout. The linear velocity resultants of each body segment was listed for each of the 18 frames in meters per second, yielding 17 linear velocity measures for frames 2 through 18. The above data analysis was performed on the farthest throw of each session.

Center of Gravity

The center of gravity in each of the frames traced was obtained from either the Old COG or FILMDAT computer programs. The farthest throw of each session (three throws) were processed into the FILMDAT program. The remaining 15 throws were processed into the Old COG program.

Path of Discus

The path of the discus throughout the throw was obtained from the FILMDAT computer program. The X and Y coordinates of the center of gravity of the discus were plotted and analyzed. The above data analysis was performed on the farthest throw of each session.

Angle of the Trunk Inclination

The angle of the trunk inclination to the horizontal in the last frame in which both feet were on the ground at the back of the circle was obtained from frame 2 of the FILMDAT computer printout. Similarly, the angle of the trunk inclination to the horizontal in the frame in which the right foot was placed down in the center of the circle was obtained from frame 5 of the FILMDAT computer printout.

Angle of the Right Knee

The angle of the right knee in which the knee was at its greatest height stepping to the center of the circle was obtained from frame 3 of the FILMDAT computer printout. The above data

analysis was performed on the farthest throw from each session.

Angle of the Right Arm

The angle from the vertical axis (midline of the trunk) of the right arm at the point of release of the discus was obtained from the film tracing of frame 13. A straight line was drawn between the sternal notch and the midpoint of the trochanters. Another straight line was drawn between the right wrist and the right acromion process. A protractor was then used to obtain the angle. The above data analysis was performed on the farthest throw from each session.

Angle of Release

The angle of release of the discus was obtained from film tracings 13 through 18 on the farthest throw of each session. Using the graph of the path of the discus, a straight line was drawn through the centers of gravity of the discus. The angle measured between a horizontal line through the discus' center of gravity and the line describing the path of the discus after release was the angle of release.

Height of Discus

The height of the discus at the moment of release for the farthest throw of each session was obtained from the digitized X and Y coordinates programmed into FILMDAT. The coordinates of the discus center of gravity and of the left foot endpoint were converted into graph scale units by dividing by the conversion factor (in

millimeters). The difference between the above points was calculated, then converted to life-size scale by multiplying by the conversion factor (in centimeters).

Velocity of Discus

The velocity of the discus at the release point was obtained from the film tracings 10 and 13. The distance between the centers of gravity of the discus was measured in millimeters, converted to meters, and divided by the elapsed time between the frames. The above data analysis was performed on the farthest throw from each session.

Validity

The measurements and assessments of this study were as valid as the equipment used and the ability of the personnel involved. Cinematography has been accepted at face validity as an accurate means of analyzing human performance.

Reliability

An assessment of the reliability was obtained by using six trials per filming session. This number best simulates a competitive situation. Testing the reliability of a technique in a competitive situation was considered useful as results could be directly applied to the validity of the technique for use in competition.

The degree to which the subject was able to duplicate her movements throughout the technique was a consideration in determining

the reliability of the technique. The duplication of movement would be a measure of the skill level of a performer in her execution of the technique.

The reliability of the generator was tested by manually timing the sweep of the one-second hand on the timing device with a stopwatch before and after each throwing session. In each test the generator was found to be consistent.

The reliability of the digitizing measurement technique was tested by re-digitizing the same frame's right hand X and Y coordinates five times under the same conditions. The Pearson product-moment correlation was used to determine reliability. The correlation coefficient of the digitizing measurement technique was found to be .99.

CHAPTER IV

ANALYSIS OF DATA

Statement of the Purpose

The purpose of this study was to describe the mechanical components of the discus throw; and more specifically, to investigate the altering effects of plyometric training within the discus ring. A comparison of the movement patterns of a female discus thrower at the University of Kansas was made before, during, and after plyometric training.

The components of the discus throw that were examined were the following:

1. The stride length of each step taken within the discus circle.
2. The time factors of various components of the throw.
3. Linear velocity resultants of selected body segments during the entire throw.
4. The center of gravity at selected points of the throw.
5. Path of the discus throughout the throw.
6. Angle of the trunk inclination to the horizontal in the last frame in which both feet were on the ground at the back of the circle and in the frame in which the right foot was placed down in the center of the circle.
7. Angle of the right knee in the frame in which the knee

was at its greatest height stepping to the center of the circle.

8. Angle from the vertical axis (midline of the trunk) of the right arm at the point of release of the discus.
9. Angle of release of the discus.
10. Height of the discus at the moment of release.
11. Velocity of the discus at the release point.

The farthest throw from each session was selected for a more in-depth computer study.

Introduction

The study was designed to observe the factors which directly relate to the length of the throw. The farthest throw of each session was selected to determine the body and segmental centers of gravity, angle of trunk inclination, linear velocities of selected segments; the time elapsed for the first step, second step, second step to release, and the entire throw; the stride lengths of the two steps, angle of the right knee at tis highest point, angle of the right arm at release, angle of release, and velocity of release. On the remaining throws, the body's center of gravity was determined as well as additional information taken from the tracings of the nine frames.

The Discus Throw

The technique of the athlete performing the discus throw is illustrated as follows in Figure 1. These frames and corresponding

frames traced from other throws filmed during the sessions were analyzed by computer and by hand measurements.

Figure 1. Discus Throw Technique

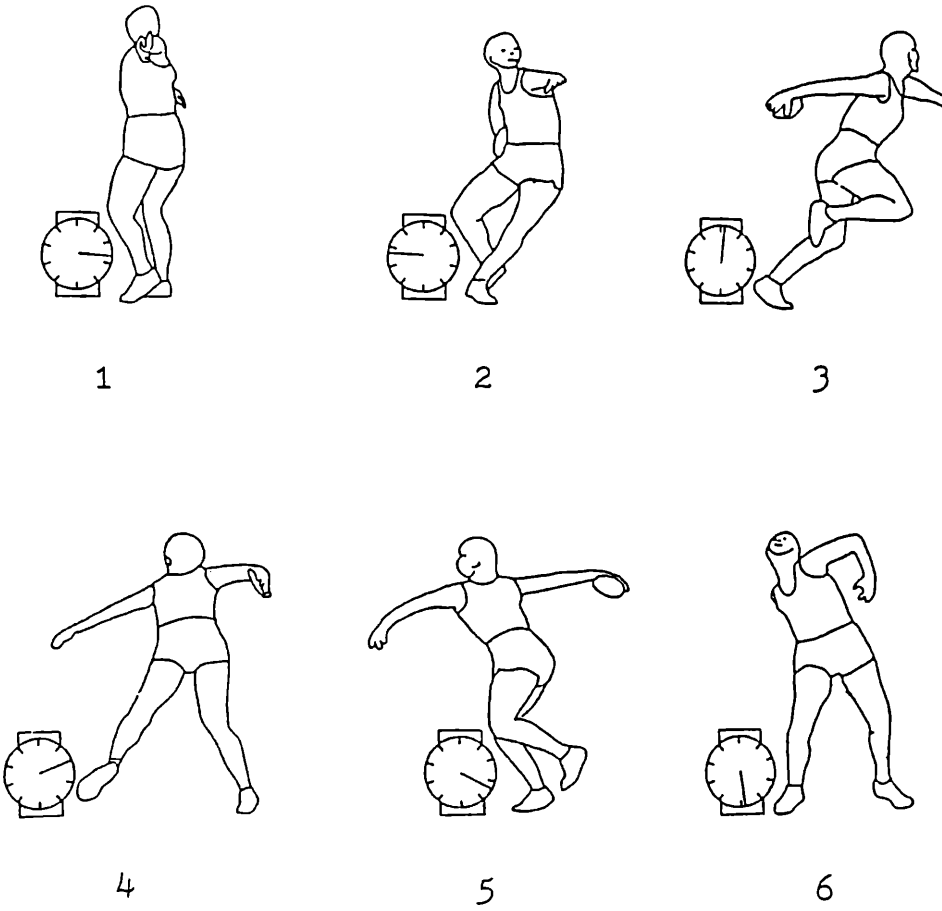
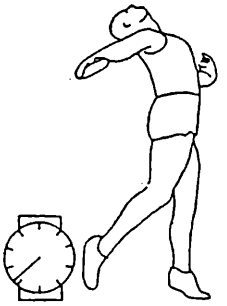


Figure 1 continued. Discus Throw Technique



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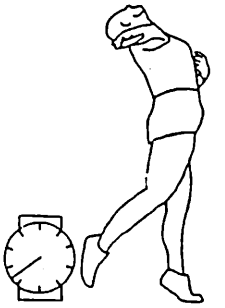

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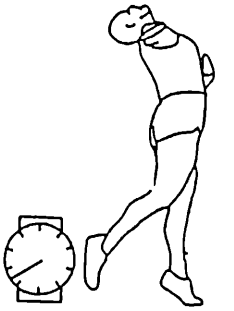

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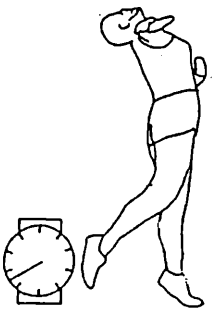

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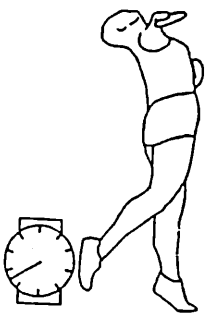

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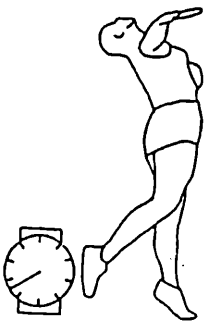

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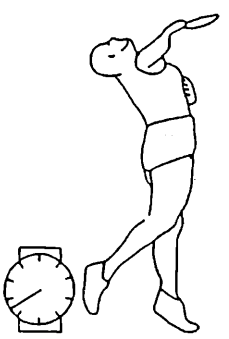
Figure 1 continued. Discus Throw Technique



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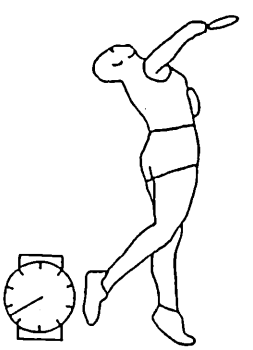

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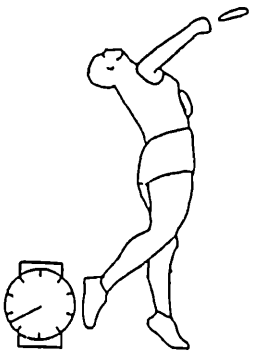

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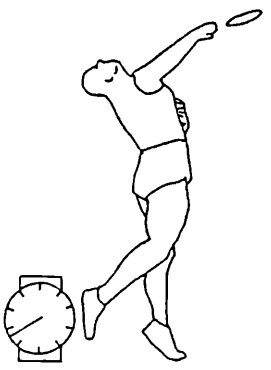

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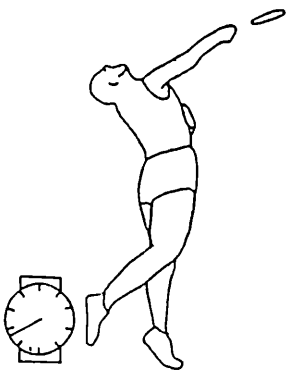

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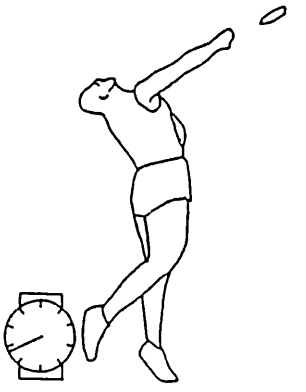

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Stride Length

The stride lengths of the first and second steps for each of the trials are presented in Table 1.* The following observations were made from this study pertaining to the above stride lengths.

First Step

1. The average stride length of the first step for each of the trials in Session I was 116.02 centimeters.
2. The stride length of the first step for the trial with the farthest throw in Session I, Trial 3, was 107.01 centimeters.
3. The average stride length of the first step for each of the trials in Session II was 104.15 centimeters.
4. The stride length of the first step for the trial with the farthest throw in Session II, Trial 2, was 107.17 centimeters.
5. The average stride length of the first step for each of the trials in Session III was 96.56 centimeters.
6. The stride length of the first step for the trial with the farthest throw in Session III, Trial 5, was 92.80 centimeters.

*The subject was to have been filmed throwing the discus six times on the three separate occasions; however, during the initial filming session only five throws were filmed due to a shortage of film. Therefore, only 17 throws will be analyzed.

Second Step

1. The average stride length of the second step for each of the trials in Session I was 84.06 centimeters.
2. The stride length of the second step for the trial with the farthest throw in Session I, Trial 3, was 78.85 centimeters.
3. The average stride length of the second step for each of the trials in Session II was 72.56 centimeters.
4. The stride length of the second step for the trial with the farthest throw in Session II, Trial 2, was 75.08 centimeters.
5. The average stride length of the second step for each of the trials in Session III was 76.03 centimeters.
6. The stride length of the second step for the trial with the farthest throw in Session III, Trial 5, was 75.87 centimeters.

TABLE 1

Stride Length

Session-Throw	Length of 1st Step (cm)	Length of 2nd Step (cm)	Length of Throw (m)
1-1	122.50	85.89	42.67
1-2	114.05	83.78	37.74
1-3	107.01	78.85	43.67
1-4	124.61	86.59	40.46
1-5	111.94	85.18	40.77
AVERAGE	116.02	84.06	41.06
2-1	106.57	71.45	44.00
2-2	107.17	75.08	44.28
2-3	101.12	76.29	42.54
2-4	104.15	72.05	43.93
2-5	102.54	70.24	42.91
2-6	103.54	70.24	44.06
AVERAGE	104.15	72.56	43.62
3-1	100.32	73.74	38.30
3-2	95.30	78.38	42.97
3-3	100.95	78.38	27.30
3-4	90.92	76.49	41.64
3-5	92.80	75.87	43.55
3-6	99.07	73.36	42.94
AVERAGE	96.56	76.03	39.56
AVERAGE - ALL SESSIONS	104.96	77.17	41.396

Time Factors

The time taken for the first step, the second step, the second step to the release of the discus, and for the entire throw are presented in Figures 2-13. The following observations were made from this study pertaining to the time factors listed above.

First Step

1. The average elapsed time taken for the first step of each of the throws of Session I was .18 seconds.
2. The elapsed time taken for the first step of the trial with the farthest throw of Session I, Trial 3, was .18 seconds.
3. The average elapsed time taken for the first step of each of the throws of Session II was .178 seconds.
4. The elapsed time taken for the first step of the trial with the farthest throw of Session II, Trial 2, was .19 seconds.
5. The average elapsed time taken for the first step of each of the throws of Session III was .173 seconds.
6. The elapsed time taken for the first step of the trial with the farthest throw of Session III, Trial 5, was .18 seconds.

Second Step

1. The average elapsed time taken for the second step of each of the throws of Session I was .296 seconds.
2. The elapsed time taken for the second step of the

trial with the farthest throw of Session I, Trial 3, was .29 seconds.

3. The average elapsed time taken for the second step of each of the throws of Session II was .316 seconds.
4. The elapsed time taken for the second step of the trial with the farthest throw of Session II, Trial 2, was .29 seconds.
5. The average elapsed time taken for the second step of each of the throws of Session III was .273 seconds.
6. The elapsed time taken for the second step of the trial with the farthest throw of Session III, Trial 5, was .28 seconds.

Second Step to Release

1. The average elapsed time taken from the completion of the second step to the release of the discus for each of the throws in Session I was .178 seconds.
2. The elapsed time taken from the completion of the second step to the release of the discus for the trial with the farthest throw in Session I, Trial 3, was .17 seconds.
3. The average elapsed time taken from the completion of the second step to the release of the discus for each of the throws in Session II was .166 seconds.
4. The elapsed time taken from the completion of the second step to the release of the discus for the trial

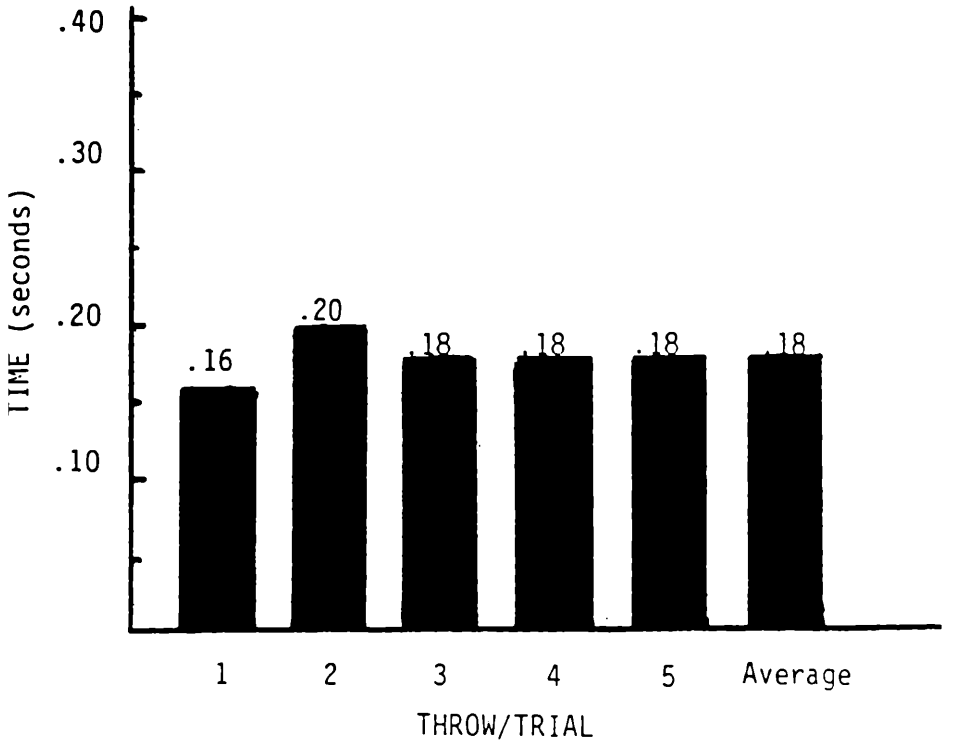
with the farthest throw in Session II, Trial 2, was .19 seconds.

Entire Throw

1. The average elapsed time taken for the entire throw of each of the throws in Session I was 1.438 seconds.
2. The elapsed time taken for the entire throw of the trial with the farthest throw of Session I, Trial 3, was 1.47 seconds.
3. The average elapsed time taken for the entire throw of each of the throws in Session II was 1.41 seconds.
4. The elapsed time taken for the entire throw of the trial with the farthest throw of Session II, Trial 2, was 1.39 seconds.
5. The average elpased time taken for the entire throw of each of the throws in Session III was 1.434 seconds.
6. The elapsed time taken for the entire throw of the trial with the farthest throw of Session III, Trial 5, was 1.41 seconds.

Figure 2

Time Elapsed - First Step
Session I



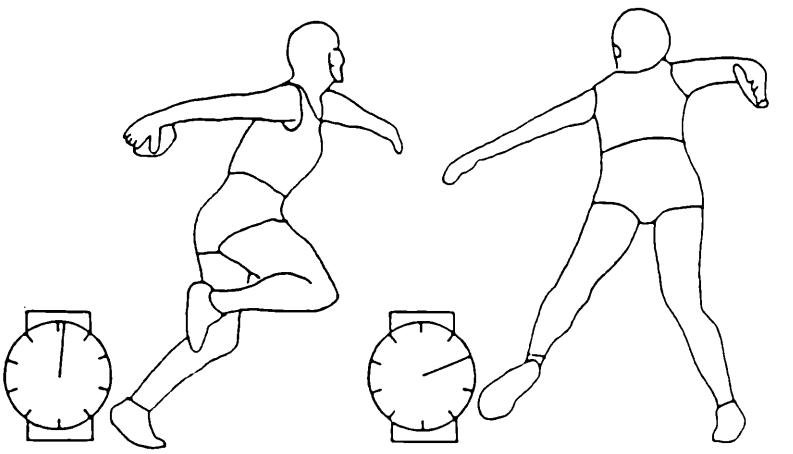
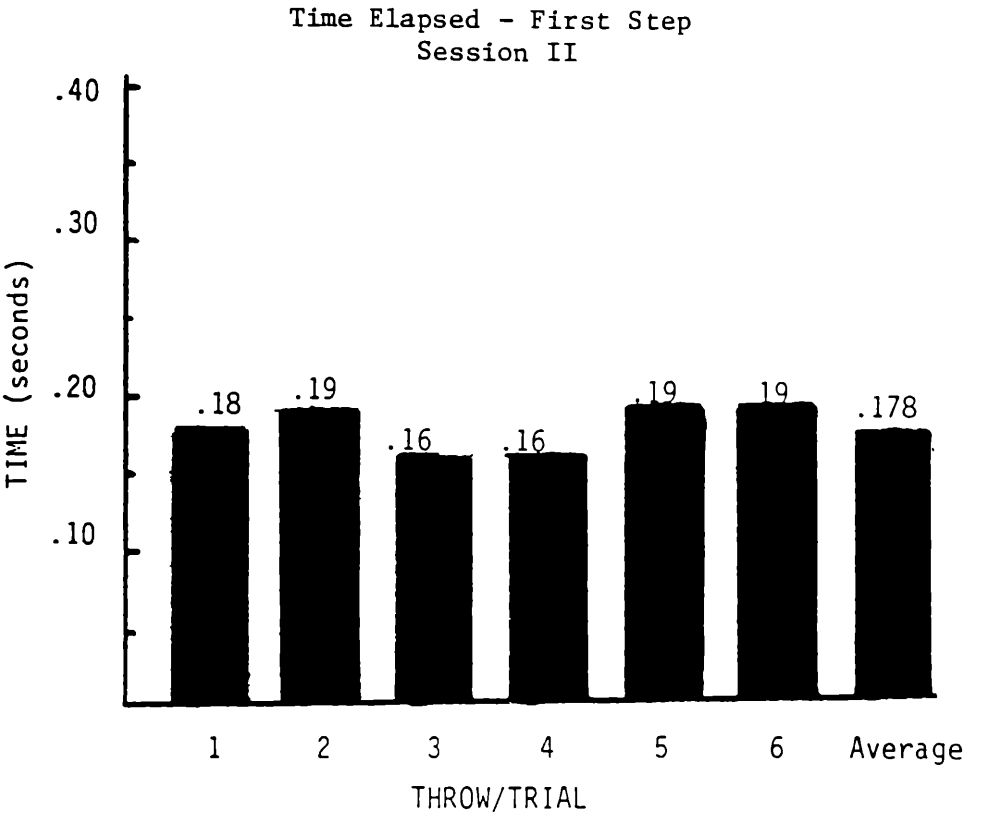


Figure 3


Time Elapsed - First Step
Session II
.40
.30
.20
.10
TIME (seconds)
.18
.19
.16
.16
.19
.19
.178
1
2
3
4
5
6
Average
THROW/TRIAL

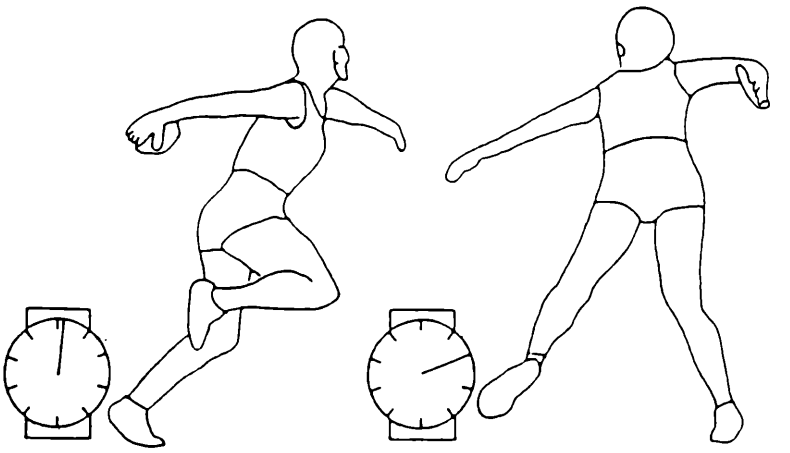
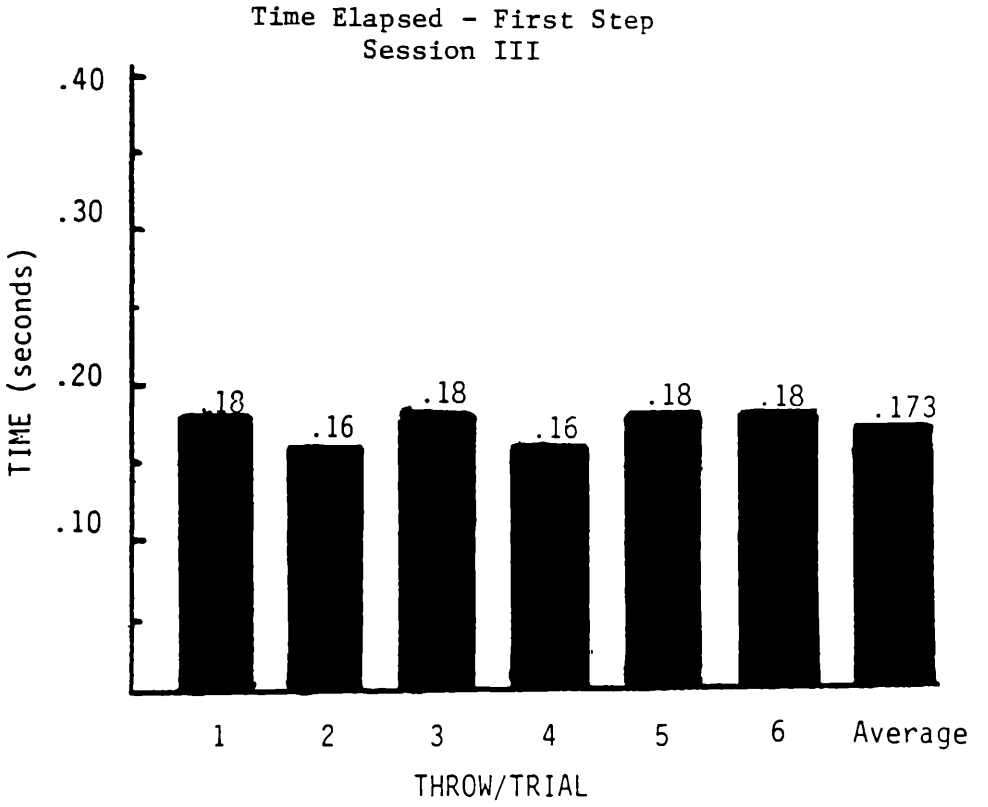


Figure 4


Time Elapsed - First Step
Session III
.40
.30
.20
.10
TIME (seconds)
.18
.16
.18
.16
.18
.18
.173
1
2
3
4
5
6
Average
THROW/TRIAL

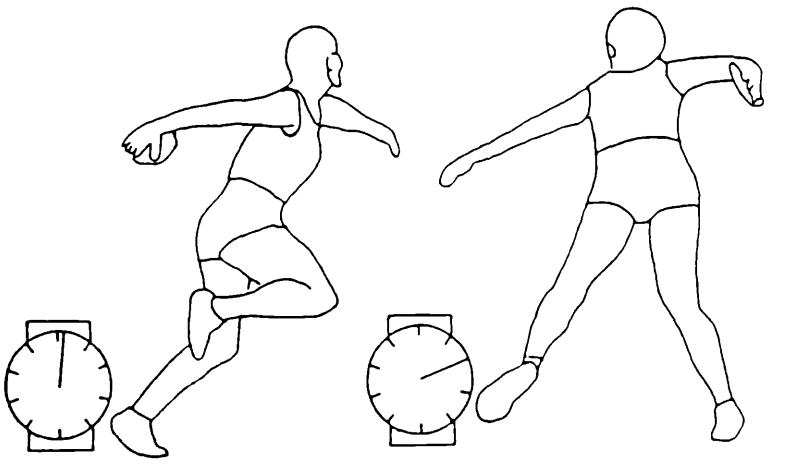
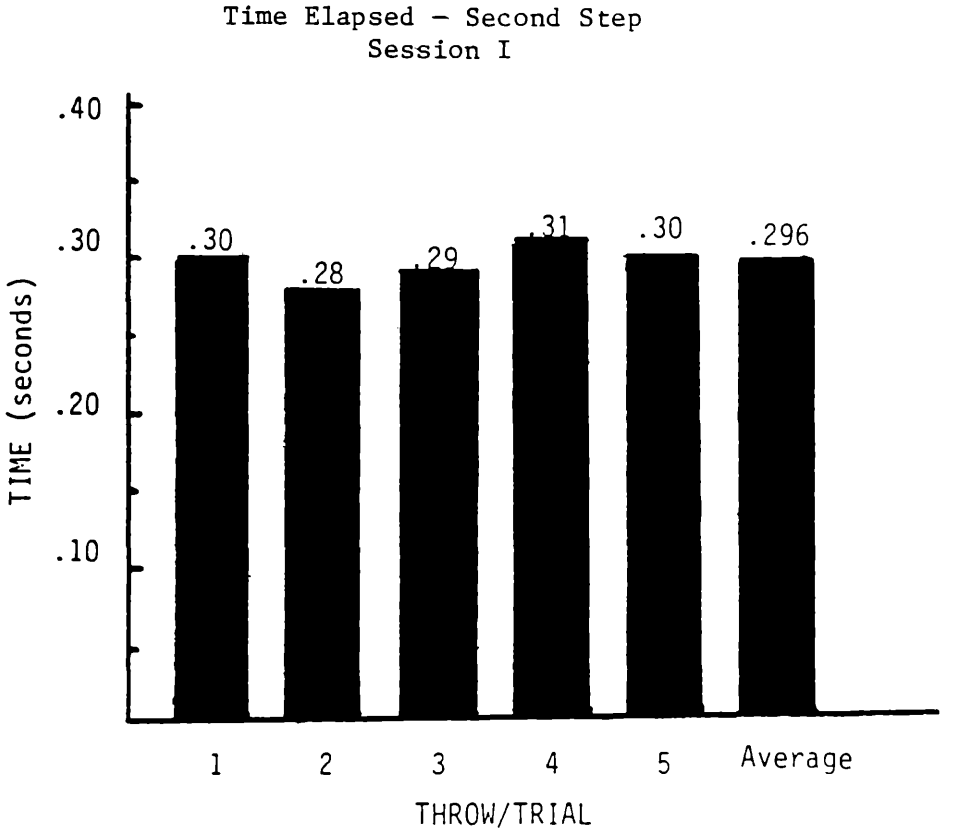


Figure 5


Time Elapsed – Second Step
Session I
.40
.30
.20
.10
TIME (seconds)
.30
.28
.29
.31
.30
.296
1
2
3
4
5
Average
THROW/TRIAL

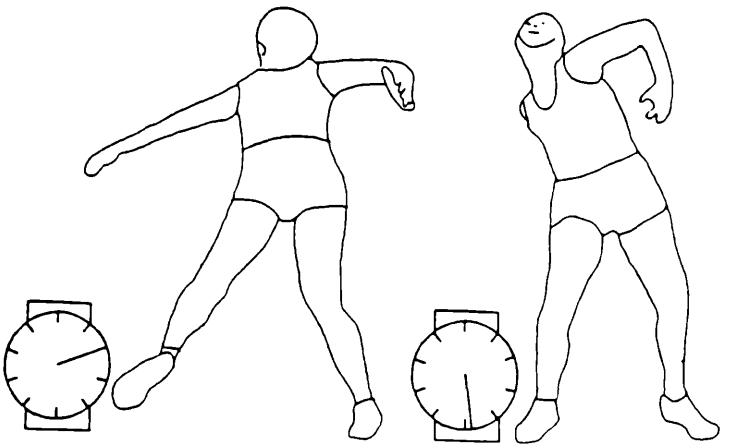
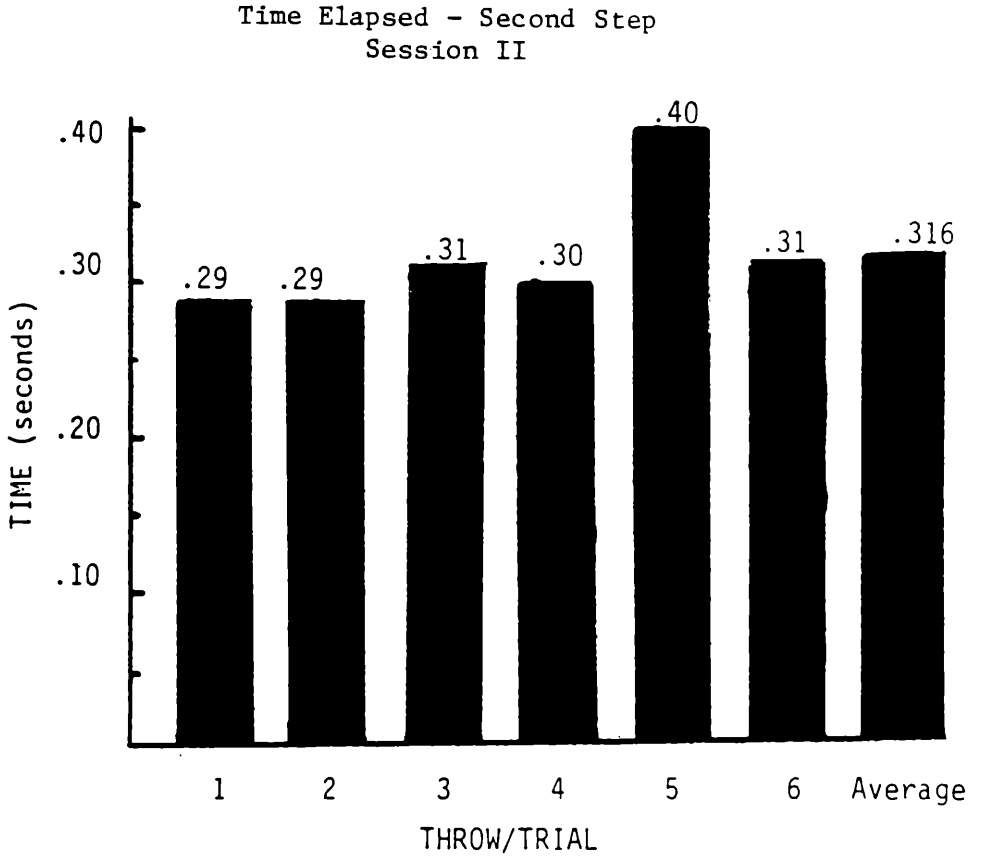


Figure 6


Time Elapsed - Second Step
Session II
.40
.30
.20
.10
TIME (seconds)
.29
.29
.31
.30
.40
.31
.316
1
2
3
4
5
6
Average
THROW/TRIAL

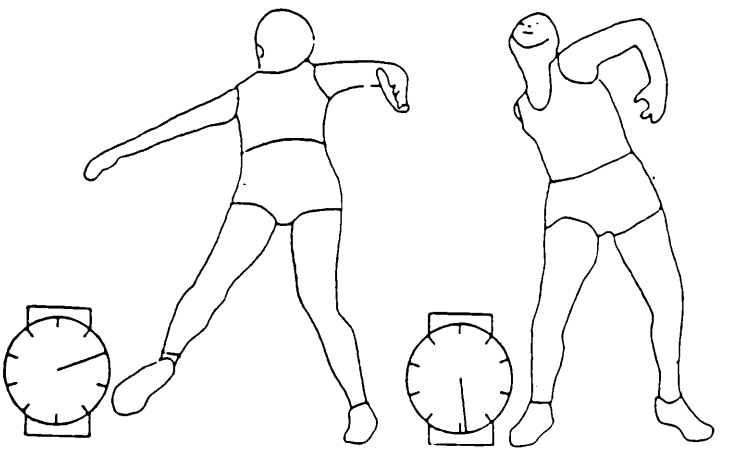
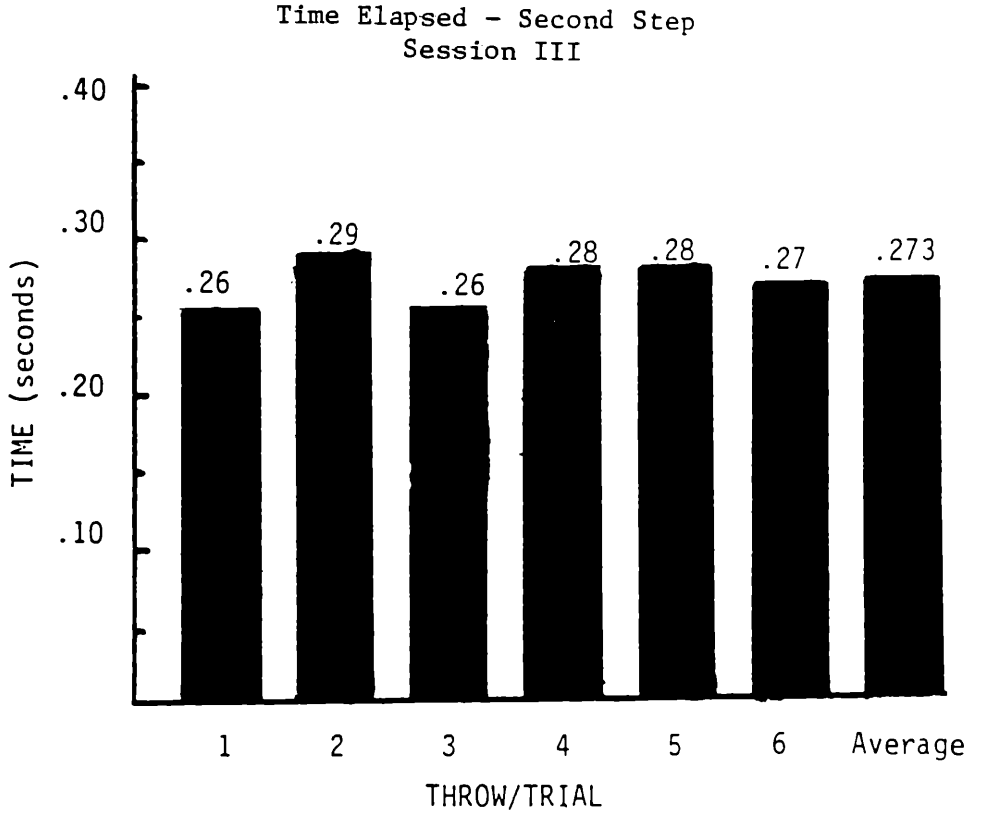


Figure 7


Time Elapsed - Second Step
Session III
.40
.30
.20
.10
TIME (seconds)
.26
.29
.26
.28
.28
.27
.273
1
2
3
4
5
6
Average
THROW/TRIAL

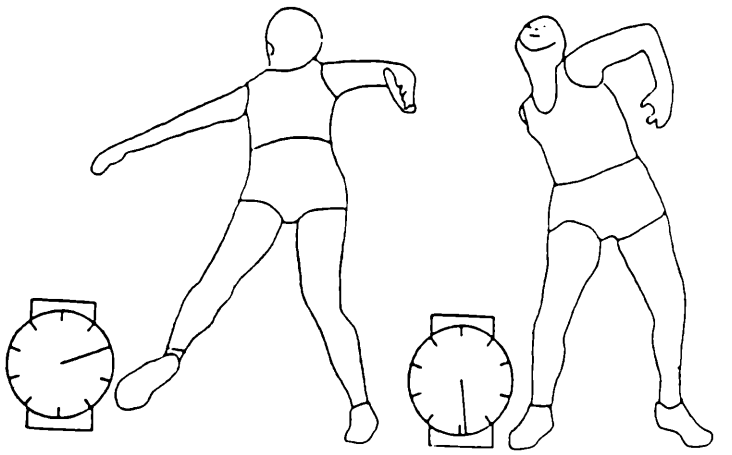
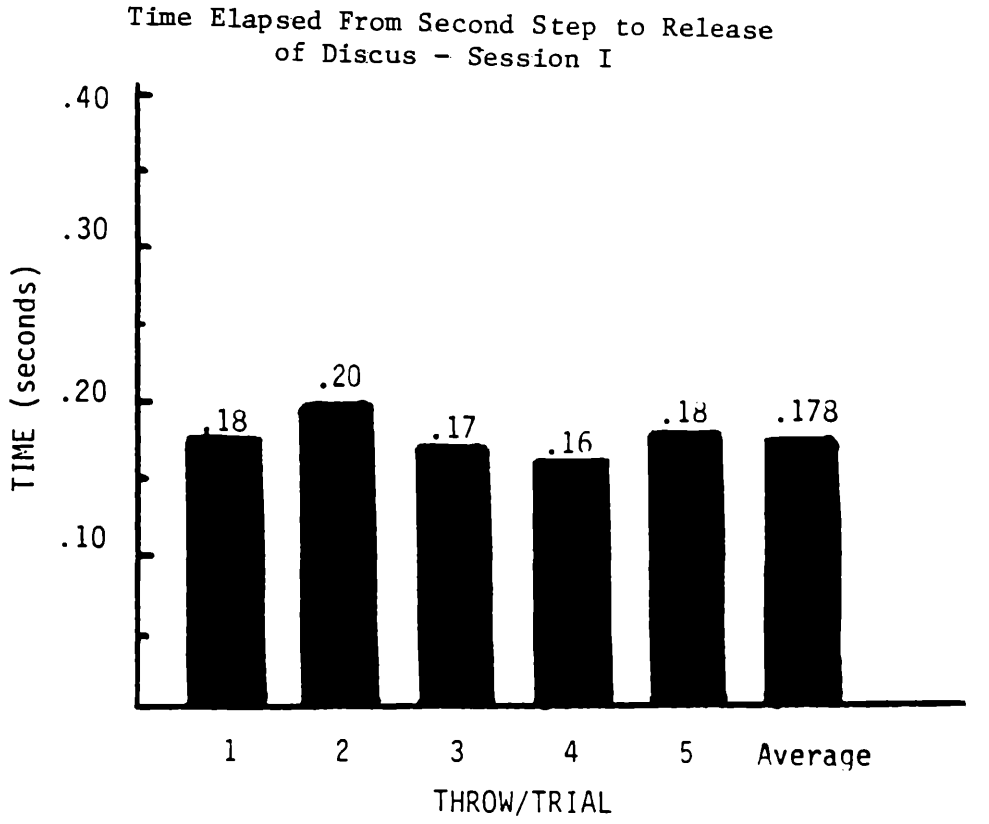


Figure 8


Time Elapsed From Second Step to Release of Discus - Session I
.40
.30
.20
.10
TIME (seconds)
.18
.20
.17
.16
.18
.178
1
2
3
4
5
Average
THROW/TRIAL

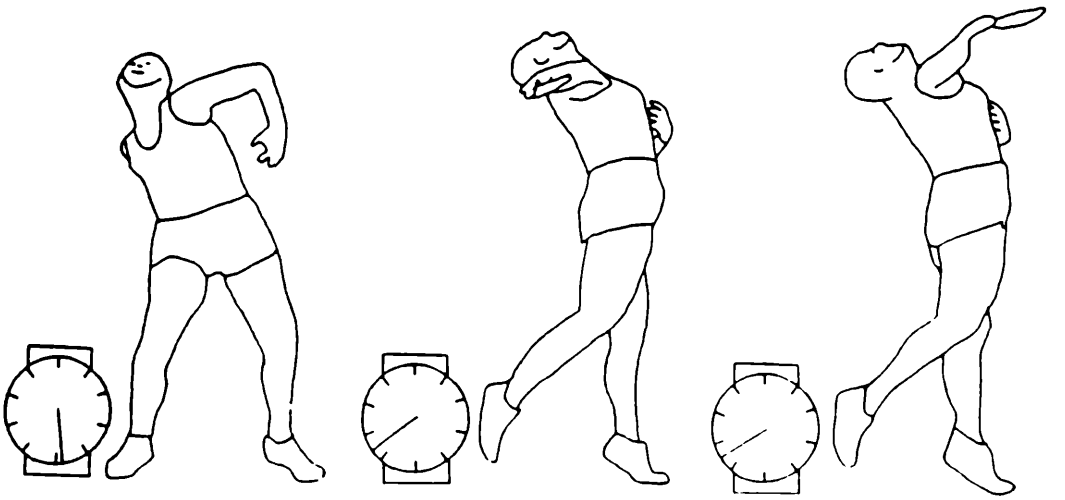
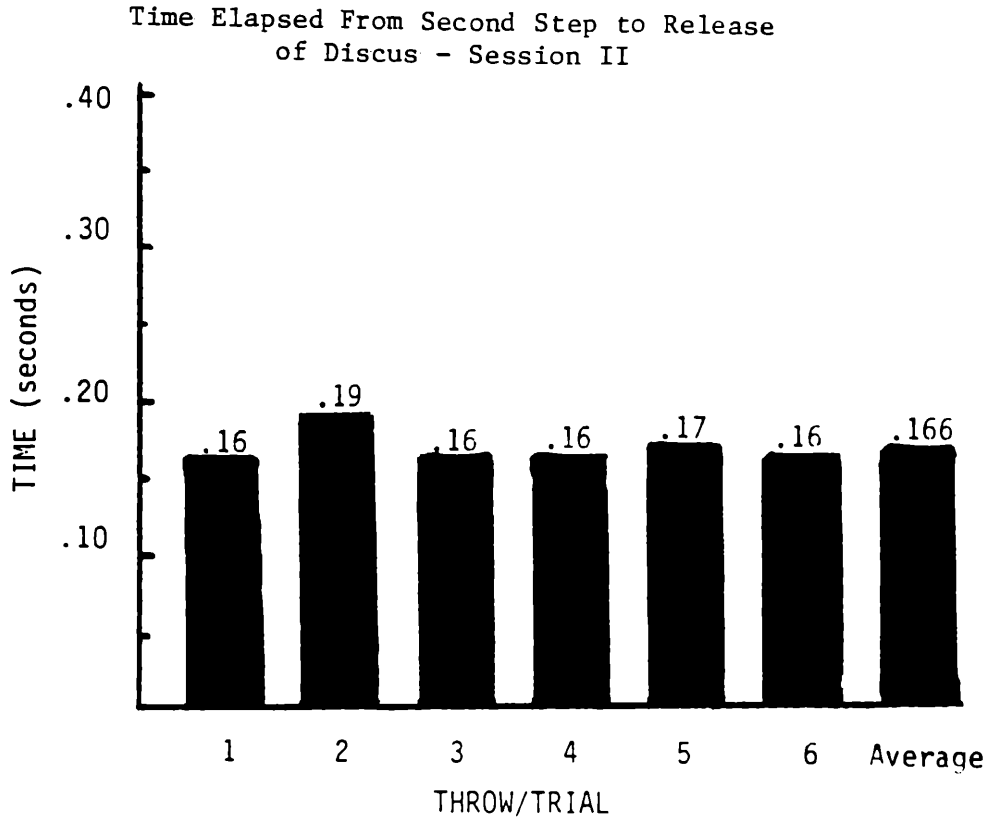


Figure 9


Time Elapsed From Second Step to Release of Discus - Session II
.40
.30
.20
.10
TIME (seconds)
.16
.19
.16
.16
.17
.16
.166
1
2
3
4
5
6
Average
THROW/TRIAL

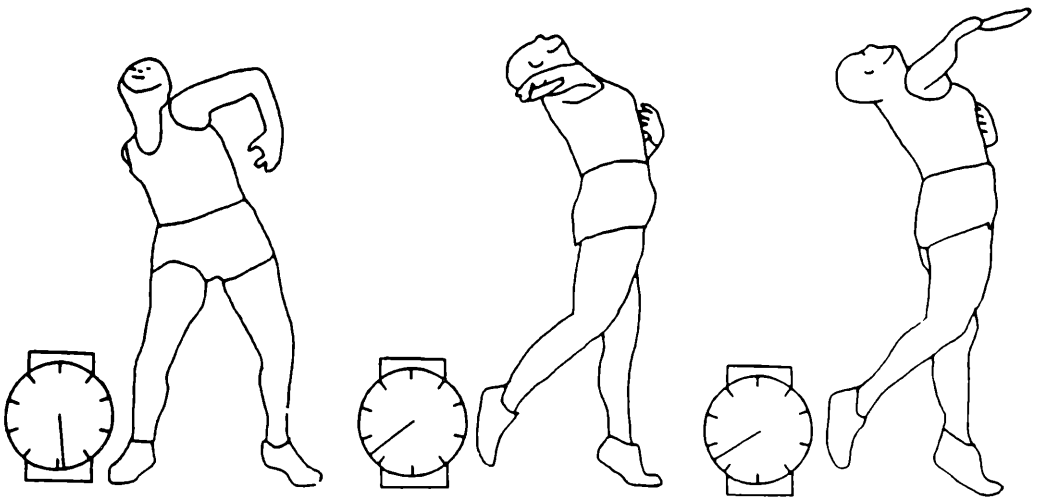
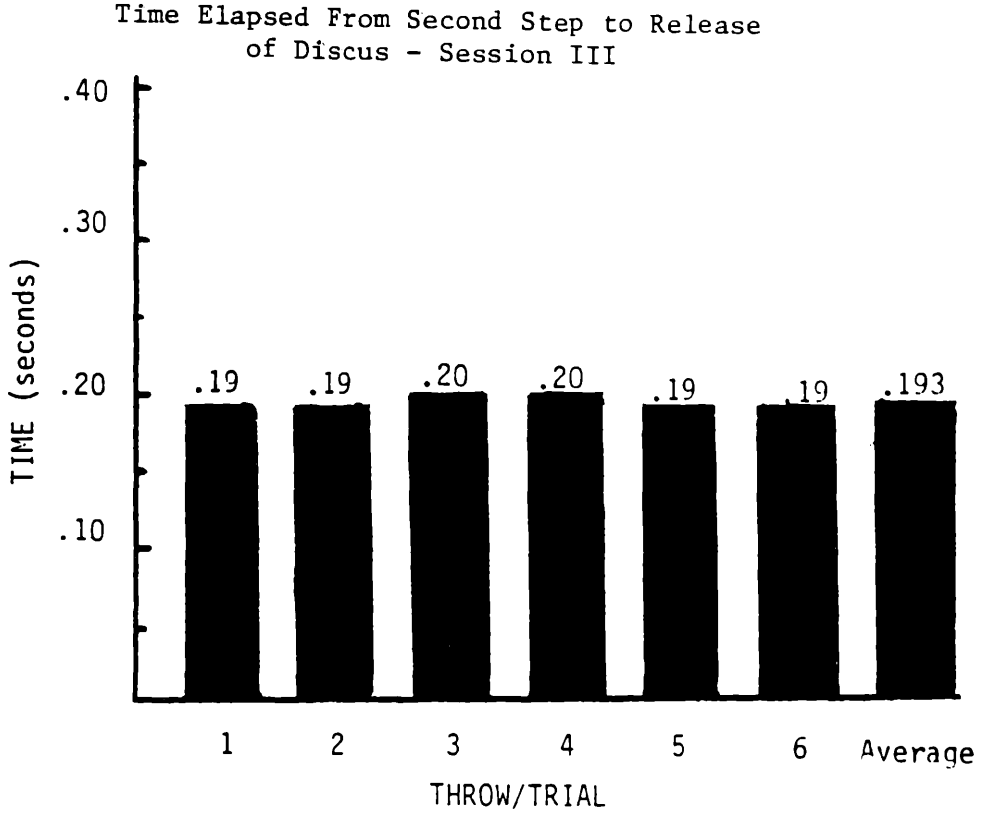


Figure 10


Time Elapsed From Second Step to Release of Discus - Session III
.40
.30
.20
.10
TIME (seconds)
.19
.19
.20
.20
.19
.19
.193
1
2
3
4
5
6
Average
THROW/TRIAL

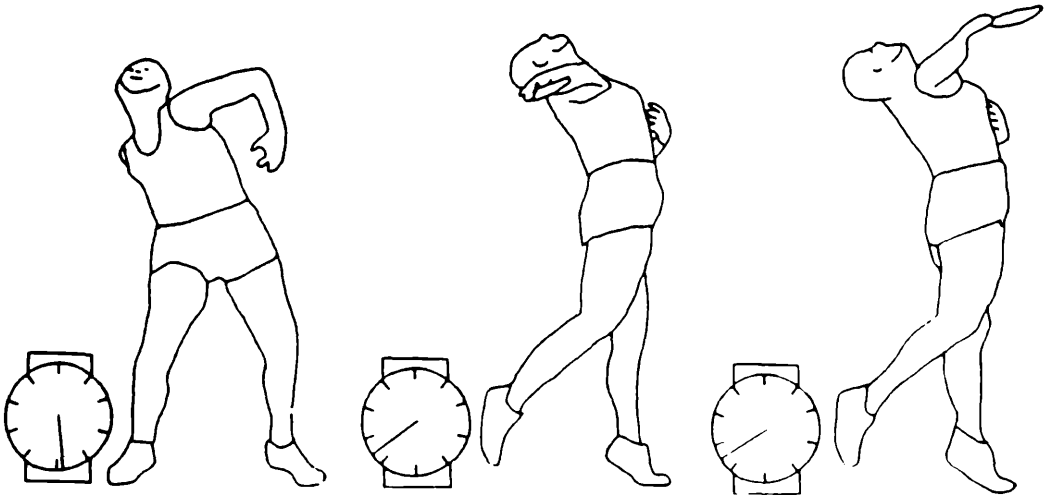
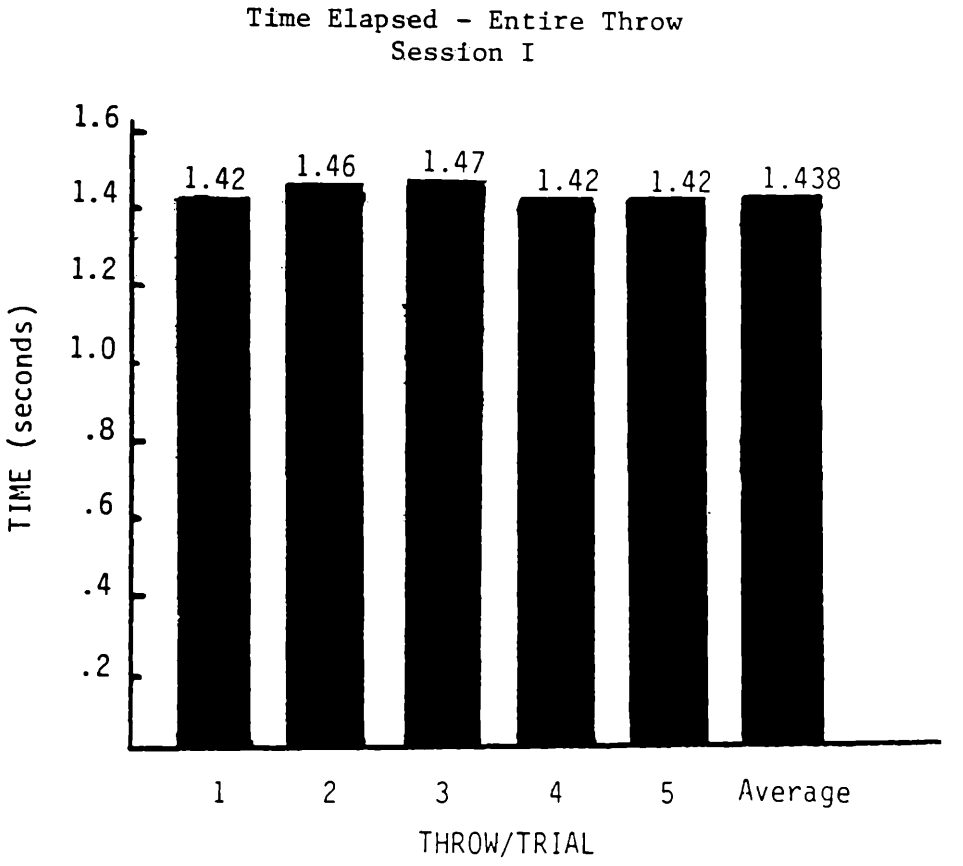


Figure 11


Time Elapsed - Entire Throw
Session I
TIME (seconds)
1.6
1.4
1.2
1.0
.8
.6
.4
.2
1.42
1.46
1.47
1.42
1.42
1.438
1
2
3
4
5
Average
THROW/TRIAL

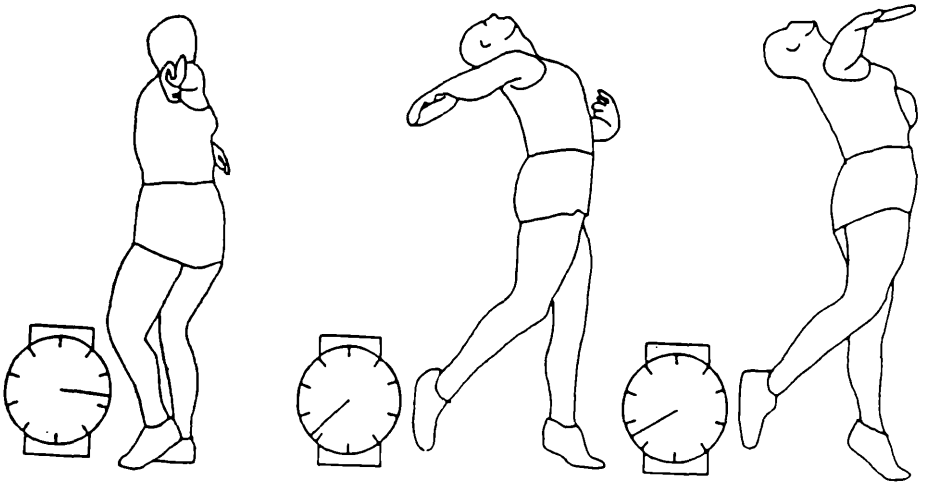
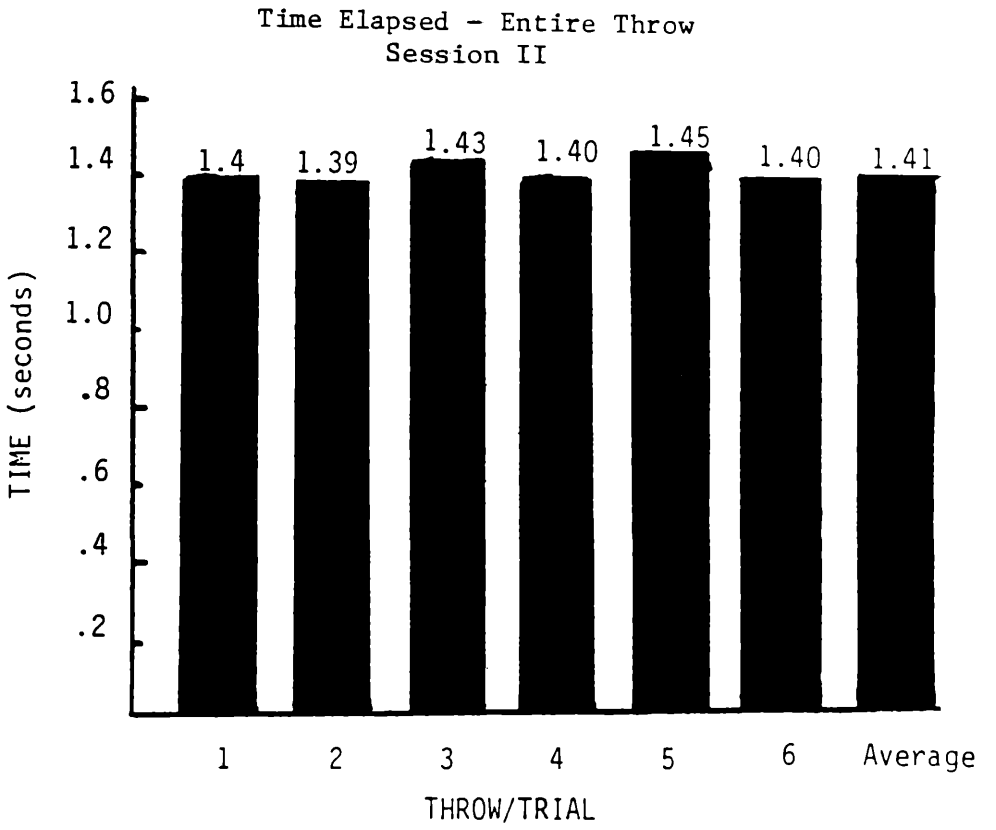


Figure 12


Time Elapsed - Entire Throw
Session II
TIME (seconds)
1.6
1.4
1.2
1.0
.8
.6
.4
.2
1.4
1.39
1.43
1.40
1.45
1.40
1.41
1
2
3
4
5
6
Average
THROW/TRIAL

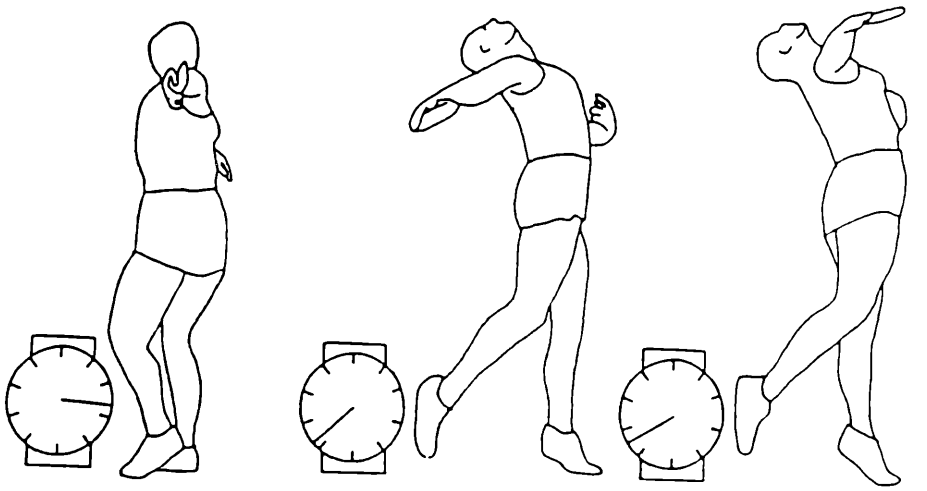
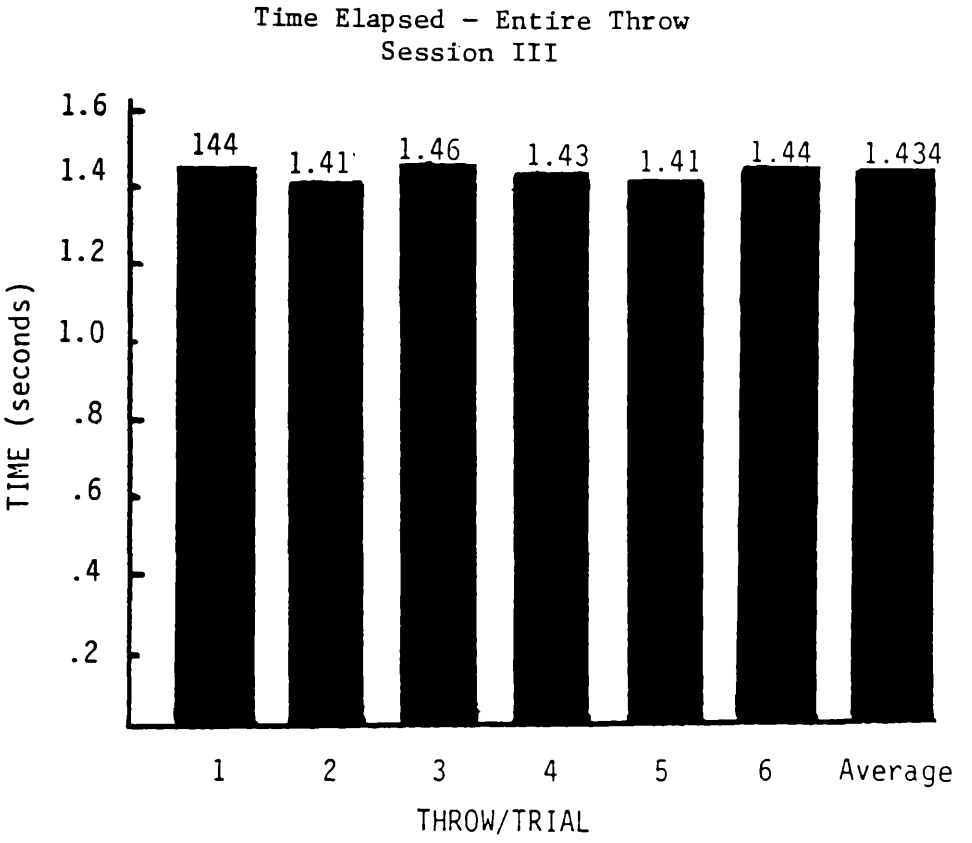
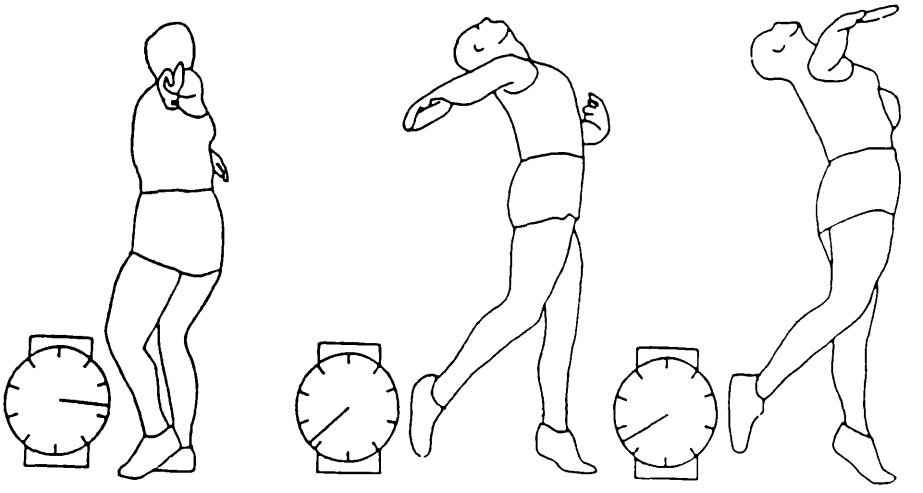


Figure 13


Time Elapsed - Entire Throw
Session III
TIME (seconds)
1.6
1.4
1.2
1.0
.8
.6
.4
.2
144
1.41
1.46
1.43
1.41
1.44
1.434
1
2
3
4
5
6
Average
THROW/TRIAL



Linear Velocity Resultants

The linear velocity resultants of the right ankle, the right knee, the right hip, and the right hand throughout the entire throw are presented in Figures 14-25. The following observations were made from this study pertaining to the linear velocity resultants of the body segments listed above.

Right Ankle

1. The linear velocity resultant of the right ankle for Trial 3, Session I, five frames prior to the release of the discus was 2.3 meters per second.
2. The linear velocity resultant of the right ankle for Trial 3, Session I at the moment of release was 3.1 meters per second.
3. The linear velocity resultant of the right ankle for Trial 3, Session I, five frames after the release of the discus was 3.4 meters per second.
4. The linear velocity resultant of the right ankle for Trial 2, Session II, five frames prior to the release of the discus was 2.1 meters per second.
5. The linear velocity resultant of the right ankle for Trial 2, Session II, at the moment of release of the the discus was 2.8 meters per second.
6. The linear velocity resultant of the right ankle for Trial 2, Session II, five frames after the release of the discus was 3.0 meters per second.

7. The linear velocity resultant of the right ankle for Trial 5, Session III, five frames prior to the release of the discus was 1.7 meters per second.
8. The linear velocity resultant of the right ankle for Trial 5, Session III, at the moment of release was 2.4 meters per second.
9. The linear velocity resultant of the right ankle for Trial 5, Session III, five frames after the release of the discus was 2.6 meters per second.

Right Knee

1. The linear velocity resultant of the right knee for Trial 3, Session I, five frames prior to the release of the discus was 2.7 meters per second.
2. The linear velocity resultant of the right knee for Trial 3, Session I, at the moment of release was 2.6 meters per second.
3. The linear velocity resultant of the right knee for Trial 3, Session I, five frames after the moment of release was 2.5 meters per second.
4. The linear velocity resultant of the right knee for Trial 2, Session II, five frames prior to the release of the discus was 2.4 meters per second.
5. The linear velocity resultant of the right knee for Trial 2, Session II, at the moment of release was 2.7 meters per second.

6. The linear velocity resultant of the right knee for Trial 2, Session II, five frames after the moment of release was 2.8 meters per second.
7. The linear velocity resultant of the right knee for Trial 5, Session III, five frames prior to the release of the discus was 2.8 meters per second.
8. The linear velocity resultant of the right knee for Trial 5, Session III, at the moment of release was 3.0 meters per second.
9. The linear velocity resultant of the right knee for Trial 5, Session III, five frames after the moment of release was 3.0 meters per second.

Right Hip

1. The linear velocity resultant of the right hip for Trial 3, Session I, five frames prior to the release of the discus was 2.4 meters per second.
2. The linear velocity resultant of the right hip for Trial 3, Session I, at the moment of release was 1.8 meters per second.
3. The linear velocity resultant of the right hip for Trial 3, Session I, five frames after the moment of release was 1.6 meters per second.
4. The linear velocity resultant of the right hip for Trial 2, Session II, five frames prior to the release of the discus was 2.2 meters per second.

5. The linear velocity resultant of the right hip for Trial 2, Session II, at the moment of release was 1.9 meters per second.
6. The linear velocity resultant of the right hip for Trial 2, Session II, five frames after the moment of release was 1.9 meters per second.
7. The linear velocity resultant of the right hip for Trial 5, Session III, five frames prior to the release of the discus was 2.3 meters per second.
8. The linear velocity resultant of the right hip for Trial 5, Session III, at the moment of release was 1.6 meters per second.
9. The linear velocity resultant of the right hip for Trial 5, Session III, five frames after the moment of release was 1.7 meters per second.

Right Hand

1. The linear velocity resultant of the right hand for Trial 3, Session I, five frames prior to the release of the discus was 13.0 meters per second.
2. The linear velocity resultant of the right hand for Trial 3, Session I, at the moment of release was 24.0 meters per second.
3. The linear velocity resultant of the right hand for Trial 3, Session I, five frames after the moment of release was 19.1 meters per second.

4. The linear velocity resultant of the right hand for Trial 2, Session II, five frames prior to the release of the discus was 7.4 meters per second.
5. The linear velocity resultant of the right hand for Trial 2, Session II, at the moment of release was 21.2 meters per second.
6. The linear velocity resultant of the right hand for Trial 2, Session II, five frames after the moment of release was 12.9 meters per second.
7. The linear velocity resultant of the right hand for Trial 5, Session III, five frames prior to the release of the discus was 7.5 meters per second.
8. The linear velocity resultant of the right hand for Trial 5, Session III, at the moment of release was 18.7 meters per second.
9. The linear velocity resultant of the right hand for Trial 5, Session III, five frames after the moment of release was 9.8 meters per second.

Figure 14

Linear Velocity of the Right Ankle
Center of Gravity - Session I

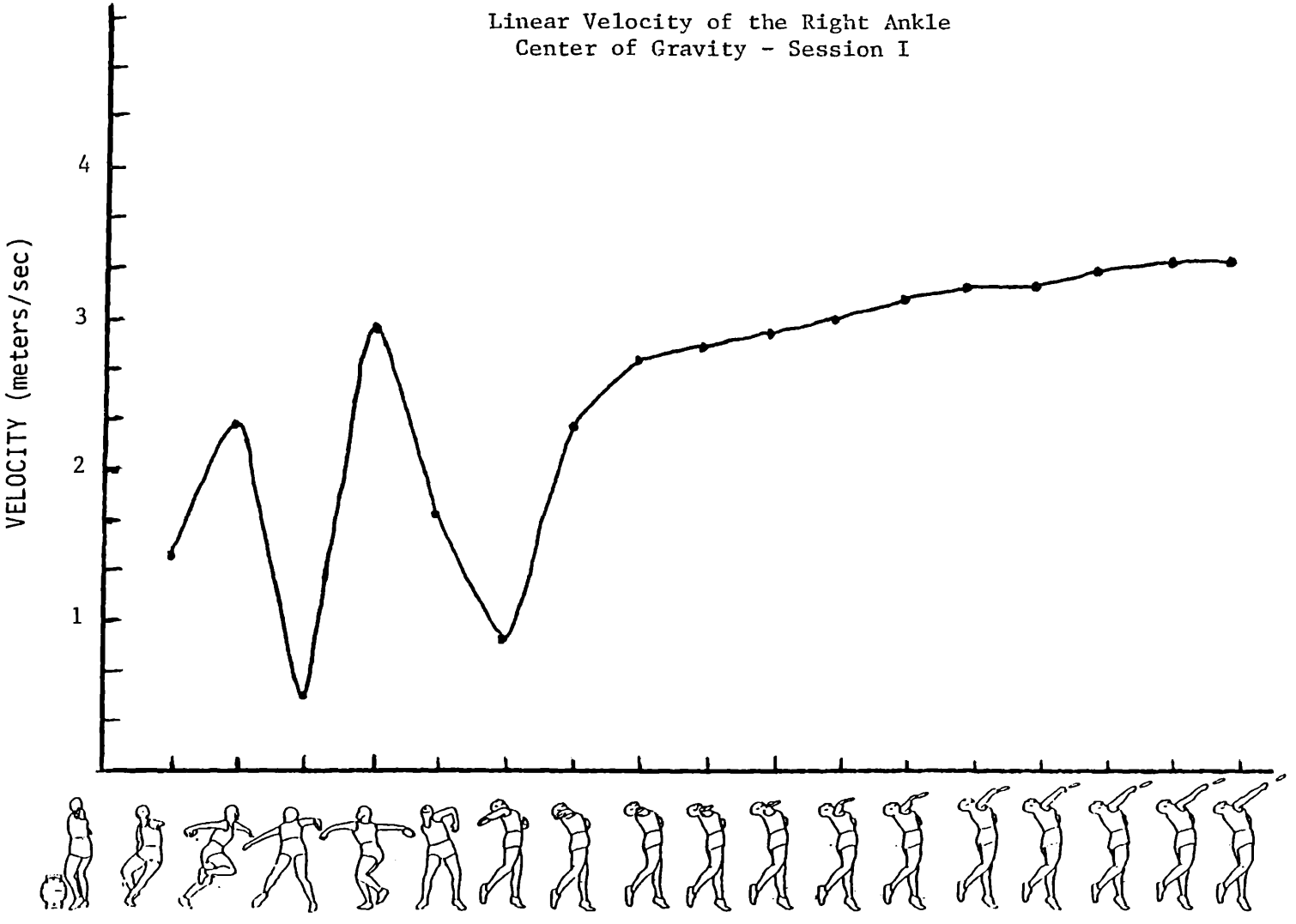


Figure 15

Linear Velocity of the Right Ankle
Center of Gravity - Session II

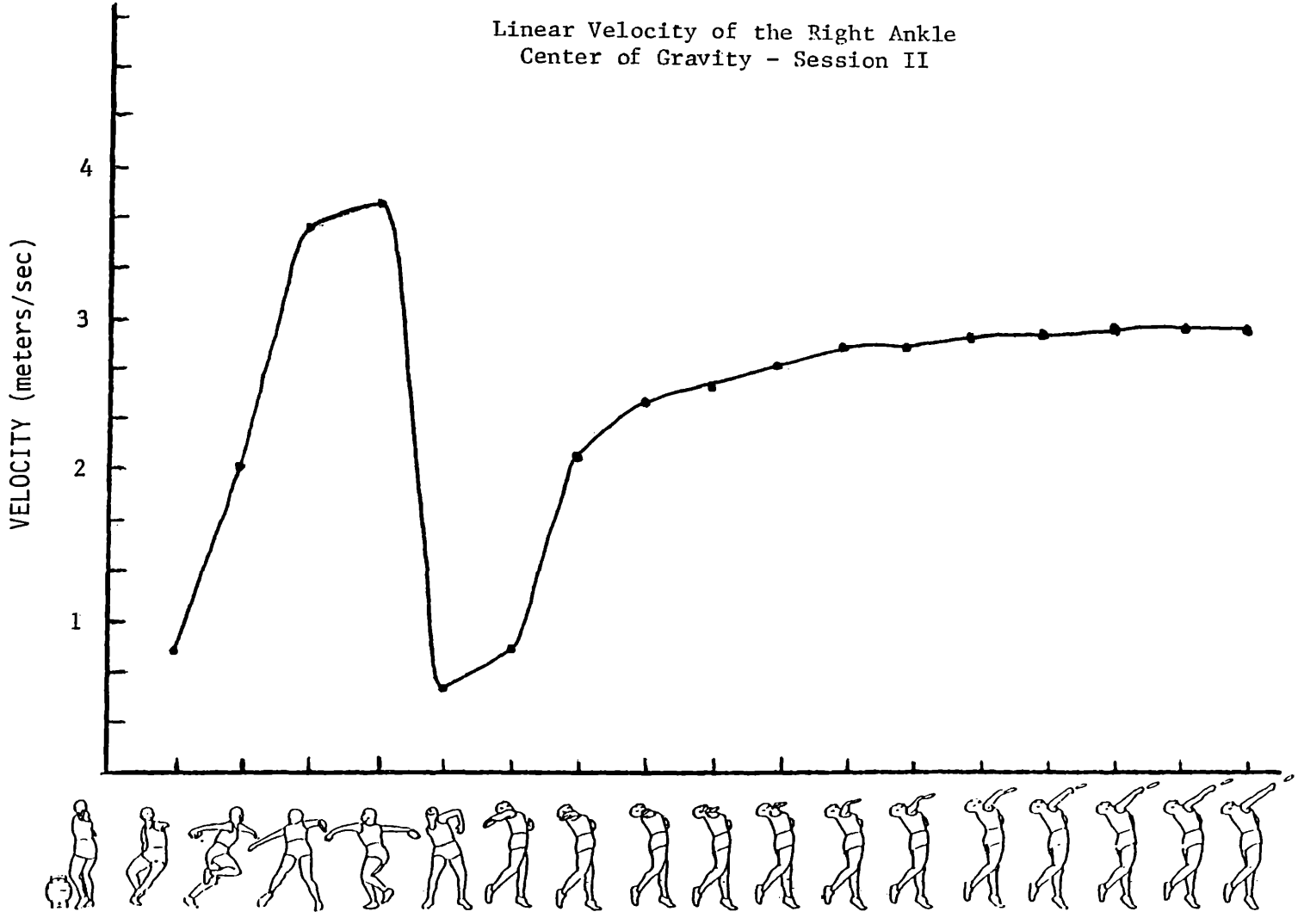


Figure 16

Linear Velocity of the Right Ankle
Center of Gravity - Session III

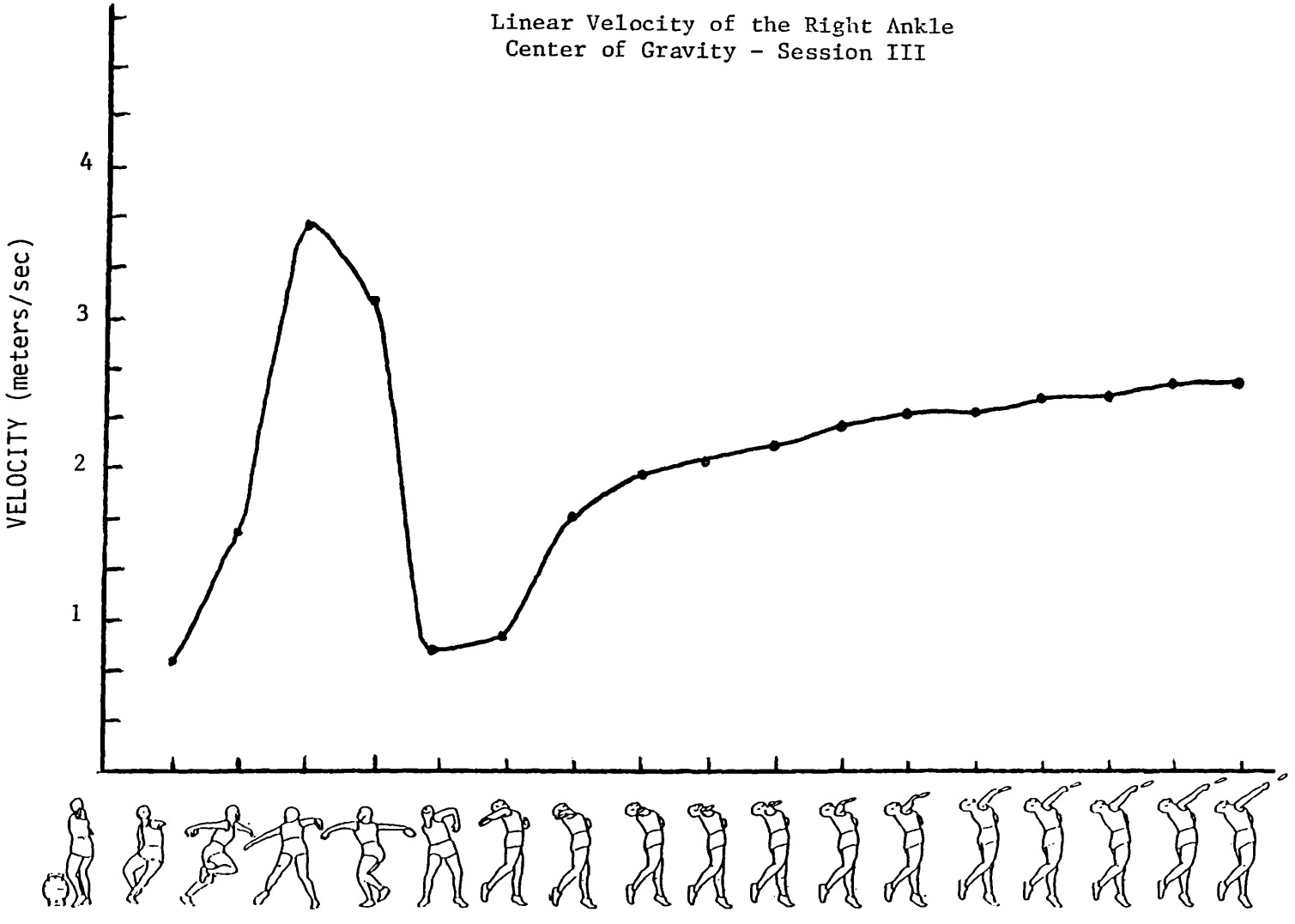


Figure 17

Linear Velocity of the Right Knee
Center of Gravity - Session I

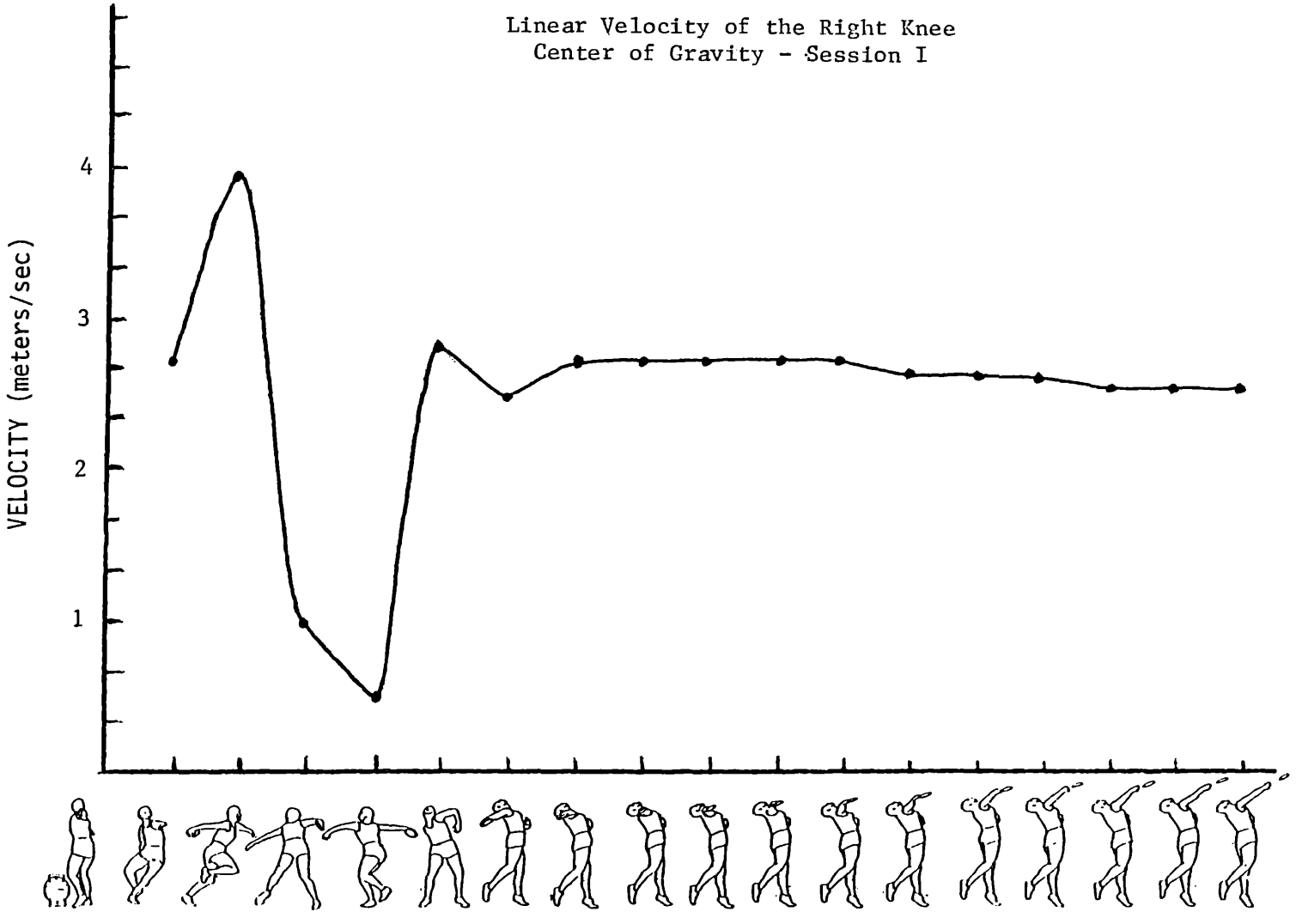


Figure 18

Linear Velocity of the Right Knee
Center of Gravity - Session II

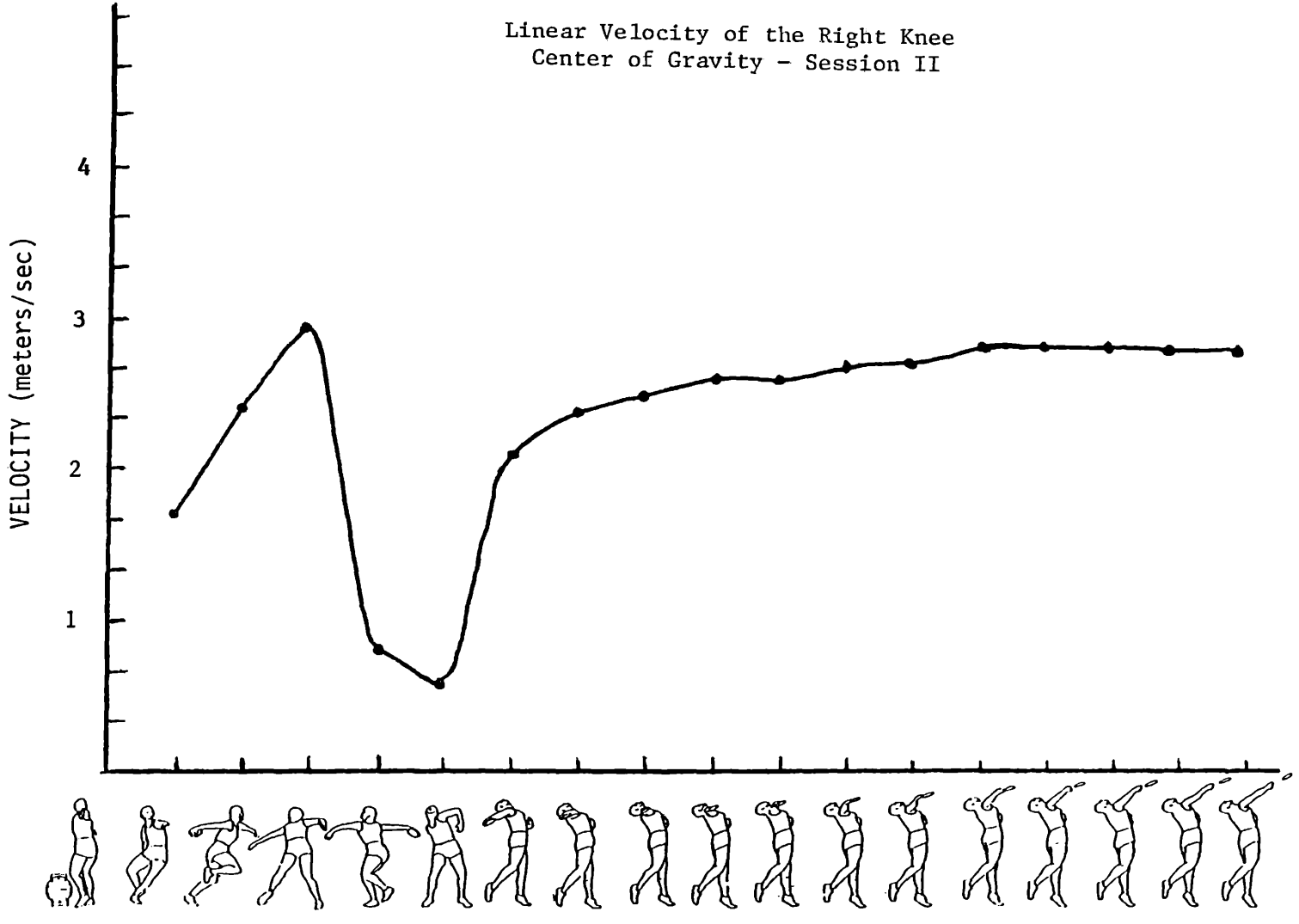


Figure 19

Linear Velocity of the Right Knee
Center of Gravity - Session III

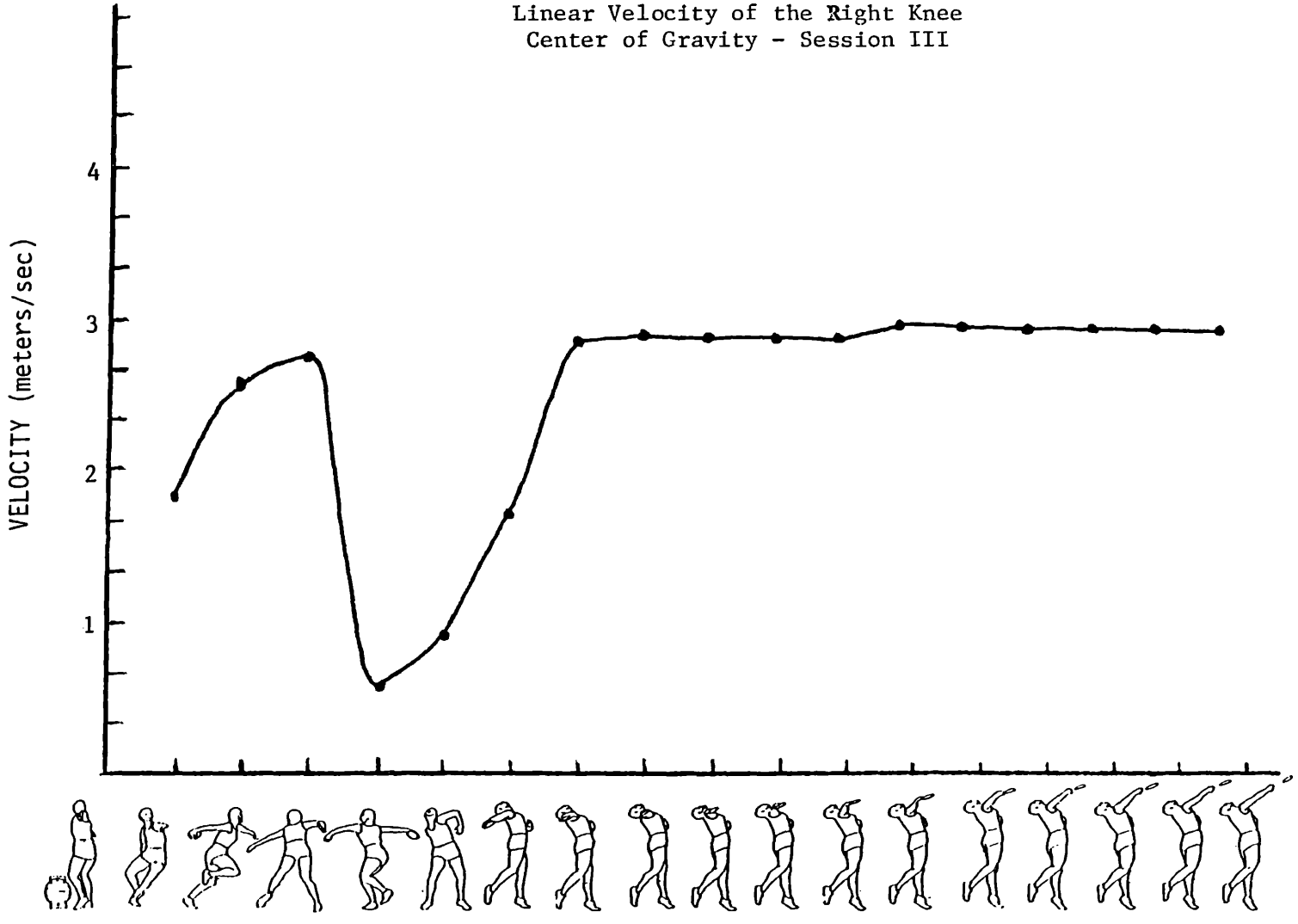


Figure 20

Linear Velocity of the Right Hip
Center of Gravity - Session I

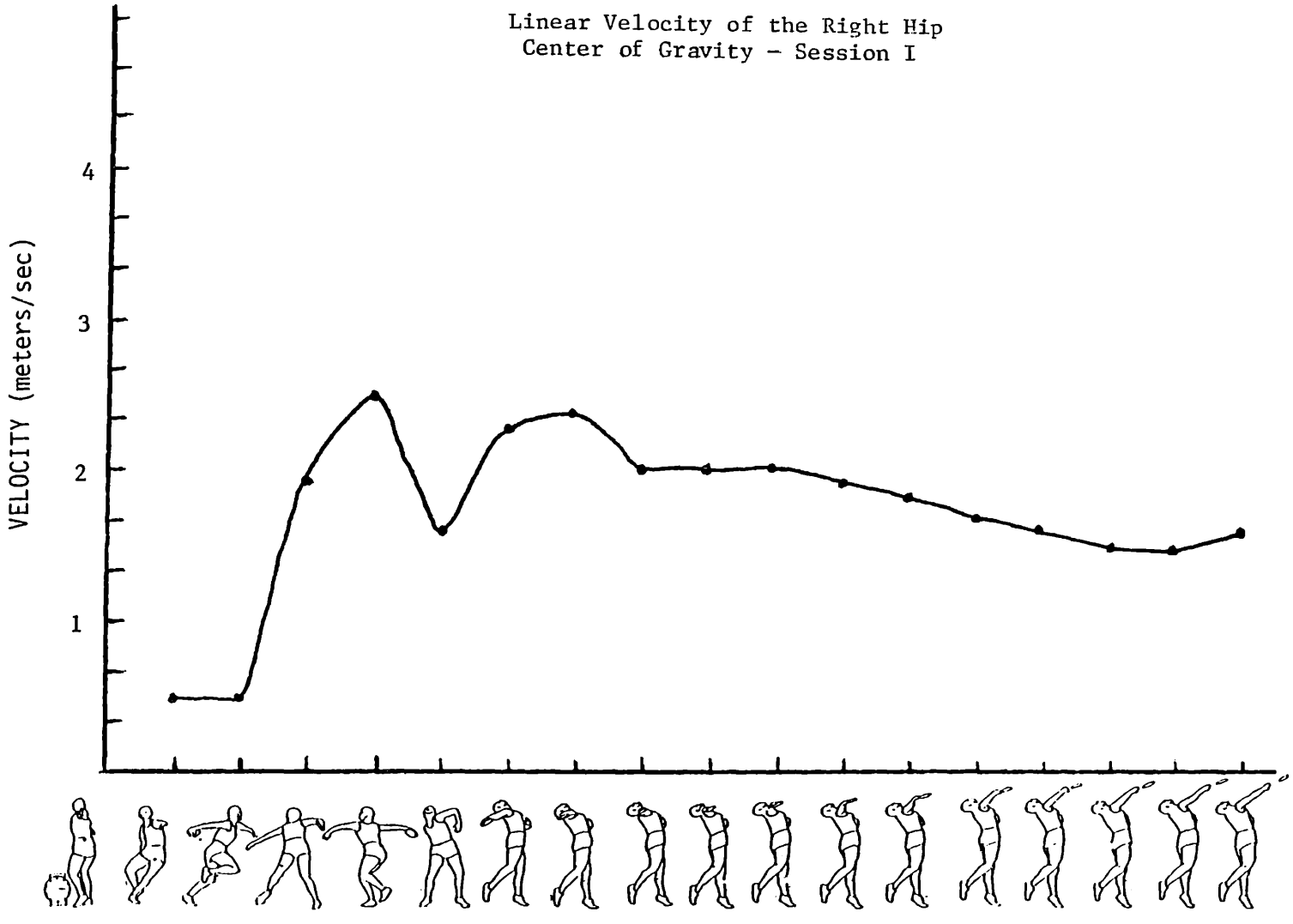


Figure 21

Linear Velocity of the Right Hip
Center of Gravity - Session II

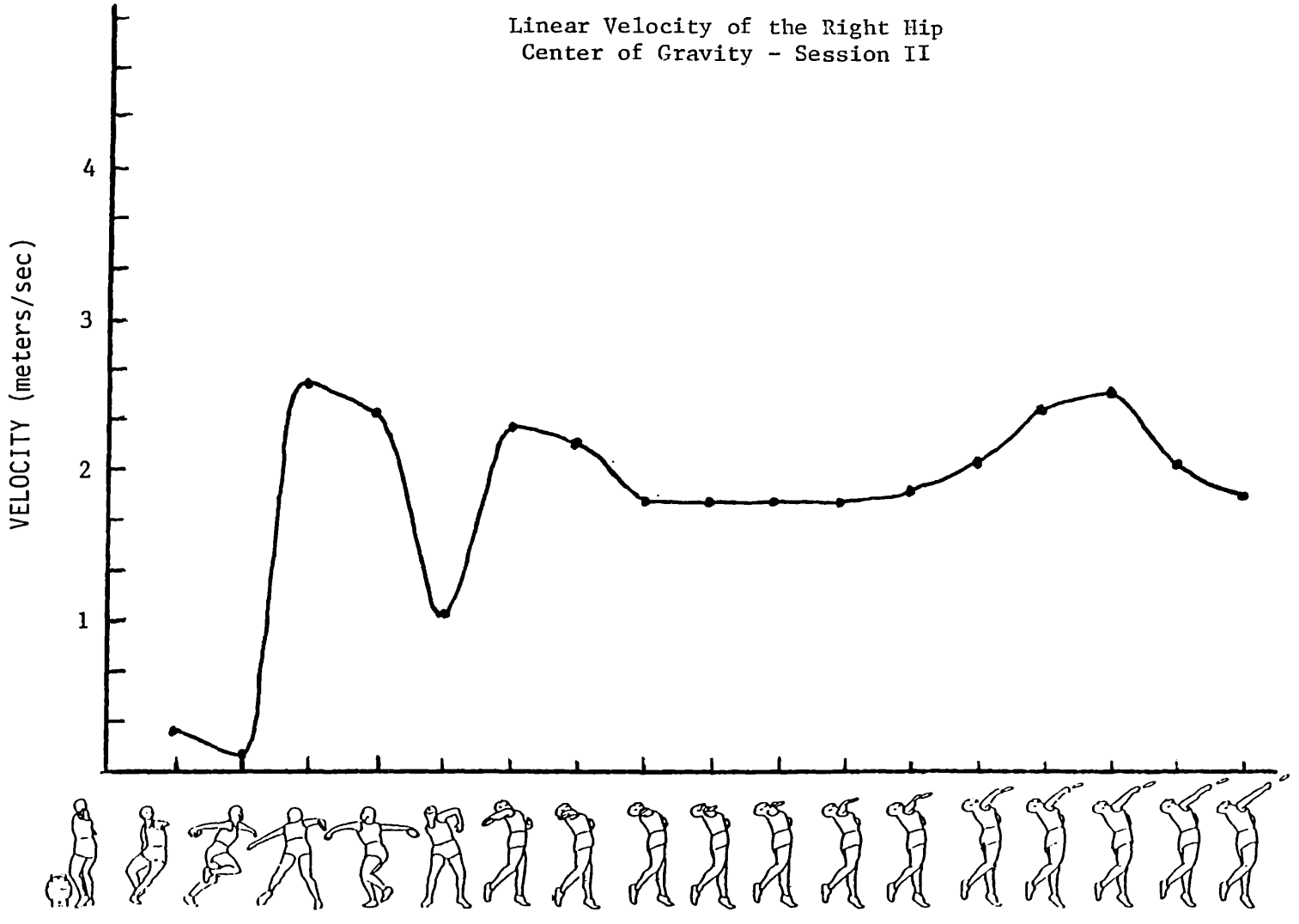


Figure 22

Linear Velocity of the Right Hip
Center of Gravity - Session III

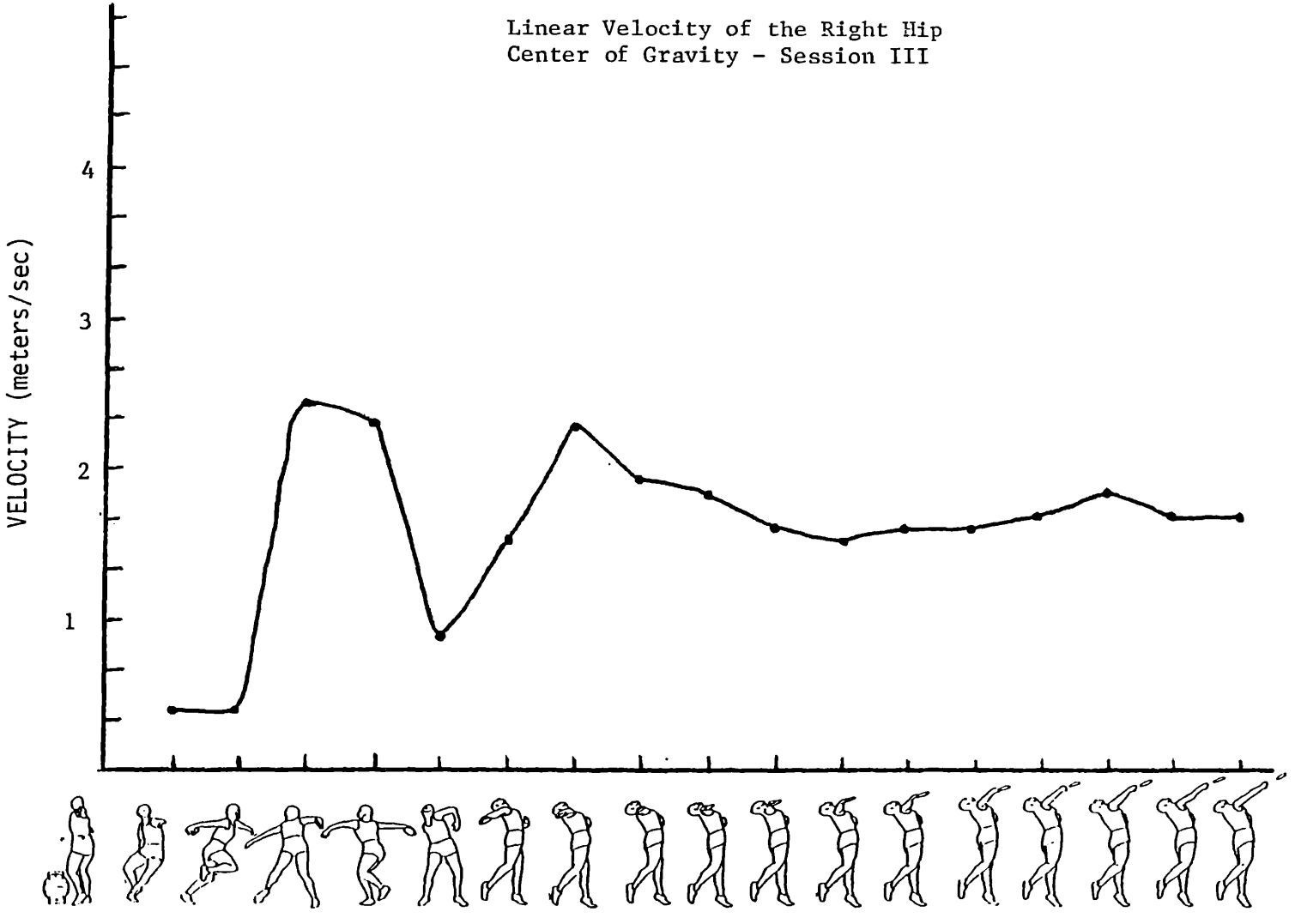


Figure 23

Linear Velocity of Right Hand
Center of Gravity - Session I

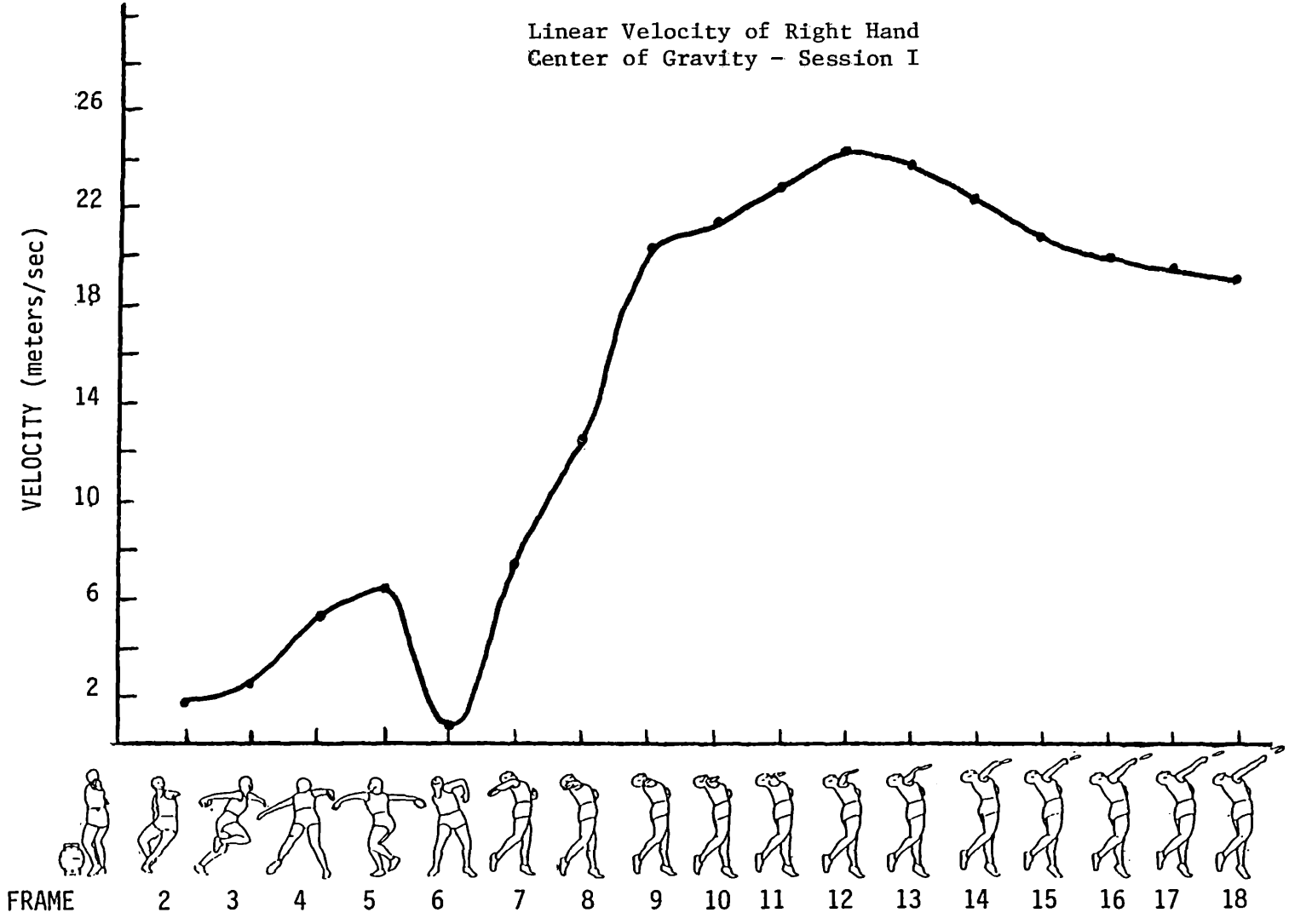


Figure 24

Linear Velocity of Right Hand
Center of Gravity - Session II

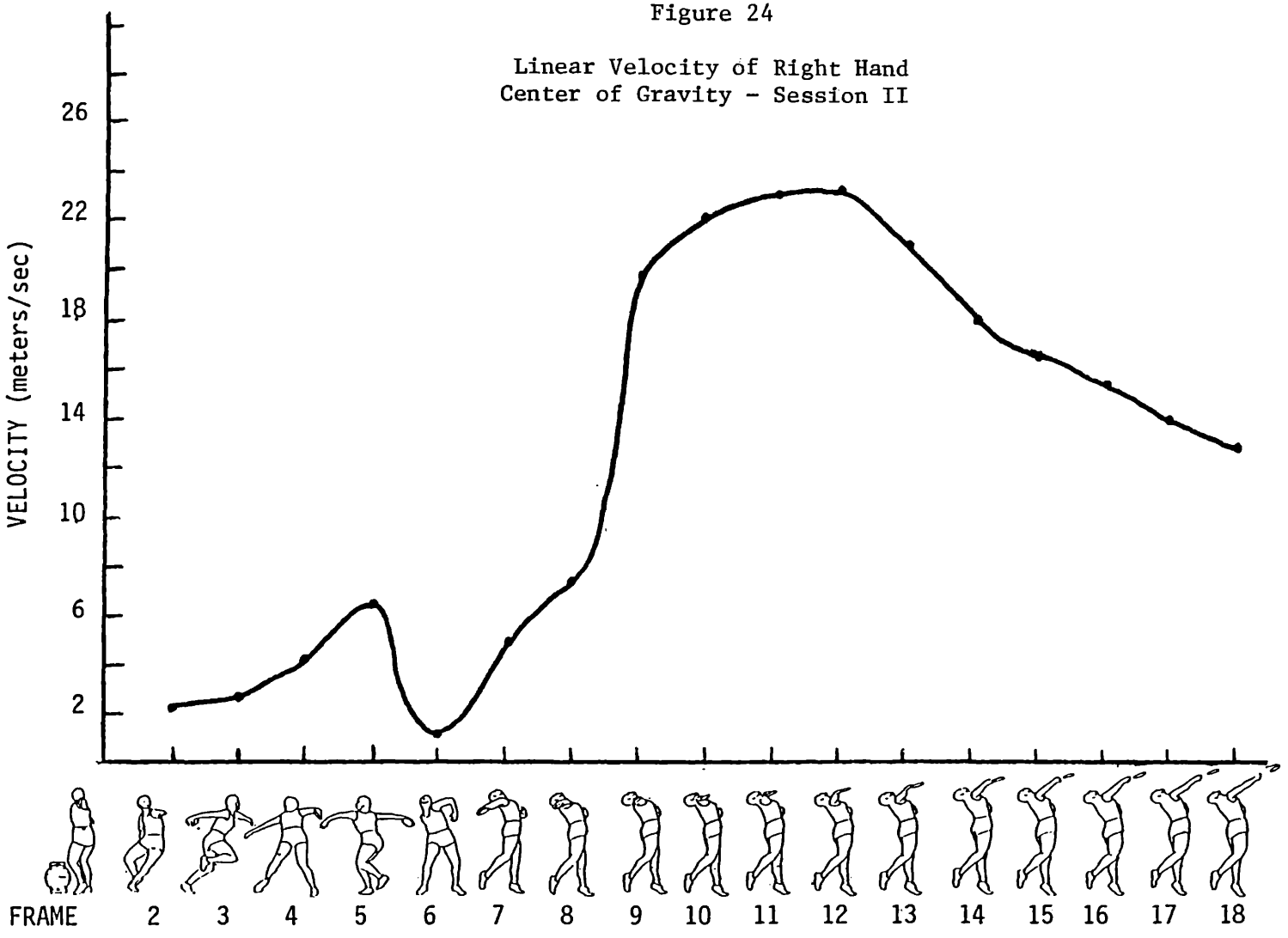
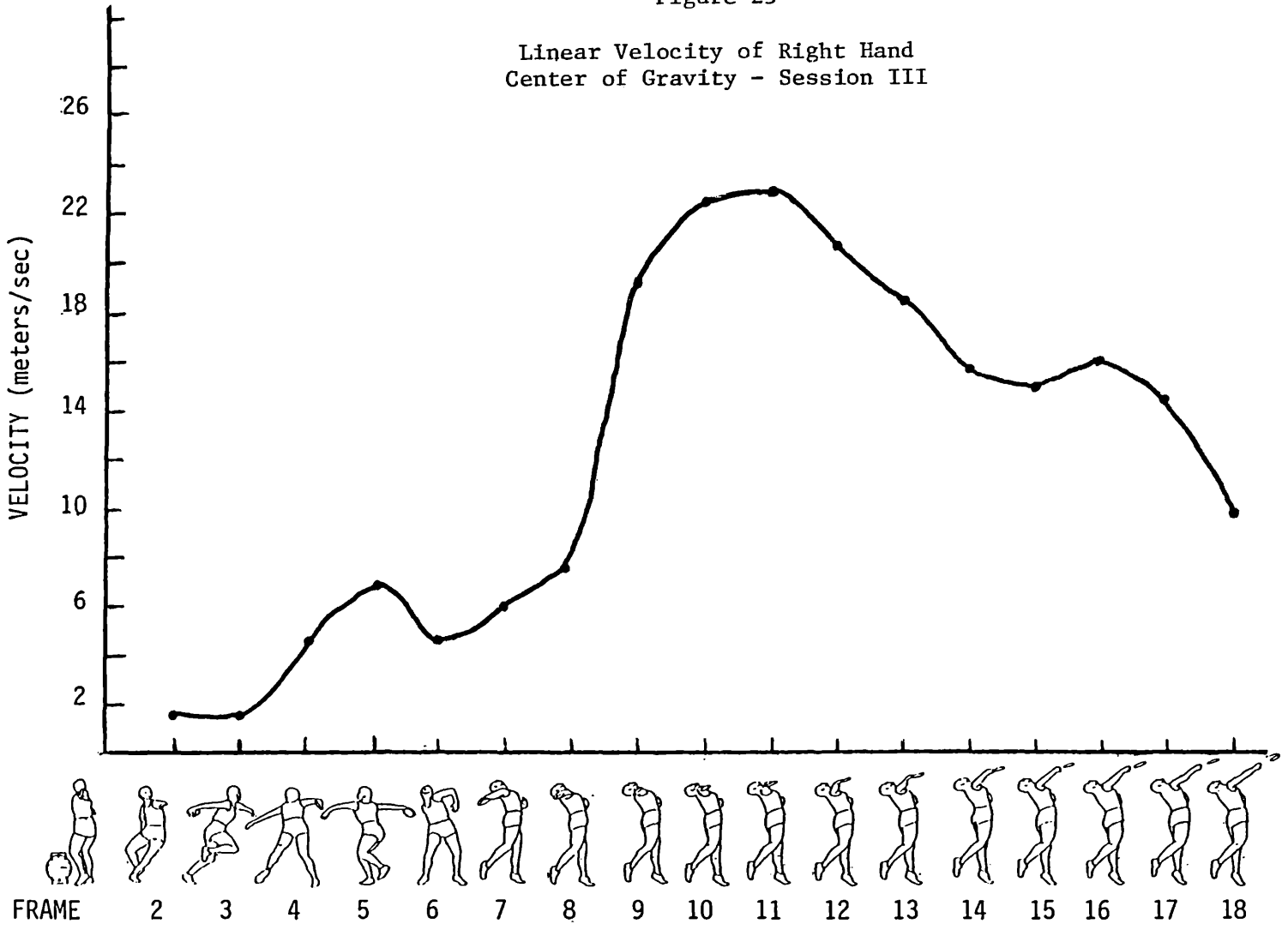


Figure 25

Linear Velocity of Right Hand
Center of Gravity - Session III



Center of Gravity

The center of gravity of the thrower's body throughout the throw is presented in Figures 26-28. These numbers were converted to a life-size scale from the digitized coordinates. The following observations were made from this study pertaining to the thrower's center of gravity during the throw.

Backswing

1. The center of gravity of the thrower completing the backswing in Trial 3, Session I, was 1.1 meters in height.
2. The center of gravity of the thrower completing the backswing in Trial 2, Session II, was 1.0 meters in height.
3. The center of gravity of the thrower completing the backswing in Trial 5, Session III, was .99 meters in height.

Left Foot Pivot to Middle of Ring

1. The center of gravity of the thrower pivoting to the middle of the ring in Trial 3, Session I, was 1.46 meters in height..
2. The center of gravity of the thrower pivoting to the middle of the ring in Trial 2, Session II, was .88 meters in height.
3. The center of gravity of the thrower pivoting to the middle of the ring in Trial 5, Session III, was

.89 meters in height.

Right Foot in Middle of Ring

1. The center of gravity of the thrower placing the right foot down in the middle of the ring in Trial 3, Session I, was 1.01 meters in height.
2. The center of gravity of the thrower placing the right foot down in the middle of the ring in Trial 2, Session II, was .83 meters in height.
3. The center of gravity of the thrower placing the right foot down in the middle of the ring in Trial 5, Session III, was .93 meters in height.

Release of Discus

1. The center of gravity of the thrower at the release of the discus in Trial 3, Session I, was 1.19 meters in height.
2. The center of gravity of the thrower at the release of the discus in Trial 2, Session II, was 1.11 meters in height.
3. The center of gravity of the thrower at the release of the discus in Trial 5, Session III, was 1.13 meters in height.

Figure 26

Path of the Body Center of Gravity - Session I

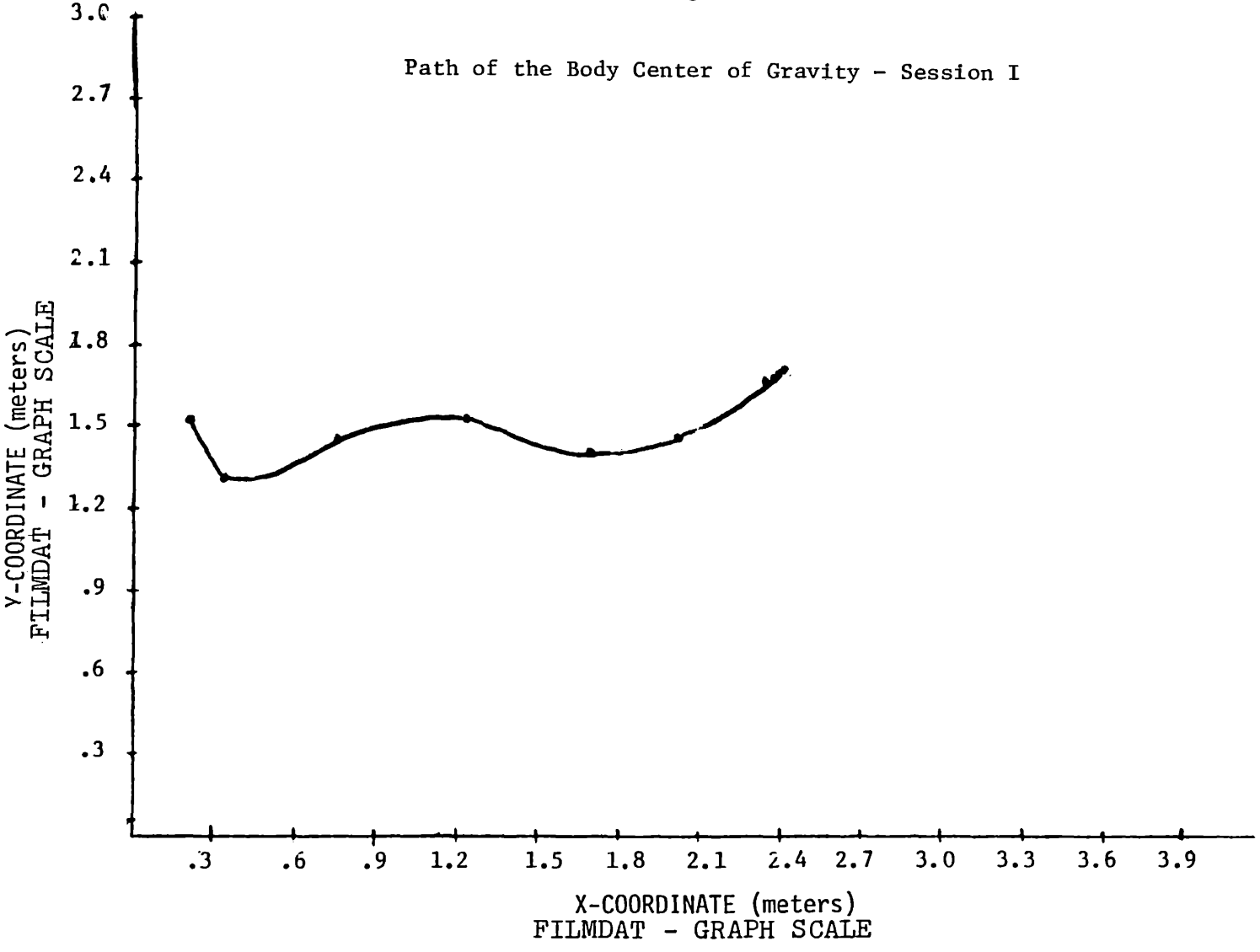


Figure 27

Path of the Body Center of Gravity - Session II

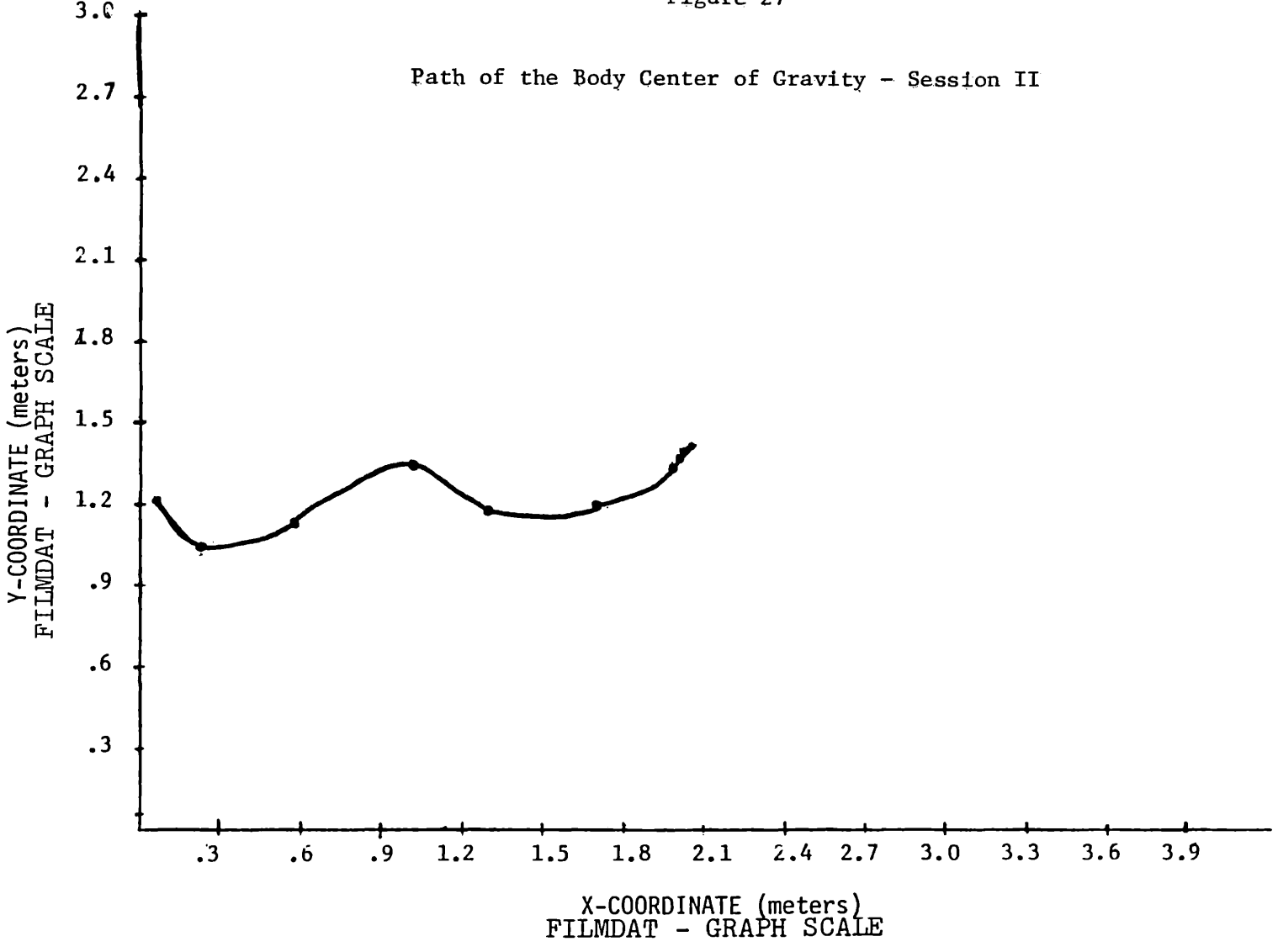
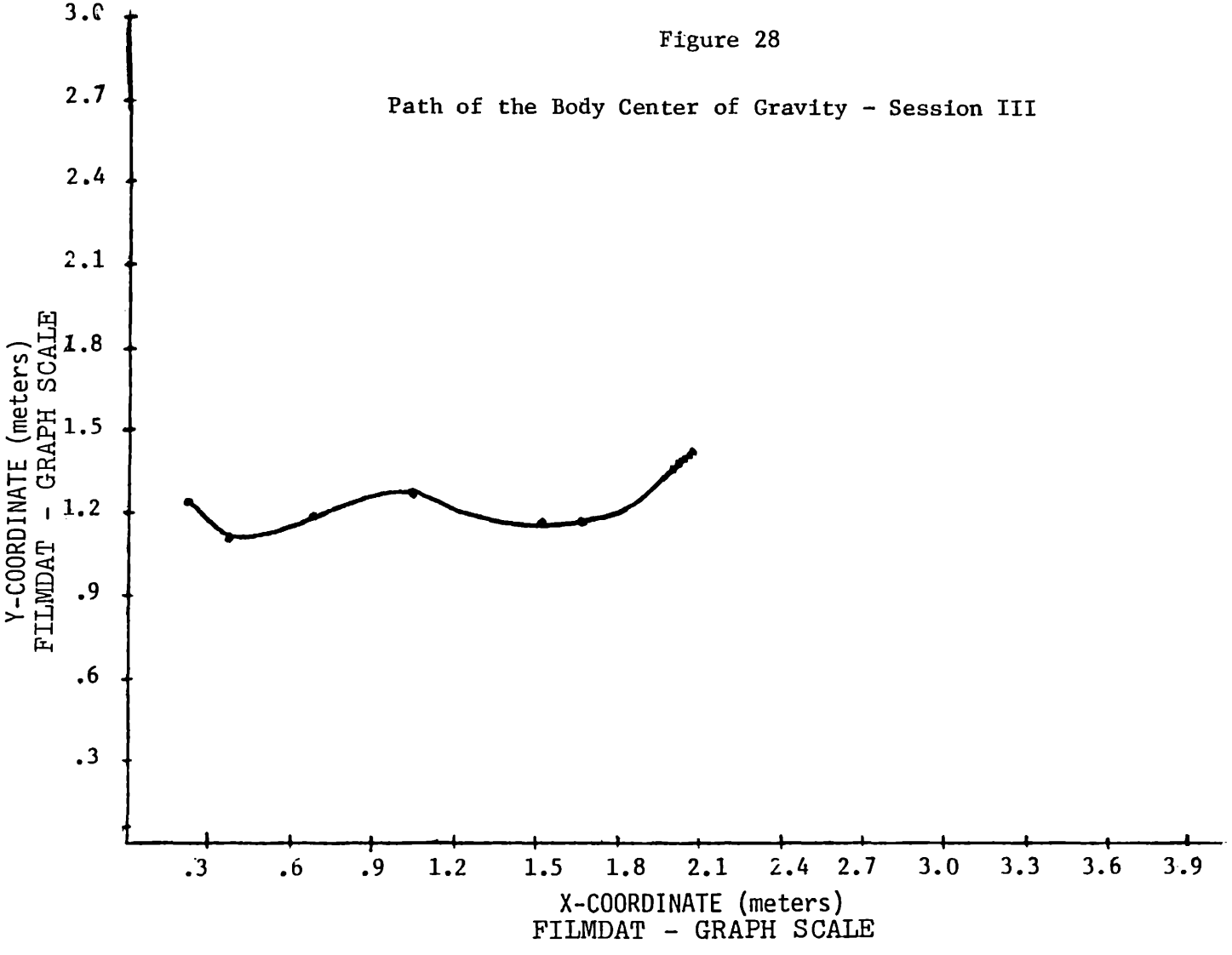


Figure 28

Path of the Body Center of Gravity - Session III



Path of Discus

The path of the discus throughout the throw is presented in Figures 29–31. These numbers were converted to a life-size scale from the digitized coordinates. The following observations were made from this study pertaining to the path of the discus during the throw.

Left Foot Pivoting to Middle of Ring

1. The path of the discus as the thrower pivoted to the middle of the ring in Trial 3, Session I, was 1.49 meters in height and trailing the rotational movement of the body.
2. The path of the discus as the thrower pivoted to the middle of the ring in Trial 2, Session II, was .91 meters in height and trailing the rotational movement of the body.
3. The path of the discus as the thrower pivoted to the middle of the ring in Trial 5, Session III, was .96 meters in height and forward of the rotational movement of the body.

Right Foot in Middle of Ring

1. The path of the discus as the thrower placed the right foot down in the middle of the ring in Trial 3, Session I, was 1.34 meters in height and trailing the rotational movement of the body.

2. The path of the discus as the thrower placed the right foot down in the middle of the ring in Trial 2, Session II, was 1.13 meters in height and trailing the rotational movement of the body.
3. The path of the discus as the thrower placed the right foot down in the middle of the ring in Trial 5, Session III, was 1.22 meters in height and trailing the rotational movement of the body.

Release of Discus

1. The path of the discus as the thrower released the discus in Trial 3, Session I, was 1.77 meters in height and forward of the rotational movement of the body.
2. The path of the discus as the thrower released the discus in Trial 2, Session II, was 1.72 meters in height and forward of the rotational movement of the body.
3. The path of the discus as the thrower released the discus in Trial 5, Session III, was 1.75 meters in height and forward of the rotational movement of the body.

Figure 29

Path of the Center of Gravity of
the Discus - Session I

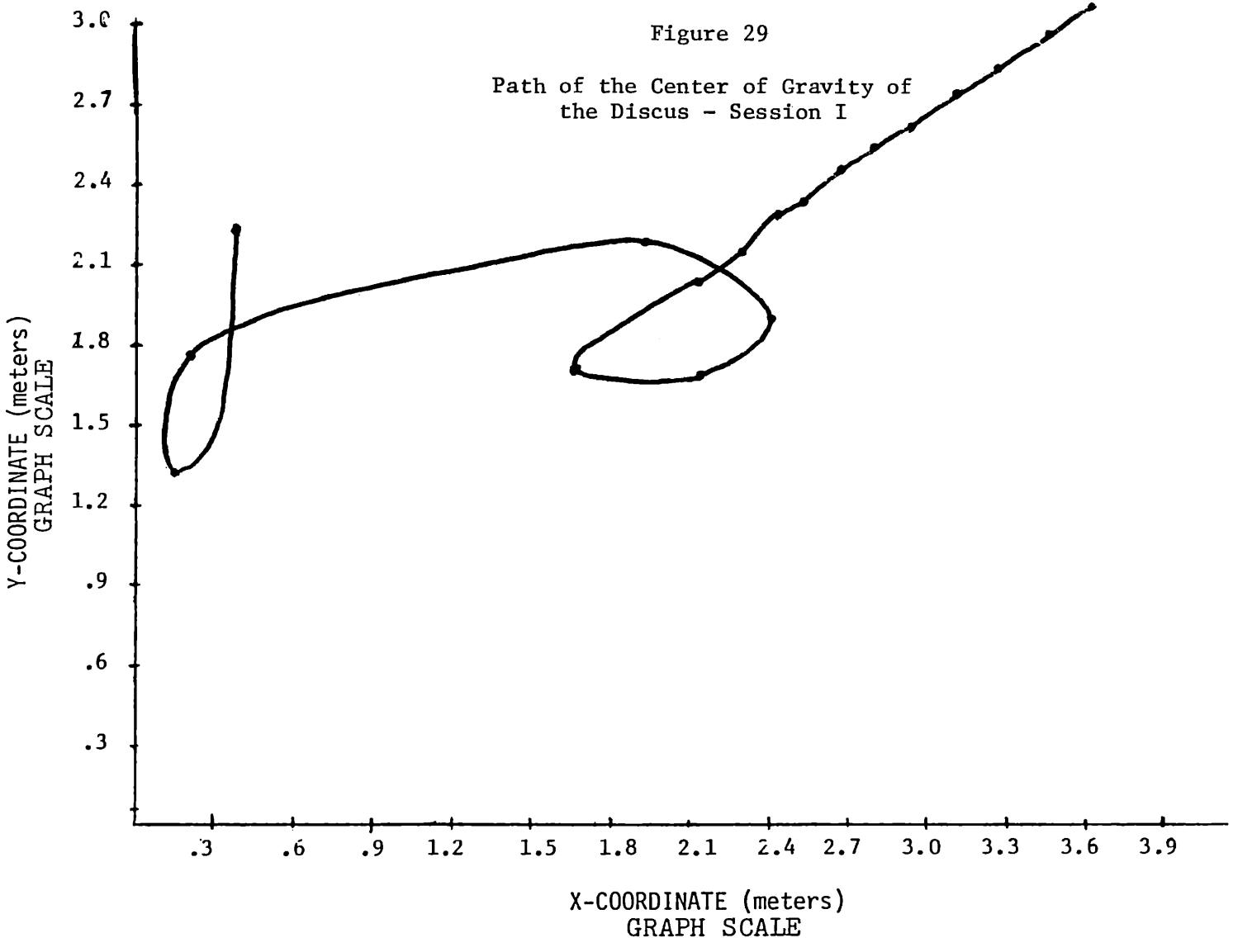


Figure 30

Path of the Center of Gravity of
the Discus - Session II

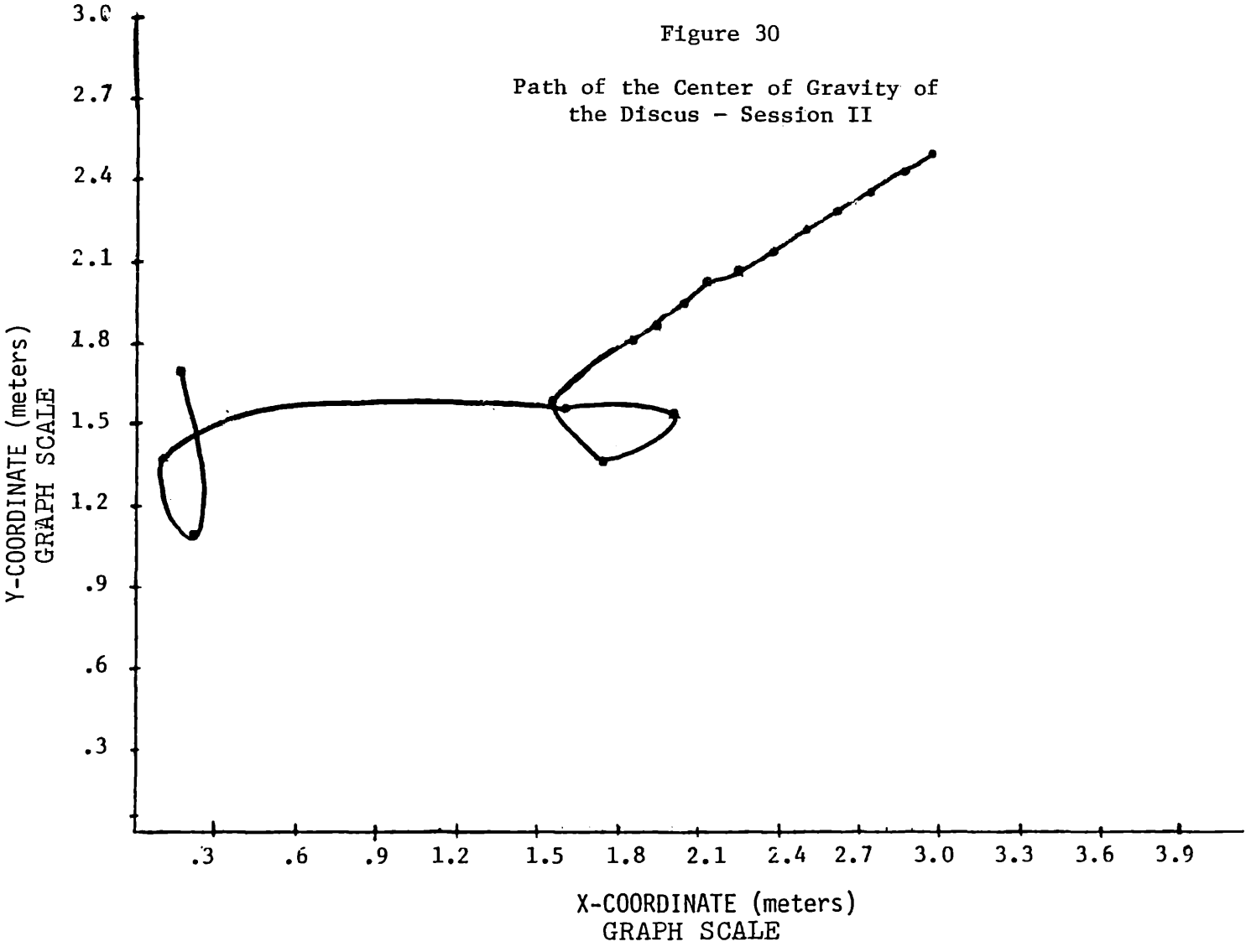
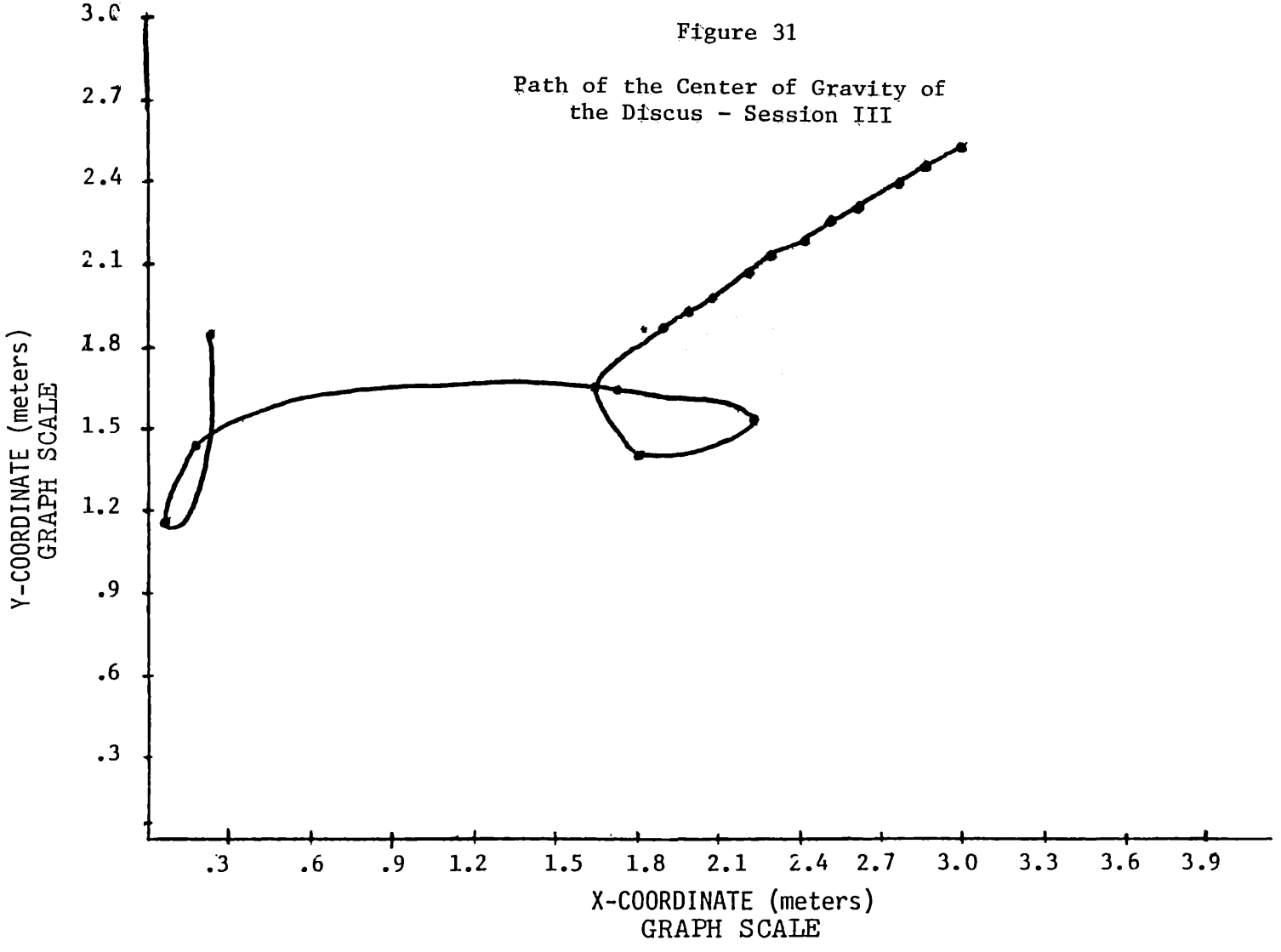


Figure 31

Path of the Center of Gravity of
the Discus - Session III



Angles of Trunk Inclination

The angle of the trunk inclination to the horizontal in the last frame in which both feet were on the ground at the back of the circle, and in the frame in which the right foot was placed down in the center of the circle are presented in Figures 32-33, respectively. The following observations were made from this study pertaining to the angles of trunk inclination in the frames listed above.

Back of the Circle

1. The angle of the thrower's trunk inclination in the last frame in which both feet were on the ground at the back of the circle in Session I was 95.96°.
2. The angle of the thrower's trunk inclination in the last frame in which both feet were on the ground at back of the circle in Session II was 101.15°.
3. The angle of the thrower's trunk inclination in the last frame in which both feet were on the ground at the back of the circle in Session III was 90.21°.
4. The average angle of the thrower's trunk inclination in the last frame in which both feet were on the ground at the back of the circle in Sessions I, II, and III was 95.64°.

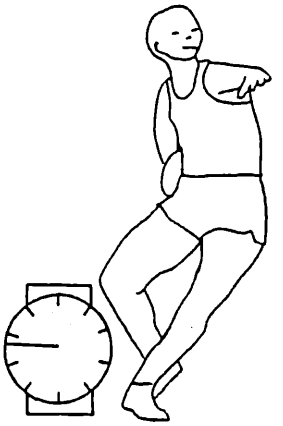
Center of the Circle

1. The angle of the thrower's trunk inclination when the right foot was placed down in the center of the circle in Session I was 111.63°.

2. The angle of the thrower's trunk inclination when the right foot was placed down in the center of the circle in Session II was 108.32^{o}.
3. The angle of the thrower's trunk inclination when the right foot was placed down in the center of the circle in Session III was 101.87^{o}.
4. The average angle of the thrower's trunk inclination when the right foot was placed down in the center of the circle in Sessions I, II, and III was 107.27^{o}.

Figure 32

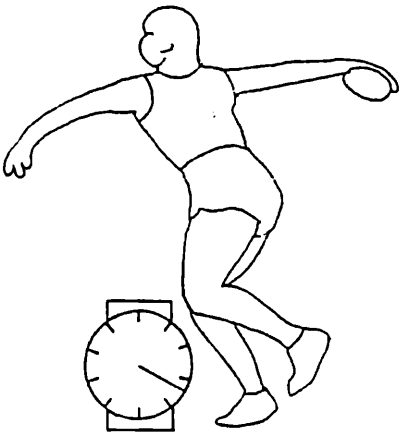
Angle of Trunk Inclination to Horizontal - Both Feet On the Ground at the Back of the Circle



	Angle (^{o})
Session I	95.96
Session II	101.15
Session III	90.21
AVERAGE	95.64

Figure 33

Angle of Trunk Inclination to Horizontal - Right Foot in the Center of the Circle



	Angle (^{o})
Session I	111.63
Session II	108.32
Session III	101.87
AVERAGE	107.27

Angle of Right Knee

The angle of the right knee in the frame in which the knee was at its greatest height stepping to the center of the circle is presented in Figure 34. The following observations were made from this study pertaining to the angle of the right knee in the frame listed above.

1. The angle of the thrower's right knee at its highest point stepping to the center of the circle in Session I was 127.5^{o}.
2. The angle of the thrower's right knee at its highest point stepping to the center of the circle in Session II was 131.0^{o}.
3. The angle of the thrower's right knee at its highest point stepping to the center of the circle in Session III was 132.0^{o}.
4. The average angle of the thrower's right knee at its highest point stepping to the center of the circle in Sessions I, II, and III was 130.17^{o}.

Angle of Right Arm

The angle from the vertical axis (midline of trunk) of the right arm at the point of release of the discus is presented in Figure 35. The following observations were made from this study pertaining to the angle from the vertical axis of the trunk to the right arm at the point of release of the discus.

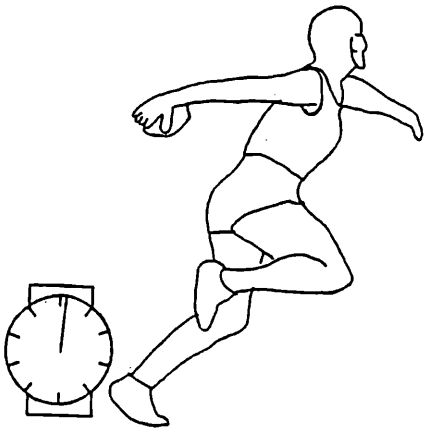
1. The angle of the thrower's right arm at the point of

release of the discus in Session I was 94.0°.

2. The angle of the thrower's right arm at the point of release of the discus in Session II was 117.0°.
3. The angle of the thrower's right arm at the point of release of the discus in Session III was 118.0°.
4. The average angle of the thrower's right arm at the point of release of the discus in Sessions I, II, and III was 109.66°.

Figure 34

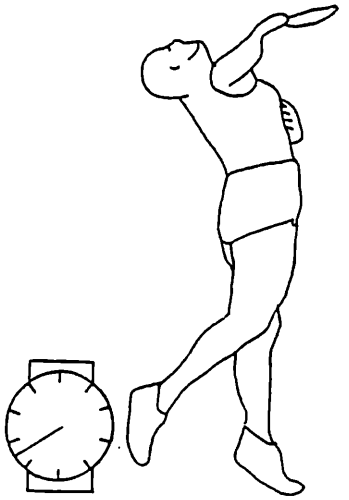
Angle of Right Knee - At Highest Point
Stepping to the Center of the Circle



	Angle (°)
Session I	127.50
Session II	131.00
Session III	132.00
AVERAGE	130.17

Figure 35

Angle of Right Arm From the Vertical
Axis (Trunk) at Release



	Angle (°)
Session I	94.0
Session II	117.0
Session III	118.0
AVERAGE	109.66

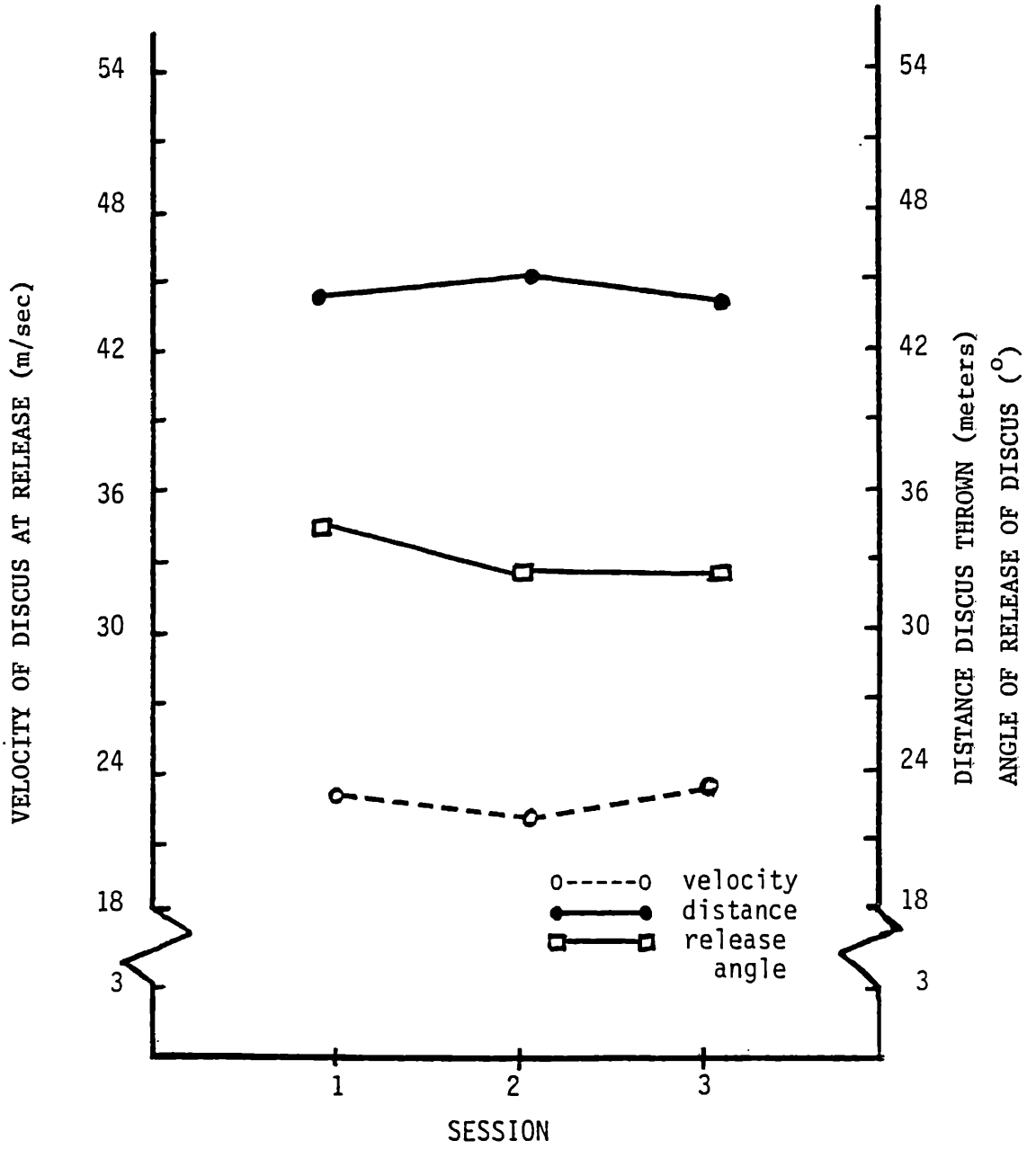
Angle of Release

The angle of the release of the discus is presented in Figure 36. The following observations were made from this study pertaining to the angle of the release of the discus.

1. The angle of the release of the discus in Session I was 34.0^{o}.
2. The angle of the release of the discus in Session II was 32.0^{o}.
3. The angle of the release of the discus in Session III was 32.0^{o}.

Figure 36

Velocity of Discus at Release, Angle of Release and Distance Discus Thrown



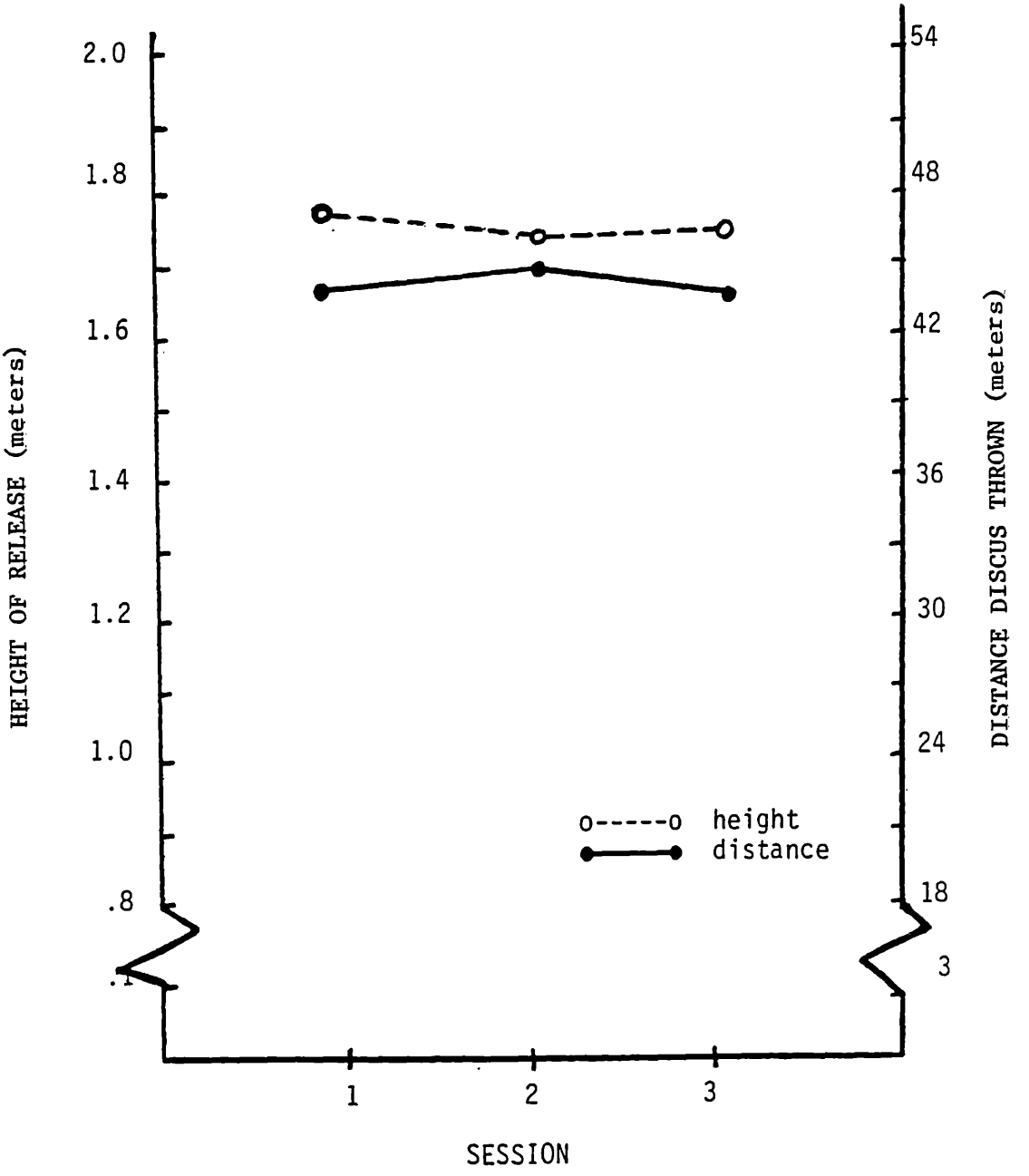
Height of Release

The height of the discus at the moment of release is presented in Figure 37. The following observations were made from this study pertaining to the height of the discus at the moment of release.

1. The height of the discus at the moment of release in Session I was 1.77 meters.
2. The height of the discus at the moment of release in Session II was 1.72 meters.
3. The height of the discus at the moment of release in Session III was 1.75 meters.

Figure 37

Height of Release of Discus and
Distance Thrown



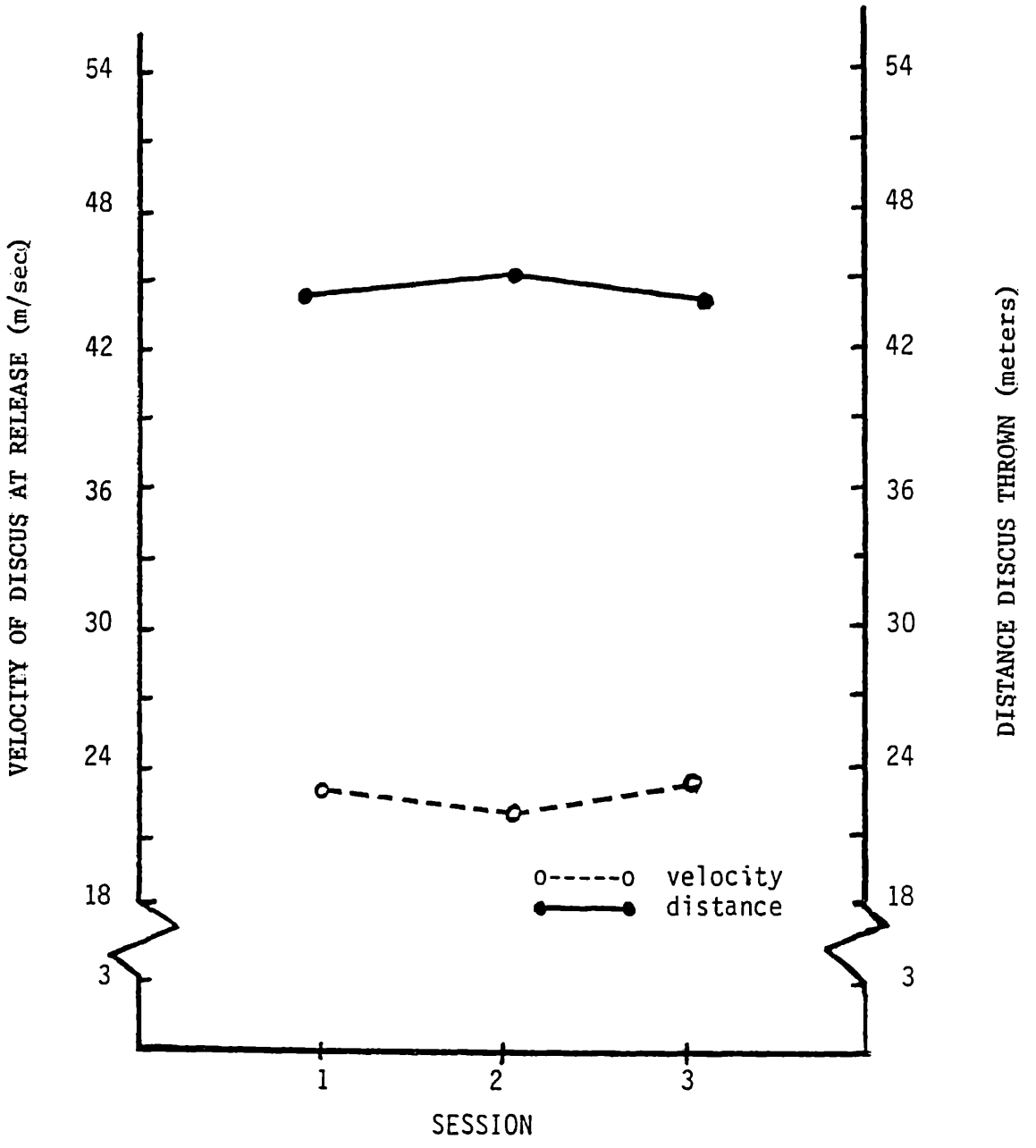
Velocity of Discus at Release

The velocity of the discus at the release point is presented in Figure 38. The following observations were made from this study pertaining to the velocity of the discus at the release point.

1. The velocity of the discus at the release point in Session I was 22.9667 meters per second.
2. The velocity of the discus at the release point in Session II was 22.61 meters per second.
3. The velocity of the discus at the release point in Session III was 22.9885 meters per second.

Figure 38

Velocity of Discus at Release and
Distance Thrown



Discussion of Findings

The results of the study indicate that specific plyometric training may alter an athlete's discus throwing technique. These alterations were found to be both positive and negative toward the performance of a successful throw. Comparisons to the literature were not always valid because the subject was female and the literature predominately referred to male subjects. Alterations in technique were noted in the following parameters of a successful discus throw:

1. Stride length
    a. Stride length of the first step towards the center of the circle.
    b. Stride length of the second step from the center of the circle to the front.
2. Time factors
    a. Time taken for the first step.
    b. Time taken for the second step.
    c. Time taken from the feet being positioned on the second step to the release of the discus.
    d. Time taken for the entire throw.
3. Linear velocity resultants of selected body segments during the entire throw.
4. The center of gravity at selected points of the throw.
5. Path of the discus throughout the throw.
6. Angle of the trunk inclination to the horizontal

in the last frame in which both feet were on the ground at the back of the circle and in the frame in which the right foot was placed down in the center of the circle.

7. Angle of the right knee in the frame in which the knee was at its greatest height stepping to the center of the circle.
8. Angle from the vertical axis (midline of the trunk) of the right arm at the point of release of the discus.
9. Angle of release of the discus.
10. Height of the discus at the moment of release.
11. Velocity of the discus at the release point.

Stride Length

Ward (72) recommended the stride length for an elite male thrower be 56 inches or 142.24 centimeters, while Doherty (12) recommended 54 inches or 137.16 centimeters. The stride length for the female subject in every trial was well below these recommendations. The subject had farther throws when the stride length was greater, indicating the importance of stride length to a successful throw.

The third filming session of the study revealed the shortest first steps and the shortest throws. The subject's training on stepping to the center of the circle from an elevation eliminated a strong drive from the left leg, an important factor for propelling the body during this movement.

The literature stated that the stride length of the second

step was a comfortable distance. Ward (72) specifically suggested a stride length of 44 inches or 111.76 centimeters for the second step. The subject's stride length was consistent but again well below the recommendation. The length of the second step was not a factor in the success of the throws. While the stride length remained consistent, the distance of the throws varied considerably.

Time Factors

The literature revealed that the faster an athlete can travel through the ring under control, the farther the throw. The time elapsed for the first and second steps by the subject did not vary when comparing the three testing sessions. Since the time for the first step remained consistent, yet the distance diminished, it can be noted that the plyometric training did not quicken the first step. In addition it can be noted that there was very little driving force propelling the thrower to the center of the circle after plyometric training.

The average time taken for the entire throw of Session II was shorter than the time of the other two sessions. The average distance that the discus was thrown during Session II was also greater, indicating that the subject traveled faster through the ring and achieved greater distances on the throws. This can be attributed to the plyometric training of the study. The subject was trained to immediately extend and drive upward after stepping to the middle of the circle from a five inch elevation. This quickened the reaction time required to respond to the eccentric contractions.

According to Powell (56) both feet should be placed down simultaneously on the last step of the throw. In the study, during the farthest throw of each session there was a consistent time lapse for the second step. In all of the throws the time-elapsed for the second step was greater than the time-elapsed for the first step, indicating a poor base. A quicker last step would have allowed a more stable base from which to throw.

Linear Velocities

The major factor involving linear velocity in the literature was the statement that the sequence of increasing velocity prior to the release of the discus began with the right ankle and continued to the right knee, right hip, and ultimately to the right hand. In all three of the farthest throws the linear velocities of the subject's right ankle and knee increased from five frames prior to release until the release of the discus. The right hip, however, did not contribute to the sequential movement in any of the three farthest throws. The linear velocity of the right hip decreased from five frames prior to the release to the release of the discus. The linear velocity of the right hip was also less than that of the right ankle and knee. The linear velocity of the hip should have been greater than both the linear velocity of the ankle and the knee. The linear velocity of the right hand increased from five frames prior to the release until the release of the discus. The increase would have been greater if the entire body had been utilized instead of only the right arm.

The subject's linear velocities of the right ankle and right knee in the three farthest throws did not decrease after the release of the discus. This indicated that the subject did not stop the rotation of these joints which was necessary to transfer the sequential movement upward to the right hip and the right hand. The poor base established by the time required to take the last step my be attributed to this fault.

Center of Gravity

An athlete is able to apply force on the discus for a greater distance if a full backswing is taken at the back of the discus circle. Ward (72) found that a high center of gravity during the backswing enabled the discus to be brought back as far as possible. In the farthest throw of each session the subject's center of gravity was high during the backswing. Hence, the subject was able to apply force on the discus for a greater distance.

Ward (72) stated that the athlete's center of gravity was at its lowest point while pivoting over the left foot at the back of the circle. In the farthest throw of each session, the subject's center of gravity was at its lowest point pivoting over the left foot. The subject achieved even greater depth in the final two sessions, which can be attributed to plyometric training. The subject was able to comfortably pivot with a lower center of gravity from the back of the circle. This was due to the fact that very little left leg drive was needed to propel the body from the elevated surface to the center of the circle. This allowed the subject to use more of the body to

lift the discus in subsequent movements in the throw.

Gemer (22) found that the force of landing in the center of the circle should create a slight settling of the entire body. Except during the pivot on the left foot, the subject's center of gravity was at its lowest point as the right foot was placed down in the middle of the circle. This indicated that the settling occurred, creating torque prior to the release of the discus.

The literature observed that the effort of lifting the discus during release must come from the entire body and not merely the right arm. The subject's center of gravity in the farthest throw of each session was at its greatest height at the moment of release. This indicated that the entire body was involved in the release of the discus and not merely the right arm.

Path of Discus

Ward (72) recommended that as the athlete pivots over the left foot at the back of the circle, the discus be the same height as the body's center of gravity. This will shorten the right arm's radius of rotation which increases the speed of rotation from the back of the circle. In the farthest throw of each session, the discus was at the same height as the subject's center of gravity at this point in the throw. From this position the subject rotated quickly from the back of the circle.

Ward (72) further stated that as the thrower steps toward the center of the circle the discus should gradually rise. This increases the radius of rotation and aids in stepping straight across the

circle by slowing down rotation. When comparing the farthest throw of each session, only in Session I did the discus rise as the subject stepped to the center of the circle. This indicated that only in Session I did the subject drive straight to the center of the circle from the back of the ring. In the other two sessions movement was inefficient at this phase of the throw. It would appear that the plyometric training inhibited the driving action of the left leg toward the center of the ring.

The literature stated that when the right foot was placed in the center of the circle, the discus should be at its highest point prior to the release. During the farthest throw of Sessions I and III, the subject allowed the discus to reach a higher point while stepping to the center of the circle. This action distracted from the subject's radius of rotation prior to the delivery phase of the throw. The discus reached its greatest height prior to the release of the discus as the right foot was placed down in the center of the circle on Session II's farthest throw. The subject was able to achieve a greater radius of rotation as a result of this action.

The discus must be gradually lifted throughout the delivery of the discus, and not merely upon the release. This gradual action insures that the entire body, not just the right arm, is propelling the discus to its proper height. In the farthest throw of each session the discus was brought up gradually to the release point. This indicated that the height had been a culmination of the entire body effort.

The literature stated that the discus must trail the body's

axis of rotation. This was accomplished in all phases of the farthest throw of each session except in Session III. As the subject pivoted around the left foot in the back of the circle the discus came forward of the axis of rotation. The indication would be that the subject held the discus down too long, keeping a shortened radius of rotation for a longer period than is necessary to overcome inertia at the back of the circle.

Angles of Trunk Inclination

The literature suggested that at the back of the circle the trunk be erect (90^{o}) with a slight tilt for balance. Balance continues to be an important element throughout the pivoting movement over the left foot.

Carr (8) and Morris (44) observed that an erect trunk over a lower body leaning to the center of the circle will aid in linear momentum without excess motion. In Sessions I and III the subject's angle of trunk inclination to the horizontal during the farthest throw of each session was consistently near 90^{o}. On the farthest throw of Session II the subject had a greater angle of trunk inclination, but was still erect. The subject created good linear momentum in all three throws without excess motion.

Morris (44) stated that the trunk's inclination to the horizontal while placing the right foot in the center of the circle should allow for a straight line to be drawn from the right shoulder to the right hip and to the ball of the right foot. Ward (72) observed that for elite male throwers a 36^{o} angle (126^{o} from the

horizontal) of the trunk from the vertical in the opposite direction of the throw would keep the trunk over the ball of the right foot.

The subject's angle of trunk inclination during the farthest throw in each session was great enough to place much of the trunk over the ball of the right foot. The subject did not have the trunk inclination that Ward (72) suggested for elite male throwers, due to lesser leg strength. The subject had sufficient leg strength to rotate effectively; but greater leg strength would allow a larger angle of inclination, permitting more weight over the drive leg.

Angle of Right Knee

The Law of Rotary Momentum states that rotational velocity is increased in proportion to the shortening of the radius. This would indicate that a discus thrower would seek to shorten the radius of a limb to increase its velocity. To quicken the step to the center of the circle, Ward (72) suggested decreasing the angle of the right knee to 135°. The angle of the subject's right knee during the farthest throw of each session aided in shortening the radius of the right leg and thus increased the velocity of the step.

Angle of Right Arm

Morris (44) observed that a discus thrower must keep the discus as far from the longitudinal axis of the body as possible to insure optimal rotary momentum. The literature also recommended releasing the discus at shoulder height. In the farthest throw of each session the discus was released slightly above shoulder height. In addition, the angle of the right arm from the vertical axis of the

trunk insured optimal rotary momentum.

Angle of Release

Ecker (15) and Dyson (14) recommended a 34^{o}-40^{o} angle of release of the discus. Ecker (15) further recommended that a greater speed of release dictated a lower angle of release. Teraud (66) lowered Ecker's and Dyson's optimal range to 25^{o}-40^{o}, with 36^{o} being the optimal angle of release. Jarver (29) also felt that the lower range of 30^{o} to 35^{o} was optimal. Webb (77) observed that 39^{o} was optimal, adding or subtracting a few degrees. The subject's angle of release for the farthest throws of each session were within Terauds' (66) and Jarver's (29) recommendations. The subject's velocity of release (22.9 meters/second) indicated that the angle of release should ideally be a few degrees higher.

Height of Release

The literature stated that the height of the discus at the moment of release should be natural to the thrower, or at shoulder level. The subject released the discus on the farthest throw of each session slightly higher than shoulder level. The higher release increased the range of the parabolic flight of the discus.

Velocity of Release

The literature stated that the velocity of the discus at the release point was the most crucial element in determining the success of a discus throw. Ward (73) found that elite male throwers released the discus at 80-85 feet per second or 24-25.5 meters per

second. The female subject was slightly below this recommendation for elite male throwers.

CHAPTER V

SUMMARY

Statement of Purpose

The purpose of this study was to describe the mechanical components of the discus throw; and more specifically, to investigate the altering effects of plyometric training within the discus ring. A comparison of the movement patterns of a selected female discus thrower at the University of Kansas was made before, during, and after plyometric training.

The components of the discus throw that were examined in the study were the following:

1. The stride length of each step taken within the discus circle.
2. The time factors of various components of the throw.
3. Linear velocity resultants of selected body segments during the entire throw.
4. The center of gravity at selected points of the throw.
5. Path of the discus throughout the throw.
6. Angle of the trunk inclination to the horizontal in the last frame in which both feet were on the ground at the back of the circle and in the frame in which the right foot was placed down in the center of the circle.

7. Angle of the right knee in the frame in which the knee was at its greatest height stepping to the center of the circle.
8. Angle from the vertical axis (midline of the trunk) of the right arm at the point of release of the discus.
9. Angle of release of the discus.
10. Height of the discus at the moment of release.
11. Velocity of the discus at the release point.

The farthest throw from each session was selected for a more in-depth computer study.

A member of the University of Kansas women's track and field team was selected for the study. The subject was filmed throwing the discus before, midway, and after specific plyometric training. The subject was filmed for six throws in each of the three sessions. Each throw was filmed perpendicular to the point of release. The filming was done at a speed of 200 frames per second.

Selected biomechanical components of the discus throw were analyzed and described with the aid of two computer programs and manual readings from film tracings. More specifically, the components were used to investigate the altering effects of plyometric training. One computer program provided the body center of gravity of each throw except the farthest throw of each session. These throws were analyzed by another computer program which provided body and segmental centers of gravity, angle of trunk inclination, linear velocities of selected segments, and various time factors. Measurements of

angles, distance, and the velocity of the discus were obtained directly from the tracings by the use of a protractor and ruler. Tables and figures were used in order to describe as best as possible the intricacies and the altering effects of plyometric training on the subject's throws.

The findings of this study were:

1. The subject's stride lengths were smaller than those lengths recommended in the literature. Longer throws occurred in the trials with longer stride lengths. After plyometric training the stride length of the first step diminished.
2. The time elapsed for the first step remained consistent for each trial, yet the distance of the step diminished. After plyometric training the driving action of the left leg in the back of the ring diminished.
3. The time elapsed for the entire throw during Session II shortened while the distance improved. The subject's training with plyometrics enhanced reaction time to the eccentric contraction in the middle of the ring.
4. The time elapsed for the second step was longer than the literature recommended. After plyometric training the leg drive of the subject diminished.
5. The subject's linear velocity of the right ankle and right knee increased prior to the release of the discus in all three sessions. The right hip did not increase, however, breaking the sequential chain from

the right ankle to the right hand in all three sessions.

6. The subject's linear velocity of the right ankle and right knee did not decrease after the release of the discus in any of the three sessions. This indicated that the subject did not stop the rotation of these joints, thus the transfer of sequential movement to the right hip did not occur. The cause was the poor base created by the extended amount of time required for the second step.
7. The highest point of the subject's center of gravity was during the backswing, while the lowest point was during the pivot over the left foot at the back of the circle. The subject was able to pivot with a more desirable lower center of gravity after plyometric training. A lower center of gravity was maintained, however, since no driving action was necessary to propel the subject to the center of the circle. Hence, the advantage of the lower center of gravity after plyometric training was not fully utilized by the subject.
8. The subject's center of gravity settled in the center of the circle as the literature recommended and then rose to its greatest height with the release of the discus.
9. The discus was at the same height as the subject's center of gravity while the subject pivoted over

the left foot. This was in agreement with the literature. Only before plyometric training took place did the discus rise to aid in the drive to the center of the circle. The plyometric training inhibited the driving action from the back of the circle.

10. The discus was lifted gradually throughout the throw. The discus trailed the subject's axis of rotation except during the pivot over the left foot in Session III. The discus remained low too long, increasing the speed of rotation and creating improper body position.
11. During all three sessions the angle of the subject's trunk inclination to the horizontal with both feet on the ground at the back of the circle was in the erect (90^{o}) position recommended by the literature.
12. The angle of the subject's trunk inclination to the horizontal, as the right foot was placed in the center of the circle, was well above the ball of the right foot in all three sessions as stated in the literature.
13. The angle of the right knee at its height stepping to the center of the circle shortened the radius of the right leg, enabling a quick step.
14. The angle of the subject's right arm at the release of the discus insured optimal rotary momentum during all three sessions.

15. The subject's angle of release was within the optimal range suggested by the literature for elite male throwers.
16. The subject released the discus slightly higher than shoulder level during each of the sessions.
17. The subject's velocity of release was slightly below the literature's recommendation for elite male throwers during each of the sessions.

Conclusions

Within the stated scope and limitations of the study, the following conclusions were drawn:

1. After plyometric training, the subject's lower center of gravity at the back of the circle indicated a more flexed left leg. The greater the left leg was flexed, the greater the contraction of the muscles of the leg, or the greater the potential available to be used by extending the left leg. Even though the subject assumed this superior position, the potential energy was not used by the thrower. Powerfully extending the left leg would have driven the lower body of the thrower to the center of the circle, while the trailing upper body remained relatively passive to develop torque (or more potential rotational energy). Instead, the subject had been trained to merely step passively with the entire body to the center of the circle by descending a

given height. This left leg drive to the center of the circle which is vital to subsequent phases of the throw was negated.

2. The time elapsed for the entire throw decreased after plyometric training. This was due to the improved reaction time to eccentric contractions during the throw, a primary objective of plyometric training. The subject had been trained to immediately drive vertically with the lower body after the forced contraction of stepping to the center of the circle from the plyometric platform.
3. Because of the longer amount of time taken to place the left foot down on the last step, a proper throwing base was not established. The left foot did not aggressively travel to the front of the circle during the final step of the throw because of its passive drive from the back of the circle. The left foot should be set down quickly to halt the forward progress of the body. Since the left foot placement was delayed, the right leg continued to use the stored energy, traveling forward. Ideally, the energy should be transferred upward through the body. Due to poor timing on the left foot placement, inefficient energy use occurred. Therefore, the entire body was not used to lift the discus prior to the release.

4. Although the angle of release was within the literature's suggested range, it did not produce optimal throwing distance considering the subject's inferior velocity of release. The low release angle (as demonstrated by the subject) provides optimal throwing distance only for throwers releasing the discus at a higher velocity. After plyometric training, the angle of release decreased due to the passive left leg establishing a block prior to the release of the discus. Since the left foot did not adequately transfer the body's energy vertically, the subject's right arm continued to travel forward, without a lifting force being initiated through the body.

Recommendations for Further Study

Based on the work done in the present study, the following recommendations for further study were suggested:

1. A study of this nature be conducted using a training program with different heights for the plyometric device and different repetitions or sets.
2. A study of this nature be conducted with testing periods prior to training, after two weeks of training, and after four weeks of training.
3. A study of this nature be conducted using force plates on the plyometric device and in the center of the discus circle.

4. A study of this nature be conducted using an overhead camera as well as the ground level camera in order to determine angular measurements in addition to linear measurements.
5. A study of this nature be conducted filming a subject while actually using the plyometric device.
6. A study of this nature be conducted comparing skilled and less-skilled athletes.
7. A study of this nature be conducted using a multiple subject pool.
8. A study of this nature be conducted using athletes from other throwing field events.

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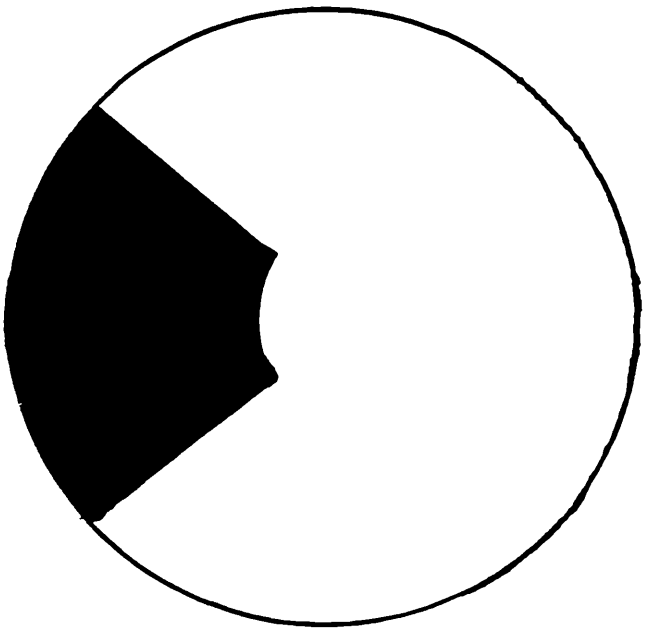
APPENDICES

APPENDIX A

PLYOMETRIC TRAINING APPARATUS

APPENDIX A



Top View

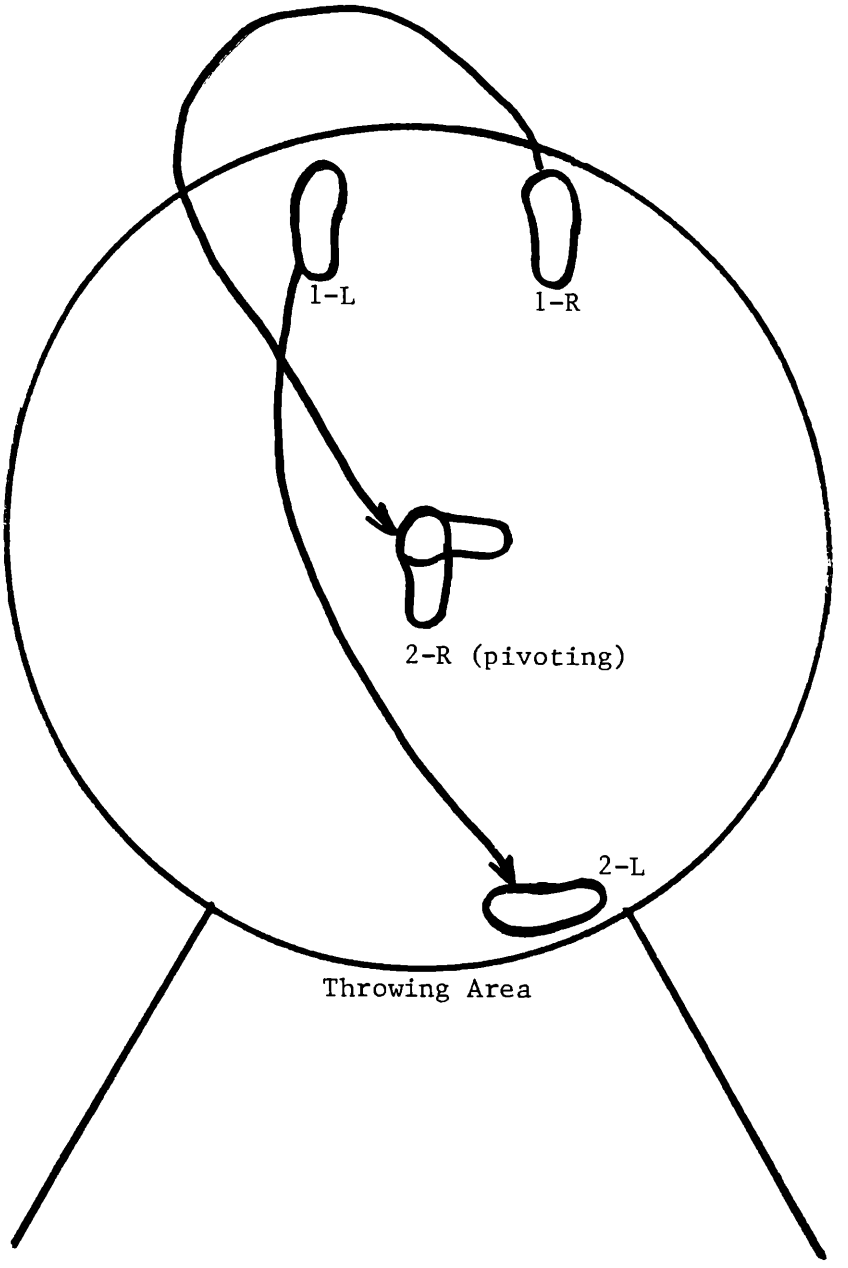
Side View

APPENDIX B

FOOT PATTERN OF THE DISCUS THROW

APPENDIX B

FOOT PATTERN OF THE DISCUS THROW



APPENDIX C

TYPICAL WEEKLY TRAINING SESSION FOR UNIVERSITY OF KANSAS DISCUS THROWER

APPENDIX C

TYPICAL WEEKLY TRAINING SESSION FOR UNIVERSITY OF KANSAS DISCUS THROWER

MONDAY, October 27, 1982

Jog 2/3 mile
Flexibilities
20 - Plyometric
10 - Normal
Weights

Tuesday, October 28, 1982

Jog 1/2 mile
Flexibilities
Stairs 6 X 50
Accelerations 4 X 60M
Weights

Wednesday, October 29, 1982

Jog 2/3 mile
Flexibilities
20 - Plyometric
10 - Normal
Weights

Thursday, October 30, 1982

Jog 1/2 mile
Flexibilities
Accelerations 4 X 100M
Stairs 4 X 50
Weights

Friday, October 31, 1982

Jog 2/3 mile
Flexibilities
Throw cone X 15
Medicine ball exercises
Fast feet drill
Weights

Saturday or Sunday, Nov.1&2

Jog 1 mile
or
Tennis
or
Racquetball
or
Basketball
Flexibilities

APPENDIX C

WEIGHT WORKOUTS
FALL 1982

Warm up: Jog 3/4 mile
Stretch - emphasize: lower back, shoulders, gluts, quadriceps, hamstrings

MWF - Upper body

Chest : Bench Press
Warm up set
4 x 10
Incline Press
Warm up set
3 x 10
Lying Chest Flies (Discus) 3 x 12-10-7
Incline Chest Flies (S.P. & Jav) 3 x 12-10-7

Shoulders : Super Set- DB Lat Flies 3 x 10
DB Bent over Flies 3 x 10
Seated Front Military Press 3 x 8

Traps : DB Shoulder Shrug 4 x 10

Back : Low Cable Row 4 x 15-10-7-7
Lat Pull Downs (behind head) 3 x 10

Arms : Super Set- Close Grip Bench Press 3 x 8
Standing Straight Bar Curl 3 x 8
Super Set- Tricep Press Down (lat machine) 3 x 10
Resting Incline DB Curl(simultaneously) 3 x 10

Abdominals : Hanging Knee ups
Incline Sit ups (AMF board)] Combination minimum- 150

TR - Lower body

High Pulls 3 x 10-7-5
Super Set- Extensions 3 x 10
Flexions 3 x 10
Squats (Increase weight) 4 x 12-10-7-5

Back Hypers 3 x 18+
After 3 x 20 can be completed :
Bent Leg Dead Lift 3 x 8-8-8

Adduction 3 x 10
Abduction 3 x 10
Calf (continuous) 3 x 10 toes in
3 x 10 toes out
3 x 10 toes straight

APPENDIX D

CONSENT STATEMENT

APPENDIX D

Consent Statement

The Department of Health, Physical Education, and Recreation at the University of Kansas supports the practice of protection for human subjects participating in research. The following information is provided so that you can decide whether you wish to participate in the present study. You should be aware that even if you agree to participate you are free to withdraw at any time.

The study is concerned with the biomechanics used by a collegiate discus thrower before, during, and after specific plyometric training. Parameters of investigation include height of release, angle of release, velocity of the discus upon release, the time elapsed during the first step, the time elapsed during the second step, the time elapsed from the second step to the release of the discus, the time elapsed during the entire throw, the length of the first step, the length of the second step, linear velocity of the right hip, right ankle, right knee, and right wrist, the body's center of gravity, the path of the discus, the angle of trunk inclination, the angle of the right knee, the angle of the right arm at release, the height of the discus at release, and the velocity of the discus at release. In order that the above variables may be examined, all of your throws during the testing will be filmed.

No compensation for physical injury that may result from the research is available.

Your participation is solicited, but strictly voluntary. Do not hesitate to ask questions about the study. Thank you very much for your cooperation.

Sincerely,

Scott E. Calder
Principal Investigator
(913) 876-2367

_____
Signature of subject agreeing to participate

*A copy of this consent form is available upon request.

APPENDIX E

WEATHER CONDITIONS, LIGHT METER READINGS, AND PERFORMANCE RESULTS - ALL SESSIONS

APPENDIX E

Weather Conditions, Light Meter Readings, and Performance Results - All Sessions

September 22, 1982: Wind direction: Southeast
Temperature: 74° F
Light Meter: 4

Trial	Distance (m)	Wind Velocity (m/sec)
1	42.67	2.56
2	37.74	3.04
3	43.67	3.96
4	40.46	1.72
5	40.77	3.81

October 22, 1982: Wind direction: Southeast
Temperature: 66° F
Light Meter 4

Trial	Distance (m)	Wind Velocity (m/sec)
1	44.00	1.03
2	44.28	2.53
3	42.54	.67
4	43.93	2.82
5	42.91	1.30
6	44.06	3.01

November 19, 1982: Wind direction: Southeast
Temperature: 66° F
Light Meter: 2.8

Trial	Distance (m)	Wind Velocity (m/sec)
1	38.30	5.95
2	42.97	6.96
3	27.30	8.03
4	41.64	7.29
5	43.55	8.77
6	42.94	8.51

APPENDIX F

OLD COG WORKSHEET

APPENDIX F

COORDINATES FOR DETERMINING CENTER OF GRAVITY using program "OLD COG"

No.	Endpoint	X	Y
1.	Crotch		
2.	Top of Sternum		
3.	Top of Head		
4.	Right Hip		
5.	Right Knee		
6.	Right Ankle		
7.	Right Toe		
8.	Left Hip		
9.	Left Knee		
10.	Left Ankle		
11.	Left Toe		
12.	Right Shoulder		
13.	Right Elbow		
14.	Right Wrist		
15.	Distal Part of Rt. Hand		
16.	Left Shoulder		
17.	Left Elbow		
18.	Left Wrist		
19.	Distal Part of Lt. Hand		

Double lines shown above indicate breaks in coordinate entries in comput program "OLD COG"

Enter Scale Units _____

Computer Results

Graph Units: X-coord._____, Y-coord._____

APPENDIX G

FILMDAT WORKSHEET

APPENDIX G

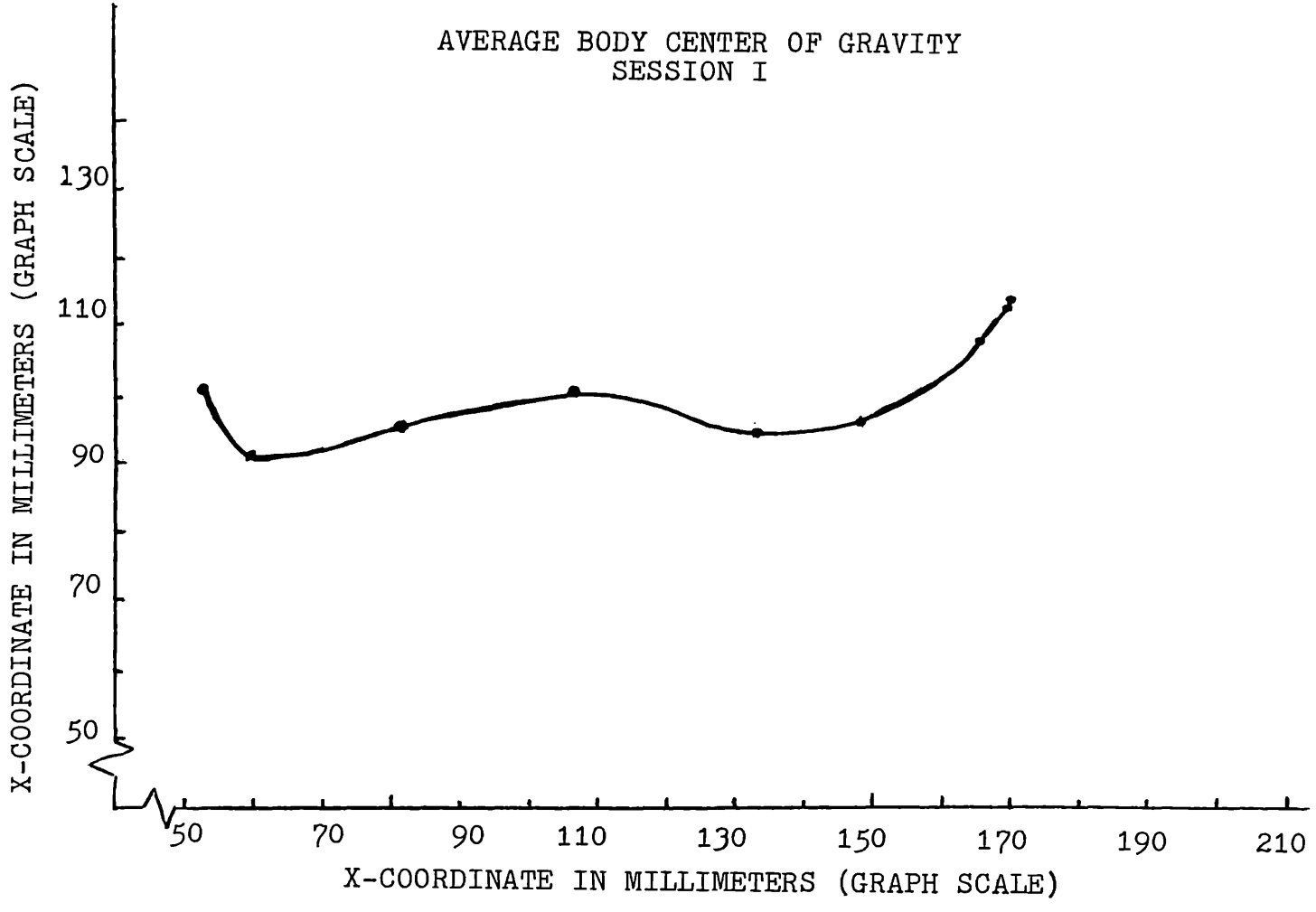
CINEMATOGRAPHICAL ANALYSIS

FRAME #:						
TIME:						
POINT LOCATION:	X	Y	X	Y	X	Y
1. Rt. Hand						
2. Rt. Wrist						
3. Rt. Elbow						
4. Rt. Shoulder						
5. L. Shoulder						
6. L. Elbow						
7. L. Wrist						
8. L. Hand						
9. Rt. Foot						
10. Rt. Ankle						
11. Rt. Knee						
12. Rt. Hip						
13. L. Hip						
14. L. Knee						
15. L. Ankle						
16. L. Foot						
17. Tragus (Ear)						
18. Sternal Notch						
19. Crotch						
20. Object						
21. Top of Head						
22. Ref. Point						

APPENDIX H

AVERAGE BODY CENTER OF GRAVITY - SESSION I

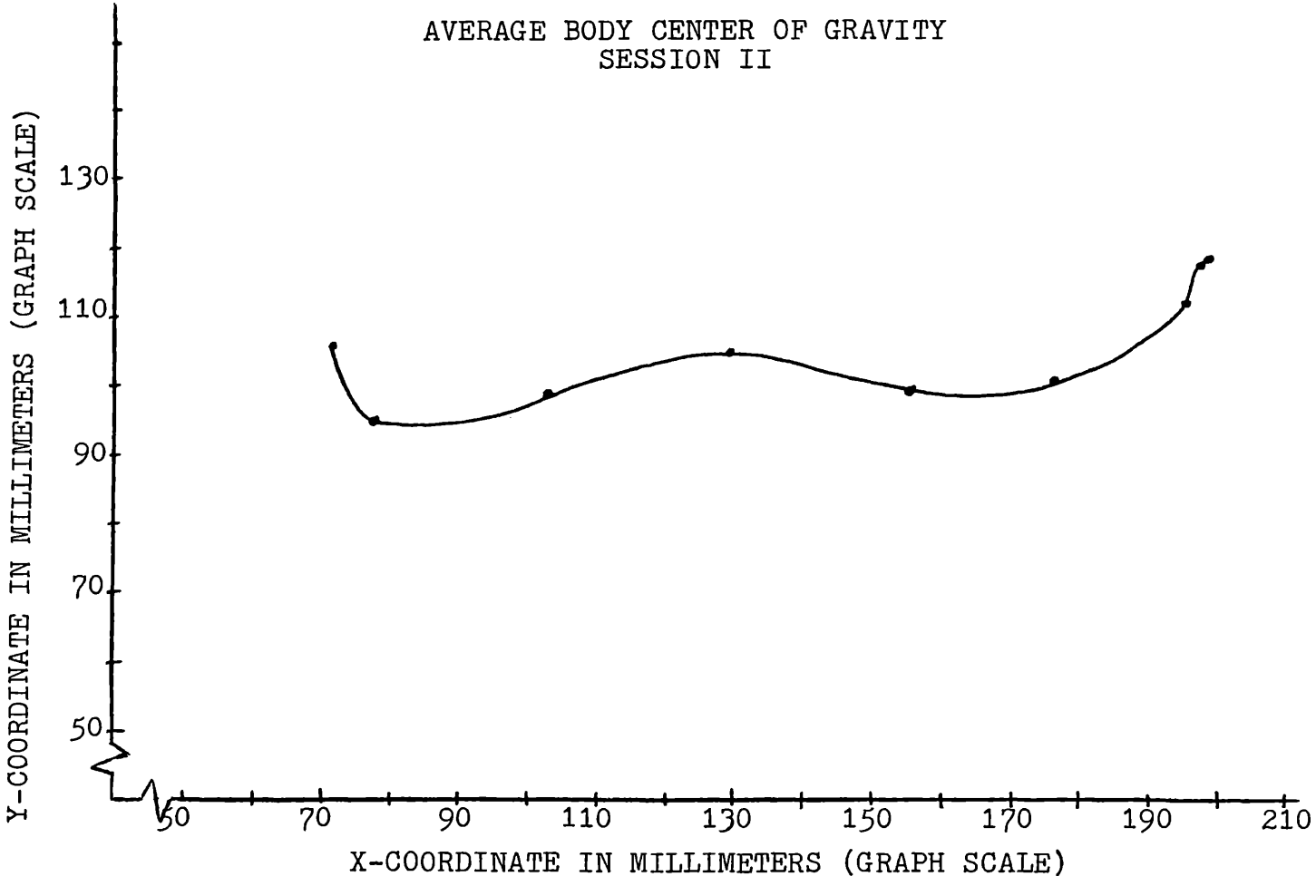
APPENDIX H


AVERAGE BODY CENTER OF GRAVITY
SESSION I
X-COORDINATE IN MILLIMETERS (GRAPH SCALE)
130
110
90
70
50
50
70
90
110
130
150
170
190
210
X-COORDINATE IN MILLIMETERS (GRAPH SCALE)

APPENDIX I

AVERAGE BODY CENTER OF GRAVITY - SESSION II

APPENDIX I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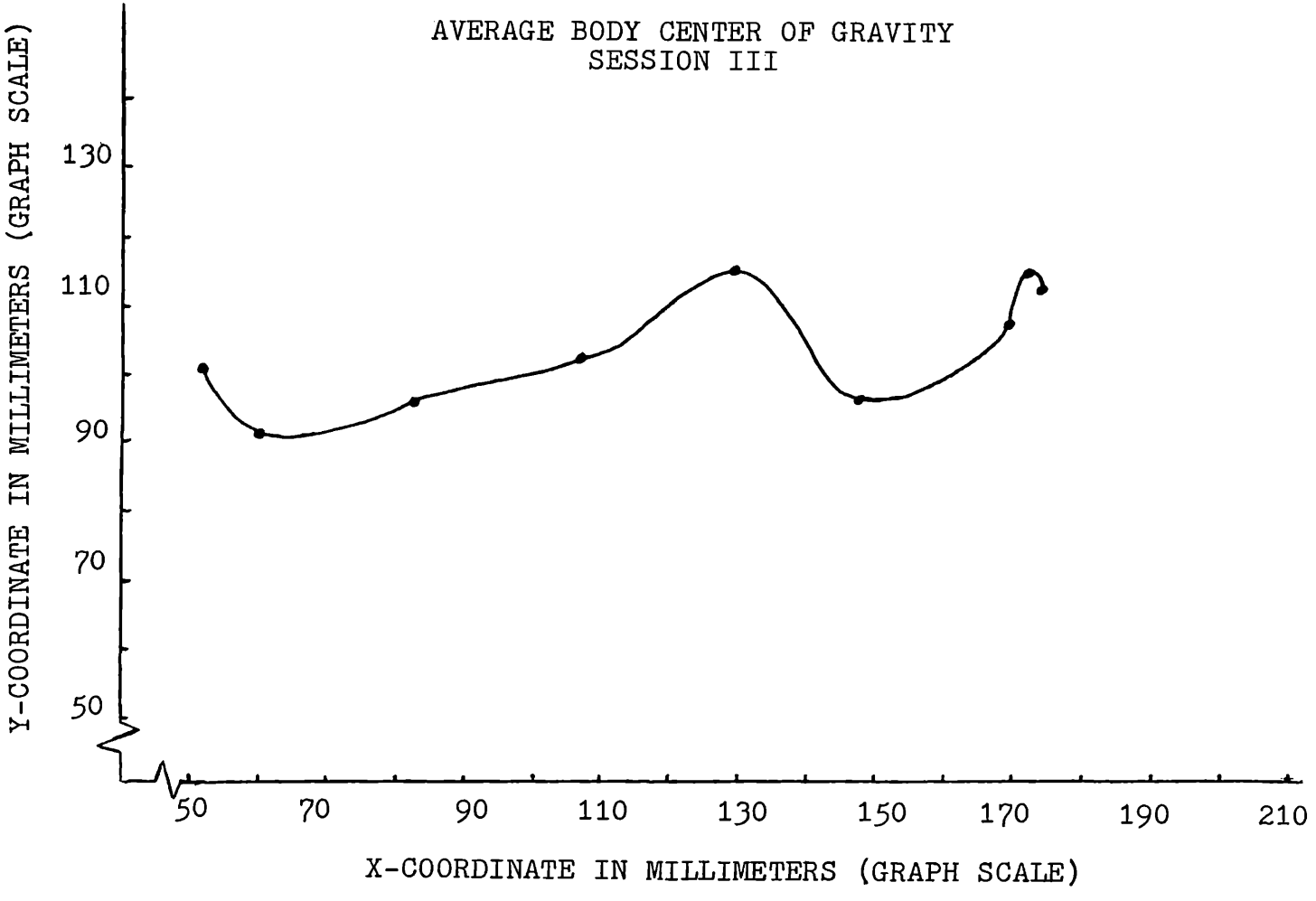
SESSION II
Y-COORDINATE IN MILLIMETERS (GRAPH SCALE)
130
110
90
70
50
50
70
90
110
130
150
170
190
210
X-COORDINATE IN MILLIMETERS (GRAPH SCALE)

APPENDIX J

AVERAGE BODY CENTER OF GRAVITY - SESSION III

APPENDIX J


AVERAGE BODY CENTER OF GRAVITY
SESSION III
Y-COORDINATE IN MILLIMETERS (GRAPH SCALE)
130
110
90
70
50
50
70
90
110
130
150
170
190
210
X-COORDINATE IN MILLIMETERS (GRAPH SCALE)