A THREE-DIMENSIONAL CINEMATOGRAPHIC ANALYSIS OF SELECTED ASPECTS OF THE OVERARM AND SIDEARM SOFTBALL THROW

by

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A Thesis Submitted to the Faculty of the

DEPARTMENT OF PHYSICAL EDUCATION

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1981

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ACKNOWLEDGMENTS

The author wishes to express sincere appreciation to Dr. Anne E. Atwater for her guidance, suggestions, and patience throughout the completion of this study. The author is also indebted to the members of the committee, Dr. Patricia C. Fairchild and Dr. Margaret Anderson, for their interest and prompt assistance.

Lastly, a debt of gratitude is extended to the writer's family and friends for their confidence, encouragement, and comic relief.

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ABSTRACT

The purpose of this study was to qualify and quantify differences between selected aspects of the overarm and sidearm softball throw by use of three-dimensional cinematographic analyses. Specifically, this investigation examined the three-dimensional resultant linear velocities of the ball, right elbow joint center, and right shoulder joint center; the three-dimensional component velocities of the ball; the three-dimensional angular displacement and velocity of the right elbow joint; and, the body position at release.

The four adult female subjects, who were or had been college varsity softball players, performed both overarm and sidearm softball throws. They were filmed using two high-speed motion picture cameras aligned so their optical axes intersected at a 90 degree angle. The film data were then reduced to three-dimensional coordinates by means of the Susanka vector approach.

It was concluded that there were more similarities between the overarm and sidearm throwing patterns than there were differences. The two throws were similar in ball velocity; rate, sequence, and timing of joint center velocities; and, degree of elbow extension. Differences were found in the Y (lateral) and Z (vertical) component ball velocities, and in the trunk position at release as seen from a rear view. However, the differences between the two throws were felt to be significant enough to warrant separate learning experiences for each type of throw.

CHAPTER I

INTRODUCTION

Introduction to the Problem

According to many coaches, a good defense is the best offense in the game of softball, and throwing is one of the most essential aspects of a good defense. No matter how well the ball is fielded, if it is not thrown efficiently, with speed and accuracy, the value of the defensive action is reduced considerably. But, which type of throw is more efficient--overarm or sidearm? Better yet, is there really any difference between the two throwing patterns? Most sport technique and kinesiological literature discusses the overarm throw and sidearm throw as two separate patterns. Consequently, many coaches and teachers provide separate learning experiences for their athletes and students, noting distinctions that are "felt" or "observed" between the two throws. But some sources (Atwater and Roberts, 1968; Collins, 1960) feel that there is little evidence to support the differentiation between the two movement patterns.

Meyer and Schwarz (1965) contend that the type of throw to be used in softball varies with the kind of play executed, the place where the ball is recovered in relation to the body, and the distance of the throw. Many authors state that the overarm throw should be used exclusively by outfielders for the long throws to the infield, or any time the throw requires distance or speed. It is also generally felt that the sidearm throw should be used in the infield when the fielder does not have time to take a full backswing or to straighten the trunk for an overarm throw.

Another factor that is used to determine which throw is more appropriate for a given situation is the spin imparted to the ball upon release. Siedentop and Kaat (1971) state that the overarm throw is a necessity for outfielders because the ball spins in a vertical plane, causing it to continue forward in a straight line toward the intended target. The sidearm throw generally imparts spin in a more horizontal plane which causes the ball to break or "tail off." The disadvantage of the latter type of throw should be obvious in the case of a long throw which bounces in front of the intended target.

Contrary to much of the literature, though, kinematic analyses have failed to uncover any clear distinctions between the two throwing patterns. Collins' (1960) study included evidence showing that the two throws were very similar, while Atwater and Roberts (1968) found more similarities than differences between the two patterns. Cooper and Glassow (1976) discussed differences between the two throws, but concluded their discussion by recommending further study to validate the differences, if any, between the patterns.

Insight into the mechanics of the overarm and sidearm throws can be gained most effectively by three-dimensional film analysis. As a curvilinear (out-of-plane) movement, throwing requires analysis from a three-dimensional standpoint in order to accurately qualify and quantify the differences, if any, between patterns. This investigation was designed to further the understanding of the nature of throwing, both as a basic movement pattern and as a highly complex skill, in hope that the implications for teaching and coaching will prove profitable.

Statement of the Problem

The purpose of this study was to descriptively and objectively analyze selected aspects of the overarm and sidearm softball throw for women using three-dimensional cinematographic techniques. Specifically, this investigation attempted to answer questions concerning whether or not there are any differences in the elbow and shoulder action or position in space during the force-producing phase of the overarm and sidearm throws, and if so, what is the magnitude and direction of these differences with regard to the following areas:

A. Three-dimensional velocities

   1. Resultant linear velocity of the:

      a. ball,
      b. right elbow joint center,
      c. right shoulder joint center.

   2. Component velocity of the ball for the:

      a. X component (forward/backward),
      b. Y component (left/right),
      c. Z component (up/down).

B. Body position at release

   1. Trunk position relative to the vertical.

   2. Shoulder position relative to the horizontal.

   3. Angle between the shoulder line and right upper arm.

C. Right elbow joint three-dimensional angular displacement and peak angular velocity prior to release.

Scope of the Study

This study was limited to four highly skilled female softball players who had previous experience with or were currently involved in a varsity intercollegiate softball program. It was further limited to the examination of selected aspects of overarm and sidearm throwing involving only the shoulders and throwing arm.

The review of literature was confined to those sources which discussed any possible differences or similarities between the two throwing patterns, and to those three-dimensional cinematographic techniques which involved the use of two high speed motion picture cameras.

Definition of Terms

Force-Producing Phase -- The force-producing phase of the throw was defined for this study as the action occurring from twenty frames prior to release, to the release frame, which was a period of time .276 seconds before release.

Shoulder Line Position in Space -- The shoulder line position was determined by drawing a straight line between the midpoints of the left and right shoulder joints. The position of this line was then measured, from the rear view tracings, with reference to deviation from the horizontal.

Upper Arm -- The upper arm was that segment anatomically known as the brachium.

Angle Between Right Upper Arm and Shoulder Line -- This angle was formed by the intersection of the shoulder line and the right upper arm line with the midpoint of the right shoulder joint as the vertex. The right upper arm line was that line determined by connecting the midpoints of the right elbow joint and the right shoulder joint.

Right Elbow Angle -- This angle was formed by the intersection of the right upper arm line and the right forearm line with the midpoint of the right elbow joint as the vertex. The right forearm line was that line determined by connecting the midpoints of the right elbow joint and the right wrist joint.

Significance of the Study

Efficiency of movement is one of the primary goals of the physical educator and coach. Since movement tends to be goal-oriented, the use of the most efficient movement pattern for a given situation would tend to meet the requirements of the goal more completely. Suppose the goal of a student is to throw a ball as far as possible. The student may know the basic throwing pattern, but the instructor must reorganize the movement into that which is most effective for the desired end product. On the other hand, suppose the goal of the student is to throw the ball as quickly as possible from one base to another. Will the same throwing pattern that the student used for achieving great distance be as efficient in her desire for throwing speed over a limited distance?

The basic goal in throwing is to project a ball with one hand. More specifically, the goal may be either (a) to throw the ball as forcefully and as fast as possible for a given distance, (b) to throw the ball as accurately as possible for a given distance, (c) to throw the ball as far as possible, or (d) to throw the ball with some defined combination of speed and accuracy to a given location (Atwater, 1970). It is logical to assume, then, that specific situations may not always require the same throwing pattern. In general, many sources feel the overarm pattern is most efficient in situations where speed and distance is required, while the sidearm pattern is most efficient in situations where speed of release over shorter distances is required.

If the assumption of specificity in throwing patterns is true, then it is the responsibility of the physical educator and coach to provide learning experiences which deal directly with both types of throwing. Learning principles have shown that the learning environment must be similar to the performance environment if satisfactory transfer is to occur. Therefore, if the sidearm throw is the more efficient pattern for an infielder, then the performer must practice that throw in routine infield drills. If the overarm pattern is the more efficient pattern for an outfielder, then the performer must practice that throw in routine outfield drills. If both throwing patterns are used in playing a particular position, such as shortstop or third base, then specific situations must be presented incorporating both throws.

The question of whether or not there are any differences between the sidearm and overarm throwing patterns leads to several implications for the teacher and coach. If there is a difference between the two patterns, then separate learning experiences should be provided for the student or athlete. If there is no difference between the two throws, then a single generalized learning experience would incorporate all aspects of throwing into one basic movement pattern.

Another significant aspect of this study is the three-dimensional filming technique employed. Researchers in the area of kinesiology and biomechanics have become increasingly aware of the potential value of high speed filming in the analysis of human motion, yet up until recent years there have been few attempts made to validate these filming and data collection procedures. Spray's (1973) validation study of the Susanka method verified a three-dimensional cinematographic technique which provided the potential means for obtaining valuable information regarding curvilinear human movement. Use of this technique in analyzing the overarm and sidearm throwing patterns will hopefully contribute useful information to the body of knowledge in kinesiology and biomechanics.

CHAPTER II

REVIEW OF SELECTED LITERATURE

The intent of this review of literature is to present the existing knowledge concerning differences between overarm and sidearm throwing patterns, while summarizing the conflicting ideas which serve as a basis for this investigation. Many technique books have been written describing the movement pattern incorporated in throwing. But, the amount of research conducted with regard to differences, if any, between the overarm and sidearm throwing patterns has not been extensive nor extremely conclusive. Many sources make no distinction between the two patterns, while others base their comparisons strictly on a kinesthetic analysis; that is, the two throws "feel" different. Still other researchers have investigated differences in the two patterns, but their procedures or results lack validity. For this reason, the review of literature concerned with the throwing motion will be limited to those sources which investigated differences in the throwing patterns, those sources which acknowledged specific differences in the patterns, and those sources which treated the patterns as being different, but made no direct comparison.

The second part of this review will deal with three-dimensional cinematographic analysis techniques which were developed during the late 1960's and 1970's. According to Spray (1973), it has been fairly well-established among those researchers interested in the study of human motion that, in order to gain the most information concerning curvilinear (out-of-plane) movement, three-dimensional analysis techniques must be incorporated. Since overarm and sidearm throwing patterns are curvilinear, a three-dimensional analysis provides more valid information than a two-dimensional analysis.

Only those sources deemed pertinent to the nature and background of the three-dimensional cinematographic technique employed in this study will be reviewed. These methods are comparable in general procedures to the Susanka (1970) vector approach used to analyze this investigator's data. Several related three-dimensional methods using single camera, stereometric, and single camera-mirror procedures have not been included, but may be found in Kinesiology III (Miller and Petak, 1973), or in Biomechanics of Sport (Miller and Nelson, 1973).

Comparison of Skill Patterns

In order to differentiate between those sources who actually analyzed overarm and sidearm throwing from those sources who merely made a comparison of the two patterns, this portion of the chapter will be divided into two sections.

Analyses of Overarm and Sidearm Throwing Differences

In one of the few film studies conducted specifically with regard to differences in the overarm and sidearm throws, Collins (1960) found a similarity in the basic mechanics of the two throws. Her two subjects, one highly skilled man and one highly skilled woman, were instructed to throw in three different manners. These consisted of their conception of an overarm throw, a sidearm throw, and a throw where the subject made a conscious effort to keep the elbow at ninety degrees of flexion. Within the limitations of her study, Collins concluded that:

> 1. In the overarm, sidearm, and ninety degrees of flexion throws, the basic pattern of joint action is much the same.
>
> 2. The percentage contribution which each joint makes to the velocity of the ball ranks the same in the three throws.
>
> 3. The range of movement of acting joints and the percentage of time they are in action follow a similar basic pattern in all throws.
>
> 4. The velocities imparted to the ball rank in the following order: overarm, sidearm, and ninety degrees of flexion.
>
> 5. The velocity of the ball in these throws can be attributed to the action of moment arms of the hip, spine, shoulder, and wrist (assuming that the small percentage of differences could be due to measurement error). (Collins, 1960, pp. 96-97)

The only difference mentioned between the overarm and sidearm throws occurred in the early preparatory movement of the throw. Collins (1960) said that, at release, the segments of the upper trunk and arm were in almost identical positions, but she failed to specify whether the segments were in similar positions relative to one another or relative to spatial constants (horizontal and vertical). An apparent limitation to this study would be that, despite a two-camera set-up, the investigator conducted a planar (two-dimensional) analysis rather than a curvilinear (three-dimensional) analysis.

Atwater and Roberts (1978) also suggested that there appear to be more similarities between the overarm and sidearm throwing patterns than there are differences. As in Collins' (1960) study, the skilled male and female subjects were instructed to perform an overarm throw and a sidearm throw. The resultant three-dimensional velocity of the ball prior to release was calculated for each throw, but other measurements and descriptions of joint actions were obtained by planar analysis. Their three-camera film data extracted the following information.

> 1. It is characteristic, in the sidearm throw, that the trunk is laterally inclined toward the side of the throwing arm. In the overarm throw, the trunk is laterally inclined toward the side of the non-throwing arm.
>
> 2. The height of the ball at release is influenced as much or more by lateral inclination of the trunk than it is by abduction of the humerus.
>
> 3. For both sidearm and overarm throws, the rate, sequence, and timing of the following joint actions were strikingly similar: pelvic rotation, spinal rotation, shoulder lateral rotation, shoulder medial rotation, elbow extension, and wrist action. (Atwater and Roberts, 1968 abstract)

In a planar cinematographic analysis of overhand and sidearm pitching techniques, Sakaris (1978) found that there were no differences between the velocities of the two fastball pitches. His data also indicated that there was less lateral body lean in the sidearm throw than the overarm throw, and that elbow flexion was greater in the overarm throw than in the sidearm throws.

The significance of the studies by Collins (1960), Atwater and Roberts (1968), and Sakaris (1978) lies in their use of cinematographic techniques in gathering data and making conclusions. Most other sources cited in this review failed to identify or justify procedures employed in their comparison of the two patterns.

Description of Overarm and Sidearm Throwing Differences

Cooper and Glassow (1976) stated that the distinguishing feature in the broad category of sidearm pattern activities is the limitation or the lack of action at the shoulder joint. They said the arm (humerus) is held fairly stable in an abducted position and that pelvic rotation is the main action in the pattern. On the other hand, the overarm throw was said by the authors to be characterized by medial and lateral rotation of the humerus at the shoulder joint. Cooper and Glassow also pointed out that the sidearm pattern occurs in a transverse plane while many movements of the underarm and overarm patterns are made in a sagittal plane.

In citing a study believed by this investigator to be that of Collins (1960), Cooper and Glassow (1976) reported that the preliminary parts of the two throwing patterns were very similar. This directly contradicts Collins' findings that the only observed differences between the throws were found in the preparatory movements. In addition, Cooper and Glassow (1976) reported that the main differences between the two types of throws were in the position of the arm and the degree and timing of elbow extension. In the sidearm throw, the arm was close to the horizontal when hip rotation began and the elbow was more fully extended at release. The hip action was reported as contributing a greater proportion of the velocity in the sidearm throw than in the overarm throw.

Cooper and Glassow (1976) commented that many investigators feel that the distinguishing feature in sidearm throwing is a circular movement of the arm preceding release. Still others question the validity in classifying the two throws as different patterns. Further study of this aspect was recommended by the authors.

Jensen and Schultz (1970) classified throwing actions according to the arm motion at the shoulder joint. They stated that the overarm pattern was characterized by "shoulder inward rotation and horizontal flexion," and that the sidearm pattern was characterized by "shoulder horizontal flexion" (Jensen and Schultz, 1970, p. 308). As in many sources, these authors did not clearly discuss any differences between overarm and sidearm throwing. They did mention that greater reliance is placed upon the hip and spinal rotator muscles in the sidearm throw, but failed to clarify this relation to what other pattern. The importance of hip rotation in the sidearm throw was in agreement with Cooper and Glassow's (1976) discussion.

Finley (1961) concluded that the sidearm throw takes less time than the overarm throw because the arm is not retracted as far back.

Jensen and Schultz (1970) also mentioned that there is less arm action in the sidearm throw than in the overarm throw. Finley (1961) stated that the sidearm throw imparts less initial velocity to the ball than the overarm, but that this is not a drawback when using the sidearm throw as an infielder. Collins (1960) reported similar findings in her study.

In agreement with Finley, Wickstrom (1977) stated that movements in the sidearm throw are generally abbreviated in comparison to the exaggeration of the pitching motion or the throw to home plate from the outfield using an overarm throw. He said that the amount of body movement in the different forms of throwing used in the baseball varies considerably, but the same fundamental movement pattern is present in each.

Plagenhoef (1971) maintained that the more overhead a pitcher throws, the greater will be the medial rotation of the upper arm, the impingement of the vertebrae of the lower back on the discs, and the flexion-extension action of the trunk. On the other hand, the sidearm throw of a pitcher places greater emphasis on total trunk rotation. This coincides with the comments of Cooper and Glassow (1976) and Jensen and Schultz (1970). In addition, Plagenhoef (1971) stressed that in order to "maintain a strong throwing position," the upper arm should be in line with or lower than the shoulder line. His illustration of a sidearm delivery of a pitcher showed the upper arm directly in line with the shoulders.

In another discussion of baseball pitchers, Hay (1978) identified the angle between the pitcher's upper arm and his forearm (at release) as being approximately 90 degrees in an overarm pitch and approximately 180 degress in a sidearm pitch. He reported that the majority of pitchers, though, will fall somewhere between these two extremes. Hay's statement appears to conflict dramatically with other authors' findings on the elbow angle at release. Wickstrom (1977) stated that this aspect of form (elbow angle at release) is critical because it involves one of the distinguishing characteristics of a true throw. Generally, the closer the elbow angle is to 90 degrees at release, the closer the arm motion is to a push. In a cinematographic analysis of the overarm baseball throw, Lyon (1961) found that the elbow angle just prior to release ranged from 147 to 166 degrees. Wickstrom (1977) concluded that the better mature throwers tend to have a straighter arm at the instant of release when throwing for maximum velocity.

In this same train of thought, Broer and Zernicke (1979) stated that, on an overarm throw, the ball is released well before the arm reaches full extension. According to pictures taken to accompany an electromyograhpic study performed by Broer and Houtz (1967), as reported by Broer and Zernicke (1979), there was an angle of approximately 105 degrees at the elbow as the ball was leaving the fingers. Gollnick and Karpovich (1964) also reported elbow angles of 102 degrees at the time of release in a study of joint action in young men throwing a baseball.

It seems that there is a great amount of conflict among investigators as to the exact degree of elbow extension at release on the overarm throw. The question now arises as to where the sidearm throw enters this 90 to 180 degree continuum of elbow extension.

In Broer and Zernicke's (1979) discussion of throwing, they stated that when small objects are thrown, the sidearm pattern is the same as the overarm pattern in all of the factors that develop velocity. In the overarm pattern, the many segments of the body are brought into the movement in sequence, giving a "whiplike" action at the distal end of the system of levers. They described the action as such: forward rotation starts in the pelvis and moves through the trunk; the shoulder comes into the action followed by the elbow and wrist; the hand is the last segment to be brought forward.

Flattening the arc through which the hand moves increases the possibilities for throwing accuracy, and Broer and Zernicke (1979) cited this as the one major difference between overarm and sidearm throws. In the overarm throw, the sequential extension of the joints of the arm as the shoulder moves forward affects the flattening of the arc, while in the sidearm throw, the rotation of the trunk moves the shoulder forward and out toward the side of the throwing hand. But, because the arc of the swing is horizontal, left-right accuracy is a greater problem in sidearm throwing than in overarm throwing.

Throughout their discussion, Broer and Zernicke (1979) seemed to intimate that trunk rotation plays a greater part in force-production in the sidearm throw than in the overarm throw. This is in agreement, again, with many of the other sources. In addition, Broer and Zernicke's statement regarding the hand moving through a more horizontal arc in the sidearm throw would seem to suggest that the ball path prior to release is somewhat circular. This possibility reinforces Cooper and Glassow's (1976) suggestion for further study.

Dobson and Sisley (1971) reported that in the sidearm throw the throwing arm is more horizontal as the hip action begins and more fully extended at release than in the overarm throw. They also stated that lateral flexion of the trunk allows for greater hip action in the sidearm throw. Horizontal accuracy also is cited as a problem in the sidearm throw due to the fact the arc of the arm swing is in the horizontal plane. All of these characteristics coincide with those reported by many of the other sources.

In discussing the techniques and advantages in overarm pitching in comparison to sidearm pitching, Shaw (1972) stated that the elbow must be up, at shoulder level or above, in the overarm pitch. If a pitch is thrown with the elbow dropped below shoulder level, as in the sidearm throw, the hand will be traveling almost parallel to the ground, losing the mechanical advantage. Shaw explained that, from the moment the arm motion begins until its completion, the arm will draw a circle in the air, with the shoulder as the center point. The longer the arm, or the higher the elbow is raised, the larger will be the circle. In the same respect, the larger the circle, the more momentum the arm has when it reaches the release point. When the elbow is dropped, as in the sidearm pitch, the circle is smaller and the hand speed, in turn, is reduced. However, Shaw did not describe the joint actions that are used to raise or lower the elbow.

Lindner's (1971) work focused on the throwing characteristic concerned with the upper arm position relative to the shoulder line. He felt that the arm was "in extension of the shoulder" at release, and that this position of the arm at release was almost at the greatest possible distance from the head. Plagenhoef (1971) also discussed the relationship between the upper arm and shoulder, but felt that the upper arm should be in line with the shoulder or lower than the shoulder line, which conflicts with Shaw's (1972) description of overarm throwing.

The difference among the sidearm, three-quarter, and overarm throws is in body lean and not in arm position relative to the trunk, according to Siedentop and Kaat (1971). The angle between the arm and the side of the body is quite similar in both throws, with the arm slightly above the line of the shoulders in the overarm throw and slightly below in the sidearm throw. In agreement with Atwater and Roberts (1968), Siedentop and Kaat felt that any differences found in these two aspects of the throws are insignificant. The main difference is that in the overarm throw the trunk is laterally inclined toward the non-throwing arm, while in the sidearm throw the shoulder line is more nearly horizontal.

Some of the sources dealt directly with the question of velocity differences between the two throws. Collins (1960) and Finley (1961) agreed with Shaw (1972) in stating that the sidearm throw generally has less velocity than the overarm throw. Wickstrom (1977) alluded to this same premise by stating that movements in the sidearm throw are generally abbreviated in comparison to the overarm throw. Sakaris (1978) found that there were no differences between the velocities of the two throws.

Three-Dimensional Cinematographic Analysis

Since most human motion is curvilinear, the use of three-dimensional cinematographic analysis provides more accurate information concerning out-of-plane motion than do planar techniques (Spray, 1973). In the following sections, the three-dimensional film analysis techniques reported by physical educators, in particular kinesiologists and biomechanists, will be classified according to their potential ability to achieve spatial coordinates of the points in question. This classification consists of those methods which use film data to produce an "estimate" of the coordinates, and those methods which could theoretically achieve "actual" coordinates from film data (Spray, 1973).

Estimated Spatial Coordinate Methods

Noss (1967) proposed a technique for determining true angles of static objects by measuring the projected angles from films obtained using a tri-axial three camera arrangement. The true angle formula was based upon the mean of the film angles as measured from the three camera views. Lack of documentation, experimental results, and mathematical bases for analysis gives the study little credence. Spray (1973) and Putnam (1979), having attempted to prove or disprove the Noss formula mathematically, found several cases where the formula was completely invalid.

One of the first studies attempting to validate curvilinear motion from a three-dimensional filming technique was conducted by Noble and Kelley (1969). Their three camera set-up consisted of filming a ball rolling down a trough which described a helix of a right circular cylinder, with two cameras placed at 90 degree angles in a horizontal plane and the third camera placed overhead, sighting down the axis of revolution of the cylinder. This method was not totally satisfactory as only one constant conversion factor for each film was determined, resulting in perception errors when the ball moved closer or farther away from the origin point.

Atwater (1970) reduced some of the error range by using multiple conversion factors in her three-dimensional film analysis of overarm throwing characteristics of men and women performers. Using a similar tri-axial camera set-up, she found multiple conversion factors for the ground level camera views at intervals of plus and minus one foot from the origin, and for the overhead camera at intervals of plus one foot from the origin. This method of determining conversion factors, as well as maintaining reasonably large camera lens-to-origin distances probably reduced the range of error and produced apparently valid measures of resultant ball velocity.

Also employing a tri-axial filming set-up, Anderson (1970) used two-dimensional trigonometric relationships to obtain the three-dimensional coordinates of center of gravity locations on arm segments. She attempted to short-cut the time-consuming analysis which Atwater had used to subjectively estimate point positions in space, by developing a procedure in which a variable conversion factor was calculated by computer analysis of film data. According to Spray (1973), even though time was saved by this technique, it is doubtful that Anderson's process produced more valid results than Atwater's.

Actual Spatial Coordinate Methods

Miller (1970) proposed a method of three-dimensional film analysis which used geometric relationships existing within the coordinate system to determine the spatial coordinates. She used two high speed cameras whose optical axes intersected at a 90 degree angle. This three-dimensional analysis was performed in connection with planar analyses of selected diving skills.

Expanding upon this method, Miller and Petak (1973) attempted to overcome problems related to perspective error by developing a system in which spatial coordinates could be determined provided a point was visible in any two of the three cameras used. When employing this method, the cameras were positioned so that their optical axes intersected at a single point and formed 120 degree angles with one another, rather than the 90 degree angles used in Miller's (1970) original work. The theory behind this and Miller's (1970) technique was based on geometric principles, particularly the fact that the ratio of the film image size to the lens-film distance was equal to the ratio of the object size to the lens-object distance. The equations used to analyze the data automatically compensated for movement of the subject toward or away from the cameras, thus eliminating the need to constantly recalculate conversion factors (Miller and Petak, 1973).

Another actual spatial coordinate determination technique was proposed by Susanka and Diblik (1969) in an abstract prepared for the Second International Biomechanics Seminar in Eindhoven, Holland. {The abstract was written in German and later translated into English by Doris I. Miller. This translation appears in its entirety in Appendix D of Spray's (1973) study.} Susanka (1970), the chief investigator in the original study, used a camera set-up similar to Miller's (1970); that is, the cameras' optical axes intersected at a 90 degree angle in order to become the X and Y axes of the coordinate system. This method employed vector mathematics to secure final spatial coordinate values.

Spray (1973), in a validation study using the three-dimensional approaches of Miller and Susanka, found that both methods tend to yield the same results under ideal filming situations, or at very high film speeds. She also found that under less-than-ideal conditions, the Susanka method might be preferred since it tends to solve the problem of camera asynchronization in a direct manner, supplying one solution (Spray, 1973).

The three-dimensional techniques discussed this far all require precise location of the cameras, thus limiting the application of three-dimensional methods to the scientific filming of competitive athletics. Bergemann (1974) tried to reduce the constraints on camera placement by allowing the cameras to "float" within the coordinate system. The only restrictions were that a common origin point must be in the field of view and that the optical axes of the camera should intersect. This method was identical to the Susanka technique except for the elimination of camera restrictions. Further validation is necessary as Bergemann only collected data on static objects.

Walton (1979) attempted to develop a generalized technique requiring little or no information describing the position and orientation of the cameras. His study was based on precise control points accurately located within the coordinate system. The data reduction, based on the Miller technique, takes Miller's (1970) work one step further by using a least square approximation to solve the problem of camera asynchronization.

Two recent approaches to three-dimensional cinematographic analysis have further advanced the concept of freeing the camera set-up of geometrical or spatial restrictions. The procedure proposed by Van Gheluwe (1978) and the "direct linear transformation" method described by Shapiro (1978) are potentially techniques that may considerably improve the accuracy of three-dimensional cinematographic analysis as well as enhancing the ease and speed by which it can be accomplished.

Summary

Comparison of Skill Patterns

As stated earlier in this chapter, the amount of research conducted on sidearm and overarm throwing patterns has not been extensive nor extremely conclusive to date. The sources cited in this review were selected because they dealt directly with the possible differences between the two movement patterns.

However, in assessing the differences presented by the various investigators, a great limiting factor was the ambiguity in terminology. For example, since the elbow action appeared to be one area of controversy, the literature left many unanswered questions when authors referred to "arm action" in general. The determination of whether the the sources were discussing the forearm, the upper arm, or the entire limb from shoulder to wrist was left up to the reader's imagination.

Another area which remains clouded is exactly how the sources came up with their deductions regarding the two throwing patterns. Several of the sources (Atwater and Roberts, 1968; Collins, 1960; Finley, 1961; Lyon, 1961; and, Sakaris, 1978) used film analysis as a means of drawing conclusions. Most of the other authors merely presented their opinions without justifying the source of their knowledge. This fact, in conjunction with the many conflicting ideas concerning overarm and sidearm throwing, led to this investigator's desire to qualify and quantify the differences, if any, between the two throwing patterns.

The two sources which mentioned the preliminary action of the overarm and sidearm throws are in total disagreement, as well as being rather vague. Collins (1960) stated that the only difference between the overarm and sidearm throws was found in the early preparatory movements, while Cooper and Glassow (1976) reported that these early movements were extremely similar. As previously stated, it is thought that Cooper and Glassow were referring to Collins' study and that this aspect was misinterpreted. Neither source gave specific examples of the action in question.

Collins (1960), Atwater and Roberts (1968), and Broer and Zernicke (1979) all stated that the joint actions were basically the same for both the overarm and sidearm throws. They found the rate, sequence, and timing of the action to be very similar. Wickstrom (1977) agreed with this, but discussed the sidearm throw as a somewhat abbreviated form of the overarm throw.

Greater reliance is placed on the hip action (pelvic and trunk rotation) during the sidearm throw than in the overarm throw, according to Cooper and Glassow (1976), Jensen and Schultz (1970), Dobson and Sisley (1971), and Plagenhoef (1971). On the other hand, Atwater and Roberts (1968) and Siedentop and Kaat (1971) stated that the main difference in the trunk action during the two throws was concerned with body lean, or lateral trunk inclination. When throwing overarm, the trunk was laterally inclined away from the throwing arm while during the sidearm throw, the trunk was laterally inclined toward the throwing arm or vertical. Both of these latter sources reported that the angle formed between the arm and the side of the body was quite similar in both throws.

One of the distinguishing movement characteristics pointed out by Cooper and Glassow (1976), Jensen and Schultz (1970), and Plagenhoef (1971) was that medial rotation of the humerus occurs during the overarm throw. Dobson and Sisley (1971) and Jensen and Schultz (1970) stated that, on the other hand, horizontal flexion accounts for the humeral action during the sidearm throw. Cooper and Glassow (1976) reported that the humerus is relatively stable during the sidearm throw and that pelvic rotation is the action which pulls the arm forward.

The most controversial aspect in this review dealt with the degree of elbow extension between the two throws. Many of the sources specified that the elbow is more fully extended at release with the sidearm throw, but they failed to quantify the exact degree of extension. The discrepancies found in measurement of the elbow angle at release in the overarm throw ranged from Hay's (1978) 90 degrees of flexion to

Lyon's (1961) 166 degress of extension. It appears that some conclusive evidence needs to be presented on elbow extension during the overarm throw before a comparison can be made with sidearm throwing.

It was stated by several sources that the sidearm throw generally has less velocity than the overarm throw (Collins, 1960; Finley, 1961; and, Shaw, 1972). Wickstrom (1977) alluded to this same premise by saying that movements in the sidearm throw are generally abbreviated in comparison to the overarm throw. However, one author (Sakaris, 1978) found that there were no differences between the velocities of the two pitches.

To summarize, it seems that the questions at hand regarding the comparison of the ovearm and sidearm throwing patterns deal with trunk action (shoulder line position in space), shoulder action (medial rotation of the humerus versus horizontal flexion of the humerus), and elbow action (degree of extension).

Three-Dimensional Cinematographic Analysis

Several three-dimensional filming techniques were presented in this section of the review, being classified by their potential ability to estimate spatial coordinates or to determine actual spatial coordinates. The estimation techniques reduced film data to final spatial coordinate estimates. This sometimes required no conversion factor (Noss, 1967), one conversion factor (Noble and Kelley, 1969), or multiple conversion factors (Atwater, 1970; and, Anderson, 1970).

It appears that, in agreement with Spray (1973), any method of three-dimensional filming and data reduction which can theoretically yield actual spatial coordinates is superior to one which can only provide an estimate of the same point. Additionally, the vector approach of the Susanka technique tends to compensate for less-than-ideal filming conditions and procedures. In general, any technique that has the potential ability to predict real data values must be superior and should be used whenever possible.

New three-dimensional techniques are now being developed to eliminate the need for precise camera location. This would allow for the filming of superior athletic performances during actual competition rather than under scientific conditions in a laboratory.

CHAPTER III

DESIGN OF THE STUDY AND PROCEDURES USED

This study was designed to compare selected aspects of the overarm and sidearm softball throws for women using three-dimensional cinematographic techniques. The criteria for selection of subjects is described in this chapter, as well as the three-dimensional filming set-up and subject filming procedure. Data collection and reduction procedures used in the investigation will also be included in this chapter.

Since a knowledge of basic vector analysis and three-dimensional analytic geometry is required to fully comprehend the Susanka vector approach employed in this study, a description of this method will only be briefly described. A complete description may be found in "Three-Dimensional Film Data Validation Procedures: A Vector Approach," by Judith Ann Spray (1973).

Selection of Subjects

Four female subjects were chosen for this study on the basis of timed throwing velocity pre-tests and previous experience as varsity softball players at the intercollegiate level of competition. Originally, six subjects were chosen to participate in the investigation, but the sample was reduced to four after one subject failed to report for the filming session and one subject's films were underexposed due to a camera malfunction. All subjects chosen were right-handed throwers as a left-handed thrower would have required major relocation of the photographic equipment.

The subject's playing experience was the initial criterion for selection. Three of the subjects were currently participating on the University of Arizona women's varsity intercollegiate softball team, while the fourth subject competed for four years on the Weber State College women's varsity intercollegiate softball team. All of the subjects had additional experience at the local and state level, and two of the subjects competed on a regional and national level.

A throwing velocity pre-test was administered prior to the filming of the subjects. The purpose of the pre-test was to obtain estimates of each subjects' maximal throwing velocity for both the overarm and sidearm throw. The pre-test required the subjects to throw a softball as forcefully as possible against a target outlined on a wall. The target consisted of a six foot by ten foot rectangle with the bottom horizontal line two feet from the ground and the top horizontal line eight feet from the ground. The subject's distance from the target was determined by a restraining line 50 feet from and parallel to the wall. The 50 foot distance was chosen to facilitate timing of the throws.

Knowing the background of the subjects, it was predicted that the performers would throw in the vicinity of 70 to 80 feet per second, the velocity characteristic of skilled women throwers (Atwater, 1970). This velocity would result in a time of ball flight between 0.63 and 0.76 seconds as measured by a stopwatch. Times less than 0.50 seconds are difficult to record accurately using a stopwatch because the starting and stopping of the watch occur very close together. Therefore, a 50 foot distance was used for the pre-test.

The test administrator pre-tested one subject at a time. The performers were instructed to throw the ball as forcefully as possible into the target area using an "overarm" throw. After the subjects had completed the overarm throws, they were then instructed to throw the ball as forcefully as possible into the target area using a "sidearm" throw. No other instructions on the form used in the two throws were given; the throws were the subjects' conception of an "overarm" pattern and a "sidearm" pattern.

Five trials for each type of throw were administered. The subjects were allowed to take a step prior to the throw as long as they did not step over the restraining line before releasing the ball. If the subject did step over the line or if the ball did not land within the target area, a retrial was given.

The throws were timed to the nearest hundredth of a second using a stopwatch with a three-second sweep hand. The throws were timed from the instant the ball was released from the hand to the instant the ball contacted the wall. The timing was performed by Dr. Anne E. Atwater, who has extensive experience in administering this test. Times were recorded immediately after each throw.

The time for each throw was then converted to velocity in feet per second using unpublished velocity tables compiled by the Department of Physical Education, University of Wisconsin, Madison. After the time for each throw was converted to feet per second, the mean of the five trials was determined for the overarm and sidearm throws. The subjects' throwing velocities for both the overarm and sidearm throws ranged from 80 to 95 feet per second, placing them in a highly skilled category relative to other female performers (Atwater, 1970).

Pertinent information regarding the subjects is listed in Table 1.

Filming Procedures

The filming for this study took place on May 21, 1976, at the University of Arizona's north tennis courts. The outdoor filming site was chosen to permit convenience of camera set-up and availability of adequate lighting. Dr. Anne E. Atwater supervised the filming and was assisted by the investigator and three graduate students from the Department of Physical Education, University of Arizona.

Three-Dimensional Filming Equipment and Set-Up

The cameras used for this study were two spring-driven, high-speed 16 mm Pathé motion picture cameras, each equipped with a one inch (25 mm) lens and a reflex (through-the-lens) viewing mechanism. Each camera was loaded with Kodak Tri-X Reversal type black and white film on a daylight reel (ASA 200). Both cameras were set at a film transport speed of 80 frames per second with variable shutters set at one-quarter (45 degrees) open, and a lens opening between f/4 and f/5.6. The cameras were mounted on adjustable tripods.

The camera set-up followed the coordinate system alignment used by Spray (1973) in her three-dimensional validation study. One camera's optical axis theoretically determined the X axis of the system (camera A or X), while the other camera's optical axis determined the Y axis

Table 1. Subject Background Information.

Subject	A	B	C	D
Age	23	19	24	23
Height	5'6"	5'4"	5'7"	5'5"
Weight	142	123	115	125
Position	Infield/ Pitcher	Infield	Infield/ Outfield	Infield
Pattern *	Overarm	Overarm	Overarm	Overarm
Pre-Test Vel.				
Overarm ($\bar{X}$)	82.8 fps	87.6 fps	89.8 fps	91.2 fps
Max.	84.0 fps	90.0 fps	94.0 fps	98.0 fps
Min.	81.0 fps	85.0 fps	83.0 fps	87.0 fps
Sidearm ($\bar{X}$)	85.2 fps	87.0 fps	88.8 fps	91.0 fps
Max.	91.0 fps	90.0 fps	91.0 fps	95.0 fps
Min.	81.0 fps	84.0 fps	87.0 fps	87.0 fps

* This was the subjects' conception of their dominant throwing position.

(camera B or Y). Both cameras were set so their optical axes would intersect at a 90 degree angle (Figure 1).

An origin pole, bearing three tape marks at one foot intervals, was placed at the theoretical intersection of the optical axes of the two cameras. Cross hairs within the reflex viewing optics of each camera were centered on the middle of the three tape marks on the origin pole, and this point was defined as the origin of the system. The center tape mark was 4.65 feet above the court surface. This vertical distance was reproduced from the center of each camera lens to the ground by plumb bob techniques. The camera A (X) lens was 53.29 feet from the origin pole, while the camera B (Y) lens was 54.90 feet from the origin pole. These camera-to-origin distances were measured with a steel measure to the nearest 1/16 of an inch and the inches and/or fraction thereof were later converted to decimal units.

Also included in the filming set-up was a "time pole," a pole marked with one foot intervals, used in conjunction with a ball drop to aid in the synchronization of the two camera views.

Subject Filming Procedure

The subjects were asked to arrive at the filming site at least 30 minutes before the filming. The subjects had been instructed to wear a swimming suit and/or shorts and a close-fitting sleeveless blouse and tennis shoes. They were asked to avoid loose-fitting clothing which could obscure segment outlines in the film.

Reference lines on the shoulder, elbow, and wrist joints of the subjects were marked by an assistant with a black water-base ink prior

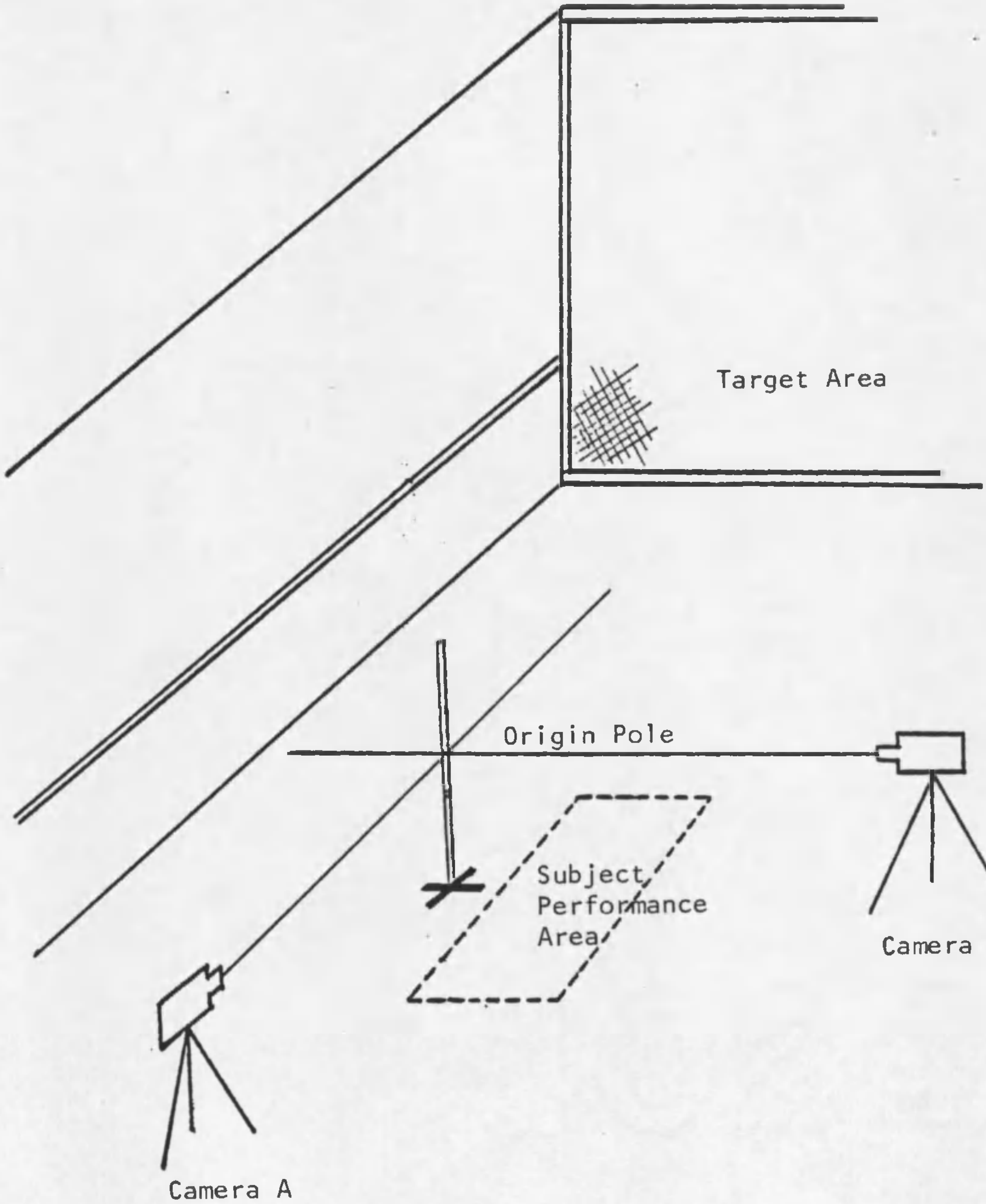


Figure 1. Filming Site.

to warm-ups and practice throws. This method of marking was chosen over tape to insure that the reference lines would not change or fall off during the throwing motion. The location of these markings is shown in Figure 2.

After marking the reference lines on the performer, the assistant filled out a data sheet regarding pertinent information for each subject. This included vital statistics and measures of forearm and upper arm length and shoulder width. Velocities from the pre-test were also included on the data sheet.

Softballs and gloves were provided so that the subjects could warm-up properly for a minimum of four maximal effort throws under filming conditions. The subjects were familiarized with the filming condition and procedure by taking several sub-maximal throws at the performance site. This was done to insure that the performer would be in the field of view of both cameras throughout the throwing action.

An official softball (12 inch circumference, 6 ounce weight) was marked with black tape around its longitudinal and latitudinal circumference. This softball was used exclusively for filming and not for practice.

In addition to the assistant responsible for marking the subjects and recording subject information prior to filming and after each film trial, two other assistants were used during the filming. One individual was responsible for the ball drop timing procedure which occurred simultaneously with the subject's throw. Sitting on top of a ladder, the assistant was instructed to drop a softball from the top of the timing pole, in full view of both cameras, just prior to release.

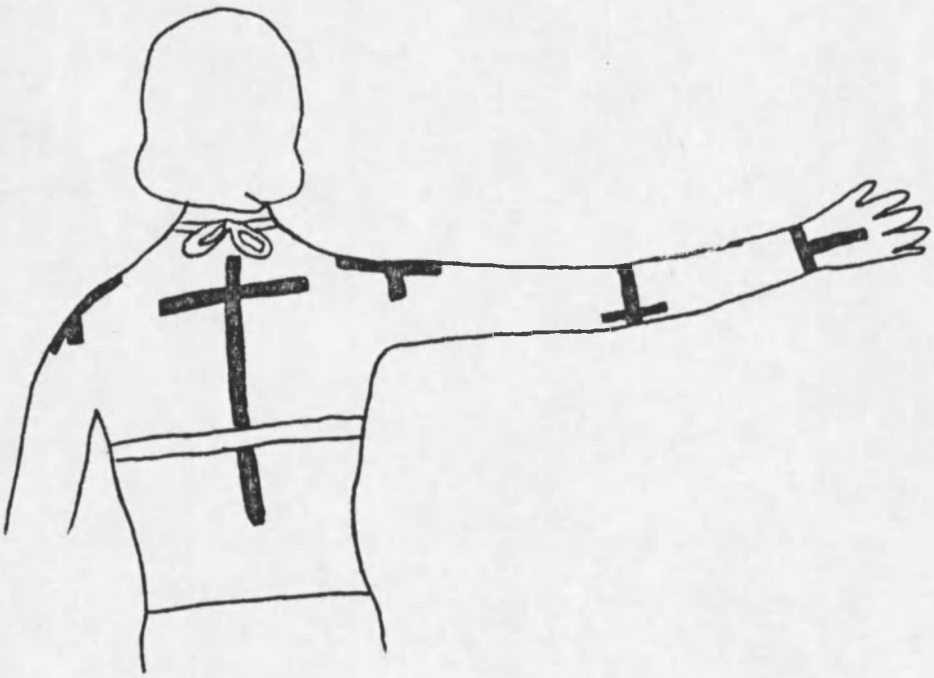


Figure 2. Subject Reference Lines

Information gathered from the ball drop procedure is discussed later in this chapter under "Data Collection Procedures."

The third assistant was responsible for operating the rear view camera (camera A). Dr. Anne E. Atwater operated the side view camera (camera B). The investigator in this study supervised the marking of the subjects and coordinated the performance of the subject and camera operators during the filming. Instructions for the performer and the camera operators were issued prior to each trial. The camera operators were asked to rewind their camera and check all the settings, notifying the investigator when they were prepared for the next film trial. When the subject was ready, the operators were instructed to begin filming as the performer started her preparatory movements for the throw. Immediately after the ball was released, the cameras were stopped.

Before filming any of the subjects, a stopwatch and an object of known length were filmed by both cameras. This information was used later in the calculation of frame interval times, actual camera speeds, and conversion factors. A detailed explanation is presented in "Data Collection Procedures."

Each subject was filmed twice performing the overarm throw and twice performing the sidearm throw. All trials were to be maximum efforts with the subject throwing to a "target person" approximately 70 feet away. On the overarm trials, the subject started her throwing motion with the ball held in both hands. On the sidearm trials, the investigator rolled the ball on the ground to the subject, who then fielded the ball and threw. After each trial, the subject was asked to evaluate her throw in terms of "fair, good, or very good." This information was recorded on the data sheet for later use in selection of the trials to be analyzed.

Data Collection and Reduction Procedures

After viewing the developed films, it was apparent that one subject would have to be eliminated from the study because the film from the side camera (camera B) was blacked out. This brought the number of subjects down to four and the total number of usable trials down to nineteen. (At the time of the filming session, additional trials were filmed on some performers where it was deemed necessary.)

Selection of Film Trial

For each subject, one trial of the overarm throw and one trial of the sidearm throw were selected for analysis. These were chosen on the basis of the general quality and completeness of the film trial. The subject's post-trial evaluation of her throw was also taken into consideration.

Preparation of Film

Having selected the desired film trials, each film was prepared for analysis by scratching marks on the emulsion side of the film at the edge between the sprocket holes. Every fifth frame between the Kodak edge numbers that appeared each 20th frame was marked (frame #5-, frame #10=, frame #15≡) so that a single frame could be easily located.

Camera Film Speed and Frame Interval Time

Determination of actual camera speed was necessary as spring-driven cameras tend to vary from the precise speed set on the "frame-per-second" camera dial. Although both cameras were set for 80 frames per second, they did not run at this speed. A stopwatch with a three-second sweep was filmed by each camera for each reel of film used. By counting the number of film frames exposed over a one-second interval, a true measure of the film transport speed was determined.

This information was then used to calculate the amount of time that had elapsed between the exposure of any two successive film frames. Table 2 presents the frame interval times for each film for each camera.

The average of the rear view camera frame interval time was .0140 seconds; the average of the side view camera frame interval time was .0136 seconds. The mean frame time for both camera views was .0138 seconds.

Film Conversion Factors

In order to convert film measures to actual measures, an object or distance of known length must be filmed by both cameras. Film multipliers for each camera were obtained by tracing the one foot segments marked on the origin pole from a single frame which was enlarged by a Recordak Film Reader, Model P-40. The tracing was then placed onto a digitizer platen (Hewlett Packard, Model 9864A) where a program written for the Hewlett Packard calculator and digitizer was used to determine the line length to the nearest hundredth of an inch. The ratio of actual length to film length resulted in a multiplier or conversion factor which

Table 2. Frame Interval Calculation and Times.

	Rear (A, X) Camera	Side (B, Y) Camera
Film #1	72 frames/second, or 1/72 sec./frame interval, or .0139 sec./frame interval.	73.5 frames/second, or 1/73.5 sec./frame interval, or .0136 sec./frame interval.
Film #2	71 frames/second, or 1/71 sec./frame interval, or .0141 sec./frame interval.	73 frames/second, or 1/73 sec./frame interval, or .0136 sec./frame interval.
Film #3	72 frames/second, or 1/72 sec./frame interval, or .0139 sec./frame interval	73 frames/second, or 1/73 sec./frame interval, or .0136 sec./frame interval

was inserted in the three-dimensional program as a basis for determining the actual X, Y, and Z coordinates of any point with respect to the origin. Table 3 presents the conversion factors for each camera view.

Table 3. Conversion Factors.

Rear (A, X) Camera	Side (B, Y) Camera
One foot = 0.79 film inches	One foot = 0.75 film inches
or	or
One film inch = 1.266 feet	One film inch = 1.333 feet

Camera Synchronization and Time Sampling Error

Since the original assumption was that the camera speed might not be exactly the same for both cameras, a "time pole" was used to aid in the determination of the degree of synchronization between the cameras. This pole was marked in one foot intervals and was visible in both camera views. An assistant was instructed to drop a softball from the top of the time pole just prior to the thrower's release of the softball. As the dropped ball fell, passing the marked intervals, a "known occurrence" was created which could be seen simultaneously from both cameras. With this reference point, the side and rear view films could be matched, or synchronized, at a particular point in time.

The time reference point, or "event," that proved to be most useful in matching the side and rear view films of each trial was ball release by the thrower. Selection of this film frame was performed by closely observing the subject's ball-hand relationship and by viewing the position of the dropped ball relative to the time pole in the background. Once "release frame" was selected and matched in the two views, the film frames prior to and after release also were considered to be matched for the rear and side films due to the high degree of similarity in the frame interval time of both cameras (Table 2).

The film frame identified as the ball release frame was the one judged to be closest in time to the actual instant of release. However, ball release may have either slightly preceeded or followed the film frame identified as the release frame. A time period of plus and minus one-half the film frame interval time was estimated to be the "sampling error" that could be assigned as the degree of precision in matching the side and rear view films. Therefore, the "sampling error," when quantified on the basis of the mean frame time for both cameras, was .0138 seconds.

Film Reading Procedures

The films were placed in a Recordak Film Reader (Model P-40), in order to determine the frame in which the ball was released from the subject's hand. The release frame for each film trial analyzed became time zero, the "frame of reference:" that is, all action was discussed in reference to the release point.

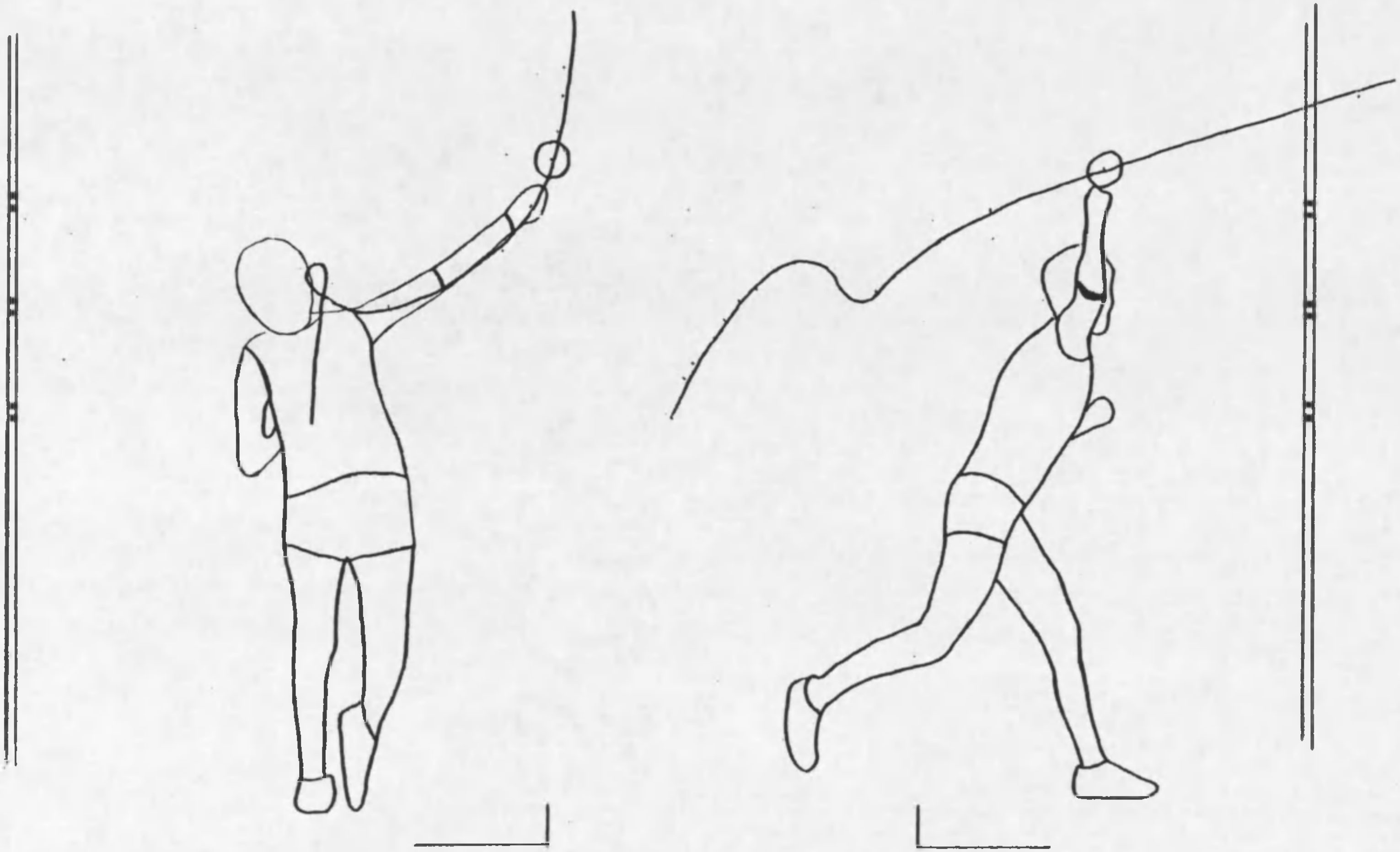
The subject, origin pole, and time pole were then traced onto graph-ruled engineering paper for both the rear and side camera views. A sample of the tracings prepared for subject C for the overarm throw illustrates the type of tracings prepared for all subjects on each trial

(Figures 3, 4, 5). Care was taken to align the tracing paper in relation to fixed objects in the background of the camera views. Realigning the tracing as the film frame was changed, a dot was placed on the paper representing the center of the ball. The path of the ball was followed for twenty frames prior to release, at release, and for five frames after release, resulting in a total of 26 frames or 0.36 seconds of the action. The tracing was then removed from the Recordak and a line of best fit was drawn through the points, using a French curve.

Tracings of this type were made for both the overarm trial (rear and side views) and the sidearm trial (rear and side views) for each subject. Separate tracings were also made following the path of the right shoulder joint center and the right elbow joint center, as well as the ball path tracings.

Data Collection Procedures

Each tracing was placed on a digitizer platen (Hewlett Packard, Model 9864A) where the data points for the 26 film frames were digitized in relation to the origin point visible in the two camera views. This was done for the separate tracings of the ball path, elbow joint center path, and shoulder joint center path as recorded from both the side and rear view films. The rear camera view (X-axis camera) provided the Y and Z coordinates of the points in question, and the side view camera (Y-axis camera) provided the X and Z coordinates of the points. Figure 6 illustrates this and identifies the sign (plus or minus) of the coordinate in relation to the origin. All points were read to the nearest one hundredth of an inch by the digitizer.



a) Camera A b) Camera B

Figure 3. Sample Tracings of Ball Path for Subject C.

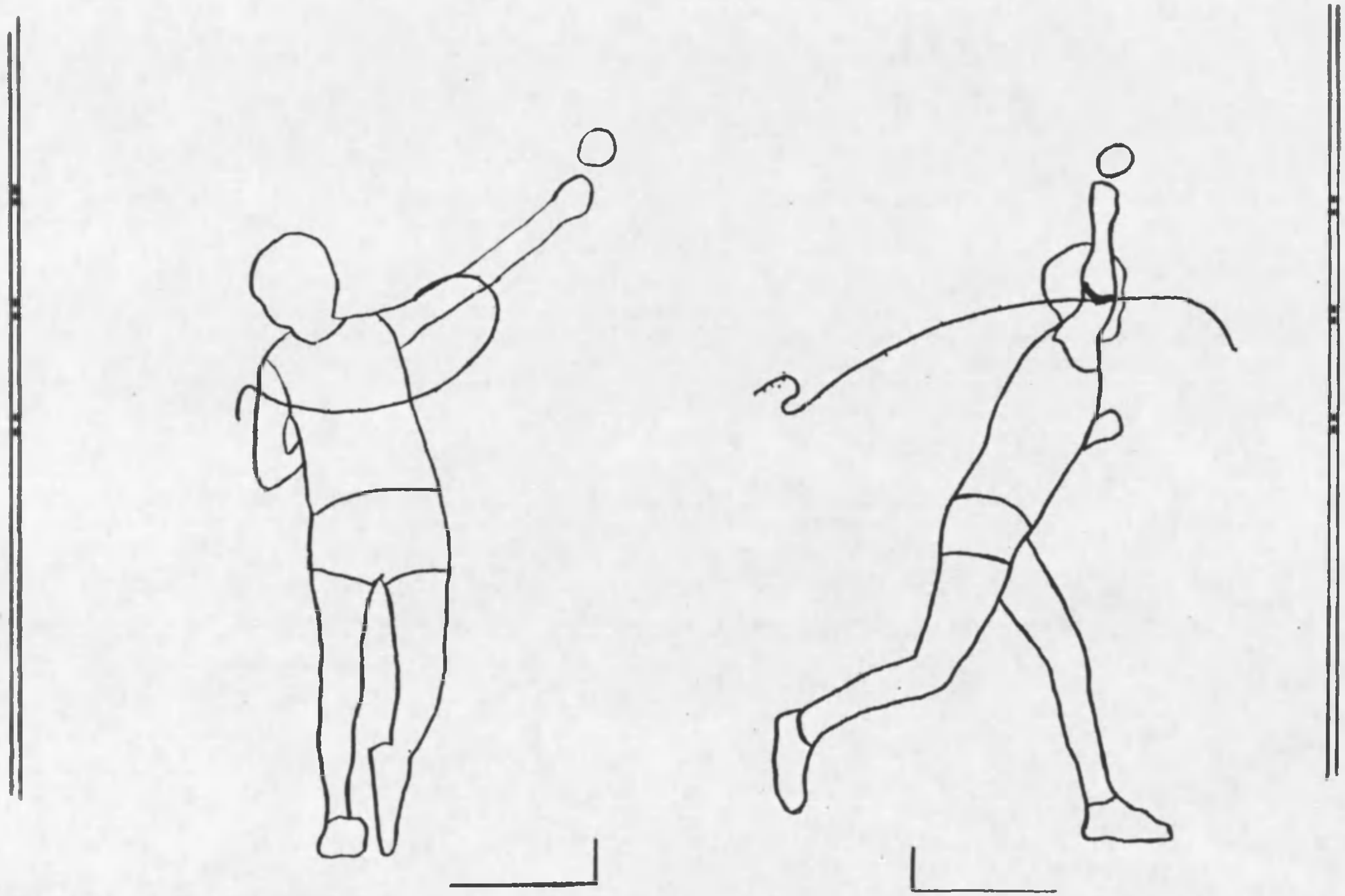
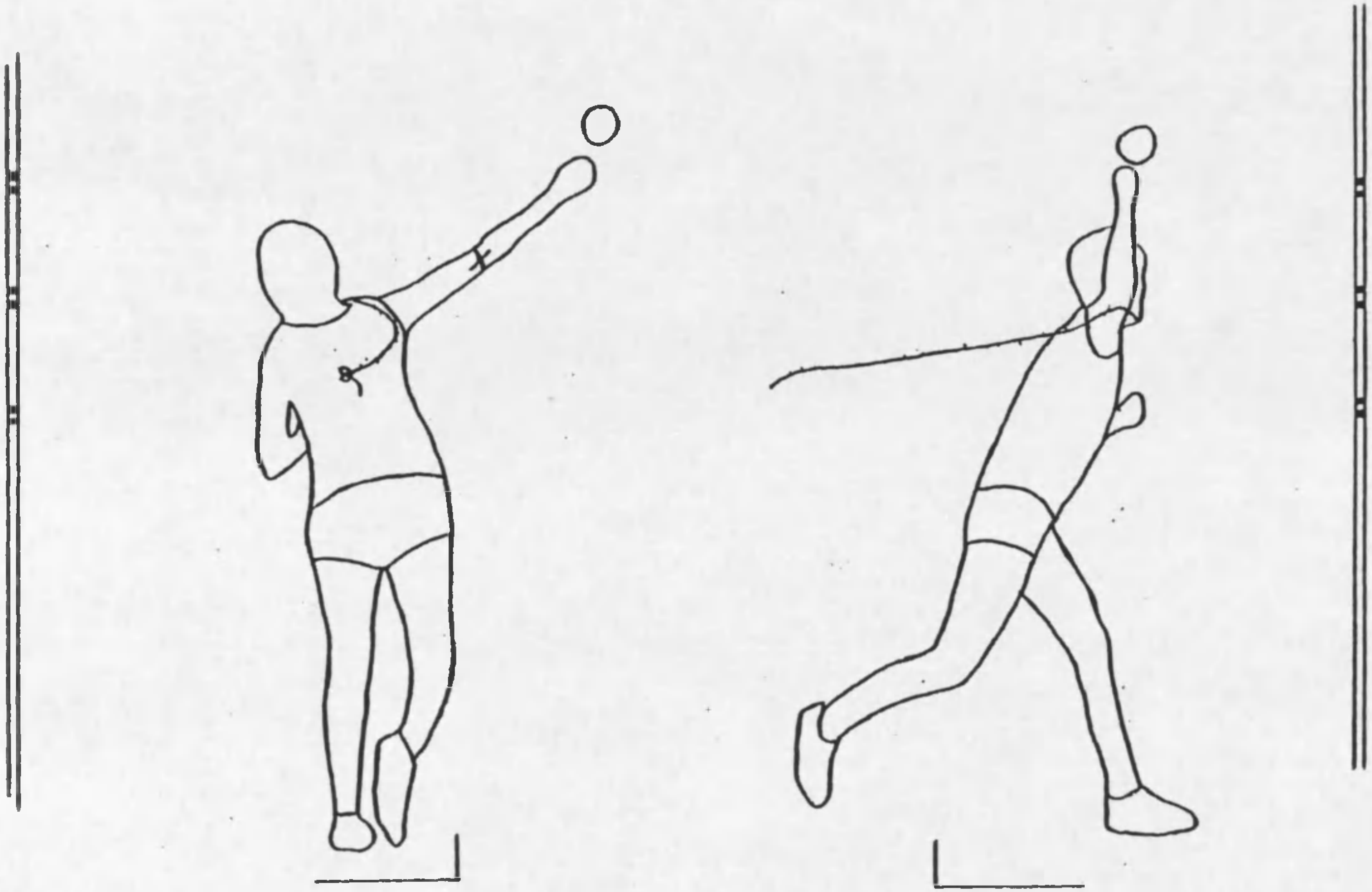


Figure 4. Sample Tracings of Elbow Joint Center Path for Subject C.



a) Camera A   b) Camera B

Figure 5. Sample Tracings of Shoulder Joint Center Path for Subject C.

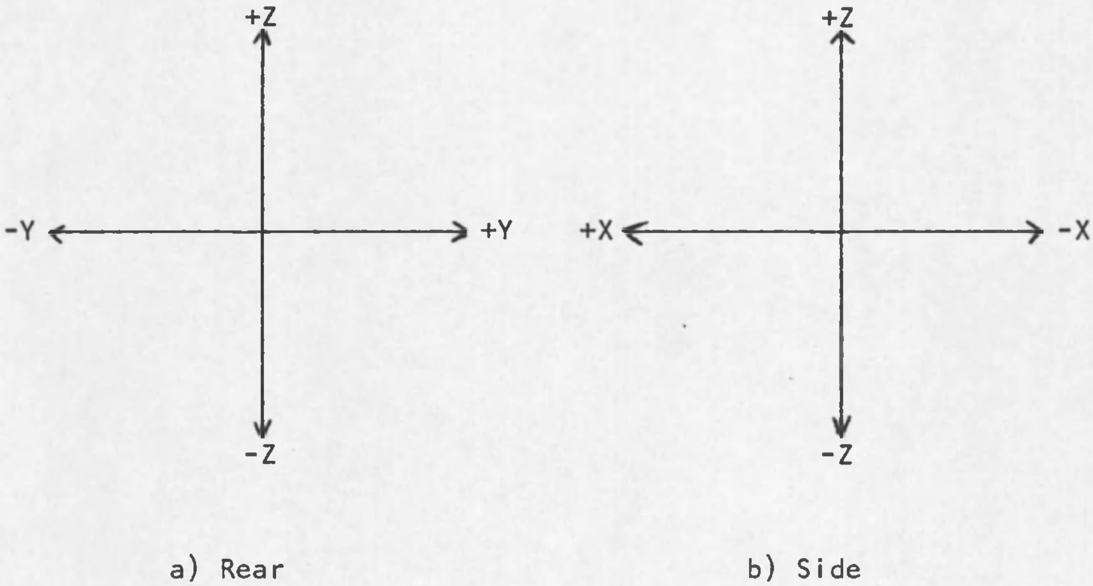


Figure 6. Coordinates and their Sign as Determined from Each Camera View.

The points which were read from the rear camera (A, X) were recorded just as they were digitized. The points which were read from the side camera (B, Y) were not recorded as they were digitized. Instead, the sign of the X coordinate was always changed because the projection plane for the side camera, in relation to the camera position on the Y-axis is "reversed" (Spray, 1973).

Data Reduction Procedures

Three-Dimensional Coordinates. The collected points (X, Z and Y, Z) were then processed on a mini-computer and calculator system (Hewlett Packard, Model 9810A) using the program written by Spray (1973) to determine the actual spatial coordinates by mean of the Susanka vector equations.

The basic concept behind this approach involved the determination of the two vectors from two pairs of coordinates, and the calculation of the intersecting point common to both vectors. A simplified diagram from Spray (1973) may clarify this relationship (Figure 7).

Theoretically, if the two cameras were synchronized, the two vectors would intersect. However, if the two cameras or camera shutters were not perfectly synchronized (as in this study), or if the film coordinates were inaccurate to any degree, the vectors would not intersect. Therefore, the program "averaged" the distance between the two non-intersecting vectors in order to determine a spatial coordinate. This degree of non-intersection was expressed as the scalar triple product. In general, the closer the scalar triple product was to zero,

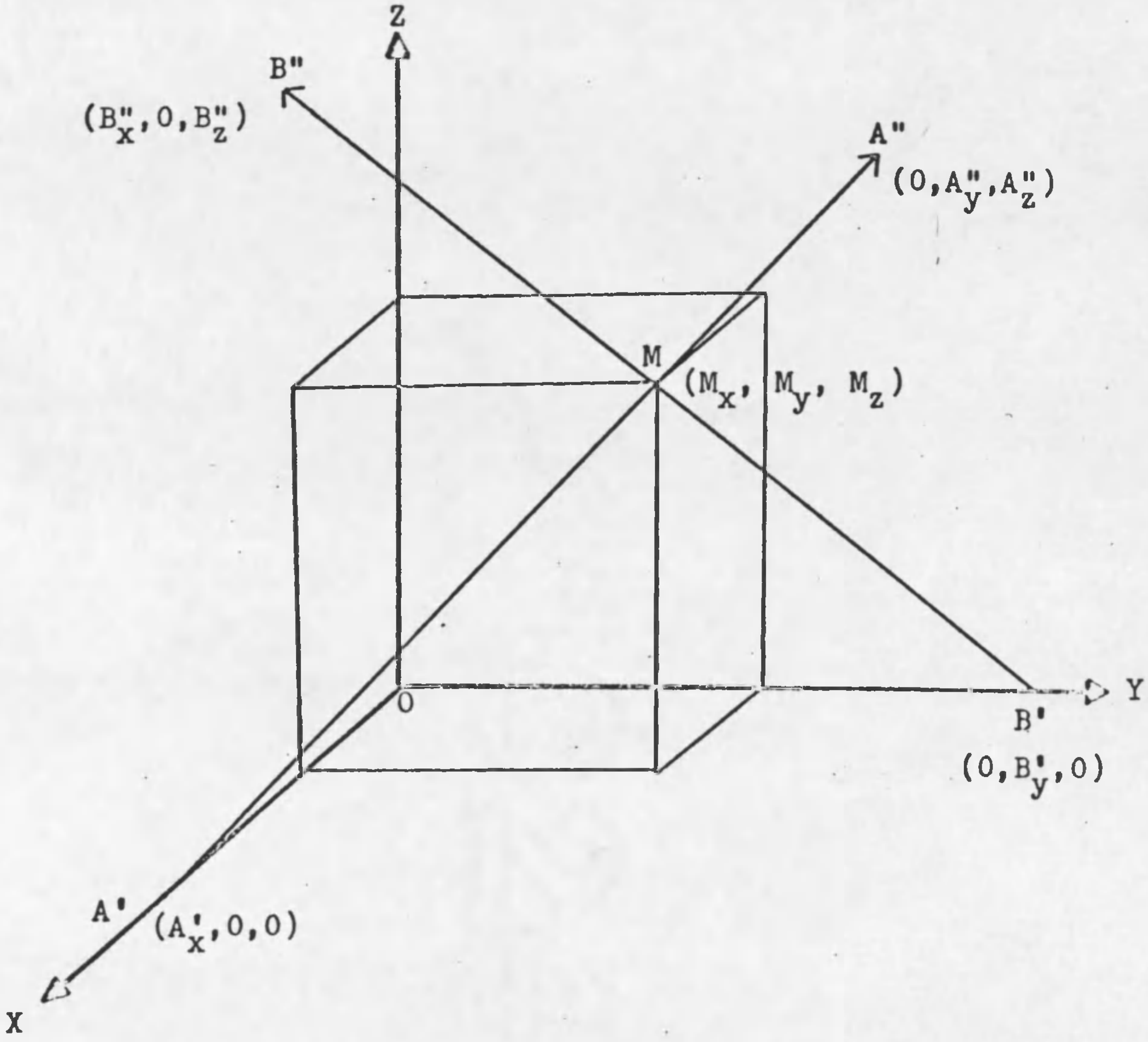


Figure 7. Vector Intersection.

the better the approximation was to the true value of the spatial coordinate. A more detailed explanation of this approach can be found in Spray's study (1973).

In order to determine the spatial coordinates, it was necessary to provide the film conversion factors (rear and side view), the distance from each camera to the origin of the coordinate system, and the paired coordinates for each film frame (X, Z and Y, Z). This procedure was used for each of the 26 points for each tracing.

After each pair of coordinates was entered, the program calculated the three-dimensional coordinates and the scalar triple product. An example of the input and output data for one point in the overarm ball path of subject C is presented in Table 4.

Resultant Velocity. The three-dimensional coordinates were then used to calculate the instantaneous resultant velocities for the ball, elbow joint center, and shoulder joint center. A program written for the Hewlett Packard system determined the vector distance between each pair of successive points. Using this distance and the average frame interval time (average of both camera views), the instantaneous resultant velocity was calculated. These velocities were graphed and a line of best fit was determined using a French curve. An example of the resultant linear velocity of the ball, elbow joint center, and shoulder joint center for subject C is illustrated in Figure 8.

Component Velocity. In order to determine the magnitude and direction of the velocity, the sequential component (X, Y, and Z) positions were graphed separately. Using a 5th degree polynomial regression equation to fit a curve to the 26 data points (component positions),

Table 4. Sample of Three-Dimensional Coordinate Determination Program Input and Output.

INPUT	OUTPUT
	SPATIAL COORDINATE DETERMINATION
Number of points to be analyzed 26.000	
Conversion factors for each camera 1.266 1.333	
Camera-to-origin distances 53.292' 54.896'	
	ANALYSIS FOR PAIR NUMBER 1.000
Y and Z coordinates from rear camera 2.260 -0.870	
X and Z coordinates from side camera 4.830 -0.820	
	SCALAR TRIPLE PRODUCT = 198.164
	MIDPOINT COORDINATES
	MBAR (X) = 6.141
	MBAR (Y) = 2.532
	MBAR (Z) = -1.009

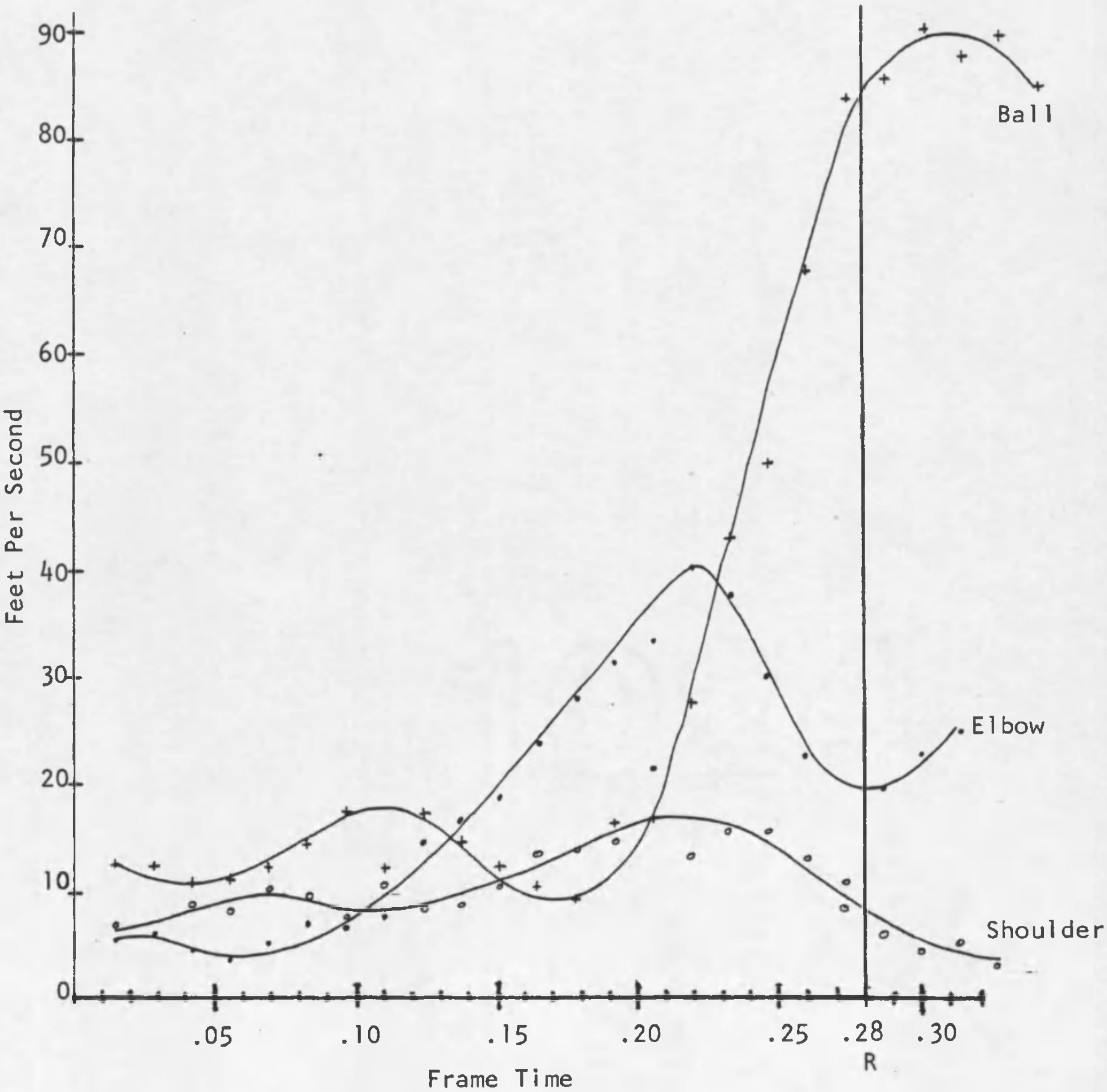


Figure 8. Sample Instantaneous Resultant Velocities of the Ball, Elbow Joint Center, and Shoulder Joint Center for Subject C.

the X, Y, and Z component velocities were derived and plotted. Figures 9 and 10 illustrate the Y position (displacement) and Y velocity component for subject C. This procedure was carried out only on the data concerning the resultant ball velocity.

Body Position at Release. Using a tracing of the subject from the rear view at release, the trunk position relative to the vertical was measured. A line of best fit was drawn through the midpoint of the upper trunk, and the intersection of this line with the vertical formed the angle of deviation. The degree of lateral inclination was measured by use of a protractor.

The same technique was used to determine the shoulder line position relative to the horizontal. A line of best fit was drawn through the midpoints of the left and right shoulder joints, and the intersection of this line with the horizontal determined the angle of deviation.

The angle created by the shoulder line and the right upper arm was determined by the intersection of the shoulder line and the line of best fit drawn through the midpoints of the right shoulder joint and the right elbow joint. The arc beneath these two segment lines was defined as the angle of interest. This was also measured by a protractor. Figure 11 illustrates the measurement of body position for subject C in both the overarm and sidearm views.

Elbow Joint Action and Angular Velocity. The right elbow angle through the force-producing phase was determined by using the three-dimensional (X, Y, and Z) coordinates of the shoulder, elbow, and ball,

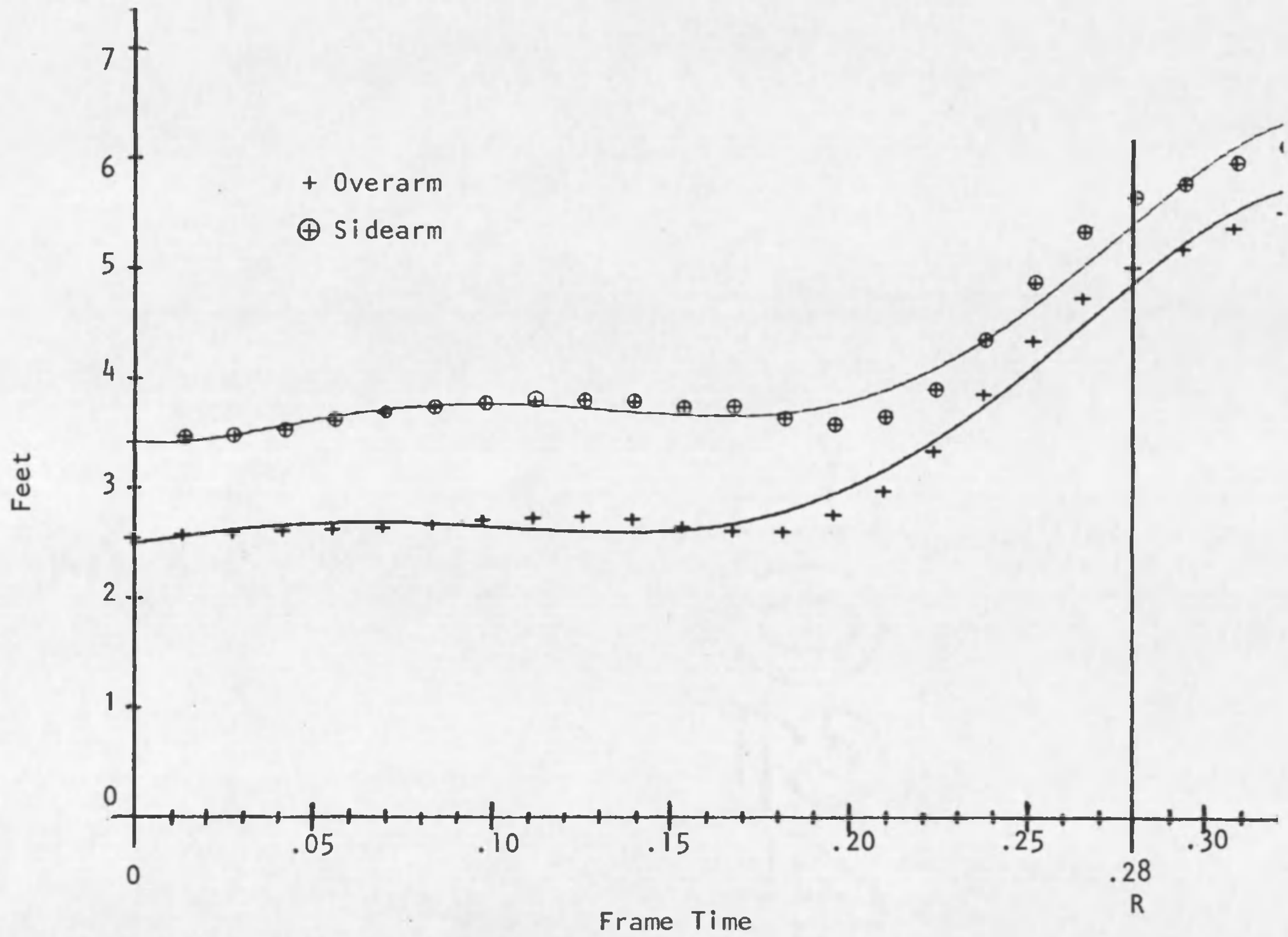


Figure 9. Sample Y Component Displacement Graph.

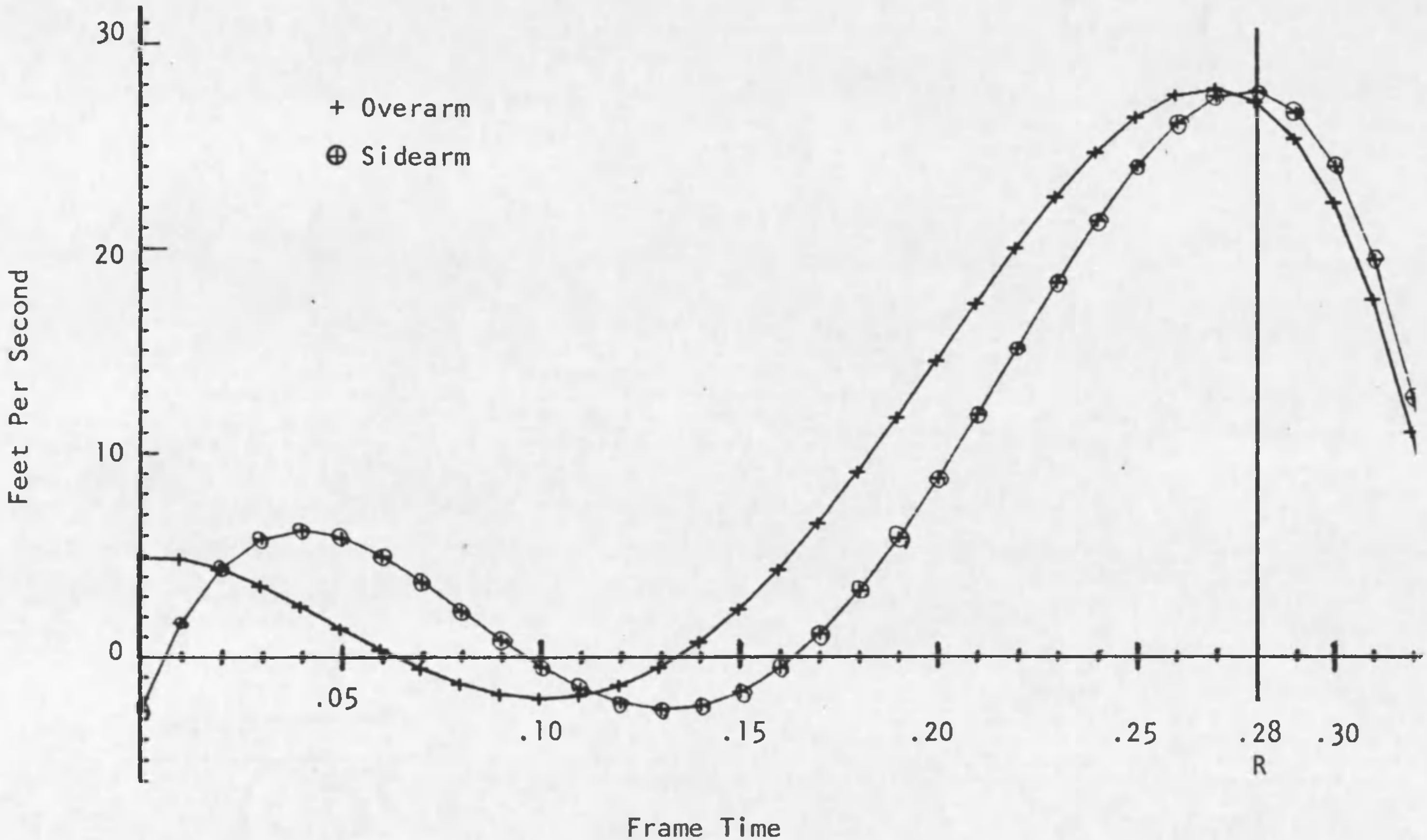
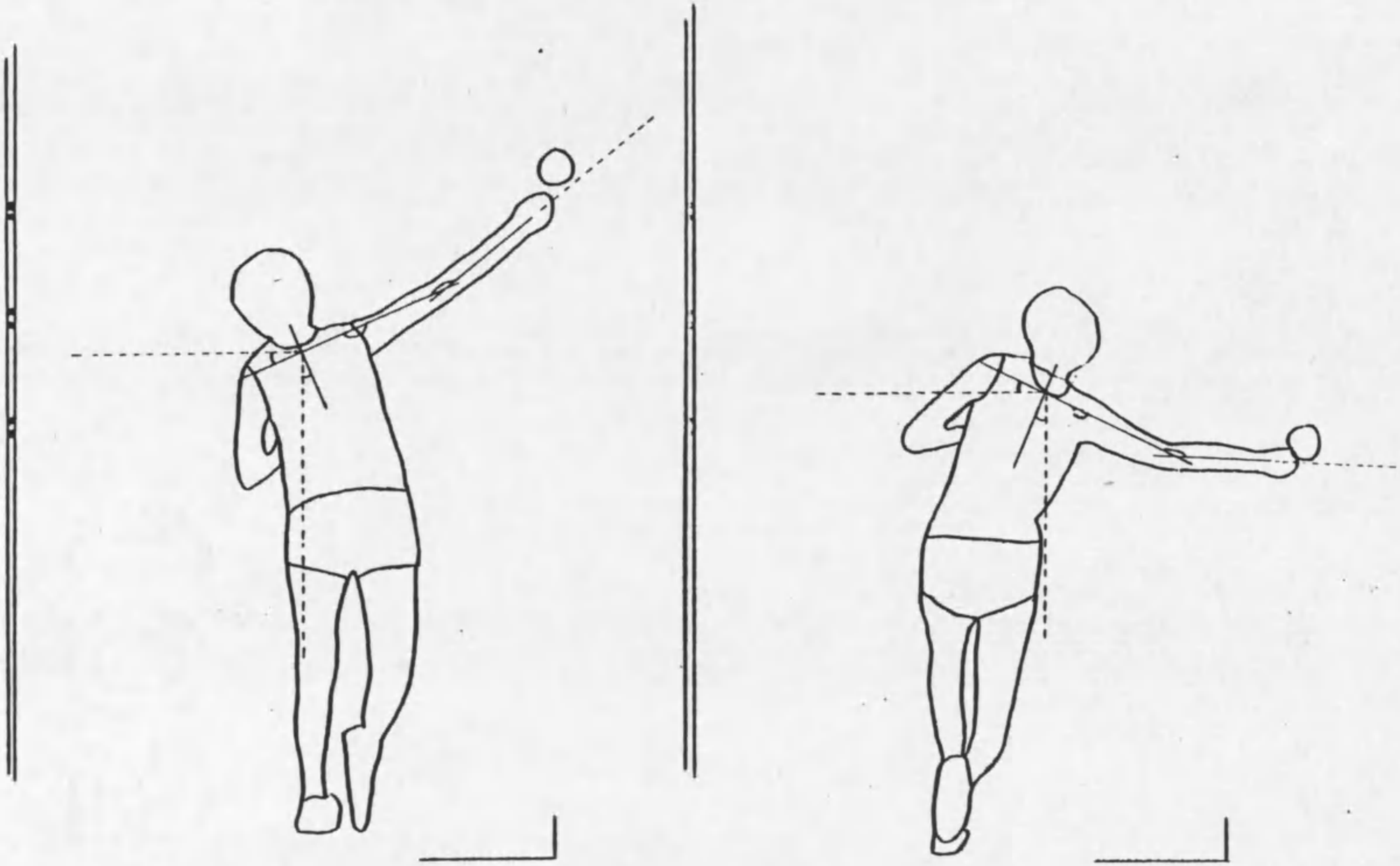


Figure 10. Sample Y Component Velocity Graph.



a) Overarm

b) Sidearm

Figure 11. Sample Measurements of Body Position at Release.

and a program which utilized the law of consines. In addition, the planar elbow angle at release was measured with a protractor from the rear view film tracing.

These angles were then plotted against time and a line of best fit determined with the aid of a French curve. The angular velocities were calculated by using the tangent to the curve method and a program written for the Hewlett Packard digitizer and calculator system. An example of the elbow joint angular displacement graph and the tangent line for subject C is presented in Figure 12.

Summary

Four highly skilled female subjects were chosen for this comparison of selected aspects of the overarm and sidearm softball throw. A throwing pre-test was administered to all subjects prior to the filming to obtain estimates of their maximal throwing velocity for both types of throws. All the pre-test velocities ranged between 82.8 and 91.2 feet per second.

To provide convenience of camera set-up and availability of adequate lighting, the filming took place on the north tennis courts at the University of Arizona. Two 16 mm motion picture cameras were aligned at right angles to each other, each creating one of the theoretical axes of the coordinate system. The rear (A, X) camera's optical axis determined the X axis, and the side (B, Y) camera's optical axis determined the Y axis. An origin pole was placed at the theoretical intersection of the optical axes, thus being defined as the origin of the system.

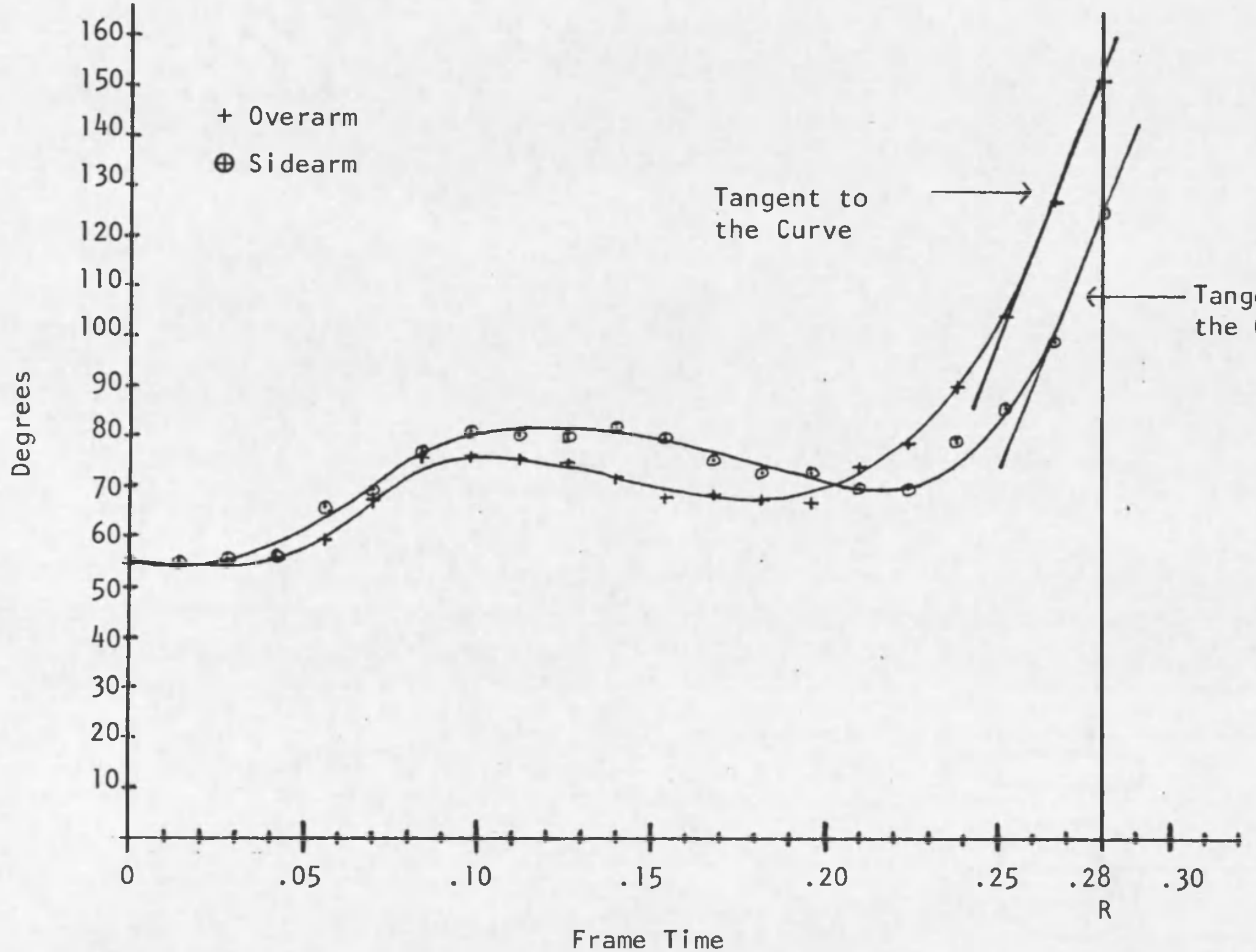


Figure 12. Elbow Joint Angular Displacement Graph and Tangent to the Curve.

Each subject was filmed a minimum of two times for each type of throw. Selected reference lines were marked on each subject prior to the filming. These lines were located on the trunk, both shoulders, the right elbow, and the right wrist.

For each subject, films of one trial of the overarm throw and one trial of the sidearm throw were selected for analysis. Prior to the actual data collection, the camera film speeds, frame interval times, and conversion factors were calculated. In addition, the release frame was selected for both the rear and side views of each throw and each trial.

At the film frame showing ball release, the subject, origin pole, and time pole were traced from the film onto graph-ruled engineering paper by means of a Recordak Film Reader. On this same tracing, the path of the ball was followed from twenty frames prior to release to five frames after release. The same procedure was used for the path of the right shoulder and right elbow joint.

Each tracing (rear and side views) was placed on a digitizer where the data points for the 26 film frames were determined in relation to the origin point visible in the two camera views. The rear camera provided the Y and Z coordinates of the points in question and the side camera provided the X and Z coordinates.

These collected points were processed on a mini-computer/calculator system using a program written by Spray (1973) to determine the actual spatial (X, Y, and Z) coordinates by means of the Susanka vector equations. The three-dimensional coordinates were then used to calculate the instantaneous resultant velocities for the ball, elbow joint center, and shoulder joint center. From there, the resultant velocity of the ball was broken down further into component velocities in order to analyze the contribution each component made to the resultant velocity.

Using tracings of the subjects from the rear view at release, the trunk and shoulder line positions were measured in relation to the vertical and horizontal, respectively. The angle formed by the intersection of the shoulder line and the right upper arm was also measured. All measurements of the body position at release were made with a protractor.

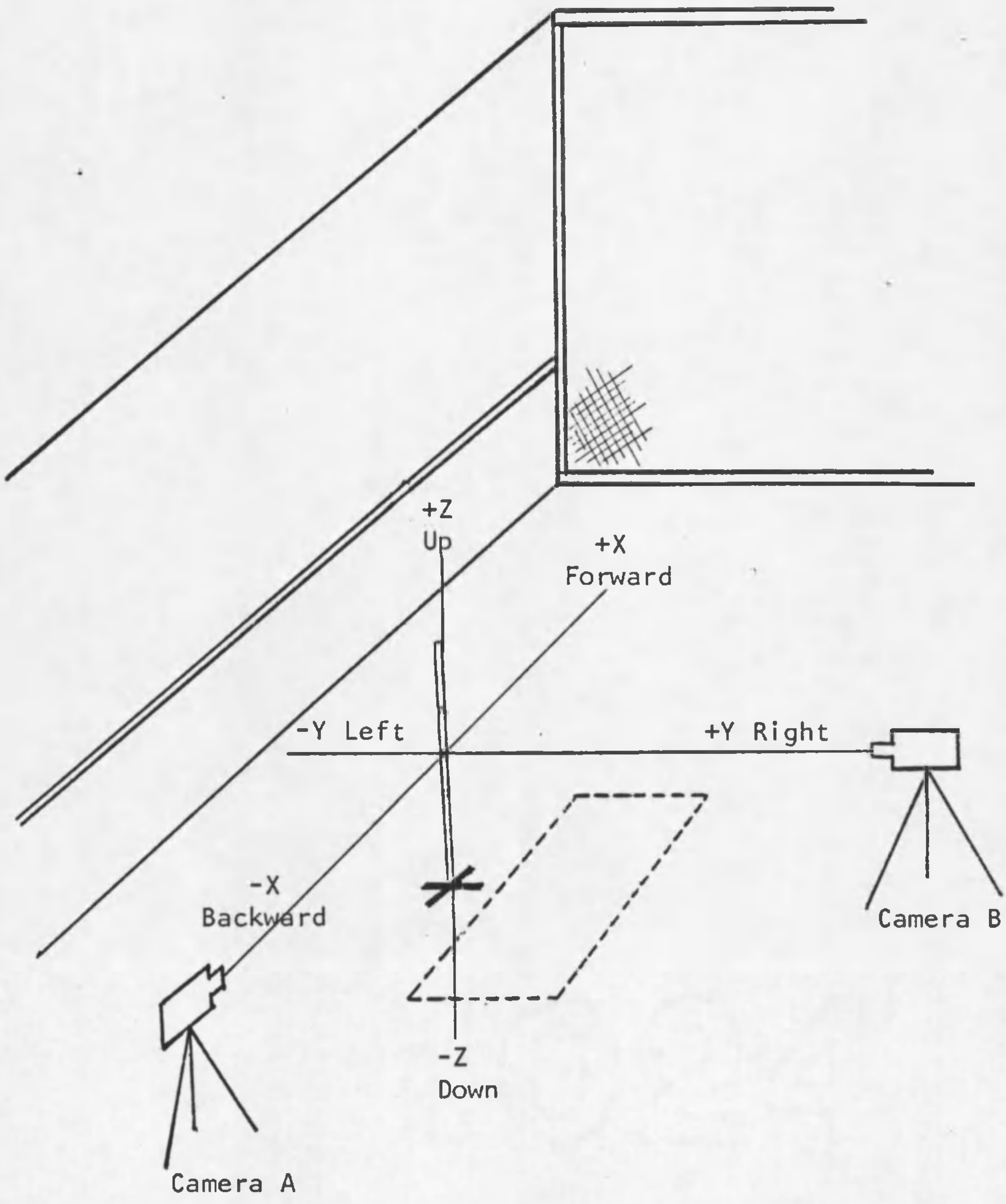
The right elbow joint angle was calculated using a three-dimensional version of the law of cosines and the spatial coordinates of the shoulder joint center, elbow joint center, and the ball. The elbow joint angles were plotted against time on a displacement graph, and then the tangent to the curve method was used to find selected angular velocities.

CHAPTER IV

PRESENTATION OF THE FINDINGS

The purpose of this chapter is to present the results of this study. Three main topics will be considered: the three-dimensional velocities, the body position at release, and the right elbow joint action. Each topic, and its subdivisions, will examine characteristics of the overarm throw and the sidearm throw, followed by a comparison of the two patterns. Preceeding the discussion of the main topics, the release velocities of the timed throws and the filmed throws will be compared.

The three-dimensional coordinate system should be reviewed prior to the presentation of results in order to clarify the direction of movement represented by each component (Figure 13). Movement in the X plane represented the backward and forward motion. In Chapter III, it was stated that, when collecting the points from the digitizer, the sign of the X coordinate was always changed because the projection plane for the side camera, in relation to the camera position on the Y-axis, is "reversed" (p. 48). To aid in the understanding of this component's movement, the velocity signs were again reversed so that positive velocities indicated the forward displacement and negative velocities indicated the backward displacement. This sign reversal was necessary only on the X component and was done strictly to aid in comprehension of the movement. It did not affect the results of the study.



Note: Signs of the X coordinate have been reversed.

Figure 13. Three-Dimensional Coordinate System.

The Y plane represented the left to right movement and was referred to as the "lateral" component. Negative velocities indicated displacement to the left (as seen from the rear view) and positive velocities indicated displacement to the right. Movement in the Z plane, sometimes referred to as the "vertical" component, represented the up and down change. Positive velocities indicated upward movement and negative velocities indicated downward movement.

Release Velocities

Prior to the discussion of the three-dimensional velocities, a comparison between the pre-test ball velocities at release and the three-dimensional resultant linear ball velocities determined from films at release will be made in order to determine whether the throws under the two conditions differed and to help substantiate the validity of the film data.

The pre-test ball velocities at release reflected the mean of several throws by each subject for both the overarm and sidearm patterns. The difference between the slowest (82.8 feet per second) and fastest (91.2 feet per second) average overarm pre-test velocities was 8.4 feet per second (Table 5). The overarm three-dimensional ball velocities ranged from 84.1 to 90.2 feet per second, the difference between the fastest and slowest throw being 6.1 feet per second. In comparing the pre-test velocities and the three-dimensional velocities for each subject, the greatest difference for the overarm throw was 4.8 feet per second in subject C.

Table 5. Ball Velocity at Release: Pre-Test vs. Film Data.

Subject	Overarm		Sidearm	
	Pre-Test[a]	3-D[b]	Pre-Test[a]	3-D[b]
A	82.8'/s	86.2'/s	86.2'/s	81.3'/s
B	87.6'/s	84.1'/s	87.0'/s	83.5'/s
C	89.8'/s	85.0'/s	88.8'/s	84.8'/s
D	91.2'/s	90.2'/s	91.0'/s	83.4'/s
$\bar{X}$ =	87.9'/s	86.4'/s	88.3'/s	83.3'/s

[a]Pre-test ball velocity is the mean of several throws timed by a stop-watch (see Chapter III for timing procedure).

[b]Three-dimensional resultant linear velocity of the ball at release as measured from rear and side view films of one trial for each subject.

The sidearm pre-test ball velocities ranged between 86.2 and 91.0 feet per second, a difference among subjects of 4.8 feet per second. The sidearm three-dimensional velocities ranged from 81.3 to 84.8 feet per second, the difference between the fastest and slowest throw being 3.5 feet per second. Within each subject, the greatest difference between the pre-test velocities at release and the three-dimensional velocities at release was 7.6 feet per second in subject D.

The difference among the pre-test ball velocities for the four subjects and among the three-dimensional ball velocities for all four subjects was relatively small (less than 10 feet per second) for both the overarm and sidearm throws. In addition, the difference between the two average release velocities for each subject in each type of throw was as small as the within subject variability obtained on repeated trials of each type of throw. In other words, the intersubject and intrasubject variation between the two release velocities was minimal for both of the throwing patterns.

When consolidating these results into differences in release velocity between the overarm and sidearm throws, it was found that the mean difference in the pre-test measures was 0.4 feet per second with the sidearm throw being slightly faster than the overarm throw. In the three-dimensional velocities, the mean difference was 3.1 feet per second, with the overarm throw being slightly faster than the sidearm throw.

To briefly summarize, it was found that in all subjects, the three-dimensional resultant linear ball velocity was somewhat greater for the overarm throw than the sidearm throw. However, results of the pre-test ball velocities indicated that the two throwing patterns had very similar release velocities, and one subject even exhibited a slightly greater sidearm velocity than overarm. Therefore, conclusive evidence was not provided that the overarm throw, in general, is always faster than the sidearm throw. It should also be kept in mind that these results reflected a small sample in which all of the subjects considered the overarm throw to be their dominant pattern.

This portion of the investigation also served, in a sense, as a validation of the film data. Comparing the two estimates of release velocity (determined by a stopwatch and by measurements from films), it was found that there was a high degree of similarity in the measures for each subject. It was then accepted that the film data provided a reasonably valid measure of release velocity and that the subject's maximal throwing measures were not seriously affected by the filming situation.

Three-Dimensional Velocities

Many sources felt that the overarm throw should be used in preference to the sidearm throw whenever there is a need for speed; that is, they felt that the overarm throw is faster than the sidearm throw. In order to qualify and quantify the differences in speed, if any, between the two throws, the resultant linear velocities of the ball, elbow joint center, and shoulder joint center were analyzed. After examination of these three resultant velocities, the component (X, Y, Z) velocities of the ball were found, helping to determine to what degree each component contributed to the three-dimensional resultant ball velocity of the two throwing patterns. Only the ball component velocities were analyzed as the ball speed is a reflection of all the previous and more proximal actions that have occurred.

Resultant Linear Velocities

Ball. The overarm three-dimensional resultant linear velocity of the ball was very similar for each subject over the course of the force-producing phase (Figure 14). In all subjects, the velocity reached a slight peak between .161 and .203 seconds prior to release, and then decreased between .007 and .105 seconds prior to release (Table 6). This early peak in velocity ranged from 16.5 to 20.0 feet per second, while the subsequent low point in velocity ranged from 4.0 to 9.5 feet per second. Immediately following the decrease, the velocity began to increase and continued to increase up to and through release. The velocities at release ranged from 84.1 to 90.2 feet per second.

The sidearm three-dimensional resultant linear velocity of the ball was also very similar for each subject (Figure 14). All subjects' reflected a slight velocity increase between .160 and .217 seconds prior to release, and then the velocity decreased between .091 and .147 seconds prior to release. The slight "peak" in velocity ranged from 12.0 to 17.0 feet per second, and the subsequent low point in velocity ranged from 6.0 to 9.0 feet per second. Following this decrease, the velocity began to increase up to and through release. The release velocities ranged between 81.3 and 84.8 feet per second.

In both the overarm and sidearm throw, the three-dimensional resultant linear velocity of the ball reflected an early, slight peak of approximately 16.5 (±4.5) feet per second at a time close to .187

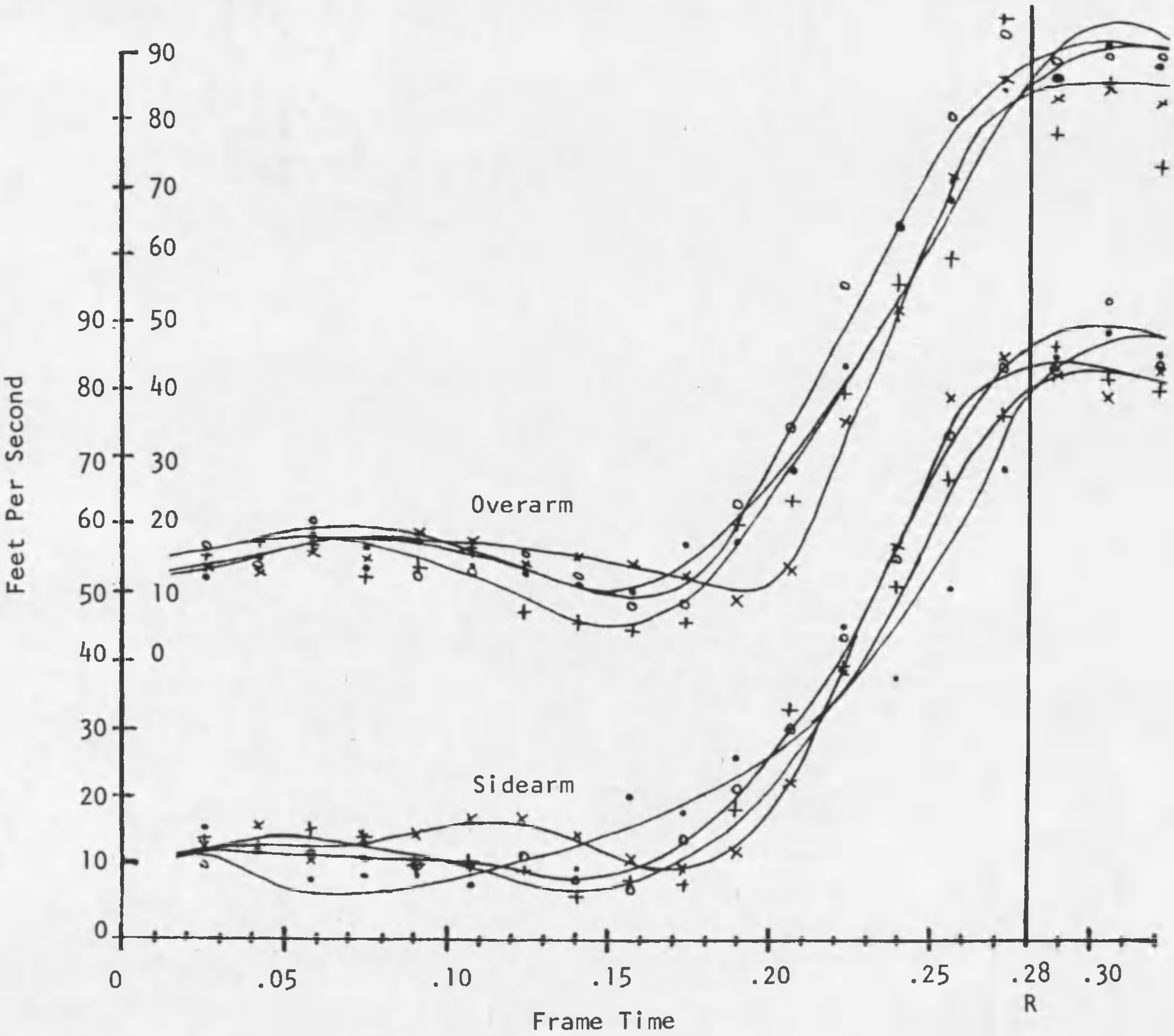


Figure 14. Three-Dimensional Resultant Velocity of the Ball for All Four Subjects.

Table 6. Overarm and Sidearm Peak Three-Dimensional Resultant Linear Velocities of Ball, Elbow, Shoulder.

Subject	Ball		Elbow		Shoulder	
	Time	Velocity	Time (Prior to Release)	Velocity	Time (Prior to Release)	Velocity
Overarm						
A	Release	86.2'/s	.074 s	36.5'/s	.060 s	14.5'/s
B	Release	84.1'/s	.064 s	39.0'/s	.084 s	17.0'/s
C	Release	85.0'/s	.062 s	40.5'/s	.066 s	17.0'/s
D	Release	90.2'/s	.060 s	36.0'/s	.058 s	15.5'/s
$\bar{X}$ =		86.4'/s	.065 s	38.0'/s	.067 s	16.0'/s
Sidearm						
A	Release	81.3'/s	.090 s	33.5'/s	.080 s	14.5'/s
B	Release	83.5'/s	.074 s	42.0'/s	.060 s	16.5'/s
C	Release	84.8'/s	.070 s	37.0'/s	.091 s	17.5'/s
D	Release	83.4'/s	.078 s	33.0'/s	.065 s	16.0'/s
$\bar{X}$ =		83.3'/s	.078 s	36.4'/s	.074 s	16.1'/s

(± .030) seconds prior to release. The velocity then decreased just prior to the final velocity increase leading to release. On the average, the sidearm velocity decreased somewhat sooner (.109 ± .040 seconds prior to release) than did the overarm velocity (.098 ± .020 seconds prior to release), but this difference did not appear to be too important as it was actually less than one frame time interval (.0138 seconds). The resultant velocities at release for both throws were very homogeneous, but the overarm velocity in all subjects was an average of 3.1 feet per second faster than the sidearm velocity (Table 5). In both throws, the velocity continued to increase up to and through release, reaching a peak velocity immediately after release.

Elbow. Throughout the force-producing phase of the overarm throw, the three-dimensional resultant linear velocity of the elbow joint center was very similar for all subjects (Figure 15). The peak velocity was reached at a time between .060 and .074 seconds prior to release, the difference equalling approximately one frame interval (Table 6). These peak velocities ranged from 36.0 to 40.5 feet per second. After reaching this peak, the velocity decreased again to a speed between 10.0 and 20.0 feet per second. The time when this low velocity occurred ranged between .014 seconds prior to release and .006 seconds after release.

For all subjects in the sidearm throw, the velocity of the elbow joint center was also very similar (Figure 15). It attained a peak velocity between 33.0 and 42.0 feet per second (Table 6). This occurred from .070 to .090 seconds prior to release, an approximate time span of 1.5 frame intervals. As in the overarm throw, the velocity decreased

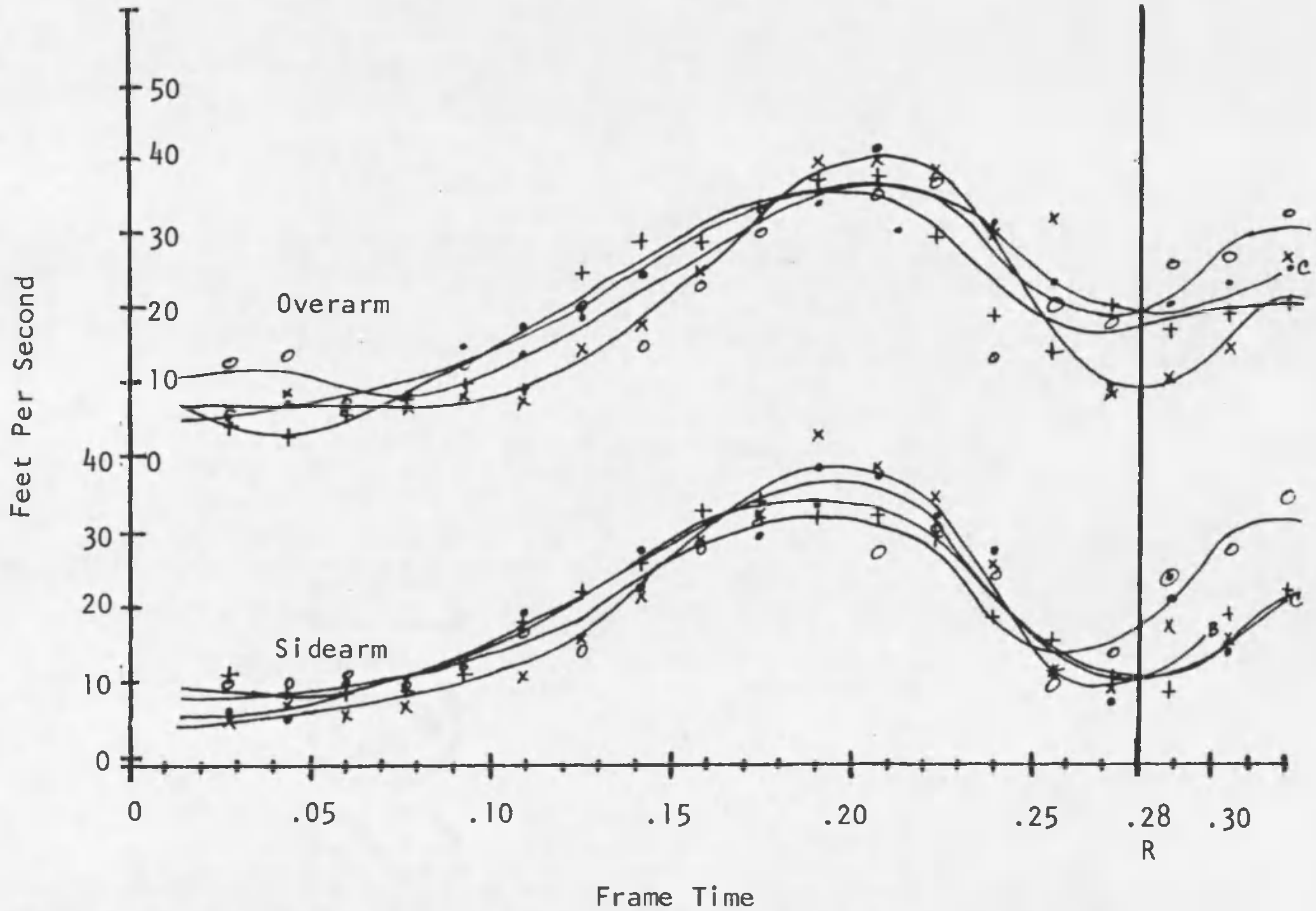


Figure 15. Three-Dimensional Resultant Velocity of the Elbow Joint Center for All Four Subjects.

following this peak to a speed between 9.0 and 13.0 feet per second. This low velocity occurred between .018 seconds prior to release and .002 seconds after release.

The peak three-dimensional resultant linear velocities of the elbow joint center, for both the overarm and sidearm throws, reflected similar magnitudes (an average difference of 3.1 feet per second), and occurred at a similar point in time (a difference of approximately one frame time interval). After reaching this peak, the velocity then decreased to a speed not less than 9.0 feet per second nor greater than 20.0 feet per second. These low velocities occurred within plus or minus two frame intervals prior to or after release.

As expected, the peak velocity of the elbow joint center in both the overarm and sidearm throws was reached prior to the peak velocity of the ball, and was considerably less in magnitude (Table 6).

Shoulder. In the overarm throw, the three-dimensional resultant linear velocity of the shoulder joint center was very comparable among subjects (Figure 16). A peak velocity, ranging from 14.5 to 17.0 feet per second, was reached at a point between .058 and .084 seconds prior to release (Table 6). After reaching the peak, the velocity continued to decrease through the point of release.

The resultant velocity of the shoulder joint center for the sidearm throw was also very similar among all subjects (Figure 16). The peak velocity was reached between .060 and .091 seconds prior to release (Table 6). The velocity ranged from 14.5 to 17.5 feet per second, and immediately following this peak, the velocity began to decrease and continued to decrease through release.

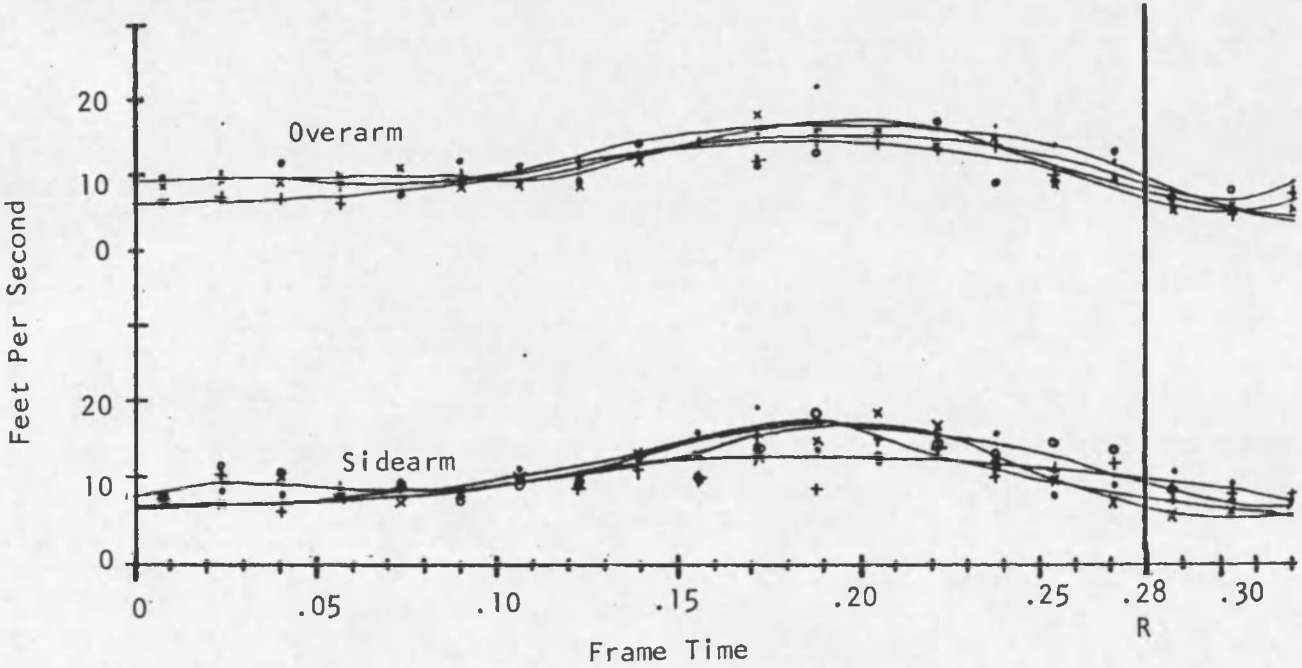


Figure 16. Three-Dimensional Resultant Velocity of the Shoulder Joint Center for All Four Subjects.

In comparing the overarm and sidearm peak resultant linear velocities for the shoulder joint center, it was found that there was virtually no difference between the two throws (an average difference of 0.1 feet per second). In addition, this peak was reached at basically the same time prior to release (a difference of less than one frame time interval).

It should be noted, and observed in Figure 16, that this "peak" in the resultant velocity of the shoulder joint center was not very distinct nor of a large magnitude. It reflected the gradual increase and decrease in the shoulder joint center's speed that corresponded to, but was less in magnitude than, the elbow joint center's speed.

Summary. After analyzing the overarm and sidearm three-dimensional resultant linear velocities of the ball, elbow joint center, and shoulder joint center, it was really evident that the peak velocity of the three points increased in magnitude from proximal to distal. In other words, the shoulder joint center peak velocity was less than the elbow joint center peak velocity, and in turn, the elbow joint center peak velocity was less than the ball release velocity. In addition, there was a great deal of homogeneity between the overarm and sidearm resultant velocities for each of the three points. The ball reached its early peak in resultant velocity at almost the same point in time (.187 seconds ± .03 seconds) relative to release for both the overarm and sidearm throws. In the same light, the elbow joint center reached its peak velocity at comparable times in both types of throws. The same was true for the shoulder joint center velocities in each throw.

When examining the actual sequence of the peak velocities (the release velocity for the ball), it was noticed that several of the throws did not follow a "shoulder-elbow-ball" pattern. In some cases, it appeared that the elbow joint center velocity peaked slightly prior to the peak of the shoulder joint center velocity. However, the shoulder joint center velocity remained relatively constant throughout the force-producing phase and increased only gradually rather than reaching what could be considered a peak. Furthermore, the differences in time between the peak elbow velocity and the increase in shoulder velocity were, in most cases, less than one frame interval and could probably be attributed to frame sampling error. This meant that the elbow peak velocity did occur prior to or simultaneously with the shoulder peak velocity.

Component Ball Velocities

The three-dimensional resultant linear velocities of the ball at release did not indicate any notable difference between the overarm and sidearm throws. The greatest dissimilarity occurred in subject D, with the overarm throw being 6.8 feet per second faster than the sidearm; the greatest similarity occurred in subject C, with the overarm throw only being 0.2 feet per second faster than the sidearm. Yet, one might expect the direction of the component (X, Y, Z) velocities of the ball to vary in each type of throw, even if the resultant velocities were identical. Logically, the sidearm throw should exhibit a greater Y component velocity, or lateral velocity, than the overarm throw. Many sources felt that in the sidearm throw, the arm traveled in a horizontal arc within the transverse plane, accounting for a greater Y component.

In the same respect, it would be logical to assume that the Z component velocity, or vertical velocity, would be greater in the overarm throw than in the sidearm throw because the arm is said to be moving in a near-sagittal plane.

In a further attempt to find differences, if any, between the overarm and sidearm throws, the component (X, Y, Z) velocities of the ball were analyzed for each type of throw. This helped determine to what degree each component contributed to the resultant ball velocity in the two throwing patterns. Only the ball component velocities were analyzed as this is generally accepted as being a reflection of all action which occurs.

X Component (Backward-Forward). The X component velocity in the overarm throw was very much the same for all four subjects (Figure 17). Early in the force-producing phase, the velocity reached a slight peak which ranged from approximately 14.0 to 18.0 feet per second. This occurred between .210 and .220 seconds prior to release in all subjects. The speed of the forward movement then began to decrease and approached zero velocity between .103 and .130 seconds prior to release (Table 7). Subject A's velocity actually became a negative value, indicating that there was a slight change in direction of the ball (backward) prior to the final increase in speed leading to release. Immediately following this decrease, the velocity began to increase and continued to increase up to and through release. The magnitude of the overarm X component velocity at release was very similar for all subjects (63.6 to 65.6 feet per second), with the exception of subject D, whose forward component velocity was 10 to 12 feet per second faster than that

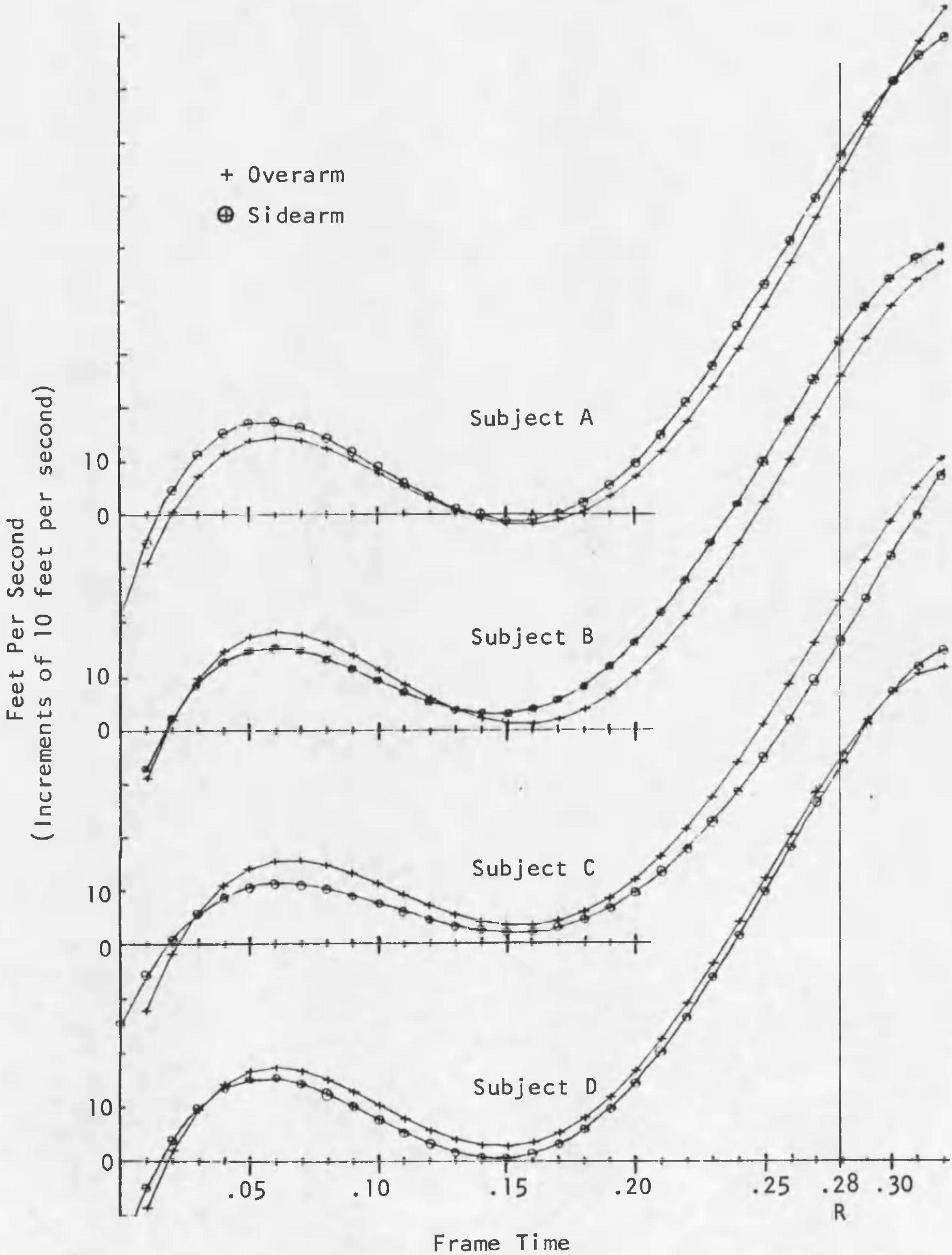


Figure 17. X Component Velocity of the Ball.

Table 7. Overarm and Sidearm X Component Ball Velocity: Time Prior to Release of Velocity Increase and Magnitude of Velocity at Release.

Subject	Overarm		Sidearm	
	Time Prior to Release of Velocity Increase*	Release Velocity	Time Prior to Release of Velocity Increase*	Release Velocity
A	.103 s	64.6'/s	.120 s	67.2'/s
B	.120 s	65.6'/s	.130 s	71.9'/s
C	.120 s	63.6'/s	.120 s	56.2'/s
D	.130 s	75.8'/s	.130 s	74.0'/s
$\bar{X}$ =		67.4'/s		67.3'/s

* As indicated by arrow on Figure 17.

of the other subjects. There was no peak velocity prior to release which was greater than the velocity at release. Table 7 summarizes the key points of the overarm X component.

In the sidearm throw, the X component velocity was also very comparable among subjects (Figure 17). The velocity exhibited a slight peak at .220 seconds prior to release, which ranged from 11.0 to 18.0 feet per second. Still moving forward, the velocity began to decrease, approaching a zero velocity between .110 and .130 seconds prior to release (Table 7). Subject A's velocity became negative again, indicating a slight backward movement of the ball prior to the final increase in speed. Directly after this decrease, the velocity started the increase leading up to release. The magnitude of the sidearm X component velocity at release was comparable for all subjects (67.2 to 74.0 feet per second), except for subject C, whose forward ball velocity was 11 to 18 feet per second less than that of the other subjects. There was no peak velocity prior to release which was greater than the velocity at release. Table 7 summarizes the key points of the sidearm X component.

The characteristics of the X component velocity were almost identical in the overarm and sidearm throws. At the beginning of the force-producing phase of both throws, the forward ball velocity reached a slight peak between .210 and .220 seconds prior to release. Following this peak, the velocity began to decrease, approaching zero velocity between .103 and .130 seconds prior to release. Only one subject exhibited velocities in which the forward movement actually stopped and the ball moved momentarily in a backward direction prior to the final forward velocity increase leading to release. This "crossing of the zero velocity line" occurred in both the overarm and sidearm throws for subject A.

Despite the fact that two subjects, A and B, had somewhat greater sidearm release velocities than overarm (2.6 and 6.3 feet per second faster, respectively), and the other two subjects had slightly greater overarm release velocities than sidearm (7.4 and 1.8 feet per second faster, respectively), the average X component release velocities were almost identical for both throws ($\bar{X}$ overarm = 67.4 feet per second, $\bar{X}$ sidearm = 67.3 feet per second). It does not appear that there were any marked differences in the X component of the two throws.

Y Component (Left-Right). As previously stated, one might expect the Y component velocity to be greater in the sidearm throw than in the overarm throw as it is generally felt that the arm moves in a more horizontal plane throughout the sidearm motion. In the early part of the force-producing phase, analysis of the Y displacement revealed that the ball was moving toward the left and then began to move toward the right, increasing its velocity in preparation for release (Figure 18). The time at which the velocity reached zero, indicating that the ball began moving to the right, occurred between .085 and .147 seconds prior to release in all subjects (Table 8). Just prior to this, when the ball was moving toward the left, the magnitude of the velocity varied somewhat from subject to subject. The velocity then began to increase, moving toward the right, and finally reached a peak between .010 and .040 seconds prior to release. This peak velocity range from 16.9 to 27.8 feet per second. After reaching the peak, the velocity began to decrease

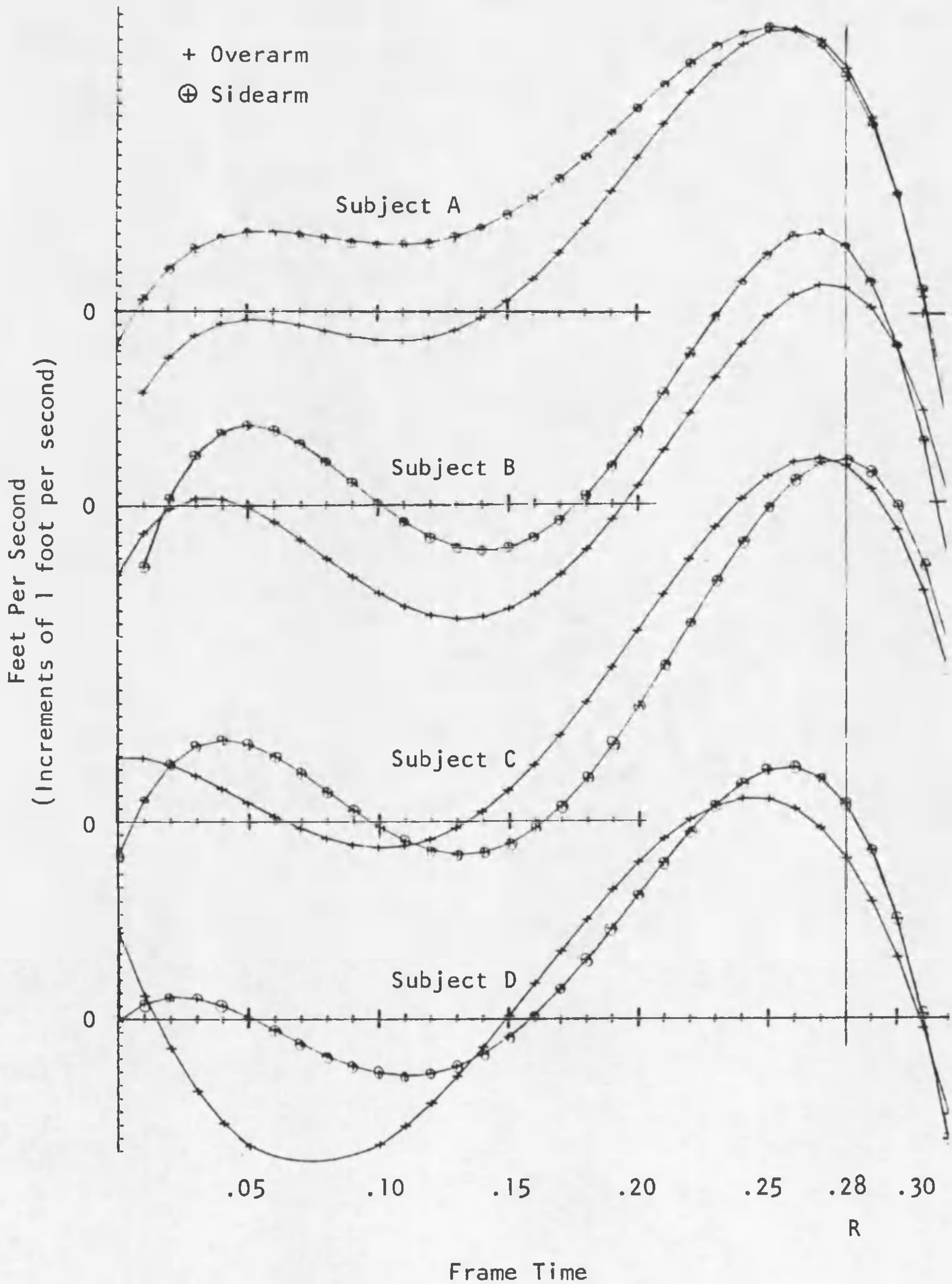


Figure 18. Y Component Velocity of the Ball

Table 8. Overarm and Sidearm Y Component Ball Velocity: Time and Magnitude of Key Points in Velocity Graph.

Subject	Time of 0 Velocity Prior to Release	Time Prior to Release of Peak Velocity	Peak Velocity	Velocity at Release
Overarm				
A	.137 s	.020 s	21.9'/s	18.8'/s
B	.085 s	.010 s	16.9'/s	16.6'/s
C	.147 s	.010 s	27.8'/s	27.0'/s
D	.130 s	.040 s	16.9'/s	12.3'/s
$\bar{X}$ =			20.9'/s	18.8'/s
Sidearm				
A	.270 s	.030 s	22.2'/s	18.3'/s
B	.103 s	.010 s	20.8'/s	19.7'/s
C	.118 s	release	27.6'/s	27.6'/s
D	.121 s	.020 s	19.2'/s	16.4'/s
$\bar{X}$ =			22.5'/s	20.5'/s

and continued to decrease through the point of release. The magnitude of the overarm Y component release velocity ranged between 12.3 and 27.0 feet per second. This release velocity was three to four feet per second less than the peak velocity for subjects A and D, and approximately the same for the other two subjects. Table 8 summarizes the key points of the overarm Y component velocity.

The sidearm Y component velocity exhibited basically the same trend as in the overarm, with the ball moving toward the left in the early part of the force-producing phase, and then changing direction (moving toward the right) between .103 and .121 seconds prior to release (Figure 18, Table 8). However, in one subject, A, the ball changed direction considerably earlier (.270 seconds prior to release), but did not start to increase in velocity until .160 seconds prior to release. After all subjects began moving the ball toward the right, the Y velocity increased until it reached a peak between 19.2 and 27.6 feet per second, at a point between .010 and .030 seconds prior to release. In one subject, C, the peak velocity was reached at release. But, in the other subjects, the peak velocity was greater than the release velocity, which ranged from 16.4 to 19.7 feet per second. Table 8 summarizes the key points of the sidearm Y component velocity.

In comparing the characteristics of the Y component velocity between the overarm and sidearm throws, it appeared that there was more similarity within each subject than between subjects. The time in which the ball began its final movement to the right occurred earlier in the sidearm throw than the overarm throw in subjects A and B (.133 and .018 seconds earlier, respectively), and occurred earlier in the overarm than the sidearm in subjects C and D (.029 and .009 seconds earlier, respectively). The time difference in subject D should not be considered too notable as it was less than one frame time interval and could be a result of frame sampling error.

Following the change in direction to the right, the velocities increased up to a peak velocity which was basically the same in both the overarm and sidearm throws for each subject. All subjects reached this peak velocity at approximately the same time in each type of throw (average difference of .010 seconds), with the exception of subject D, whose overarm throw Y velocity peaked sooner than the sidearm throw (difference of .020 seconds). The magnitude of this peak velocity prior to release was somewhat greater in the sidearm throw than the overarm throw (average of 2.2 feet per second faster), with the exception of subject C, where it was almost the same. Again with the exception of subject C's sidearm throw, the magnitude of the peak velocity was greater for both types of throws than the magnitude of the release velocity (average of 2.4 feet per second faster). In subject C, the sidearm peak velocity occurred at release. And, lastly, the magnitude of the velocity at release was three to four feet per second greater in the sidearm throw for subjects B and D, and was approximately the same in both throws for subjects A and C.

To briefly summarize, it appeared that, in general, the sidearm Y component peak velocity and release velocity were equal to or slightly greater than the overarm peak Y component velocity and release velocity. That is, on the average, the ball was moving slightly faster in a lateral direction in the sidearm throw than it did in the overarm throw.

And, at release, it was still moving slightly faster in a lateral direction in the sidearm throw than in the overarm throw. It was originally thought that the sidearm Y component velocity prior to release would be considerably greater than the overarm Y component velocity, but the data did not exhibit any marked differences. There did appear to be a slight trend in which the sidearm Y component velocity was greater than the overarm, but the significance of this was questionable.

Z Component (Up-Down). One might expect the Z component velocity to be greater in the overarm throw than in the sidearm throw as it is generally felt that the arm is moving in a near-sagittal plane throughout the overarm motion. In the overarm throw of all subjects, the ball velocity increased, decreased, and then increased in the upward (positive Z) direction (Figure 19). During the brief period of decreasing Z velocity, subjects B, C, and D actually exhibited a slight increase in the negative Z velocity as the ball was moved downward slightly. At a point between .078 and .105 seconds prior to release, the Z velocity began to increase again in an upward direction, reaching a velocity of between 21.8 and 29.5 feet per second at release (Table 9). There was no peak velocity prior to release which was greater than the release velocity, except in subject A, where the velocity peaked .01 seconds prior to release.

In the sidearm throw, the Z velocity of the ball increased in the early part of the force-producing phase, decreased toward zero, and then increased in the downward direction for a period of time prior to release (Figure 19). Between .016 and .043 seconds prior to release, the ball began to move upward again and continued to increase in

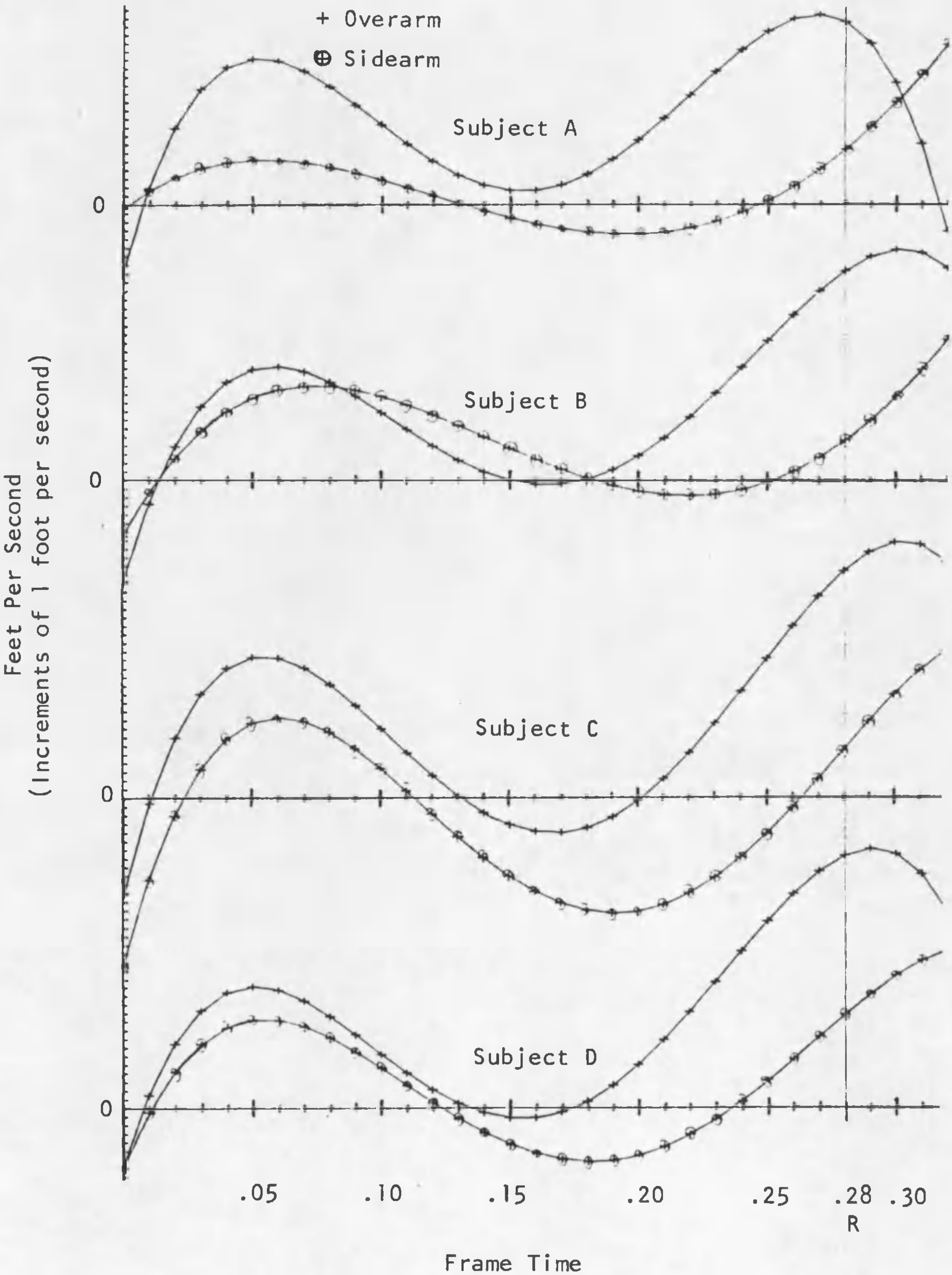


Figure 19. Z Component Velocity of the Ball.

Table 9. Overarm and Sidearm Z Component Ball Velocity: Time Prior to Release of Zero Velocity and Magnitude of Velocity at Release.

Subject	Overarm		Sidearm	
	Time Prior to Release of 0 Velocity	Release Velocity	Time Prior to Release of 0 Velocity	Release Velocity
A	.120 s *	21.8'/s	.033 s	6.4'/s
B	.100 s	24.3'/s	.030 s	4.6'/s
C	.078 s	26.5'/s	.016 s	5.4'/s
D	.105 s	29.5'/s	.043 s	10.8'/s
$\bar{X}$ =		25.5'/s		6.8'/s

* Did not reach zero velocity.

velocity up to and beyond release (Table 9). The magnitude of the sidearm Z component velocity at release ranged between 4.6 and 10.8 feet per second.

In all subjects, the Z velocity appeared to follow a similar trend in both the overarm and the sidearm throw; that is, the ball was moving upward, then slowed its ascent and even moved slightly downward for a short period of time before it began its final increase in positive Z (upward) velocity leading to release. However, there appeared to be some difference between the two throws in the timing of this final upward velocity increase and the velocity at release. All of the subjects' overarm Z velocities began to cross the zero line, moving upward, between .062 and .087 seconds earlier than did in the sidearm velocities. In addition, the overarm Z component velocities were an average of 18.7 feet per second faster than the sidearm release velocities.

Therefore, as surmised, there were differences between the two throwing patterns in the timing and magnitude of the vertical (Z) component velocity. In the overarm throw, the ball began moving upward earlier, and as a result, exhibited a much greater upward velocity at release than in the sidearm throw.

Summary. The three-dimensional resultant linear velocities did not appear to identify any notable differences between the overarm and sidearm throwing patterns. However, by probing further into the component (X, Y, Z) velocities, several dissimilarities were noted.

The X component velocity followed an increase-decrease-increase trend in both throwing motions. Regarding the Y component velocity, it was believed that the left-to-right velocity would be greater in the sidearm throw than in the overarm throw, but this did not prove to be totally correct. However, there did appear to be somewhat of a trend for the sidearm lateral (Y) velocities to be slightly faster than the overarm lateral velocities both prior to and at release. The most notable differences were observed between the overarm and sidearm throws in the Z velocity component, both in the timing of the increase in this velocity component and in its magnitude at release. In the overarm throw, the ball began moving upward considerably earlier than in the sidearm throw, and it reached a greater Z velocity at release.

Body Position at Release

One of the more controversial areas regarding differences, if any, between the overarm and sidearm throwing patterns dealt with the orientation of the body in space at release. Some sources felt that the dissimilarity was in the trunk position, while others felt that the throwing arm position relative to the trunk was the key difference. To aid in the qualification and quantification of any diversity between the two throws, the body position at release was analyzed with regard to: 1) the trunk position relative to the vertical; 2) the shoulder position relative to the horizontal; and, 3) the angle between the shoulder line and right upper arm.

Trunk Position Relative to the Vertical

In the overarm throw, the trunk line at release was inclined away from the throwing-arm side in all subjects (Figure 20). In other words, the trunk was laterally flexed to the left. The degree of deviation from the vertical ranged from 23 to 32 degrees (Table 10).

In the sidearm throw, the trunk line at release was inclined toward the throwing-arm side in all subjects; that is, the trunk was laterally flexed to the right (Figure 21). The degree of deviation from the vertical ranged from 13 to 23 degrees (Table 10).

The most visible comparison in trunk line position at release was that the trunk was inclined to opposite directions for the two types of throws. In subjects A and B, the trunk position deviated farther from the vertical in the overarm throw than in the sidearm throw. The angle of deviation was very similar (although in opposite directions from the vertical) in both throws for subjects C and D. The difference between each subjects' trunk position at release in the overarm versus the sidearm throws was between 44 and 48 degrees (Table 10).

Shoulder Line Position Relative to the Horizontal

The shoulder line position relative to the horizontal was similar for all subjects in the overarm throw (Figure 20). The shoulder line inclined in such a way that the left shoulder dropped below the horizontal. The degree of deviation from the horizontal ranged from 21 to 33 degrees (Table 11).

In the sidearm throw, the right shoulder was dropped below the horizontal at release in all subjects (Figure 21). The degree of deviation ranged from 12 to 25 degrees (Table 11).

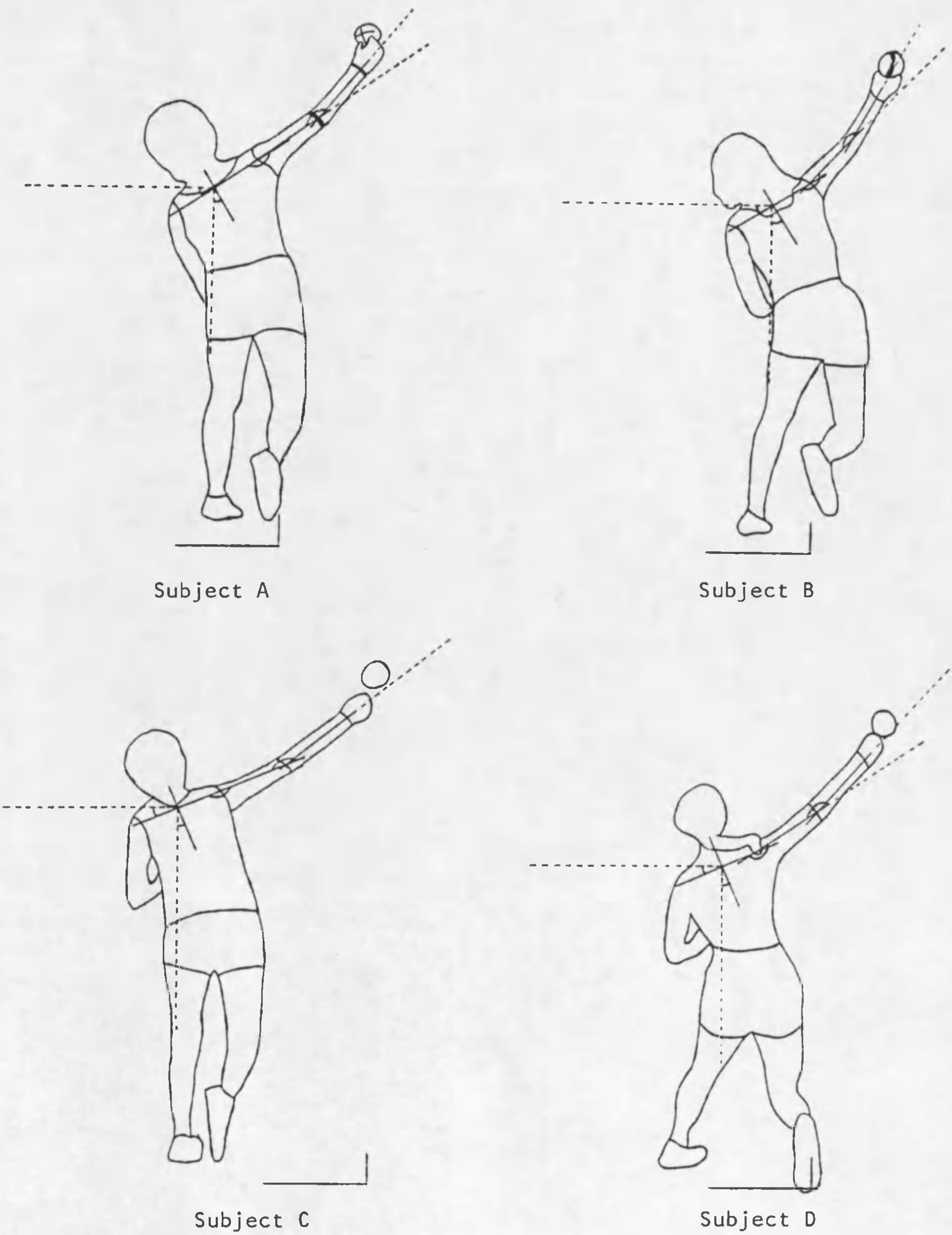


Figure 20. Overarm Body Position at Release.

Table 10. Trunk Position at Release Relative to the Vertical: Rear View.

Subject	Overarm	Sidearm	Difference Between Overarm and Sidearm
A	-30^{o}	18^{o}	48^{o}
B	-32^{o}	13^{o}	45^{o}
C	-23^{o}	23^{o}	46^{o}
D	-23^{o}	21^{o}	44^{o}
$\bar{X}$ =	-27^{o}	18.75^{o}	45.75^{o}

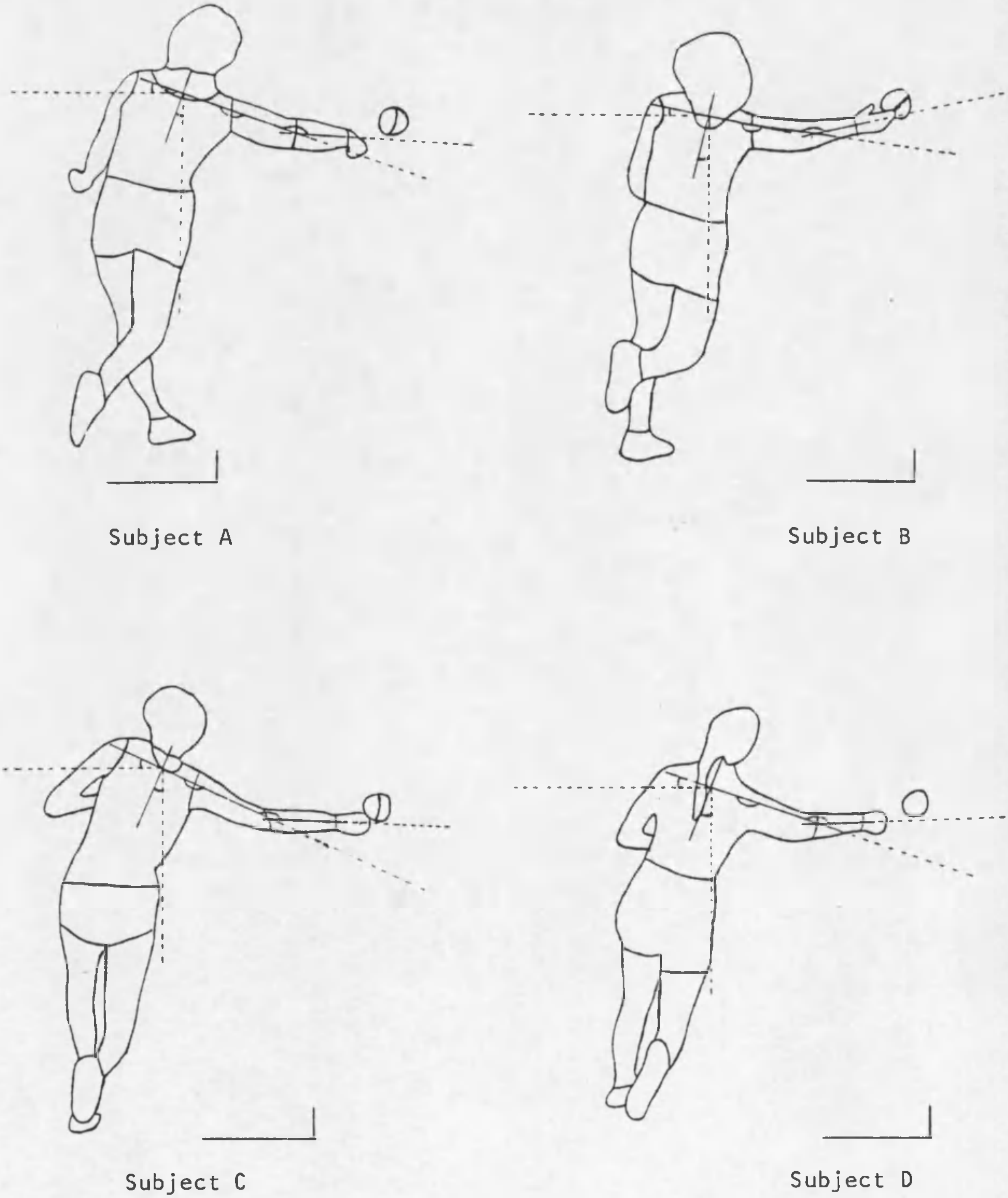


Figure 21. Sidearm Body Position at Release.

Table 11. Shoulder Line Position at Release Relative to the Horizontal: Rear View.

Subject	Overarm	Sidearm	Difference Between Overarm and Sidearm
A	-33°	19°	52°
B	-33°	12°	45°
C	-21°	25°	46°
D	-24°	18°	42°
$\bar{X}$ =	-27.75°	18.5°	46.25°

In comparing the shoulder line position at release in both throws, there was a greater degree of deviation from the horizontal in the overarm throw than in the sidearm throw. This was true for all subjects except C, who exhibited a slightly greater deviation of the shoulder line from the horizontal in the sidearm throw. As in the trunk line position, the most visible difference was that the shoulder line was tilted in the opposite direction in each type of throw. The difference in shoulder line at release between the overarm and the sidearm throws was between 42 and 52 degrees (Table 11).

Shoulder Line and Upper Arm

As seen from the rear view at release, the angle formed by the intersection of the right upper arm and the shoulder line ranged from 181 to 194 degrees in the overarm throw (Table 12). Subject A reflected, basically, a straight line from the left shoulder joint to the right elbow joint. In subjects B, C, and D, the upper arm was in a slightly more abducted position, creating an angle with the shoulder line that measured greater than 180 degrees (Figure 20).

In the sidearm throw, the angle between the shoulder line and the right upper arm ranged from 180 to 187 degrees (Table 12). In subject B, the right upper arm was slightly more abducted at release while all other subjects appeared to reflect a straight line from the left shoulder joint to the right elbow joint (Figure 21).

Subjects A and C, basically, had the same angle between the shoulder line and the right upper arm at release for both the overarm and sidearm throw. Subjects B and D reflected an angle somewhat greater

Table 12. Angle Between Shoulder Line and Right Upper Arm: Rear View.

Subject	Overarm	Sidearm	Difference Between Overarm and Sidearm
A	181°	180°	1°
B	194°	187°	7°
C	186°	182°	4°
D	189°	183°	6°
$\bar{X}$ =	187.5°	183°	4.5°

in the overarm throw, yet, in both throws, the position was very near or equal to 180 degrees.

Summary

The analysis of the body position at release for the overarm and sidearm throws contributed the most noticeable differences between the two throwing patterns. In the overarm throw, the trunk line at release was inclined away from the throwing-arm side which, in turn, tilted the shoulder line so that the left shoulder dropped below the horizontal. In contrast, the sidearm throw was characterized by lateral trunk inclination toward the throwing-arm side and subsequent tilting of the shoulder line so that the right shoulder dropped below the horizontal.

In addition to manifesting some of the most marked differences between the overarm and sidearm throws, the analysis of the body position at release also presented one of the greatest similarities between the two types of throws. The angle formed by the shoulder line and the right upper arm at release was equal to or very near 180 degrees. In other words, the right upper arm was still basically in line with the shoulders even though the trunk and shoulders were laterally inclined in opposite directions for the two throws. Any deviation from a straight line appeared to be more of an individual characteristic of the subject rather than of the throwing pattern (subject B, for example).

Elbow Joint Action

The most debatable aspect among the sources had to do with the action at the right elbow joint. There was a great deal of ambiguity in the terminology used to describe the elbow joint action and a great deal of discrepancy in the actual angular measures. In an attempt to clarify what action occurred at the right elbow joint, the three-dimensional angular displacement was analyzed, as well as the peak angular velocity prior to release. It should be kept in mind that the elbow joint action was considered to be that action which moved the ball and not the elbow joint center. It reflected the three-dimensional resultant angular change between the two segments adjacent to the elbow joint, namely the upper arm and the forearm.

In the overarm throw, the angular displacement of the right elbow joint reflected rather divergent action among the subjects in the early part of the force-producing phase (Figure 22). However, this preliminary fluctuation in direction was not considered to be as important as the point in time where the elbow flexed slightly just prior to the rapid increase in extension leading up to release (indicated by arrow in Figure 22). In all subjects, this occurred between .042 and .098 seconds prior to release, and the angular position at this time just prior to rapid extension ranged from 49 to 74 degrees of flexion (Table 13). The overarm peak instantaneous resultant elbow joint angular velocity during this rapid extension ranged from 1807 to 3816 degrees per second (31 to 66.6 radians per second) in all subjects. At release, the angular position of the elbow joint ranged from 144 to 159 degrees when determined three-dimensionally. This angular position at release

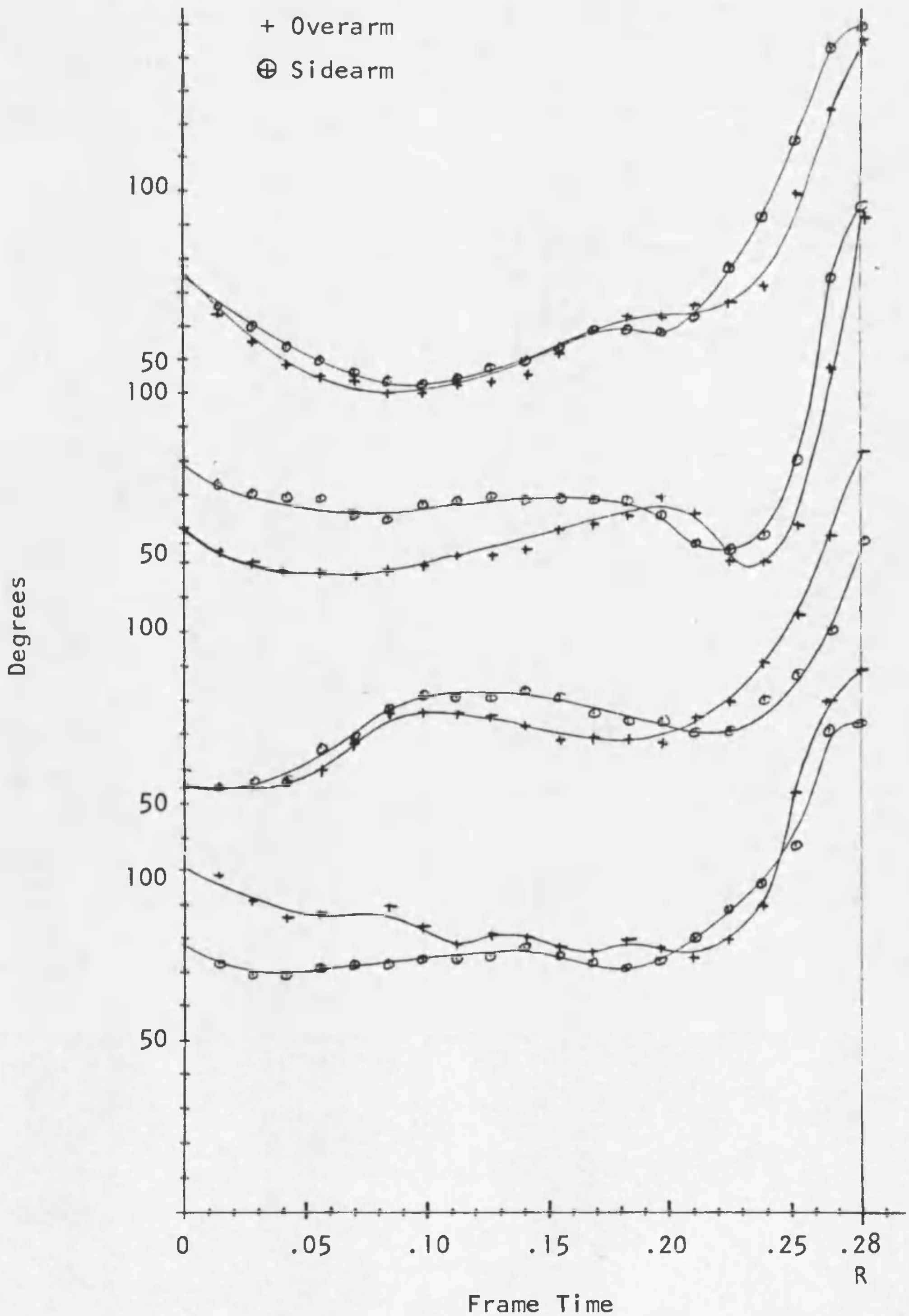


Figure 22. Three-Dimensional Elbow Joint Angular Displacement.

Table 13. Overarm and Sidearm Elbow Joint Action.

Subject	Start of Extension (Time Prior to Release)	Angular Position at Start of Extension	Peak Angular Velocity		Angular Position at Release	
			Degrees	Radians	3-D	2-D
Overarm						
A	.070 s	66°	2099°/s	36.6r/s	144°	165°
B	.042 s	49°	3816°/s	66.6r/s	151°	166°
C	.098 s	67°	1807°/s	31.5r/s	151°	165°
D	.070 s	74°	3006°/s	52.5r/s	159°	166°
$\bar{X}$ =	.070 s	64°	2682°/s	46.8r/s	151.2°	165.5°
Sidesrm						
A	.084 s	57°	1806°/s	31.5r/s	148°	165°
B	.056 s	52°	4517°/s	78.8r/s	151°	160°
C	.056 s	69°	1702°/s	29.7r/s	135°	158°
D	.098 s	70°	2094°/s	36.5r/s	142°	160°
$\bar{X}$ =	.074 s	62°	2529.75°/s	44.13r/s	144°	160.8°

was also measured two-dimensionally using the rear view tracing of each subject and a protractor. These planar measures were 165 degrees for two of the subjects and 166 degrees for the other two subjects (Table 13).

The large discrepancy between these two measures of elbow joint angular position at release can be attributed to two factors. First, the two-dimensional measurement cannot take into account out-of-plane movement. However, since the angle in question was in the film plane which was perpendicular to the optical axis of the camera, the magnitude of the measurement error due to incorrect perspective was judged to be minimal. Secondly, the three-dimensional angles were calculated using the spatial coordinates of the shoulder joint center, the elbow joint center, and the center of the ball. By using the spatial coordinates of the ball at release rather than the wrist, a certain degree of error was automatically "built in" to this measurement as the ball was actually above the forearm line and would thus create a smaller elbow joint angle. From observation of the body position at release using both the rear and side view tracings, it appeared that all of the subjects, in both throws, were basically "perpendicular" to the optical axes of the cameras. Therefore, considering all of the factors influencing the measurement of the elbow joint position at release, it was believed that the planar (two-dimensional) measures were actually more valid than the three-dimensional measures.

In the sidearm throw, the angular displacement also reflected rather divergent action among all subjects in the early part of the force-producing phase (Figure 22). As mentioned previously, these fluctuations in direction were not considered to be important. The start of the rapid extension began between .056 and .098 seconds prior to release, and the angular position at this point (indicated by arrow in Figure 22) in time ranged from 52 to 70 degrees (Table 13). The sidearm peak instantaneous resultant elbow joint angular velocity ranged from 1702 to 4517 degrees per second (29 to 78 radians per second) for all subjects. At release, the angular position of the elbow joint ranged from 135 to 151 degrees when measured three-dimensionally and from 158 to 165 degrees when measured two-dimensionally.

In comparing the overarm angular displacement curves with the sidearm angular displacement curves, there appeared to be more similarity within subjects than between subjects, particularly in the early part of the force-producing phase. These early differences were most likely a reflection of individual characteristics of each subject rather than inherent characteristics of the two throwing patterns. However, in all subjects for both throws, the elbow flexed slightly just prior to the rapid increase in extension leading up to release. Subjects C and D exhibited a noticeable difference between the overarm and sidearm throws in the time prior to release when rapid extension started. This extension started .042 seconds earlier in the overarm throw than in the sidearm throw for subject C and .028 seconds later in the overarm than the sidearm for subject D. The time difference for subjects A and B was less than one frame interval and could be attributed to frame sampling error. The angular position of the elbow at the start of the rapid extension was similar (within 10 degrees) in both the overarm and sidearm throws for each subject.

There was a great amount of variation in the peak instantaneous resultant elbow joint angular velocity for the two throws. With the exception of subject B, the overarm peak angular velocity was considerably greater (between 105 and 912 degrees per second or 1.8 and 15.9 radians per second) than in the sidearm throw. In subject B, the sidearm elbow joint angular velocity was considerably greater (701 degrees per second or 12.2 radians per second) than in the overarm throw. Again, there appeared to be more similarity within subjects than between subjects.

The three-dimensional angular position of the elbow at release was fairly similar among all subjects for both types of throws ($\bar{X}$ overarm = 151.2 degrees, $\bar{X}$ sidearm = 144.0 degrees). The two-dimensional angular position at release was even more similar among subjects for both throwing patterns ($\bar{X}$ overarm = 165.5 degrees, $\bar{X}$ sidearm = 160.8 degrees). Considering the factors previously mentioned which influenced the measurement of the angular position at release, it would appear that the two-dimensional values were more believable.

Summary

In the early part of the force-producing phase, there appeared to be more similarities between the two throwing patterns within subjects than between subjects. However, in all subjects for both throws, the elbow flexed slightly just prior to the rapid extension leading up to release. The amount of flexion of the elbow joint at this point in time was very similar in both the overarm and sidearm throws for each subject.

There was a great deal of variation in the peak instantaneous resultant elbow joint angular velocity for the two throws and for each subject. Again, there appeared to be more similarity within subjects than between subjects.

In the two measures of angular position of the elbow at release, there was a great deal of similarity among subjects. That is, the three-dimensional angular position measures were very much the same in both throws and the two-dimensional angular position measures were very much the same in both throws. Considering the factors mentioned earlier, it appeared that the two-dimensional values were more valid than the three-dimensional values.

Summary

Three main topics were examined in this chapter: the three-dimensional velocities, the body position at release, and the right elbow joint action. Preceeding the discussion of these topics, the ball release velocities were considered. It was found that there was a tendency for the overarm throw to be slightly faster than the sidearm throw for these subjects, but the actual magnitude of this difference did not seem to provide conclusive evidence that the overarm throw, in general, is always faster than the sidearm throw. In addition, it was felt that the subjects' maximal throwing measures were not affected by the filming situation and that the film data was a reasonably valid measure of release velocity.

For both the overarm and sidearm throw, there was a great deal of homogeneity between the resultant velocities of the ball, elbow joint center, and shoulder joint center. The peak velocity of the three points increased in magnitude from proximal to distal. In other words, the shoulder joint center exhibited the least velocity throughout the throw and at release and the ball exhibited the greatest velocity throughout the throw and at release. Furthermore, the peak velocities in all of the throws basically followed a "shoulder-elbow-ball" sequence. However, the three-dimensional resultant linear velocities did not distinguish between the two types of throws.

The analysis of the component (X, Y, Z) velocities revealed several differences between the overarm and sidearm throws. The X (forward-backward) component velocity, displaying an increasing-decreasing-increasing pattern during the force-producing phase of both throws, did not manifest any marked differences between the two throws. The Y (lateral) component velocity exhibited somewhat of a trend, with the sidearm lateral velocities (movement toward the right) being slightly greater than the overarm lateral velocities at their peak and at release. The most notable differences were observed in the Z (upward-downward) component velocity timing and release velocity. In the overarm throw, the ball began moving upward considerably earlier than in the sidearm throw, and it subsequently reached a greater upward velocity at release.

The examination of the body position at release presented the most visible differences between the two throwing patterns. The trunk position and shoulder line were inclined away from the throwing-arm side in the overarm throw and inclined toward the throwing-arm side in the sidearm throw. But, the right upper arm in its relation to the shoulder line was not affected by this difference in lateral lean of the trunk or shoulder line deviation in the two throws. The arm was either extended in a straight line with the shoulder line or abducted very slightly above the shoulder line.

In the analysis of the elbow joint action, it was found that in all subjects for both throws the elbow flexed slightly just prior to the rapid increase in extension leading up to release. During this rapid extension, the peak instantaneous resultant elbow joint angular velocity was measured, but the results only presented a great deal of diversity between the two throws and between the subjects. The degree of extension at release was much the same for both the overarm and side-arm throws.

CHAPTER V

ANALYSIS AND DISCUSSION OF RESULTS

In Chapter II, there appeared to be three main areas of controversy in the literature reviewed regarding the comparison of the overarm throw and the sidearm throw. These dealt with the position and/or action of the trunk, the shoulder, and the elbow. This study encompassed aspects of each of these concerns, as well as additional selected characteristics of the two throws which were not discussed or were indirectly discussed by the authors. An analysis of these results and a discussion of the findings is found in the contents of this chapter.

Release Velocities

Several authors felt that the overarm throw had a greater release velocity than the sidearm throw due to its inherent characteristics or because the sidearm throw is actually an abbreviated form of the overarm pattern and, therefore, produces less speed (Collins, 1960; Finley, 1961; Shaw, 1972; and Wickstrom, 1977). On the other hand, Sakaris (1978) stated that there were no differences in the velocities of the two throws. In this study, it was found that there was a tendency for the overarm throw to be slightly faster than the sidearm throw, but the actual magnitude of this difference did not seem to provide conclusive evidence that the overarm throw, in general, is always faster than the sidearm throw.

In the pre-test measures of ball velocity at release, the greatest difference between the overarm and sidearm throws was 3.4 feet per second and the least difference was 0.2 feet per second. In the three-dimensional velocity measures, the greatest difference was 6.8 feet per second and the least was 0.2 feet per second. These discrepancies could be attributed to the fact that the overarm throw was the more natural throwing pattern (as indicated by the subjects' conception of their dominant pattern), and thus, the faster of the two throws.

Three-Dimensional Velocities

Collins (1960), Atwater and Roberts (1968), and Broer and Zernicke (1979) all stated that the joint actions were basically the same for both the overarm and sidearm throws. They found the rate, sequence, and timing of the actions to be very similar. Wickstrom (1977) agreed with this, but discussed the sidearm throw as a somewhat abbreviated form of the overarm throw. After analyzing the overarm and sidearm three-dimensional resultant linear velocities for the ball, elbow joint center, and shoulder joint center, it was evident that this investigation agreed with these authors. Between the two throwing patterns, there was a great deal of homogeneity in the resultant velocities for each of the three points and the peak velocities increased in magnitude from proximal to distal. Furthermore, the peak velocities in all of the throws basically followed a shoulder-elbow-ball sequence.

None of the authors cited dealt with the three-dimensional component (X, Y, Z) velocities of the ball per se, but a comparison between the two throws in this study supported some of the generalized statements made by these sources regarding differences in the two throws. The analysis of the X component velocity revealed an increasing-decreasing-increasing pattern of forward speed of the ball during the force-producing phase of both throws. Slight backward movement of the ball occurred simultaneously with the lateral rotation of the shoulder as the body moved out from under the ball. This component did not manifest any marked differences between the two throws.

The Y component (indicating left to right movement) exhibited somewhat of a trend, with the sidearm lateral velocities being slightly greater than the overarm lateral velocities at their peak prior to release and at release (an average of 2.3 feet per second faster at both of these points). It was originally surmised that there would be a much greater lateral velocity in the sidearm throw as several of the authors felt the distinguishing characteristic of this throw was its horizontal and circular arc (Broer and Zernicke, 1979; Cooper and Glassow, 1976; and, Dobson and Sisley, 1971). The findings of this study did not firmly support this conjecture, but did indicate that it may be a tendency in some subjects. In all subjects for both throws, the Y component of the velocity reached its peak prior to release which indicated that the X (forward-backward) and Z (up-down) components contributed more to the final stages of the throw than did the Y component.

The most significant difference in all of the component velocities was found in the Z component which reflected the upward movement of the ball. For all of the subjects', the Z velocities began to increase upward between .062 and .087 seconds earlier in the overarm throw than in the sidearm throw and subsequently exhibited a velocity at release which averaged 18.7 feet per second faster in the overarm than in the sidearm throw. This difference can be explained by observing the trunk position at release for both throws. In the overarm throw, the trunk was laterally inclined away from the throwing-arm side, causing the right shoulder to raise above the horizontal. This inclination had a direct relationship to the height of the ball above the ground, or the height above or below head level at which the ball was released. When the elbow extended, this moved the ball forward (X component) and upward (Z component). In the sidearm throw, the trunk was inclined in the opposite direction toward the throwing-arm side, dropping the right shoulder below the horizontal. As the elbow extended, the ball was moved predominantly forward and only slightly upward.

Body Position at Release

As previously mentioned, the most noticeable difference in the body position at release between the two throwing patterns was the trunk and shoulder inclination. In agreement with several authors (Atwater and Roberts, 1968; Sakaris, 1978; Siedentop and Kaat, 1971), in the overarm throw, the trunk and shoulder line were inclined laterally away from the throwing-arm side and in the sidearm throw, the trunk and shoulder line were inclined laterally toward the throwing-arm side at release. Two of these sources (Siedentop and Kaat, and Sakaris) also felt that the sidearm body position at release exhibited less lateral lean from the vertical than in the overarm throw. This study agreed somewhat with this premise.

Broer and Zernicke (1979) and Dobson and Sisley (1971) felt that the arm was more horizontal at release in the sidearm throw than in the overarm throw. This was found to be true (by viewing the rear view tracings), but the position of the arm was determined more by lateral trunk inclination than by humeral abduction and/or elbow extension.

In this study, the angle formed by the shoulder line and the right upper arm was equal to or somewhat greater than 180 degrees for both the sidearm and the overarm throw. Siedentop and Kaat (1971) stated that the upper arm was slightly above the shoulder line in the overarm throw and slightly below the shoulder line in the sidearm throw. Shaw (1972) agreed with the sidearm position described by Siedentop and Kaat, but felt that the elbow was in line with the shoulder line on the overarm throw rather than above it. Plagenhoef (1971) also discussed the relationship between the upper arm and shoulder but felt that the upper arm should be in line with the shoulder or lower than the shoulder line. Lindner (1971) simply stated that the arm was an extension of the shoulder and did not specify whether the arm was abducted or adducted somewhat in either throw.

Elbow Joint Action

One of the most controversial aspects of the two throwing patterns dealt with the degree of elbow extension at release. Several sources specified that the elbow was more fully extended at release for the sidearm throw than the overarm, but they failed to quantify the exact degree of extension (Cooper and Glassow, 1976; and, Dobson and Sisley, 1971). Broer and Zernicke (1979) stated that the ball was released before the arm reached full extension, but the reported angle of approximately 105 degrees appeared to be rather low. This was also true for Gollnick and Karpovich's (1964) study which reported an elbow angle of 102 degrees at release in the overarm throw.

This study found the degree of elbow extension at release, as calculated three-dimensionally, ranged from 144 to 159 degrees for the overarm throw, and between 135 and 151 degrees for the sidearm throw. The two-dimensional angular measures ranged from 158 to 166 degrees for both throws and all subjects. These latter measures tend to coincide more with Lyon's (1961) findings which reported the elbow angle to be in the 147 to 166 degree range just prior to release. It was believed that the planar (two-dimensional) measures were actually more valid than the three-dimensional measures because the spatial coordinates of the ball at release were used in the computation of the three-dimensional elbow angle rather than the spatial coordinates of the wrist. Since the ball was actually above the forearm line at release, use of the ball spatial coordinates rather than those of the wrist created a smaller elbow joint angle. Thus, the three-dimensional measures were really an underestimate of the "true" elbow angle.

There was a great deal of variation in the peak instantaneous resultant elbow joint angular velocity for the two throws and for each subject. There did appear to be some similarity between the two throws within subjects, but conclusive statements could not be made concerning this aspect. It seemed that some discrepancies between throws and subjects could be attributed to the low film speeds which, in turn, presented some error in measurement.

Implications for Teaching

Learning principles have shown that the learning environment must be similar to the performance environment if satisfactory transfer is to occur. Although there appeared to be more similarities between the overarm and sidearm throwing patterns than there were differences, the differences were significant enough that physical educators and coaches should provide separate learning experiences for each type of throw.

The motion of the shoulder and elbow joint centers was very similar between the two throws and would, therefore, be taught as one part of the movement pattern for both throws. However, the trunk position during the throwing motion was noticeably different between the overarm and sidearm throws. In the overarm throw, the trunk was laterally inclined away from the throwing-arm side, raising the arm so that it was moving in a near-sagittal plane. The final action of the fingers on the ball imparted backspin (spin in the vertical plane) to the ball which would carry the ball forward in a straight line (Siedentop and Kaat, 1971).

In the sidearm throw, the trunk was laterally inclined toward the throwing-arm side, lowering the arm so that it was moving in a more transverse plane. The final action of the fingers on the ball imparted sidespin (spin in the horizontal plane) to the ball which would cause the ball to "tail off" to the right over a distance for a right-handed thrower (Siedentop and Kaat, 1971).

Meyer and Schwarz (1965) stated that the type of throw to be used in softball varied with the kind of play executed, the place where the ball was recovered in relation to the body, and the distance of the throw. It was felt that these premises were basically true, but could be stated better in the following manner: the type of throw to be used should depend jointly on the time available for execution of the play, the place where the ball is recovered in relation to the body, and the distance of the throw.

The physical educator or coach should instruct the student more in terms of the differences in body position at release in the overarm and sidearm throws rather than in terms of differences in the motion of the elbow or shoulder joint centers. It would also be beneficial to stress the previously mentioned factors determining the type of throw to be used rather than stating that the overarm throw is used exclusively by outfielders and the sidearm throw is used exclusively by infielders. When time is sufficient or the ball is fielded in a fairly upright position or the ball must travel a great distance, the overarm throw should be used due to the type of spin imparted to the ball. If time is a crucial factor and the ball is fielded near the ground and the throw is relatively short (within the infield, for example), the sidearm throw would be preferred. Use of the sidearm throw eliminates the time needed to move to a fielding position with the hands near the ground to the near-vertical position employed in the overarm throw.

Summary

In this study, it was found that there was a tendency for the overarm throw to have a slightly greater release velocity than the sidearm throw, but the actual magnitude of this difference did not seem to provide conclusive evidence that the overarm throw, in general, is always faster than the sidearm throw. It was also found that the rate, sequence, and timing of the movement pattern in the two throws was very similar. The only differences found in the component (X, Y, Z) velocities between the two throws were 1) a tendency for the Y (left to right) component to be slightly greater in the sidearm throw than in the overarm throw and, 2) a definite existence of a greater magnitude in the overarm Z (upward) component velocity than in the sidearm Z component velocity.

In the overarm throw, the body position at release was very different than in the sidearm throw. The trunk and shoulder line were inclined laterally away from the throwing-arm side in the overarm throw and inclined laterally toward the throwing-arm side in the sidearm throw. The angle formed by the shoulder line and the right upper arm was equal to or slightly greater than 180 degrees in both types of throws.

The degree of elbow extension at release, one of the most controversial aspects of the throwing patterns, was found to range between 158 and 166 degrees for both throws. The measurement of the peak instantaneous resultant elbow joint angular velocity did not provide any conclusive evidence as to the exact peak magnitude reached during elbow extension.

The differences between the overarm and sidearm throws were significant enough that physical educators and coaches should provide separate learning experiences for each type of throw. The type of throw to be used should depend jointly on the time available for execution of the play, the place where the ball is recovered in relation to the body, and the distance of the throw.

CHAPTER VI

SUMMARY, MAJOR FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This investigation attempted to answer questions concerning whether or not there were any differences in the arm and shoulder action or position in space during the force-producing phase of the overarm and sidearm throws. Three-dimensional filming techniques were employed in order to accurately qualify and quantify the differences, if any, between these two three-dimensional, curvilinear movement patterns.

Four highly skilled female softball players were filmed using two high-speed (73 frames per second) motion picture cameras aligned so that the original axes intersected at a 90 degree angle. The subjects were filmed performing what they conceived to be an overarm throw and a sidearm throw.

The film data was then reduced to three-dimensional coordinates by means of the Susanka vector approach. These coordinates were used to determine resultant velocities of the ball, elbow joint center, and shoulder joint center, component (X, Y, Z) velocities of the ball, and elbow joint angular displacement. In addition, the body position at release was analyzed using tracings from the rear view film.

The primary value of this study was the further understanding of the nature of throwing, both as a basic movement pattern and as a highly complex skill. Such knowledge was felt to be of importance to physical educators and coaches in determining whether or not separate learning experiences for each type of throw should be provided for the student or athlete.

Major Findings

The major findings of this study were as follows:

1. There was no conclusive evidence that the overarm throw is consistently faster than the sidearm throw. Both throws were similar in speed.

2. The rate, sequence, and timing of the two throws was very similar. Just prior to release, the shoulder joint center reached a peak velocity. This was followed by the peak velocity of the elbow joint center. The peak velocity of the ball occurred at release.

3. The Z (up-down) component velocity was considerably greater in the overarm throw than in the sidearm throw, whereas there was only a slight tendency for the sidearm throw to exhibit a greater Y (left-right) component velocity than the overarm throw.

4. It was characteristic in the overarm throw that the trunk and shoulder line were laterally inclined away from the throwing-arm side and, in the sidearm throw, the trunk and shoulder line were laterally inclined toward the throwing-arm side.

5. At release, the degree of elbow extension ranged from 158 to 166 degrees for both throws.

Conclusions

Within the limitations of this study and based upon the results, it was concluded that there are more similarities between the overarm and sidearm throwing patterns than there are differences. The two throws are similar in speed; rate, sequence, and timing of joint center velocities; and, degree of elbow extension. The differences are found in the Y (left-right) and Z (up-down) component velocities, and in the body position at release.

However, the differences are significant enough that physical educators and coaches should provide separate learning experiences for each type of throw. The shoulder and elbow action is very similar for each type of throw and would, therefore, be taught as one part of the movement pattern for both throws. However, the trunk position during the throwing motion is noticeably different, with the trunk laterally inclined away from the throwing-arm side in the overarm throw and laterally inclined toward the throwing-arm side in the sidearm throw.

The type of throw to be used should depend jointly on the time available for execution of the play, the place where the ball is recovered in relation to the body, and the distance of the throw.

Recommendations

Due to the speed at which the elbow action occurs, a higher speed camera than those employed in this study would provide more accurate data for analysis. It is recommended that further research be performed with higher speed cameras on the elbow joint action during the two types of throws. It is further recommended that additional data be gathered from a larger sample concerning the release velocities of the overarm and sidearm throws.

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