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The effect of ball size and basket height on the mechanics of the basketball free throw as performed by seventh grade boys

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The University of North Carolina at Greensboro, 1986

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THE EFFECT OF BALL SIZE AND BASKET HEIGHT ON

THE MECHANICS OF THE BASKETBALL FREE THROW

AS PERFORMED BY SEVENTH GRADE BOYS

by

Miriam N. Satern

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APPROVAL PAGE

This dissertation has been approved by the following committee of the Faculty of the Graduate School at The University of North Carolina at Greensboro.

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The purpose of this study was to analyze the mechanics of the basketball free throw as performed by 13 seventh grade boys. A regulation and an intermediate sized basketball in combination with a 10-foot and an 8-foot basket were used. Two LoCam cameras, each operating at a film transport speed of 100 fps, provided simultaneous, non-synchronous sagittal and frontal views of repeated trials. Two successful trials per subject under each of the four environmental conditions were digitized with a Numonics digitizer interfaced to an Apple II+ microcomputer.

The statistical analysis revealed significant differences ($p \leq .05$) for the main effect of basket height and non-significant differences ($p > .05$) for the main effect of ball size for the following kinematic parameters: (a) the angle of projection of the basketball, (b) the release angle of the shoulder, (c) the starting angle of the elbow, and (d) the forearm in relation to the vertical at ball release. Significant interaction effects ($p \leq .05$) between ball size, basket height, and the individual subjects were also revealed for some of the aforementioned kinematic parameters.

The descriptive analysis revealed the following: (a) increased horizontal displacement of the mean center of gravity under the regulation environmental condition, (b) release of the basketball while the mean center of gravity was still moving vertically under all four environmental conditions, (c) a weak relationship between the subjects' standing height and average projection angle when shooting

with the intermediate sized basketball at the 10-foot basket, (d) similar mean linear velocities at ball release, (e) similar mean angles of trunk inclination, and (f) similar mean wrist angular velocities across the four environmental conditions. Similar timing and coordination of the wrist, elbow, shoulder, and knees were also noted across the four environmental conditions.

The results of this study suggest that using developmentally appropriate basketball equipment during the early developmental stages may be instrumental in helping to build a sound foundation in the fundamental sport skill of shooting free throws.

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Finally, heartfelt appreciation is extended to my parents, Dick and Vera Satern, and to my brother, Mark Satern, for the encouragement, love, and support extended by them that helped to facilitate the completion of this dissertation.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Through competition in sports, boys are provided with an arena in which their athletic or motor ability can be publicly demonstrated for evaluation by people who are significant to them (Scanlan & Passer, 1978). Presumably, the participant's objective is to be regarded by parents, coaches, teachers, and peers as one who skillfully performs the movements that are fundamental to the sport of interest.

Motor patterns used by skilled adults are generally accepted as the standards against which the quality of a child's performance are judged (Wickstrom, 1975). Children, however, are not merely scaled down versions of their adult counterparts. Differences in segmental body weight proportions between the child and the adult, compounded by the child's unique growth rate, may affect the way a child mechanically executes a skill in comparison to that of the adult (Haywood, 1981). Sport programs that are conducted with the rules, equipment, floor dimensions, and strategies of adult competition may also affect the way in which a skill is performed and developed over time (Seefeldt, 1981).

Hypothetical limits are placed upon motor achievement by one's genes, but the environment determines the extent to which the potentialities are realized within genetic limits. To capitalize on one's motor capacities, environmental factors that affect motor development can be manipulated in order to optimize development (Smoll, 1982). In a sport setting, the game as played by adults can be used as the model against which modifications are made for smaller and younger participants, thereby equating the sport's parameters in proportion to the size of the players (Seefeldt & Gould, 1980).

To evaluate the contribution that such modifications make toward skill development, physical educators have traditionally administered tests that are designed to measure performance. The type of information provided by this form of measurement, however, does not necessarily allow the teacher to understand how or why a child moved in a particular manner (Morris, 1980). Biomechanical tools used to describe the kinematics and kinetics of performance provide another method of studying the changing motor behavior (Roberton, 1984b). Biomechanical research that is related to developmental issues may provide a greater insight into the nature of mature motor performance. Such investigations may also result in a deeper understanding of the motor development process as well as how that process may be facilitated (Wickstrom, 1975).

Statement of the Problem

The purpose of this study was to analyze the mechanics of the basketball free throw as performed by seventh grade boys under four environmental conditions. The environmental conditions included: (a) shooting with a regulation sized basketball at a regulation height basket of 10 ft (3 m), (b) shooting with a regulation sized basketball at a basket lowered to a height of 8 ft (2.4 m), (c) shooting with an intermediate sized basketball at a regulation height basket of 10 ft (3 m), and (d) shooting with an intermediate sized basketball at a basket lowered to a height of 8 ft (2.4 m).

The biomechanical analysis of the free throw consisted of two parts, a statistical analysis and a descriptive analysis. The statistical analysis included the following kinematic parameters: (a) the angle of projection of the basketball, (b) the release angle of the shoulder, (c) the starting angle of the elbow, and (d) the forearm in relation to the vertical at ball release. Significant differences were examined within and across subjects under the four environmental conditions.

The descriptive analysis included the following kinematic parameters: (a) the linear velocity of the basketball at release, (b) the displacement and path of the body's center of gravity, (c) the point of release of the basketball in relation to the height of the body's center of gravity, (d) the angle of trunk inclination, (e) the timing and coordination of the joint actions of the upper and lower body, and (f) the angular velocity of the wrist joint.

Hypotheses (Null)

For the purpose of this study, the following were tested.

1. There will be no significant differences in the angle of projection of the basketball across the four environmental conditions.

2. There will be no significant differences in the release angle of the shoulder across the four environmental conditions.

3. There will be no significant differences in the starting angle of the elbow across the four environmental conditions.

4. There will be no significant differences in the forearm in relation to the vertical at ball release across the four environmental conditions.

Limitations of the Study

The results of this study were limited by the following conditions.

1. The sample for this investigation may not have been representative of the population of seventh grade boys since the subject selection procedure did not result in a random sample of the population.

2. The subjects had to be able to provide their own transportation to and from the two filming sessions scheduled at a city recreation center.

3. The subjects of this investigation were not selected on the basis of a pre-established performance criterion; rather, they represented a variety of skill levels.

4. The subjects' practice opportunities under the altered environmental conditions were limited to the two filming days.

5. The filmed performance of the basketball free throw under the altered conditions may be limited to short-term mechanical changes in performance the subjects made on the filming days and may not reflect any long-term mechanical changes in performance that repeated practice might have afforded the subjects.

6. The paucity of appropriate segmental data on children necessitated the use of values obtained from research that had been performed on adult male cadavers (Dempster, 1955).

7. No attempt was made to determine and/or control for the subjects' biological age.

Definition of Terms

<u>Free throw</u>

An unguarded shot in basketball that is taken from behind a line located 4.5 m in front of the basket.

<u>One-handed free throw</u>

A free throw that is projected toward the basket as a result of flexion of the right wrist, extension of the right elbow, and flexion of the right shoulder. The left hand is used to help support the ball but is not used during the execution of the shot.

<u>Two-handed free throw</u>

A free throw that is projected toward the basket with both hands equally, resulting from flexion of both wrists, extension of both elbows, and flexion of both shoulders.

<u>Regulation sized basketball</u>

A basketball that weighs from 5.74 to 5.87 N and measures from 74.9 to 75.6 cm in circumference.

<u>Intermediate sized basketball</u>

A basketball that weighs from 4.77 to 4.82 N and measures from 71.8 to 72.1 cm in circumference.

<u>Release angle of the shoulder</u>

The angle formed by the upper arm segment with the trunk at the point of release of the ball, as measured from the sagittal view (Figure 1).

<u>Starting angle of the elbow</u>

The smallest angle formed by the upper arm and forearm segments at the elbow joint, as measured from the sagittal view.

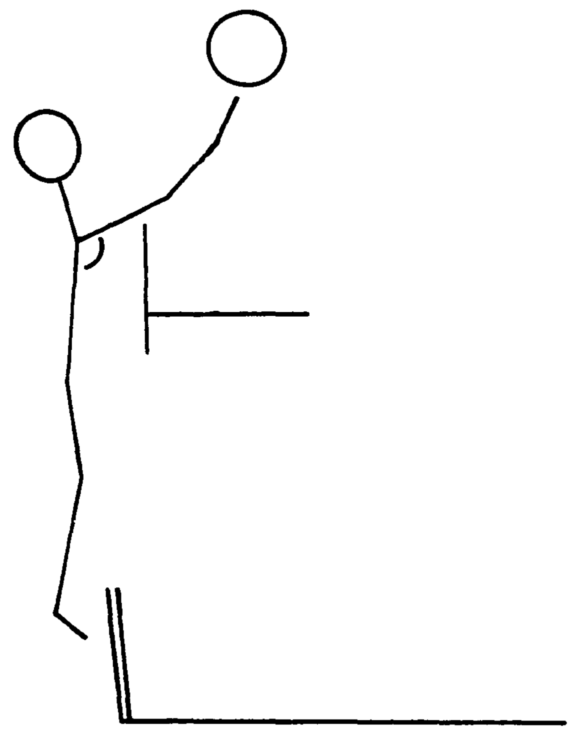

Figure 1. Release angle of the shoulder.

Forearm in relation to the vertical at ball release

The angle formed by the forearm segment with the vertical at the point of release of the ball, as measured from the anterior view (Figure 2).

Significance of the Study

The skilled adult performer is the model often used by young performers when attempting to learn movement skills that are fundamental to organized sports and games. Some young performers, however, are unable to acquire skills that resemble those of the skilled adult model. This may be due to constraints imposed upon their performance by their sex, physical size, biological as well as chronological age, and/or level of maturity. These constraints fall beyond the control of the teacher and coach. Some constraints imposed upon their performance, however, may be manipulated by the teacher and coach. For example, the environment in which a skill is learned, practiced, and performed may adversely affect performance if the environment is inappropriate for the learner's developmental and maturational level. Such performance limiting constraints may be controlled by the teacher and coach.

An appropriate learning environment is one in which the equipment, dimensions, strategies, and/or rules that are associated with a sport or game are modified in order to facilitate the achievement of the product of that sport or game. Providing opportunities for the young performer to succeed as a result of improved performance may help to maintain or increase the individual's interest level in the sport or game, thereby encouraging continued participation. Modifying the

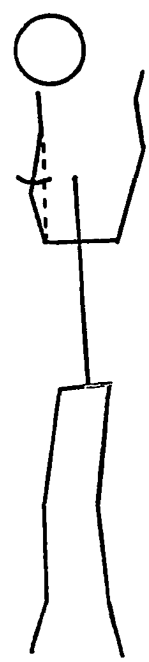

Figure 2. Forearm in relation to the vertical at ball release.

learning environment in order to facilitate the achievement of the product of the movement also allows the teacher and coach to focus more on the process of the movement that results in that product. The teacher and coach may, therefore, encourage the development of movement patterns that are associated with skilled adult performers rather than movement patterns that are necessary to achieve the resultant product.

The results of biomechanical analyses may offer the teacher and coach some insight into the movement processes associated with the successful performance of fundamental sport skills. Biomechanical research that has focused on the basketball free throw and basketball jump shot has compared high-skilled adult performers to low-skilled adult performers on specific parameters. These studies have identified characteristics that discriminate between defined levels of performance (Drysdale, 1972; Hudson, 1974; Hudson, 1982; Hudson, 1985; McGinnis, 1975; Penrose & Blanksby, 1976; Yates, 1978; Yates & Holt, 1982). Additionally, some investigators have analyzed the skilled performance of the basketball jump shot as performed by college age adults with the two-fold purpose of identifying and describing the biomechanical parameters that are present in that skilled performance (Gaunt, 1976; Gorton, 1978; Hamilton, 1970; Poon, 1965; Scolnick, 1967; Szymanski, 1967).

Developmental research that has focused on the effect of equipment modification on the basketball shooting ability of children has investigated changes in performance by focusing on the product of the movement, the number of baskets made (Gabbard & Shea, 1980; Haywood, 1978; Hopewell, 1970; Lindeburg & Hewitt, 1965; Miller, 1971; Stinar, 1981). Developmental research that has investigated the effect of environmental changes on skill performance of children by focusing on changes in the movement processes producing the resultant product, has investigated specific fundamental movement patterns such as throwing, rather than skills fundamental to a specific sport or game (Roberton, 1984a).

The present study attempted to investigate the effects of environmental changes on the performance of a specific sport skill, the basketball free throw. Available biomechanical and developmental research provided the background for changing the size of the ball and/or height of the basket in order to investigate the effect of such changes on the mechanics of the basketball free throw as performed by seventh grade boys. This investigation focused on the movement processes involved in producing the end result in the sport of basketball, the made basket. The results of this investigation may yield information that is of value to teachers and coaches who are concerned with the basketball free throw as performed by seventh grade boys.

CHAPTER II

REVIEW OF LITERATURE

The purpose of this study was to analyze the effect of ball size and basket height on the mechanics of the basketball free throw as performed by seventh grade boys. The literature reviewed for this study is discussed under the following headings; Biomechanical Analyses of the Basketball Free Throw and Jump Shot, Equipment Modification in Basketball, and Development of Complex Motor Skills.

Biomechanical Analyses of the Basketball Free Throw and Jump Shot

Cooper and Siedentop (1975) state that certain basic movement patterns underlie good basketball shooting styles. In spite of this, there exists a plethora of shooting techniques. Regarding the skill of shooting free throws, the authors assert:

> There are many styles of shooting free shots that might be used including the one-hand push, two-hand underhand toss, two-handed push, overhead one and two-hand push, and the jump shot (p. 89) . . . The main argument in favor of using the one push shot has been that the player will be more proficient if he uses the same style of shooting from the free throw lane that he uses from the field (p. 89) . . . In terms of mechanics, the jump shot is remarkably similar to that of the set shot, and it is probably correct to state that the jump shot is a set shot made by a player in the air after he has jumped (p. 65).

Because the set shot and the jump shot are the shooting styles most commonly used by basketball players in executing the free throw, studies that have investigated the jump shot as well as the free throw have been reviewed for this investigation.

Effect of Skill Level on Free Throw Shooting Ability

Hudson (1974) analyzed three distinct skill groups of 25 adult women players. These included: (a) nine players who had intramural or instructional experiences and were judged as having less skill than that required for intercollegiate competition, (b) seven non-scholarship, intercollegiate players who had not competed internationally, and (c) nine players who had participated in the World University games. Multiple regression analysis suggested the following characteristics for the most accurate shooters: (a) a high height of release ratio, (b) an acceleration of the wrist through the point of release, and (c) a lack of forward shift of the center of gravity ratio through the point of release. The best predictors for determining the success of the free throws were: (a) the height of the shooter, (b) the shooter's percentage of accuracy, (c) the center of gravity ratio immediately after release, (d) the velocity of projection of the ball, and (e) the velocity of wrist flexion immediately before release.

In a follow-up study, Hudson (1982) found significant differences ($p<.05$) among the three groups of performers on three parameters associated with the execution of the free throw: (a) percent accuracy, (b) height of release ratio, and (c) center of gravity ratio. Mean scores and standard deviations for free throw shooting accuracy by groups were: 78% $\pm$ 8, 69% $\pm$ 15, and 47% $\pm$ 14, from the highest skilled group to the lowest skilled group. The highest skilled group's shots were released 27 cm higher than those of the lowest skilled group. The center of gravity ratio was found to be similar in the high and moderate skill group, but the low skill group appeared to shift its center of gravity forward at release. Non-significant differences ($p>.05$) were found among the three skill groups for the following parameters: (a) degree of trunk inclination, (b) angle of projection of the ball, and (c) velocity of projection of the ball. Means and standard deviations for the angle of projection of the ball, from the highest skilled group to the lowest skilled group, were $52.4^\circ \pm 5.6^\circ$, $52.5^\circ \pm 4.9^\circ$, and $52.9^\circ \pm 3.2^\circ$. Means and standard deviations for the velocity of projection of the ball, from the highest skilled group to the lowest skilled group, were $7.22\ m \cdot s^{-1} \pm .52$, $7.04\ m \cdot s^{-1} \pm .30$, and $7.05\ m \cdot s^{-1} \pm .43$.

Hudson (1985) performed a discriminant analysis on the free throws executed by 22 of the original 25 performers for the purpose of predicting group membership. Both 2 and 3 group analyses, elite vs. good and elite vs. good vs. poor, were performed. Variables related to accuracy weighted heavily. Five variables that related to the angle and velocity of projection of the ball, however, did not appear in any function. Poor shooters were characterized as: (a) having the center of gravity too far forward as well as moving forward, (b) having a low release height, and (c) being inaccurate. Elite shooters were characterized as: (a) having a high release point, (b) having little trunk inclination, and (c) being accurate in a stressful testing environment.

<u>Effect of Skill Level on Jump Shooting Ability</u>

Drysdale (1972) conducted a cinematographic analysis of the one-handed basketball jump shot and selected physical attributes. She compared 10 skilled and 10 unskilled female jump shooters who shot with

70% and 50% accuracy, respectively. The skilled players were found to have higher mean scores on the following parameters: (a) the height of the center of gravity from the floor at take-off, release, and peak of the jump, (b) the angle of the body at take-off and release, and (c) the height of the ball from the floor at release. The skilled players were also found to have higher means on the following physical attributes: (a) height, (b) arm length, (c) hand size and span, (d) finger flexion, wrist flexion, elbow extension, and back extension strength, and (e) leg power. Conversely, the unskilled players were found to have higher means on the following parameters: (a) horizontal, vertical, and resultant velocity of the body at take-off, and (b) horizontal, vertical, and resultant velocity of the ball at release. The unskilled players were also found to have higher means on the following physical attributes: (a) age, (b) weight, (c) leg strength, and (d) dynamic balance. Two-tailed t-tests ($p<.05$) revealed significant differences between the skilled and unskilled players on level of performance and non-significant differences on any of the mechanical factors or physical attributes studied.

McGinnis (1975) analyzed the descriptive and quantitative variables of the one-handed jump shot of one moderately skilled and two highly skilled adult males. The factor that was found to discriminate the most between the moderately skilled player and the two highly skilled players was the magnitude of the follow through. The two highly skilled players demonstrated greater angular rotation of the hand about the wrist joint during ball release. The highly skilled subjects had greater wrist hyperextension and flexion and also demonstrated complete elbow extension during the pushing phase. All three subjects demonstrated similar angles of ball release, with the tallest player having the lowest release angle. All three players released the ball before achieving peak vertical height. The highly skilled players were consistent in their release of the ball just prior to reaching peak vertical height. McGinnis (1975) concluded that the success of the jump shot is probably not determined by any single factor nor simple combination of factors.

Penrose and Blanksby (1976) compared two groups of adult males using two different shooting techniques, the one-count and the two-count method of landing. Jump shots attempted off the dribble from slightly behind the free throw line were filmed from the anterior and sagittal views for eight highly skilled and eight average skilled players. The top level group shot with 62.5% success for both methods of shooting; the average level group shot with 37.5% success using either method of shooting. It was concluded that the top level group differed from the average level group by demonstrating: (a) more height but less horizontal distance during the hurdle step, (b) greater ball motion prior to take-off, (c) a more vertical trunk at take-off and release, (d) location of the ball further behind the shoulder in the ready position, (e) location of the elbow closer to the ball-basket line while in the ready position, (f) removal of the non-shooting hand from the ball much later, (g) release of the shot with less velocity and later in the jump, (h) less horizontal displacement, i.e. floating either anteriorly or laterally, (i) greater consistency in execution, and (j) smoother patterns of motion.

Yates (1978) studied 15 subjects selected from an initial pool of 42 who had performed 100 jump shots each from distances of 10 and 20 ft directly in front of the basket. The anterior and sagittal views of one trial per subject at each distance were filmed and analyzed. Shooting ability for the filmed subjects ranged from 5% to 82%. Multiple linear regression equations were used to predict shooting accuracy at distances of 10 and 20 ft. Five variables accounted for 92.70% of the variability in performance when shooting from a distance of 10 ft. More successful performers were found to: (a) demonstrate a greater angle at the shoulder at the point of release of the basketball, (b) have a smaller amount of horizontal movement of the center of gravity of the body, (c) have a smaller elbow angle at the start of the shot, (d) have greater ball spin during flight, and (e) demonstrate closer alignment of the upper arm with the vertical at release. Five variables accounted for 85.98% of the variability in performance when shooting from a distance of 20 ft. Four of the five variables were also important in shooting from 10 ft, although they carried a different weight when shooting from a distance of 20 ft. More successful shooters were found to: (a) have the upper arm closer to the vertical at release, (b) have greater revolutions of the ball per unit of time, (c) have a larger angle of the shoulder at release, (d) hold the elbow closer to the ball-basket line at release, and (e) have a smaller angle of the elbow at the start of the shot. When the four common variables were used in a subsequent multiple linear regression analysis, 85.07% of the variance in shooting accuracy (p=.001) were accounted for at the 10 ft shooting distance and 80.32% of the variance in shooting accuracy (p=.001) were accounted for at the 20 ft shooting distance.

Effect of Gender on Jump Shooting Ability

Gaunt (1976) analyzed the mechanical components of the jump shot as performed by three male and three female intercollegiate players. The sagittal view of two successful jump shots was filmed as each subject shot off the dribble from the free throw line. It was concluded that the performance of the jump shot varies among subjects of the same sex as well as between male and female shooters. In comparison to the females, the males: (a) had a higher mean height of both the ball and hip at release, (b) released the ball after having reached the peak of their jump, whereas the females released the ball prior to reaching the peak of their jump, (c) had greater flexion at the knee, hip, and elbow at the time of greatest knee flexion in preparation for the jump shot and at take-off, (d) spent more time in several phases of the jump shot, and (e) travelled farther from take-off to toe touch. In comparison to the males, the females: (a) spent more time in the phases from heel strike to take-off and from heel strike to greatest knee flexion, (b) reached a higher mean ball trajectory, and (c) had larger resultant ball velocities.

Gorton (1978) analyzed selected kinematic and kinetic parameters in the last step and take-off and compared the movement patterns of highly skilled male and female shooters. Anterior and sagittal views were filmed of four male and four female intercollegiate players shooting three jump shots off the dribble from a distance of 15 ft. One trial per subject was analyzed. The following comparisons were made: (a) the females spent a longer mean time in the preparatory stage, .131 s vs. .023 s, (b) the males spent a longer time in the transitional and thrusting phases, resulting in a longer total time for the shot, .688 s vs. .624 s, (c) the males had the highest vertical jump and the greatest vertical impulse per unit of mass, and (d) the females released the ball .018 s prior to reaching the peak of their jump, whereas the males released the ball .065 s after reaching the peak of their jump.

Descriptive Analyses of the Jump Shot

Poon (1965) filmed the anterior and sagittal views of five jump shots taken from behind the foul line by six male college varsity basketball players. The mechanics of the arm movement in the jump shot were analyzed and described. As a result of this study, the following arm movements were advocated for the teaching of the one-handed jump shot: (a) the wrist should be hyperextended 130° prior to release and flexed 80° at the time of release, (b) the arm should be extended 80° prior to release, with the elbow flexed 84°, (c) the upper arm should be away from the trunk 128° prior to the release of the shot, (d) the forearm should be 27° with the vertical, (e) the body should lean backward 10° at the time of release, (f) the thumb and fifth finger should be utilized in balancing and elevating the ball so that the hand will not palm the ball prior to release, and (g) the index and fourth fingers, supplemented by the middle finger, are utilized in balancing and directing the ball toward the basket.

Scolnick (1967) combined cinematography with electrogoniometry in analyzing the arm action of 16 expert male college jump shooters at shooting distances of 9 ft, 15 ft, and 21 ft directly in front of the basket. Two cameras obtained anterior and sagittal views of five successful jump shots that did not hit the rim and were taken from each of the three distances. Descriptive as well as comparative analyses were made for 22 variables computed at each shooting distance. Statistically significant differences ($p=.05$) among the performances were found as the distance from the basket increased. These differences included: (a) increased elbow flexion at the beginning of the shot, (b) increased elbow extension at ball release, (c) increased upper arm flexion at ball release, (d) increased elbow extension at the completion of the follow through, and (e) increased elbow amplitude from ball release to the completion of the follow through.

Szymanski (1967) filmed and analyzed the anterior and sagittal views of a jump shot taken from a distance of 25 ft by four guards playing in the National Basketball Association. Little similarity in the mechanical execution of the jump shot was found among the subjects at four distinct stages: (a) the point of preparation, (b) the forward thrust, (c) the point of release, and (d) the follow through. The angular relationships of the middle finger, wrist, elbow, shoulder, and hip joints were different in each case. It was concluded that neither the preparation nor the follow through had an appreciable bearing on the flight of the ball nor on the proficiency of the shooter.

Hamilton (1970) compared a running jump shot taken from a distance of 15 ft with a standing jump shot taken from a distance of 9 ft. A female college player who had a reputation as a high scoring basketball player was the subject of this analysis. The findings indicated that the difference in mechanics between the two shots was due to differences in shooting range. The differences included: (a) greater acceleration and deceleration of body segments in the 15-foot running jump shot, (b) greater muscle moments, presumably to create greater ball velocity, for the 15-foot running jump shot, and (c) later initiation of the arm action and later ball release for the 9-foot standing jump shot.

Equipment Modification in Basketball

Adults who administer youth sports' programs should recognize that children do not grow linearly and are not merely scaled down versions of their adult counterparts (Haywood, 1985). The body segments of children have varying growth rates. From age one to puberty the legs and arms are the fastest growing segments. From puberty to adulthood, the trunk is the fastest growing segment. Children are proportionately different, therefore, than adults. Proportional differences may alter a child's mechanical execution of a skill in comparison to that of his adult counterpart (Haywood, 1981). As a result, adapting rules and modifying equipment may offer the youth a single skill or a whole game that is more like the adult version. It may also provide the youth an opportunity to learn skills that are mechanically similar to those used by adults (Haywood, 1985). Studies that have investigated the effect of ball size and basket height on the success of shooting a basketball were reviewed.

Ball Size Modifications

McCloy (1937) asserted that smaller boys of elementary and junior high school age could be more easily taught skills such as shooting a basketball if a special ball were used. The special ball should be adapted to the height, strength, arm length, and size of the smaller boys' hand.

Burkness (1939) determined the ideal specifications of a basketball modified for junior high school boys. The subjects of this investigation were 61 varsity senior high school boys and 108 randomly selected junior high school boys. Nine anthropometric measurements were taken on each of the boys. The mean score on each measurement for the junior high boys was divided by the mean score for the senior high boys. The resultant ratio for each score was used to determine the following specifications for the proposed ball: (a) 27.25 in in circumference, (b) 16 oz in weight, and (c) a rebound of 47 in from the floor.

Haywood (1978) measured the palm width of the dominant hand and the maximum first finger to fifth finger spread of 31 boys and 31 girls who ranged in age from 9.0 to 12.7 years. The mean palm width was 7.4 cm and the mean hand spread was 19.1 cm. The same hand measurements were taken on college players from varsity basketball teams. The mean palm widths were 8.4 cm for the female and 9.5 cm for the male players; the mean hand spreads were 21.6 cm for the female and 23.7 cm for the male players. Comparisons of the mean hand spreads to ball circumference revealed the following: (a) the children had a mean hand spread that was 25% of the circumference of the regulation sized basketball and 27% of the junior sized basketball, (b) the female college players had a mean hand spread that was 28% of the regulation sized basketball, and (c) the male college players had a mean hand spread that was 31% of the regulation sized basketball. It was concluded that the hand spread to ball size ratio of the children to the junior sized basketball was similar to the ratio of the adult to the regulation sized basketball.

Subsequently, the Speed Pass and Front Shot subtests of the AAHPERD battery of basketball skills tests were administered to the children. The older children, aged 10.6 to 12.7 years, performed better with the regulation sized ball on the Front Shot test. The younger children, aged 9.0 to 10.5 years, were more accurate with the junior sized ball. Haywood (1978) suggested that prior experience of shooting with the regulation sized ball may have affected the results of the older children. The results suggested, however, that children younger than 10.5 years would be more accurate in distance shooting with the lighter ball.

Lindeburg and Hewitt (1965) investigated the effect of an oversized basketball on four tests of shooting and ball handling ability of 26 experienced adult male varsity and junior varsity basketball players. The experimental ball measured 31 in in circumference and weighed 22.5 oz. No significant difference on the foul shot test was found between performance with the regulation and the experimental ball. The authors concluded that the subjects quickly adapted to the experimental basketball.

Pangman (1982) investigated the effect of practicing with varying weight basketballs on the performance of free throw shooting with a regulation sized basketball. Practicing with lighter (14 oz) and regulation ball weights (22 oz) was found to be more effective in improving free throw shooting accuracy than practicing with a heavier ball (40 oz). It was concluded that the heavier ball was deleterious to skill improvement because the subjects had to alter their shooting style to adjust for the increased ball weight.

Basket Height Modifications

Hopewell (1970) selected 40 sixth grade boys to shoot a Biddy basketball (28 in in circumference, 19 oz in weight) at four adjustable goal heights of 8.5 ft, 9 ft, 9.5 ft, and 10 ft. The boys shot three shots in a round from behind the foul line at each of the four goal heights over an eight week practice session. The number of baskets made per day at each height was recorded. The highest number of made baskets occurred when the boys shot at the goal height of 10 ft, although only eight baskets separated the goal heights at which the most baskets and the fewest baskets were made. The height of the goal, therefore, did not appear to affect the shooting performance of the subjects of this investigation.

Gabbard and Shea (1980) investigated the effects of practicing at varied goal heights of 8 ft, 9 ft, and 10 ft on the foul shooting performance of 60 fifth grade boys. The subjects were assigned to four groups on the basis of their pre-test foul shooting ability. Three of the four groups practiced at one of the three goal heights for 30 minutes, three times per week, for six weeks. The fourth group practiced at varied goal heights for the same amount of time. All of the groups were post-tested at each of the three goal heights. Results of the analysis revealed a significant ($p<.01$) main effect for goal height and a significant ($p<.01$) group by goal interaction. The results of the study indicated that practicing at a specific goal height would not necessarily indicate superior performance at that particular goal height when the post-test was administered. Three of the four groups performed best at the goal height of 9 ft. The scores at the goal height of 9 ft, however, were not significantly different than the scores at the goal height of 8 ft. The scores for all four groups decreased significantly at the goal height of 10 ft. The group that practiced at the goal height of 8 ft had the best performance scores at the goal height of 10 ft.

Combination Ball Size and Basket Height Modifications

Lambert (1959) developed a questionnaire for college teachers and physical education supervisors that surveyed their opinions on the use of modified basketballs and adjusted basket heights for teaching basketball skills to children. The respondents expressed the following opinions about the age at which regulation sized basketball equipment should be used: (a) for girls, 87% thought regulation basketballs should not be included until grades 7 or 8; 13% thought they could first be used in grades 5 or 6; (b) for boys, 71% thought regulation basketballs should not be included until grades 7 or 8; 29% thought they could first be used in grades 5 or 6; (c) with regulation goal heights, 77% thought that regulation basketballs should not be used until grades 6 or 7, 23% thought regulation balls should be used below that age level; and (d) when using small basketballs, 73% thought that regulation height goals should be used beginning in grades 4, 5, or 6; 15% thought regulation height goals should not be used below grade 7.

Miller (1971) investigated the effect of ball size and basket height on the learning of selected basketball skills as measured by four standardized tests from the AAHPERD test battery. The regulation sized basketball and the official Biddy basketball were used with a regulation 10-foot basket and an 8.5-foot basket. The subjects included 88 fifth grade boys who were assigned to four experimental groups. Each group was first tested in shooting accuracy using the regulation condition and then tested using the experimental condition to which it had been randomly assigned. After completing the initial tests under both the regulation condition and the experimental condition, the subjects participated in 12 class periods of practice. Each group was then tested again under its experimental condition. Analysis of the data in which the regulation ball size and basket height were used for the foul shots indicated that practicing with a small ball was more effective than practicing with a large ball. Neither the height of the basket nor the interaction of ball size and basket height, however, had a significant effect. Analysis of the data for the testing under the same condition as the practice condition revealed the following: (a) the group that practiced with the large ball at the regulation basket height did not show a significant difference in mean score from the initial test to the final experimental test, (b) the group that practiced with the large ball at the lowered basket height showed significant (p=.05) improvement in performance, (c) the group that practiced with the small ball at the regulaton basket height showed significant (p=.01) improvement in performance, and (d) the group that practiced with the small ball at the lowered basket height did not show a significant improvement in performance.

Stinar (1981) investigated the effect of modified equipment (junior sized basketball and 8-foot basket) on the shooting ability of children in grades 5 and 6. Each group of students received the same instructions in terms of format, time, procedure, and amount of equipment, but was assigned to a different treatment group in terms of ball size and basket height. A modification of the foul shot test from the AAHPERD battery of tests was one of two tests used to evaluate shooting performance of 533 boys and girls. The students were pre-tested and post-tested on 10-foot baskets with regulation sized basketballs. All students improved their shooting performance over the course of the instructional unit. Additionally, all the treatment conditions were found to be effective in changing the students' shooting ability when tested with the regulation equipment. No significant difference in performance was found between the treatment conditions; however, the students using the modified basketball and the adjusted basket height made the greatest number of baskets. Moreover, it was noted that a shooting distance of 15 ft was too great a distance for the 5th and 6th grade students to successfully shoot the foul shot. Shooting from this distance left many of the students extremely frustrated. It was suggested, therefore, that success in the foul shot for this age group was not as much related to the ball size or basket height as it was related to the distance the shot was taken from the basket.

Development of Complex Motor Skills

Two kinds of data may be used to map the course of the development of fundamental motor skills: (a) movement product data which represents the achievement of performance scores in specific motor skills, and (b) movement process data which indicates how motor skills are performed. Product data yields information about the end result of the motor act, whereas process data reflects the mechanical actions of constituent motor patterns integrated in a space-time-force context (Smoll, 1982). Roberton (1984b) suggested that movement process data may be generated from two sources: (a) from descriptions of the movement taking place that attend to the timing and spatial relationships occurring in the movement, and (b) from the use of biomechanical tools to describe the kinematics and kinetics of the changing motor behavior.

Cross sectional product data on the performance of motor skills by children and adolescents are abundantly available in the literature. Branta, Haubenstricker, and Seefeldt (1984) compiled and compared the findings of several studies that investigated the motor performance of such skills as the standing long jump, the jump and reach test, the throw for velocity, the throw for distance, the throw for accuracy, the timed run, the maximum number of sit-ups, and the flexed arm hang. Process data that describes in spatial and temporal terms the refinement over time of such fundamental motor skills as hopping, skipping, running, jumping, throwing, catching, striking, and kicking are also available in the literature (Roberton & Halverson, 1984;

Wickstrom, 1983). Process data reporting the kinematics and kinetics of fundamental motor skills, however, are very scarce.

As skills of increasing complexity and precision are developed, the fundamental motor skills initiated in infancy and refined in childhood and adolescence are modified and combined. Complex skills used in game, sport, and dance activities require the integration and coordination of several underlying fundamental motor skills (Smoll, 1982). Although a plethora of information may be found in the literature on the development of fundamental motor skills, very little attention has been given to the development of fundamental sport or game skills.

Development as a Function of the Environment

Motor development has been defined by Wickstrom (1983) as change occurring in motor behavior over time that reflects the interaction of the human organism with its environment. Keogh and Sugden (1985) assert that development results from the transactional relationship between the individual and the environment because development involves adaptive change toward competence. As the mover becomes effective in the environment, competence is developed by resolving the movement problems posed by the environment.

Conventionally, the term "environment" is used to identify the context in which an event takes place. Through interplay with different environments, the mover creates situations by organizing a motor response that attempts to produce movements toward the intended outcomes. Changes in the environment, as well as changes in the mover's perception of the environment, can change the movement task.

The level of demand placed upon the individual in a movement situation, therefore, is a function of the movement conditions and the task requirements, balanced against the mover's resources (Keogh & Sugden, 1985).

Herkowitz (1978) suggests that young children have a need to generate interactions with their environment in order to produce effects that demonstrate the child's competence and result in feelings of effectiveness. When provided with opportunities to learn complex skills, therefore, children will develop those skills. When the environmental opportunities are limited or unavailable, however, complex motor skills are often poorly learned (Herkowitz, 1981).

Sports and games incorporate the performance of movement skills that are either used independently or in combination with one another. The types of movement skills that occur, therefore, seem to be mandated by the limits, purposes, or internal demands of the sport or game (Morris, 1980). Because motor tasks can be accomplished with varying degrees of proficiency, the learner is allowed to move on, even though the task is not well performed. Additionally, conditions limiting the level of task acquisition may be responsible for differences in proficiency levels between individuals. If these tasks are then involved in future learning, a reduction in effectiveness may result (Seefeldt, 1980).

To enhance specific motor activities, the status of the performer's current growth and development must be considered. Because the factors that influence the development of the skill have been identified, appropriately structured games will present the movement tasks in parts with which each learner can reasonably cope (Morris, 1980). To capitalize on the individual's motor capacities, therefore, environmental factors that affect motor development can be manipulated in order to optimize development (Smoll, 1982).

Learning as a Function of the Environment

Learning has been defined as "the change resulting from a circle of interaction between the child and the environment" (Roberton & Halverson, 1984, p. 25). This definition implies that the teacher is not needed to produce learning. When teachers do decide to intervene in the learner's environment, however, they must provide environmental situations that will help to move the child ahead in development if they are to be instrumental in the learning process. Based on their experience and research findings, Roberton and Halverson (1984) suggest:

> to promote motor development, the movement environment must have an atmosphere of success and satisfaction. It needs to be fun. Success is one of the greatest contributors to development just as failure is one of the prime causes of regression. Thus, the entire movement environment should be designed so that children can successfully accomplish their movement goal (p. 82).

To discover what the child can do if the limits of his environment stimulate the emergence and practice of motor patterns, Halverson (1966) suggested that teachers should consider the following: (a) elicit the pattern by setting goals and devising practice situations to bring forth a desired response, (b) design experiences to refine available movement patterns to lead the child from the beginning stages to a mature form, and (c) observe the effects of equipment (size and weight) and stress on the child's motor response such that the child is challengened enough to grow in motor maturity and skill but not frustrated by over-challenge.

Performance as a Function of the Changing Environment

Research that has investigated the effect of immediate changing environments on the developmental levels of children has been limited to young children performing fundamental motor skills. Roberton (1984a) filmed anterior and sagittal views of 22 children ranging in age from 3.25 to 8.1 years as they performed the overarm throw. Developmental sequences proposed by Roberton and associates for the body components of the humerus, forearm, pelvis-spine, and stepping action were used to describe the overarm throw. Twenty overarm throws for force were performed, five under each of the following conditions: (a) throw for force with no specific target, (b) throw for force at a stationary target which did not change position across trials, (c) throw for force at a stationary target which did change positions across trials, and (d) throw for force at a moving target which changed pathways across trials. Across the group, the children's developmental levels did not change when the immediate environment became more complex; non-significant differences ($p>.01$) were detected for the four body components studied. Further analysis suggested that the developmental level and/or variability showed by a child in the initial and least complicated condition, the throw for force with no specific target, was highly related to their behavior in subsequent, more complicated conditions. It was concluded that the environment cannot induce change unless the child is at a point where he can be receptive or "ready" for change. The fact that the subjects of this study were skewed toward the primitive ends of the developmental sequences led Roberton (1984a) to suggest that the findings were tentative but worthy of future investigation.

Research that has investigated the effect of the changing environment on shooting free throws and jump shots in basketball has analyzed the results in terms of the product data produced (Gabbard & Shea, 1980; Haywood, 1978; Hopewell, 1970; Lindeburg & Hewitt, 1965; Miller, 1971; Pangman, 1982; Stinar, 1981). The information afforded by this type of measurement, however, does not necessarily allow the teacher and coach to understand how or why a child moved in a particular manner (Morris, 1980). The paucity of research providing process data related to the performance of shooting basketballs under changing environmental conditions suggests that a need for such research exists.

CHAPTER III

METHODOLOGY

The purpose of this investigation was to analyze the effect of ball size and basket height on the mechanics of the basketball free throw as performed by seventh grade boys. The methodology used to collect and analyze the data are presented under the following headings; Subjects, Testing Environment, Testing Procedures, Data Reduction, Computational Treatment of the Data, and Statistical Procedures.

Subjects

The subjects for this investigation were 13 seventh grade boys who were enrolled in physical education classes at a Greensboro, North Carolina, junior high school. All the subjects were right handed and were between the ages of 12 and 13 years. Individual subject descriptive data are presented in Appendix A. Mean descriptive data are presented in Table 1. All the subjects were volunteers who had signed consent forms after the experimental procedures had been explained (Appendix B). The consent forms were also co-signed by the subjects' parents.

Testing Environment

Basketball Equipment

All subjects in this investigation performed repeated trials of the basketball free throw using two different ball sizes and basket heights. The Mikasa BML10 regulation size synthetic leather basketball

Table 1

Mean Descriptive Subject Data

	Age (yrs)	Height (cm)	Weight (N)	Finger Span (cm)
M	12.86	164.51	480.68	20.00
SE	.13	3.03	26.32	.49

and the Mikasa BML119 intermediate size synthetic leather basketball were used in this investigation. The regulation sized basketballs that were used ranged in weight from 5.74 to 5.87 N and in circumference from 74.9 to 75.6 cm. The intermediate sized basketballs that were used ranged in weight from 4.77 to 4.82 N and in circumference from 71.8 to 72.1 cm. The regulation basket height of 10 ft and a basket lowered to a height of 8 ft were the two basket heights used in this investigation.

Photoinstrumentation

Film records were obtained with the use of two LoCam model 51, 16 mm, pin-registered, high speed cameras (manufactured by Redlake Corporation, 1711 Dell Avenue, Campbell, CA 95008). Internal timing light generators pulsing at 100 Hz were used to verify camera speed. The two cameras were placed perpendicular to each other and to the sagittal and frontal planes. The side camera was located 14.8 m from the subject's right side on a line extending from the free throw line, while the front camera was located 8.5 m from the subject's anterior side (Figure 3). The cameras provided simultaneous, non-synchronous views of the performance.

Canon 18-108 mm zoom lenses with focal lengths set at 30 mm and 18 mm for the sagittal and anterior view cameras, respectively, were used in conjunction with Kodak 4-X, black and white reversal film. The use of one-third shutter openings and camera transport speeds of 100 fps provided exposure times of .0033 s for both cameras. Four thousand watts of supplemental lighting were used, resulting in f-stop openings of 5.6 and 8.0 (Figure 3).

A videotape camera was placed to the subject's right side at a distance that was great enough to afford a simultaneous recording of both the subject and the basket. The videotape was used to assist the investigator in selecting trials that would be suitable for analysis.

Testing Procedures

Pilot Study

A pilot study was conducted prior to collecting the data for this investigation. The number of people needed to collect the data, the amount of time to be allotted per subject for data collection, and the need to supply additional lighting for the filming session were determined as a result of this preliminary study.

Subject Attire and Markings

Each subject was scheduled to be filmed on a consecutive Saturday and Sunday over three separate weekends. Subjects were advised in an orientation letter to wear shorts, a tee-shirt that would be removed during filming, basketball shoes, and socks (Appendix C). Upon arrival at the testing site, the subject's age, height, and weight were

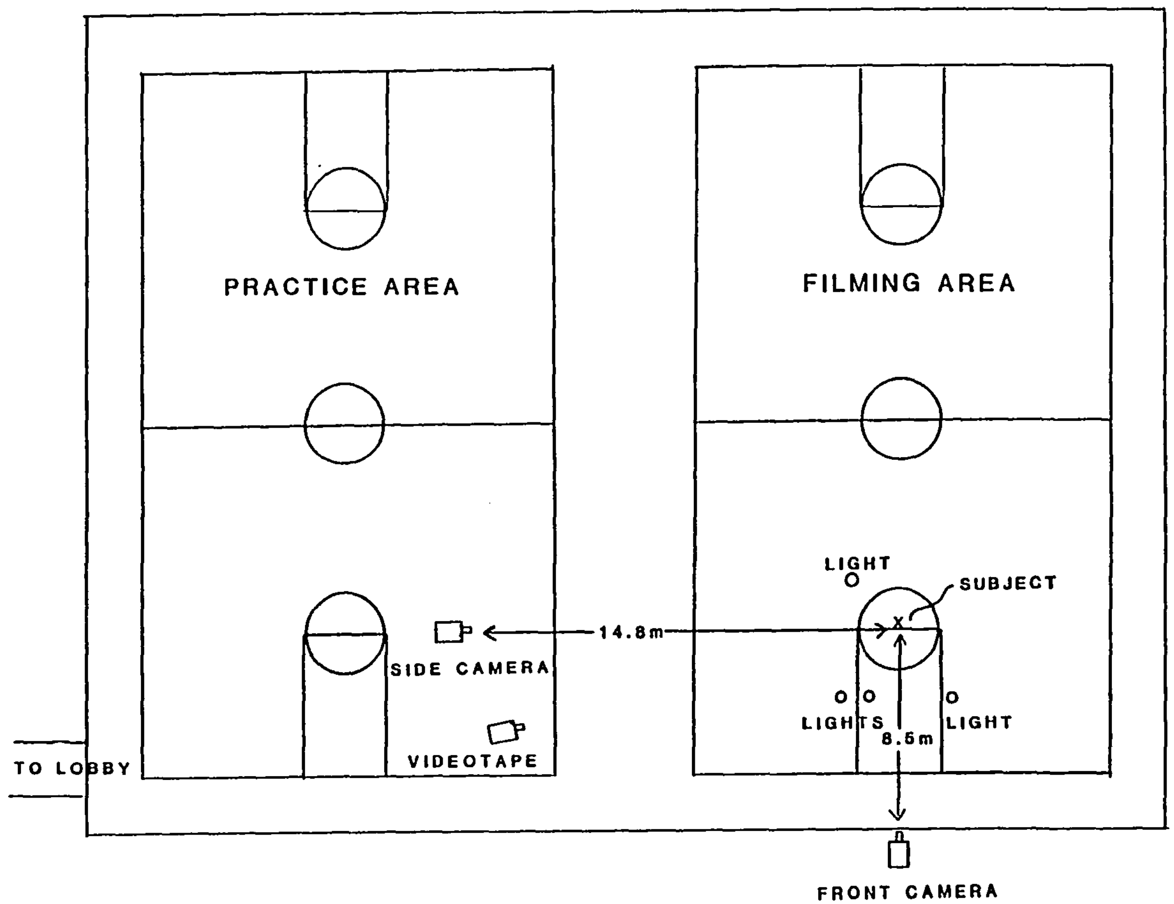

Figure 3. Filming set-up.

recorded. Additionally, finger span on the right hand was measured from little finger to thumb with an anthropometer. Joint markers were affixed directly to the subject's skin. To digitize segmental endpoints from film records, the following were marked on the lateral aspects of the right side and on the medial aspects of the left side of the body: (a) shoulder, (b) elbow, (c) wrist, (d) hip, (e) iliac crest, (f) knee, (g) malleolus, (h) directly below the malleolus on the border of the foot, (i) fifth metatarsal of the foot, (j) the heel, and (k) the outside of the foot at the little toe (Plagenhoef, 1971).

Filming Procedures

Immediately prior to participating in the filming, the subject was allowed to practice for a minimum of 15 minutes at a basket located adjacent to the filming area. While in the practice area, the procedures that would be followed during filming were explained. The subject was told that he would be filmed shooting free throws with both the regulation and intermediate size basketballs at the same basket height as the practice basket, either 8 or 10 ft. No coaching was given to the subject during either the practice or filming sessions.

Once in the filming area, the subject was allowed additional practice time to become familiar with the filming conditions, i.e. under the supplemental lighting, around the testing personnel, and with the specific ball that would be used during that session. He was allowed to practice until he indicated that he was ready to be filmed. The filming session consisted of the subject shooting 5 free throws that were not filmed, 10 free throws that were filmed, and an additional 5 free throws that were not filmed. The videotape camera recorded the entire filming session. Each free throw attempt was coded and marked on a scoresheet according to the system suggested by Pangman (1982):

4 points: the ball passed through the basket without touching the rim or backboard

3 points: the ball passed through the basket after having made contact with the rim only

2 points: the ball passed through the basket after having made contact with the backboard

1 point: the ball did not pass through the basket, having touched the rim or the rim first and then the backboard

0 points: the ball did not pass through the basket, did not hit the rim or backboard prior to being unsuccessful

A minimum of three "successful" trials, i.e. baskets coded "4" or "3", were filmed for each subject per combination of ball size and basket height. If the subject failed to execute three successful trials during the 10 free throws that were planned to be filmed, the filming continued until a third successful trial was filmed. A sample scoresheet is included in Figure 4.

Following completion of the 20 free throws under the first environmental condition, the subject was allowed a brief rest period. The same procedure of practice and testing were subsequently used for the second environmental condition. The subject returned the following day and repeated the procedures under the two remaining environmental conditions. The presentation of the four environmental conditions was alternated within and across subjects to help control for ordering effects.

NAME ______________________ HEIGHT __________ WEIGHT __________

AGE: ________ Years ________ Months Finger Span __________

	Ball Size I R	1	2	3	4	5	6	7	8	9	10
	Basket Height 8 10	11	12	13	14	15	16	17	18	19	20
	Ball Size I R	1	2	3	4	5	6	7	8	9	10
DATE	Basket Height 8 10	11	12	13	14	15	16	17	18	19	20
	Ball Size I R	1	2	3	4	5	6	7	8	9	10
	Basket Height 8 10	11	12	13	14	15	16	17	18	19	20
	Ball Size I R	1	2	3	4	5	6	7	8	9	10
DATE	Basket Height 8 10	11	12	13	14	15	16	17	18	19	20

SHOT CODING:

4 - made, did not touch backboard or rim

3 - made, after touching rim only

2 - made, after touching backboard

1 - missed, touched rim or rim and backboard

0 - missed, did not hit rim or backboard

Figure 4. Sample scoresheet.

Data Reduction

Selection of Trials for Analysis

Disch and Hudson (1980) state that the results of biomechanical studies may depend on the strategy used by the investigator in the selection and number of trials to be reduced. The following strategies were suggested: (a) select the trial which contains the greatest amount of an important variable, (b) select the trial that best represents all the trials, and (c) select all trials and use average values (Disch & Hudson, 1980).

Only trials in which the basket had been made were selected for this analysis. These trials were believed to contain the greatest amount of information about the variables that were to be analyzed. The coding system used during the filming session provided additional insight into the trial selection process by identifying similar types of made baskets. Trials in which the basket had been scored a "4" were believed to represent the subject's best trials. Two trials per subject per condition that were scored as "4" were, therefore, selected for analysis. If an insufficient number of trials coded as "4" were available, then trials coded as "3" or "2", in this order of preference, were selected for the analysis. The two selected trials were treated independently of each other in the analysis rather than averaged, since the average of two scores is often not representative of either or both scores.

The videotape was used to check the accuracy of the coded baskets as they had been recorded on the subject's scoresheet during the filming session. Viewing the videotape also made it possible to ensure the use of standardized criteria for the coding of the baskets.

Digitizing

A 224-A-MKVII motion picture analyzer (manufactured by L-W International, 6416 Variel Avenue, Woodland Hills, CA 91637) was used to project the film records onto a 91.44 cm x 91.44 cm horizontal surface. A model 1224 Numonics digitizer (manufactured by Numonics Corporation, 418 Pierce Street, Lansdale, PA 19446) interfaced with an Apple II+ microcomputer (manufactured by Apple Computer, Inc., 20525 Mariani Avenue, Cupertino, CA 95014) and software written by Richards and Wilkerson (1984) were used to record x- and y-coordinates of segmental endpoints and the ball (Appendix D). The time between digitized frames was .02 s.

To establish reliability, one trial from one condition from the sagittal view was arbitrarily selected for repeated digitizing. Three selected frames were each digitized 10 times. These three frames were selected because they represented frames in which the 21 digitized points were either relatively easy to locate or more difficult to locate. The standard error of the mean for the 21 points digitized 10 times in each of the 3 selected frames ranged from .008 to .145 cm. The average value for the standard errors of the means for the points digitized was .042 cm.

Computational Treatment of the Data

Linear and angular kinematic parameters were calculated using an Apple II+ microcomputer and software written by Richards and Wilkerson (1984). The raw data were smoothed with a cubic spline function subroutine (weight vector (DF) = .15). Body segment parameters were calculated using Dempster's (1955) segmental data. Calculated parameters included the following: (a) the angle of projection of the basketball, (b) the release angle of the shoulder, (c) the starting angle of the elbow, (d) the forearm in relation to the vertical at ball release, (e) the linear velocity of the basketball at release, (f) the displacement and path of the body's center of gravity, (g) the point of release of the basketball in relation to the height of the center of gravity, (h) the angle of trunk inclination, (i) the timing and coordination of the joint actions of the upper and lower body, and (j) the angular velocity of the wrist joint.

Statistical Procedures

Research Design

A 2x2x2 research design with repeated measures on the dependent variables for 13 subjects was used to conduct the statistical analysis of the data (Figure 5). The independent variables and their two levels were: (a) basket height--regulation basket height of 10 ft and lowered basket height of 8 ft, (b) ball size--regulation size basketball and intermediate size basketball, and (c) trial number--criteria based selected trials labelled as trial 1 and trial 2. The dependent variables were: (a) the angle of projection of the basketball, (b) the release angle of the shoulder, (c) the starting angle of the elbow, and (d) the forearm in relation to the vertical at ball release (Figure 5). The .05 level of significance was used to determine whether the null hypotheses of no significant difference should be rejected or retained.

		Environmental Condition			
Subject	Trial	8 - I *	8 - R	10 - I	10 - R
1	1	dv . . .			. . . dv
	2	dv . . .			. . . dv
2	1	.			.
		.			.
	2	.			.
3	1				
	2				
.	.	.			.
.	.	.			.
.	.	.			.
13	1	dv . . .			. . . dv
	2	dv . . .			. . . dv

Figure 5. Research Design.

* = 8 - I = 8-Foot Basket, Intermediate Sized Basketball
8 - R = 8-Foot Basket, Regulation Sized Basketball
10 - I = 10-Foot Basket, Intermediate Sized Basketball
10 - R = 10-Foot Basket, Regulation Sized Basketball

dv = dependent variable

Statistical Analysis

An analysis of variance with repeated measures was performed on the computed values for the angle of projection of the basketball. The ANOVA procedure from SAS (1982b) was used to test for significant differences within and across subjects under the four environmental conditions.

A multivariate analysis of variance with repeated measures was performed on the computed values for the following three variables: (a) the release angle of the shoulder, (b) the starting angle of the elbow, and (c) the forearm in relation to the vertical at ball release (Yates, 1978; Yates & Holt, 1982). The MANOVA procedure from SAS (1982b) was used to test for simultaneous significant differences within and across subjects under the four environmental conditions. For a post hoc analysis, the ANOVA procedure from SAS (1982b) was used with each of the three variables separately to test for significant differences within and across subjects under the four environmental conditions.

Descriptive Analysis

The MEANS procedure from SAS (1982a) was used to determine the means, standard deviations, and standard errors of estimate of the mean for the kinematic parameters of angle of projection of the basketball and the linear velocity of the basketball at release. Additionally, the CORRELATION procedure from SAS (1982a) was used to test the relationship between the subject's standing height and the average angle of projection of the basketball under the four environmental conditions.

Computed values for the following kinematic parameters were transferred from the Apple II+ microcomputer to the Vax 11/780 main computer of the University of North Carolina at Greensboro: (a) total body center of gravity, (b) angle of trunk inclination, (c) wrist, elbow, shoulder, and knee angles, and (d) wrist velocity. The computed parameters were averaged separately across the two trials per 13 subjects under each of the four environmental conditions. The CONDESCRIPTIVE procedure from SPSS (1983) was used to determine the means, standard deviations, and standard errors of estimate of the mean for each of the frames digitized.

CHAPTER IV

RESULTS AND DISCUSSION

The purpose of this study was to analyze the effect of ball size and basket height on the mechanics of the basketball free throw as performed by seventh grade boys. The results of this investigation are presented under the following headings; Statistical Analysis, Descriptive Analysis, and Shooting Percentages.

Statistical Analysis

The angles of projection calculated for the two trials analyzed per subject are presented in Appendix E. Mean values for the angle of projection by basket height, by ball size, and by the interaction of these two variables are presented in Table 2. An ANOVA with repeated measures tested for significant differences among the angles of projection within and across subjects under the four environmental conditions. A preliminary model statement yielded non-significant differences ($p>.05$) between the two trials per subject under each of the four conditions. Therefore, this variable was not included in the model statement for the subsequent ANOVA.

A significant difference among subjects ($p=.0001$) was found for the angle of projection. Additionally, significant differences for the main effect of basket height ($p=.0001$, $M_{10}=50.64^{\circ}$(.88 rad),$M_8=45.02^{\circ}$ (.79 rad)) and non-significant differences ($p>.05$) for the main effect of ball size and for the interaction effects were found (Table 3).

Table 2

Mean Angles of Projection of the Basketball (degrees)

	Basket Height		Ball Size	
	8-Foot	10-Foot	Intermediate	Regulation
M	45.02	50.64	47.82	47.84
SE	.81	.93	.96	.95
N	51	51	50	52

	Interaction of Basket Height and Ball Size			
	8 - I	8 - R	10 - I	10 - R
M	44.82	45.21	50.82	50.48
SE	1.14	1.17	1.32	1.33
N	25	26	25	26

Note: 8 - I = 8-Foot Basket, Intermediate Sized Basketball
8 - R = 8-Foot Basket, Regulation Sized Basketball
10 - I = 10-Foot Basket, Intermediate Sized Basketball
10 - R = 10-Foot Basket, Regulation Sized Basketball

Table 3

ANOVA Results for the Angle of Projection of the Basketball

Source	DF	ANOVA SS	F Value	p
ID	12	1848.38	7.85	.0001 *
Basket	1	807.37	41.14	.0001 *
Ball	1	0.01	0.00	.9789
Basket x Ball	1	3.32	0.17	.6826
ID x Basket	12	310.41	1.32	.2383
ID x Ball	12	373.56	1.59	.1262
ID x Basket x Ball	12	356.83	1.52	.1501

Note: * = Significant at the .05 level

The individual angular measures for the two trials per subject under each of the four environmental conditions for the release angle of the shoulder (Figure 1), the starting angle of the elbow, and the forearm in relation to the vertical at ball release (Figure 2) are presented in Appendix F. Mean values for the three variables are presented in Tables 4 - 6. A MANOVA with repeated measures tested for simultaneous significant differences for the aforementioned three variables under the four environmental conditions. The results of this analysis are presented in Table 7.

The MANOVA revealed a significant difference among the subjects ($p<.0001$) when the three variables were considered simultaneously. In addition, a significant main effect of basket height ($p=.0001$) and non-significant differences ($p>.05$) for the main effect of ball size and for the interaction of the two variables were revealed.

Subsequent post hoc ANOVA's with repeated measures were performed on each of the three variables separately. In each of the three ANOVA's performed, an initial test for variability between the two trials under each of the four environmental conditions yielded non-significant differences ($p>.05$) in the angular measures between trials. Therefore, this variable was omitted from the model statement for subsequent ANOVA's. Only the ten subjects who shot one-handed free throws were included in the univariate analyses. The results of the analyses are presented in Tables 8 - 10.

A significant difference among subjects ($p=.0001$) was found in the post hoc ANOVA of the release angle of the shoulder. Significant differences for the main effect of basket height ($p=.0001$, $M_{10}=2.16$

Table 4

Mean Angular Values for the Release Angle of the Shoulder (rad)

	Basket Height		Ball Size	
	8-Foot	10-Foot	Intermediate	Regulation
M	2.03	2.16	2.09	2.10
SE	.03	.03	.03	.03
N	40	40	40	40

	Interaction of Basket Height and Ball Size			
	8 - I	8 - R	10 - I	10 - R
M	2.04	2.02	2.15	2.18
SE	.04	.04	.04	.04
N	20	20	20	20

Note: 8 - I = 8-Foot Basket, Intermediate Sized Basketball
8 - R = 8-Foot Basket, Regulation Sized Basketball
10 - I = 10-Foot Basket, Intermediate Sized Basketball
10 - R = 10-Foot Basket, Regulation Sized Basketball

Table 5

Mean Angular Values for the Starting Angle of the Elbow (rad)

	Basket Height		Ball Size	
	8-Foot	10-Foot	Intermediate	Regulation
M	.88	.80	.85	.83
SE	.04	.05	.05	.05
N	40	40	40	40

	Interaction of Basket Height and Ball Size			
	8 - I	8 - R	10 - I	10 - R
M	.91	.85	.80	.81
SE	.05	.07	.07	.08
N	20	20	20	20

Note: 8 - I = 8-Foot Basket, Intermediate Sized Basketball
8 - R = 8-Foot Basket, Regulation Sized Basketball
10 - I = 10-Foot Basket, Intermediate Sized Basketball
10 - R = 10-Foot Basket, Regulation Sized Basketball

Table 6

Mean Angular Values for the Forearm in Relation to the Vertical at Ball Release (rad)

	Basket Height		Ball Size	
	8-Foot	10-Foot	Intermediate	Regulation
M	-.23	-.19	-.21	-.21
SE	.03	.02	.02	.02
N	32 *	39	35	36

	Interaction of Basket Height and Ball Size			
	8 - I	8 - R	10 - I	10 - R
M	-.23	-.24	-.19	-.19
SE	.04	.04	.03	.03
N	16 *	16 *	19	20

Note: 8 - I = 8-Foot Basket, Intermediate Sized Basketball
8 - R = 8-Foot Basket, Regulation Sized Basketball
10 - I = 10-Foot Basket, Intermediate Sized Basketball
10 - R = 10-Foot Basket, Regulation Sized Basketball

* = Equipment malfunction during one of the filming sessions prevented the calcultion of this variable for two subjects at the 8-foot basket.

Table 7

MANOVA Results for the Release Angle of the Shoulder, the Starting Angle of the Elbow, and the Forearm in Relation to the Vertical at Ball Release

Test Criteria	Wilk's Lambda	p
ID	.0002	.0000 *
Basket	.2592	.0001 *
Ball	.9628	.7361
Basket x Ball	.8170	.0797

Note: * = Significant at the .05 level

rad, M_8=2.03 rad) and for the interaction effect between subject and basket height (p=.03) were also found. Non-significant differences (p>.05) were found for the main effect of ball size and for the remaining interaction effects (Table 8).

A significant difference among subjects (p=.0001) was found in the post hoc ANOVA of the starting angle of the elbow. Significant differences for the main effect of basket height (p=.0001, M_{10}=.80 rad, M_8=.88 rad) were also found. Additionally, significant interaction effects between basket height and ball size (p=.01), subject and basket height (p=.0001), and subject and ball size (p=.002) were observed. Non-significant differences (p>.05) were found for the main effect of ball size and for the remaining interaction effects (Table 9).

A significant difference among subjects (p=.0001) was found in the post hoc ANOVA of the forearm in relation to the vertical at ball release. Significant differences for the main effect of basket height (p=.0001, M_{10}=-.19 rad, M_8=-.23 rad) were also found. Additionally, significant interaction effects between subject and basket height (p=.0003) and subject, basket height, and ball size (p=.02) were observed. Non-significant differences (p>.05) were found for the main effect of ball size and for the remaining interaction effects (Table 10).

Bonferroni confidence intervals between the means of the above mentioned three angles were computed. Paired comparisons of the means for each of the four environmental conditions by basket height and ball size (Tables 4 - 6) revealed significant differences in the release angle of the shoulder between the 8-foot and 10-foot basket when using

Table 8

ANOVA Results for the Release Angle of the Shoulder

Source	DF	ANOVA SS	F Value	p
ID	9	8049.72	41.22	.0001 *
Basket	1	1186.26	54.67	.0001 *
Ball	1	1.18	0.05	.8167
Basket x Ball	1	68.78	3.17	.0826
ID x Basket	9	451.57	2.31	.0336 *
ID x Ball	9	311.68	1.60	.1496
ID x Basket x Ball	9	43.38	0.22	.9895

Note: * = Significant at the .05 level

Table 9

ANOVA Results for the Starting Angle of the Elbow

Source	DF	ANOVA SS	F Value	p
ID	9	21796.95	193.73	.0001 *
Basket	1	443.21	35.45	.0001 *
Ball	1	37.73	3.02	.0900
Basket x Ball	1	82.91	6.63	.0138 *
ID x Basket	9	743.17	6.61	.0001 *
ID x Ball	9	405.81	3.61	.0023 *
ID x Basket x Ball	9	222.64	1.98	.0679

Note: * = Significant at the .05 level

Table 10

ANOVA Results for the Forearm in Relation to the Vertical at Ball Release

Source	DF	ANOVA SS	F Value	p
ID	9	3684.23	79.82	.0001 *
Basket	1	122.47	23.88	.0001 *
Ball	1	0.06	0.01	.9120
Basket x Ball	1	0.46	0.09	.7651
ID x Basket	7	196.76	5.48	.0003 *
ID x Ball	9	17.49	0.38	.9374
ID x Basket x Ball	7	97.53	2.72	.0232 *

Note: * = Significant at the .05 level

the regulation sized basketball. An overall experimentwise error of .04 per angle was used to test for significant differences.

Descriptive Analysis

Ball Kinematics

Software written by Richards and Wilkerson (1984) yielded values for linear ball velocity from the digitized film records of the sagittal view of the basketball free throw (Appendix G). Mean values for the linear velocities of the basketball at release by basket height, ball size, and the interaction of these two variables are presented in Table 11. The mean linear velocities among the four environmental conditions were similar. A mean linear velocity of 7.00 $m \cdot s^{-1}$ occurred when the subjects shot their free throws with the regulation sized basketball at the 10-foot basket. Under the modified environmental conditions, the subjects had mean linear velocities of 7.03 $m \cdot s^{-1}$ when shooting with the intermediate sized basketball at the 8-foot basket, 7.07 $m \cdot s^{-1}$ when shooting with the regulation sized basketball at the 8-foot basket, and 6.99 $m \cdot s^{-1}$ when shooting with the intermediate sized basketball at the 10-foot basket.

Mean values for the angles of projection of the basketball are presented in Table 2. A higher mean projection angle occurred when the subjects shot their free throws at the 10-foot basket (50.64°) than at the 8-foot basket (45.02°). Similar mean projection angles were revealed when the subjects shot their free throws with the intermediate sized basketball (47.82°) and with the regulation sized basketball (47.84°). Comparisons made by the interaction of basket height with ball size reflected the same differences previously noted. The

Table 11

Mean Linear Velocities of the Basketball at Release ($m \cdot s^{-1}$)

	Basket Height		Ball Size	
	8-Foot	10-Foot	Intermediate	Regulation
M	7.05	7.00	7.01	7.04
SE	.11	.10	.11	.10
N	51	51	50	52

	Interaction of Basket Height and Ball Size			
	8 - I	8 - R	10 - I	10 - R
M	7.03	7.07	6.99	7.00
SE	.18	.14	.14	.14
N	25	26	25	26

Note: 8 - I = 8-Foot Basket, Intermediate Sized Basketball
8 - R = 8-Foot Basket, Regulation Sized Basketball
10 - I = 10-Foot Basket, Intermediate Sized Basketball
10 - R = 10-Foot Basket, Regulation Sized Basketball

projection angles were very similar under the same basket height with the two ball sizes, but higher at the 10-foot basket than at the 8-foot basket.

A Pearson product moment was computed to evaluate the relationship between the subject's standing height and the angle of projection of the basketball. The projection angles for the two trials per subject under each of the four environmental conditions were averaged. This average projection angle was then correlated with the subject's height. The correlation matrix is presented in Table 12.

The four negative correlations between the subject's standing height and his average angle of projection of the basketball identified inverse relationships under each of the four environmental conditions. As subject height increased angle of projection decreased. The relationship between the subject's standing height and his angle of projection of the basketball was stronger when the subject used the regulation sized basketball than when he used the intermediate sized basketball. The strongest relationship (r=-.80) between the subject's height and his angle of projection occurred when the subject shot his free throws with the regulation sized basketball at the 8-foot basket. The changes that occurred in the relationship between standing height and average angle of projection as the height of the basket and the size of the ball changed were similar. Similarly higher correlations were found at both basket heights when the regulation sized basketball was used than when the intermediate sized basketball was used, -.80 to -.42 at the 8-foot basket, and -.66 and -.25 at the 10-foot basket. Similarly higher correlations were found with both ball sizes at the

Table 12

Correlation Matrix Between Average Angle of Projection per Condition and Subject's Standing Height

	Ball Size	
Basket Height	Intermediate	Regulation
8 - Foot	-.428	-.804
N	13	13
10 - Foot	-.252	-.664
N	13	13

8-foot basket than at the 10-foot basket, -.42 to -.25 with the intermediate sized basketball, and -.80 to -.66 with the regulation sized basketball.

<u>Whole Body Kinematics</u>

The location of the total body center of gravity was computed with software written by Richards and Wilkerson (1984) based on Dempster's (1955) segmental data. The location of the mean center of gravity under the four environmental conditions for the 13 subjects are presented in Figure 6. The following mean horizontal and vertical displacements of the center of gravity were noted: (a) 12 cm horizontally and 28.5 cm vertically with the intermediate sized basketball at the 8-foot basket, (b) 11.5 cm horizontally and 29 cm vertically with the regulation sized basketball at the 8-foot basket, (c) 11 cm horizontally and 30.5 cm vertically with the intermediate sized basketball at the 10-foot basket, and (d) 19 cm horizontally and 32 cm vertically with the regulation sized basketball at the 10-foot basket. Under each of the three modified conditions, the mean center of gravity was located behind the right toe throughout the free throw shooting motion. The location of the right toe is indicated on each graph as position 0. In each of these three conditions, the mean center of gravity was located approximately 14 cm behind the right toe at the start of the free throw and was located 3 cm behind the right toe at ball release. Under the condition involving the regulation sized basketball at the 10-foot basket, the mean center of gravity was located 17 cm behind the right toe at the start of the free throw and moved .5 cm in front of the right toe at ball release.

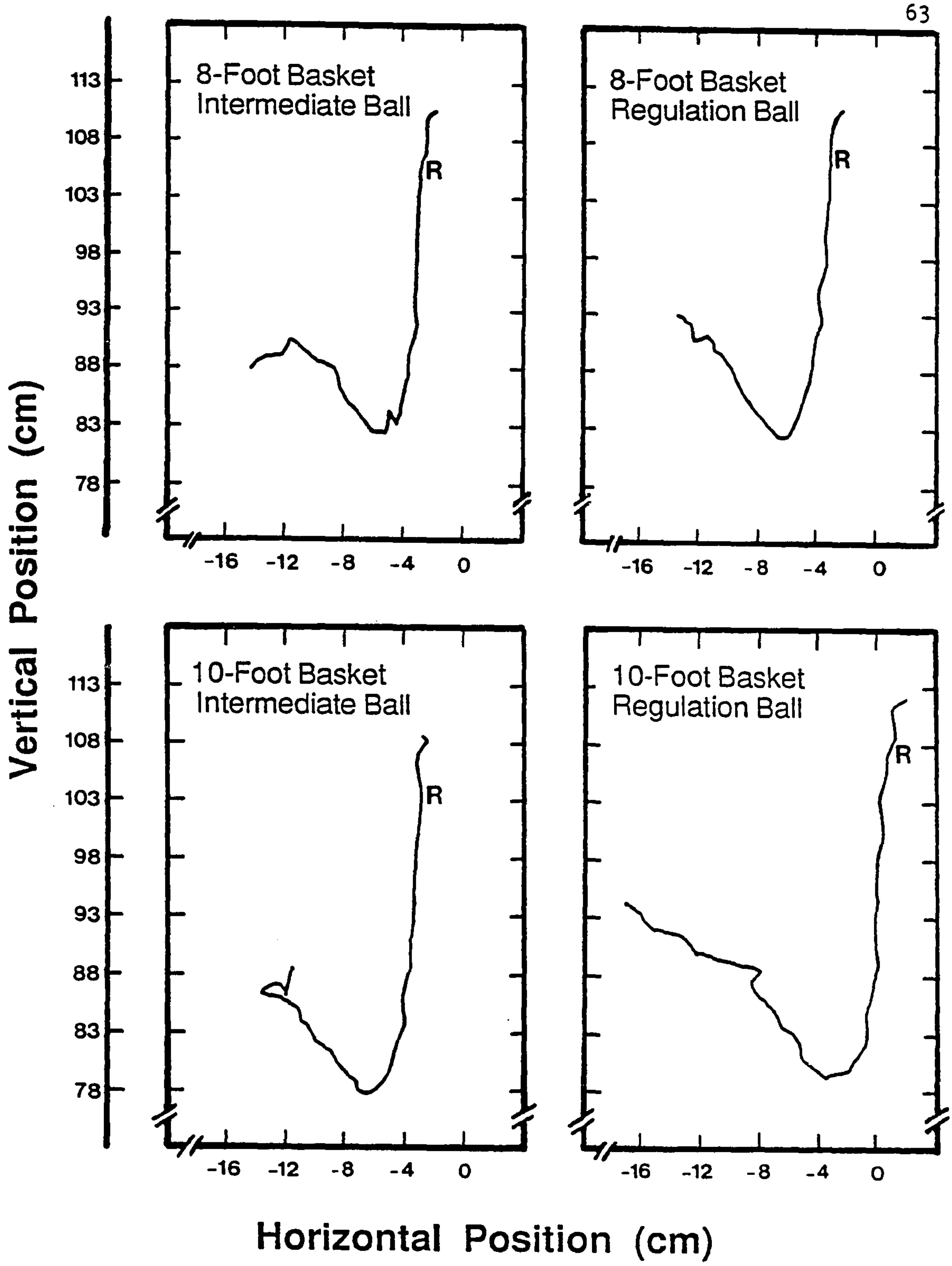

Figure 6. Displacement and path of the mean centers of gravity under the four environmental conditions; Position 0 indicates the position of the right toe in the first frame digitized.

The vertical position of the mean center of gravity for the 13 subjects under each of the four environmental conditions was plotted over time (Figure 7). The mean center of gravity reached its lowest vertical position at approximately the same time, .28 s prior to ball release, under each of the four environmental conditions. Additionally, the ball was released before the mean center of gravity had reached its highest vertical position under each of the four environmental conditions.

An interesting grouping of the mean centers of gravity under the four environmental conditions was noted. In preparation for the free throw, the mean center of gravity was displaced lower when the subjects shot their free throws at the 10-foot basket. At ball release, however, the mean center of gravity was displaced higher when the subjects shot their free throws with the regulation sized basketball. The position of the mean center of gravity for the environmental condition involving the intermediate sized basketball at the 10-foot basket had the lowest vertical position of the four conditions throughout the free throw shooting motion (Figure 7).

The angle of trunk inclination was calculated from the digitized film records of the sagittal view of the basketball free throw. A positive value for this angle indicated that the body had a forward lean. The trunk inclination values were virtually identical across the four conditions (Figure 8). Prior to ball release, the mean angle of trunk inclination under the regulation free throw shooting condition showed the trunk initially flexed, then extended to an almost vertical position .04 s prior to ball release, and subsequently flexed to a

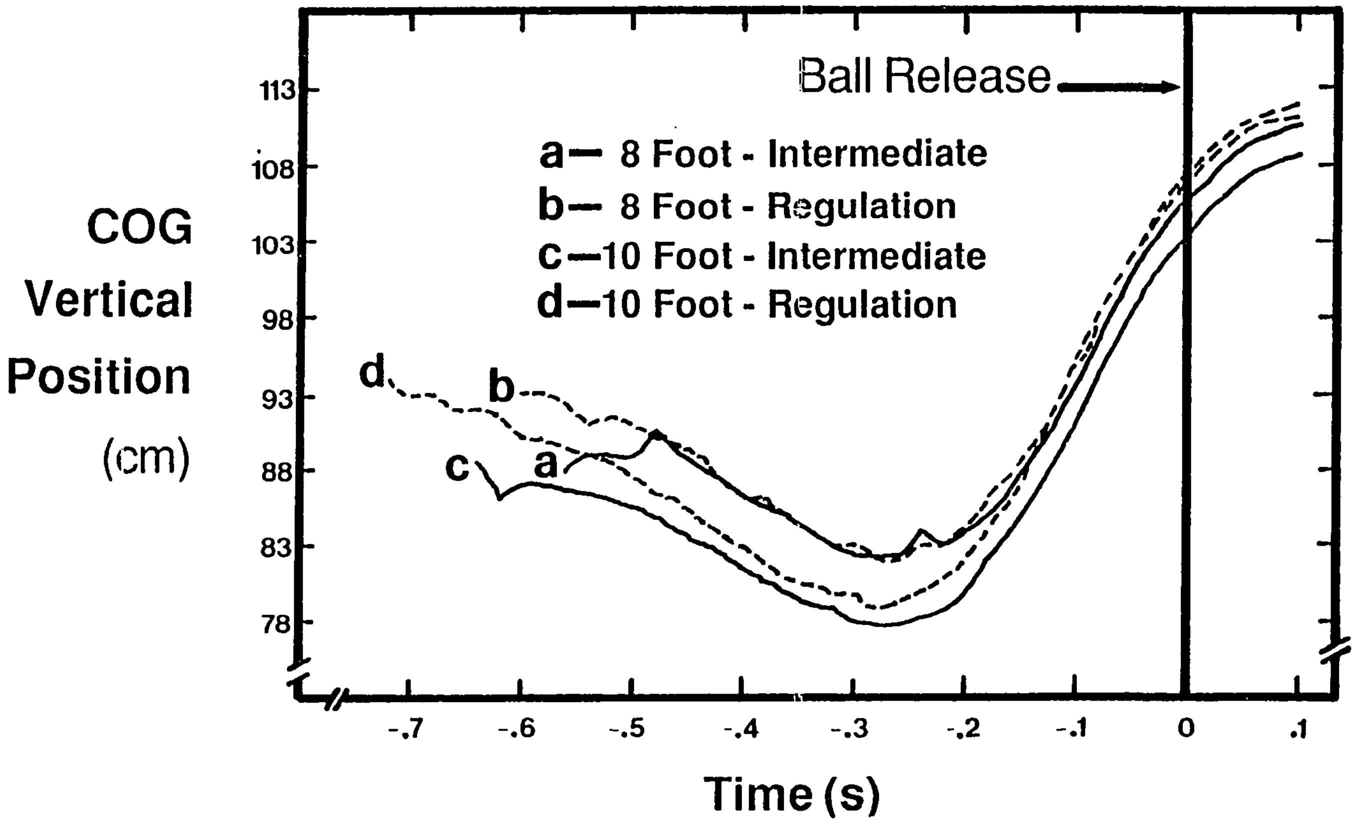

Figure 7. Vertical displacement of the mean center of gravity under the four environmental conditions.

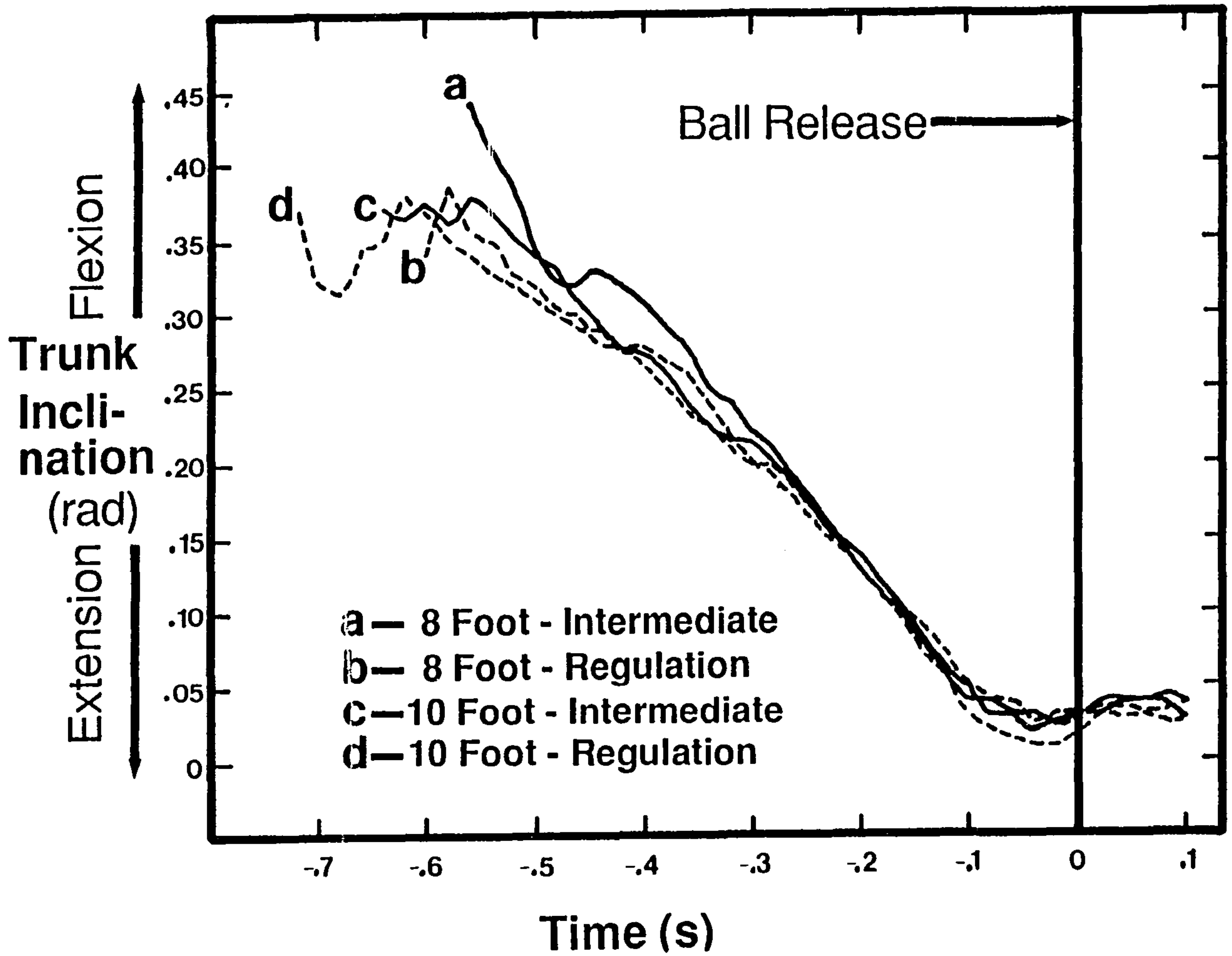

Figure 8. Mean angle of trunk inclination under the four environmental conditions.

position of +.02 rad at ball release. The angle of trunk inclination at ball release under the modified free throw shooting conditions was +.03 rad.

Angular Kinematics

The basketball free throw was performed with a two-handed, overhead shooting motion by two of the subjects of this investigation. The joint angles of these subjects, therefore, were not included in this particular phase of the mechanical analysis. The right wrist, elbow, shoulder, and knee angles, as measured from the sagittal camera view (Figure 9), were averaged across the remaining 11 subjects under each of the four environmental conditions. The mean angles were plotted over time and are presented in Figures 10 - 13.

The relative timing and coordination of the four joint actions were similar across the four environmental conditions. At the beginning of the free throw shooting motion, the legs were extended, the right upper arm was extended at the shoulder, the right elbow was flexed in order to hold the ball close to the upper body, and the right wrist was hyperextended so that the palm was placed behind the ball. The free throw shooting motion began as the joints of the lower body began to flex. Under the regulation environmental condition, the following sequence of joint actions produced the successful basketball free throw. As the knees were still flexing, the right shoulder began to flex .34 s prior to ball release. The knees reached their mean maximum flexion .08 s later, and began to extend .26 s prior to ball release. As the knees continued to extend and the shoulder continued to flex, the elbow began to extend from its mean maximum flexion .18 s

Figure 9. Joint angle orientation for the measurement of the wrist, elbow, shoulder, and knee joints.

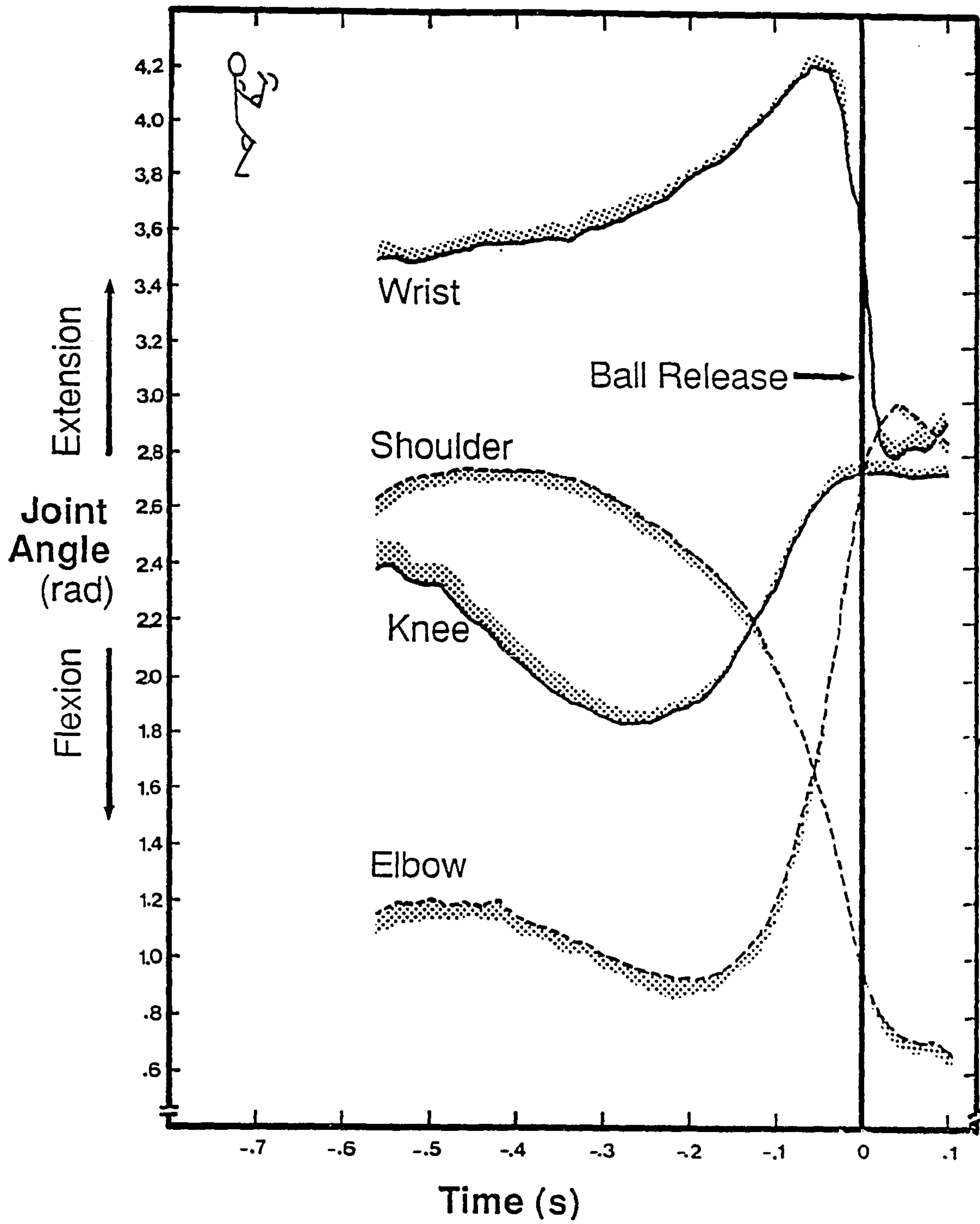

Figure 10. Timing and coordination of the right wrist, elbow, shoulder, and knees under the environmental condition involving the intermediate sized basketball and the 8-foot basket.

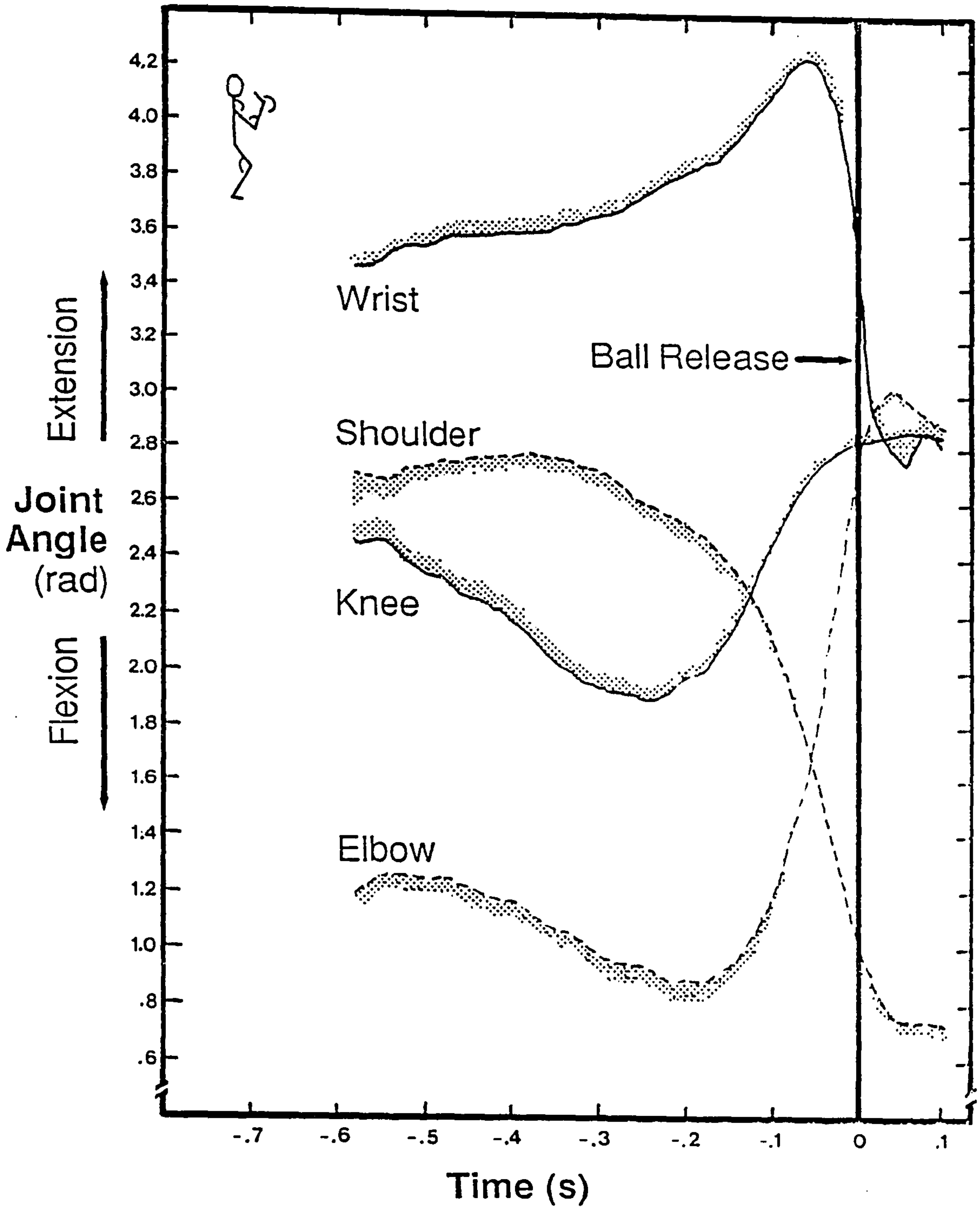

Figure 11. Timing and coordination of the right wrist, elbow, shoulder, and knees under the environmental condition involving the regulation sized basketball and the 8-foot basket.

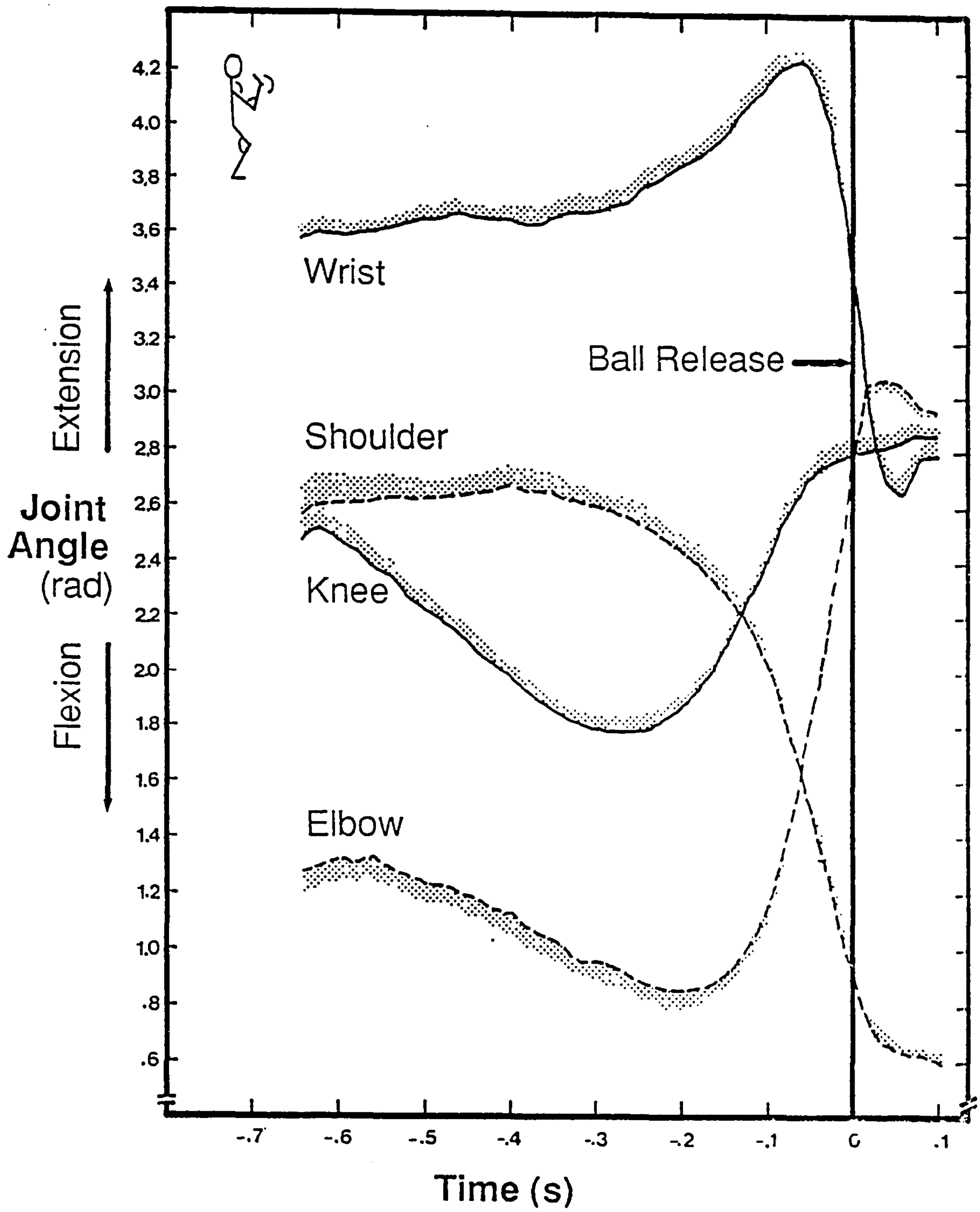

Figure 12. Timing and coordination of the right wrist, elbow, shoulder, and knees under the environmental condition involving the intermediate sized basketball and the 10-foot basket.

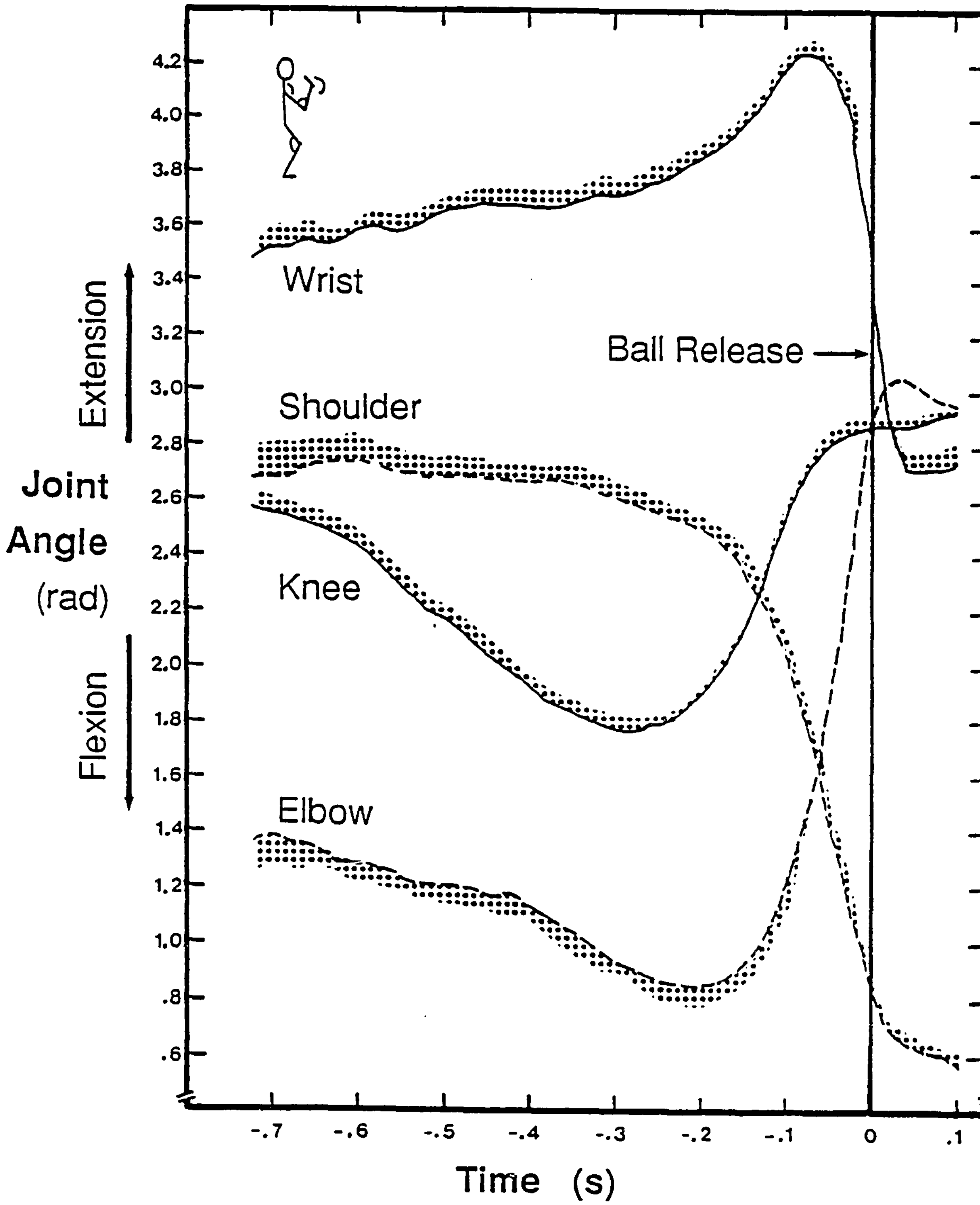

Figure 13. Timing and coordination of the right wrist, elbow, shoulder, and knees under the environmental condition involving the regulation sized basketball and the 10-foot basket.

prior to ball release. During the action of shoulder flexion and elbow extension, the right wrist continued to hyperextend for an additional .10 s after the elbow began its extension. The wrist reached its mean maximum hyperextension .08 s prior to ball release. As ball release approached, the knees were extending, the right shoulder was flexing, the right elbow was extending, and the right wrist was flexing.

Although the relative timing and coordination of the joint actions were similar across the four environmental conditions, the following differences were noted in the mean maximum joint actions that occurred in preparation for the execution of the successful free throw. The knees and right elbow had a mean maximum flexion of 1.78 rad and .84 rad, respectively, under the regulation environmental condition (Figure 13). Slightly less mean knee flexion of 1.87 rad and 1.90 rad were noted under the environmental conditions involving the 8-foot basket with the intermediate and regulation sized basketballs, respectively. Slightly less mean elbow flexion of .95 rad was noted under the environmental condition that involved the intermediate sized basketball at the 8-foot basket (Figures 10 - 12). The right shoulder had a mean maximum extension of 2.68 rad under the regulation environmental condition (Figure 13). Slightly greater mean shoulder extension of 2.78 rad was noted under both environmental conditions that involved the 8-foot basket (Figures 10 - 12).

The following differences were also noted in the joint positions at ball release across the four environmental conditions. The knees and right elbow had a mean extension of 2.88 rad and 2.86 rad, respectively, under the regulation environmental condition (Figure 13).

The knees were slightly less extended with mean angular measures ranging from 2.77 to 2.82 rad under the three modified environmental conditions. Likewise, the elbow was slightly less extended with mean angular measures ranging from 2.72 to 2.76 rad under the three modified environmental conditions (Figures 10 - 12). The right shoulder and right wrist had a mean flexion of .86 rad and 3.54 rad, respectively, under the regulation environmental condition (Figure 13). The shoulder was more extended with a mean extension of 1.02 rad under both environmental conditions that involved the 8-foot basket. The right wrist was also more extended with a mean hyperextension ranging from 3.58 to 3.65 rad under the three modified environmental conditions (Figures 10 - 12).

The angular velocities of the right wrist joint for the 10 subjects who shot a one-handed free throw were very similar across the four environmental conditions. The greatest angular wrist velocity at ball release (38.5 $rad \cdot s^{-1}$) occurred when the subjects shot their free throws with the intermediate sized basketball at the 8-foot basket. The remaining wrist velocities at ball release were: 36.5 $rad \cdot s^{-1}$, 35.2 $rad \cdot s^{-1}$, and 31.05 $rad \cdot s^{-1}$ under the environmental conditions involving the regulation sized basketball at the 8-foot basket, the intermediate sized basketball at the 10-foot basket, and the regulation sized basketball at the 10-foot basket, respectively.

Shooting Percentages

Each subject shot a minimum of 20 free throws under each combination of basket height and ball size. Some subjects shot more than 20 free throws under some of the environmental conditions in order to obtain film records of at least three "successful" trials. Individual subject shooting percentages are presented in Appendix I. The total subject shooting percentages and ranges under each of the four environmental conditions are presented in Table 13.

The highest shooting percentage, 40.77%, occurred under the regulation environmental condition that involved the regulation sized basketball and the 10-foot basket. The lowest shooting percentage, however, was only 4.7% lower than the highest shooting percentage. The greatest range in shooting percentages among the 13 subjects, 13% to 95%, occurred under the environmental condition that involved the intermediate sized basketball and the 8-foot basket. Conversely, the smallest range in shooting percentages among the 13 subjects, 25% to 65%, occurred under the regulation environmental condition.

Discussion

Statistical Analysis

The statistical analysis consisted of two parts. First, an ANOVA with repeated measures was performed on the projection angle of the basketball. Second, a MANOVA with repeated measures was performed on three angular measures simultaneously; post hoc ANOVA's with repeated measures were then performed on each angular measure individually; Bonferroni confidence intervals were calculated to test for significant differences between the means by basket height and ball size across the four environmental conditions for each of the three angular measurements.

Significant differences ($p=.0001$) were found among the 13 subjects for each of the four variables analyzed (Tables 3 and 8 - 10). These

Table 13

Total Subject Shooting Percentages

	Interaction of Basket Height and Ball Size			
	8 - I	8 - R	10 - I	10 - R
No. Baskets Made	105/264	101/276	97/269	106/260
Percentage	39.77%	36.59%	36.06%	40.77%
Range	13% to 95%	16% to 75%	16% to 85%	25% to 65%

Note: 8 - I = 8-Foot Basket, Intermediate Sized Basketball
8 - R = 8-Foot Basket, Regulation Sized Basketball
10 - I = 10-Foot Basket, Intermediate Sized Basketball
10 - R = 10-Foot Basket, Regulation Sized Basketball

results indicated that a heterogeneous sample was drawn with respect to these four variables.

The statistical analysis of the projection angle of the basketball also revealed significant differences ($p=.0001$, $M_{10}=50.64^{\circ}$, $M_{8}= 45.02^{\circ}$) for the main effect of basket height (Table 3). Neither the main effect of ball size nor any of the interaction effects revealed significant differences among the projection angles across the four environmental conditions. It would appear, therefore, that the height of the basket altered the projection angle required to produce a successful free throw, whereas the size of the ball had no apparent effect.

Teachers and coaches can simulate the release heights that children and adolescents will use as adults by lowering the height of the basket. Buckley (1962) cautioned, however, that it becomes increasingly more difficult to maintain an arch as the players get taller. Since the players can hold the ball as high as the rim, they have a tendency to shoot straight for the basket without arching the shot, thereby projecting the basketball with lower angles. The results of this investigation suggest that the 8-foot basket may have been too low for most of the subjects. The mean projection angle of 45.02° when shooting free throws at the 8-foot basket was lower than the minimum angle of 46.9° recommended by Maugh (1981).

The results of the MANOVA performed on the three variables of release angle of the shoulder, starting angle of the elbow, and forearm in relation to the vertical at ball release revealed significantly different angular measures ($p=.0001$) for the main effect of basket height for the three variables when considered simultaneously. Non-significant differences ($p>.05$) were found for the main effect of ball size and for the interaction of ball size and basket height. The subsequent post hoc ANOVA's performed on each variable separately revealed some significant main and interaction effects.

Two of the angles analyzed represented positions of the shooting arm at ball release. The position of the arm at ball release has an effect on the angle with which the basketball is projected toward the basket. The results of the analyses of these angles, therefore, would be expected to be similar to the results of the analysis of the angle of projection of the basketball. Indeed, the post hoc analyses of these two variables revealed a significant main effect of basket height (release angle of the shoulder, $p=.0001$, $M_{10}=2.16$ rad, $M_8=2.03$ rad; forearm in relation to the vertical at ball release, $p=.0001$, $M_{10}=-.19$ rad, $M_8=-.23$ rad) and a non-significant main effect of ball size (Tables 8 and 10). In addition, both ANOVA's revealed a significant interaction effect between the individual subject and the height of the basket. This result indicated that some of the subjects changed the release angle of the shoulder ($p=.03$) and the forearm in relation to the vertical at ball release ($p=.0003$) as the height of the basket changed.

Testing of the Bonferroni confidence intervals revealed significant differences ($p=.04$) in the mean release angles of the shoulder between the 8-foot basket and the 10-foot basket when the subjects were shooting with the regulation sized basketball. It appears, therefore, that the significant difference in the release angles of the shoulder between the 8-foot and 10-foot baskets when using the regulation sized basketball, may have influenced the significant overall main effect of basket height.

The post hoc ANOVA of the forearm in relation to the vertical at ball release also revealed a significant interaction effect ($p=.02$) between the subject and the height of the basket and the size of the ball (Table 10). This result indicates that some of the subjects changed this angle with changes in the height of the basket in combination with the size of the ball (Appendix F).

The results of the post hoc ANOVA of the starting angle of the elbow revealed significant differences for the main effect of basket height ($p=.0001$, $M_{10}=.80$ rad, $M_8=.88$ rad) and for the interaction effects of basket height with ball size ($p=.01$), the subject with the height of the basket ($p=.0001$), and the subject with the size of the ball ($p=.002$) (Table 9). Hartley and Fulton (1971) stated that increased elbow flexion in preparation for the shot results in increased power at ball release. The results of this investigation appear to support this observation. The mean angular values for the starting angle of the elbow, when considered by basket height and ball size, showed greater elbow flexion when the subjects shot their free throws at the 10-foot basket and with the regulation sized basketball, respectively (Table 5). Upon examination of the mean elbow angles for each of the four environmental conditions, however, slightly more elbow flexion was noted when the subjects shot with the intermediate sized basketball than with the regulation sized basketball at the 10-foot basket. A comparatively greater difference in the mean elbow angles between the two ball sizes was noted, however, when the subjects shot at the 8-foot basket. More elbow flexion was noted when the subjects shot with the regulation sized basketball than with the intermediate sized basketball at the 8-foot basket. The difference in the elbow angles between the two ball sizes at the 8-foot basket may have overly influenced the mean elbow angles when they were considered by basket height and by ball size as the difference between the means at the 10-foot basket were small. The significant interaction effects also revealed that some of the subjects found it necessary to generate additional power by decreasing the starting angle of the elbow as the height of the basket and the size of the ball increased, especially as previously noted (Appendix F).

The subjects for this analysis were not selected on the basis of size or skill (Tables 1 and 13). The results of the statistical analyses reinforced this fact by revealing significant differences among the subjects on the four variables statistically analyzed. The results of these analyses, therefore, reinforce the developmental concept that individual performance differences may accommodate individual differences in physical size and maturation level, individual differences that are especially present among adolescent male basketball players who are undergoing pubertal changes. The significant interaction results between the subjects and the other variables measured also support the developmental concept that individuals respond uniquely to their environment.

The results of this investigation suggest that teachers and coaches should consider the height of the basket and/or the size of the ball used in the sport of basketball in relation to the specific characteristics of the players who are involved rather than pre-determining these factors based on chronological age. It would appear that the 8-foot basket was not appropriate for all of the subjects of this investigation. Although a non-significant overall ball size effect was revealed, significant interaction effects that involved ball size and the significant Bonferroni confidence interval for the release angle of the shoulder for the regulation sized basketball with the 8-foot and the 10-foot baskets seem to indicate that the size of the ball did affect the performance of the basketball free throw for some of the subjects.

Developmentally appropriate equipment should be used to facilitate the development of skilled performance of the physically maturing adolescent. The results of the descriptive analysis performed provided specific information that the teacher and coach might consider when deciding the appropriate basket height and ball size to be used with adolescent basketball players.

Descriptive Analysis

Ball Kinematics. The end result of the basketball free throw is the successful basket. A range of angles of projection and related velocities will result in a successful shot. This range will depend upon the distance the shooter is from the basket and the height of the ball at the moment it is released (Martin, 1981; Maugh, 1981). Under the regulation environmental condition that involved shooting free throws with the regulation sized basketball at the 10-foot basket, the mean angle of projection for the 13 subjects was 50.48° (Table 2), and the mean linear velocity of the ball was 7.00 $m \cdot s^{-1}$ (Table 11).

Several ranges of projection angles were recommended in the literature: between 55° and 60° by Hartley and Fulton (1971); 54° by Mortimer (1951); between 49° and 55° by Hay (1985); and between 45° and 55° by Brancazio (1981). The mean projection angle used by the 13 seventh grade boys analyzed under the regulation condition (50.48°) fell within the theoretical ranges recommended by Hay (1985) and Brancazio (1981), and within the experimental ranges reported by Hudson (1982; 1985) of 52.4° to 52.9° and McGinnis (1975) of 49.5° to 53.4° for females shooting free throws and males shooting jump shots, respectively.

Lower projection angles for taller male subjects in comparison to higher projection angles for shorter female subjects have been reported elsewhere (Gaunt, 1976; Gorton, 1978). McGinnis (1975) suggested that the angle of projection of the basketball was more closely related to the subject's standing height than to his level of skill. The correlation between the standing height of the 13 subjects and the average projection angle under the four environmental conditions supports this suggestion. The Pearson product moment revealed an inverse relationship between the subject's standing height and the angle of projection of the basketball (Table 12). The strongest relationships ($r=-.80$, $r=-.66$) were found when the subjects shot their free throws with the regulation sized basketball at the 8-foot and 10-foot baskets, respectively. The weakest relationship ($r=-.25$) was found when the subjects shot their free throws with the intermediate sized basketball at the 10-foot basket. The results imply that the angle of projection used at a regulation height basket of 10 ft would have a weaker relationship to the subject's standing height if an intermediate sized basketball were used rather than a regulation sized basketball. Modifying the size of the ball, therefore, might provide a means of minimizing the advantage that taller players, e.g. older and more physically mature children and adolescents, have when shooting free throws at a basket of regulation height.

The linear velocity of the ball at release under the regulation condition (7.00 $m \cdot s^{-1}$) was less than the velocity recommended by Mortimer (1951) of 7.92 $m \cdot s^{-1}$. However, linear velocity values were similar to results reported by Hudson (1982; 1985) of 7.03 to 7.22 $m \cdot s^{-1}$ and Penrose and Blanksby (1976) of 7.02 to 7.15 $m \cdot s^{-1}$ for females shooting free throws and males shooting jump shots, respectively.

Whole Body Kinematics. Increased horizontal movement of the center of gravity appears to be characteristic of lower skilled female free throw shooters (Hudson, 1982) and male jump shooters (Yates, 1978). Hudson (1982) suggested that the reduced balance displayed by the low skilled shooters, which was manifested in their increased horizontal movement, may reflect their lack of strength.

The mean paths of the center of gravity under the three modified environmental conditions were similar (Figure 6). The path of the center of gravity under these conditions moved in a relatively vertical path. Under the regulation environmental condition, however, the mean center of gravity had an increased horizontal displacement (19 cm) over that demonstrated by the subjects under the modified environmental conditions (11.5 cm) (Figure 6). The increased horizontal movement of the center of gravity under the regulation condition suggests that the subjects relied on the additional horizontal movement to generate sufficient momentum to project the basketball to the basket. Since the path of motion followed by the center of gravity under the modified environmental conditions is the path that is commonly associated with higher skilled adult shooters, it would appear that some type of equipment modification, either ball size or basket height or both, is warranted.

Scolnick (1967) suggested that the height of the ball at release is dependent both upon the degree of trunk inclination and the vertical height of the jump. At the moment of take-off, high skilled jump shooters had trunk angles close to vertical (Drysdale, 1972; Hudson, 1985; Penrose & Blanksby, 1976), whereas low skilled jump shooters frequently showed a backward trunk angle at take-off (Drysdale, 1972; Penrose & Blanksby, 1976).

The subjects in the present investigation showed similar mean angles of trunk inclination at the moment of ball release across the four environmental conditions, +.03 rad under the modified conditions and +.02 rad under the regulation condition (Figure 8). Under all four environmental conditions, the trunk was initially flexed at the start of the free throw shooting motion and then extended to its almost vertical position at the moment of ball release. Under the modified environmental conditions, the mean position of the trunk did not change during the .10 s prior to ball release. Under the regulation environmental condition, however, the trunk continued to extend during the last .10 s prior to ball release. Perhaps this suggests that, under the regulation condition, the subjects needed to generate additional momentum in order to successfully project the basketball toward its intended target.

Angular Kinematics. The relative timing and coordination of the upper and lower body during the execution of the basketball free throw was similar across the four environmental conditions (Figures 10-13). Variability was noted, however, in the range of motion that occurred at the separate joints when the environmental conditions were changed.

Increased knee flexion and elbow flexion in preparation for the free throw shooting motion occurred when the subjects shot their free throws at the 10-foot basket (Figures 10-13). The increased knee and elbow flexion suggests that the subjects generated the additional momentum needed to project the basketball to the 10-foot basket through increased range of motion at these two joints.

At the moment of ball release, the knees and the right elbow were slightly more extended during the regulation condition than during the three modified conditions (Figures 10-13). The increased extension of the elbow and knee joints at ball release under the regulation condition implies that more momentum may have been needed to project the basketball than during the modified conditions.

The variability in the range of motion of the elbow and knee angles under the changing basket heights and ball sizes was also manifested in the results of other kinematic parameters. The increased amount of knee flexion resulted in a lower vertical displacement of the center of gravity when the subjects shot their free throws at the

10-foot basket (Figure 7). A higher vertical position of the mean center of gravity at ball release was noted, however, when the subjects shot their free throws with the regulation sized basketball at both basket heights (Figure 7). Apparently, the additional impetus generated from the increased range of motion of the joints was required for the 10-foot basket during preparation for the free throw and for the regulation sized basketball at ball release.

Yates (1978) noted that better shooters hold the ball higher and closer to their body. He further noted that decreasing the angle at the elbow allows the performer to hold the ball closer to the body, thereby allowing the arm to move directly upward during the propulsive phase of the shot. The straight alignment of the body landmarks of the right wrist, elbow, and shoulder at release allows the forces generated by the shooting motion to be guided in a direct path toward the basket.

The right shoulder was flexed more at the moment of ball release under the environmental conditions that involved the 10-foot basket (Figures 10 - 13). Decreased mean angular measures at ball release for the variables of release angle of the shoulder (Table 4) and the forearm in relation to the vertical at ball release (Table 6) indicated that the subjects' shooting arm was nearer the vertical at ball release when shooting free throws under the environmental conditions involving the 10-foot basket.

Yates and Holt (1982) noted that a greater amount of shoulder flexion and elbow extension at ball release resulted in a more vertical angle of projection and an arm that was nearer to the vertical at release. Yates (1978) commented that poorer shooters angled away from this vertical line. As noted previously, the subjects in this investigation demonstrated less shoulder flexion at ball release and lower mean angles of projection under the environmental conditions that included the 8-foot basket. The differences noted between the 8-foot basket and the 10-foot basket could be due, in part, to the lack of playing experience utilizing the 8-foot basket. Differences in the release angle of the shoulder and the angle of projection of the basketball possibly resulted from the subjects' perception of the task of shooting free throws at the 8-foot basket in addition to the changes in the physical demands of the task, rather than differences due to skill level. Two of the subjects used a shooting strategy of rebounding the basketball off the backboard when shooting their free throws at the 8-foot basket that they did not use when shooting their free throws at the 10-foot basket (Appendix E).

The relatively similar timing and coordination patterns identified across the four environmental conditions of the mean joint actions of the upper and lower body during the execution of the basketball free throw seemed to indicate that the nature of the skill did not change as the size of the basketball and/or the height of the basket changed. Rather, changes in the magnitudes of the joint actions, particularly in preparation for the free throw and at ball release, indicated that the physical demands imposed upon the subjects by the skill were changing as the size of the basketball and the height of the basket changed.

Martin (1981) stated that a maximum force resultng from wrist flexion is not required for projecting the successful basketball shot. Rather, a force that is compatible with the distance from the basket and the angle of projection is required. The mean release velocities were similar across all four environmetal conditions (Table 11). The right wrist had its greatest mean angular velocity at ball release. Under the regulation environmental condition, the mean wrist velocity at ball release was 31.05 rad$\cdot$s^{-1}. Under the modified conditions, the mean wrist velocities were slightly higher, ranging from 35.2 to 38.5 rad$\cdot$s^{-1}. This result implies that the higher wrist velocity at ball release resulted from the decreased physical demands that were placed upon the subject by the smaller ball size and lower basket height. Increased wrist velocity is advantageous to the basketball player as it helps to increase the amount of spin imparted to the basketball at release. Recall that ball spin was one of the four variables that discriminated between the high-skilled and low-skilled male jump shooters reported by Yates (1978).

Measuring muscular strength and power exerted at the individual joints that are involved in basketball shooting has resulted in negative correlations with the criterion measure of the number of shots made (Dahl, 1972). Dahl's (1972) finding suggests that it is the coordination and the timing of the joints' actions rather than their individual strength that result in the generation of the force needed to successfully project the basketball toward the basket. The results of this study tend to support Dahl's (1972) suggestion.

The findings of the present investigation further suggest that modifying the size of the basketball and/or the height of the basket will not immediately affect the coordination and timing of the joint actions involved in the basketball free throw. The results do imply, however, that the use of modified basketball equipment with children and adolescents may result in motor patterns that allow children and adolescents to be more successful shooters as adults. The teacher and coach should provide opportunities for the young performer that will allow him to produce a basketball free throw shooting motion that is similar in its movement pattern to those produced by skilled adults. The teacher and coach can decide whether or not the size of the basketball and/or the height of the basket is developmentally appropriate for the players of the game by observing the following mechanical end products of the basketball free throw: (a) the horizontal displacement of the center of gravity, (b) the angle of projection of the basketball, (c) the angle of trunk inclination during the shooting motion and at ball release, and (d) the position of the shooting arm in relation to the vertical at ball release.

Farley (1962) warned teachers and coaches that trying to correct poorly developed or improperly learned shooting form is very difficult. Furthermore, he recommended that teaching what is right at the right time is the only answer to building a sound foundation in fundamental basketball skills. The results of this study also suggest that using developmentally appropriate basketball equipment during the early developmental stages may be instrumental in helping to build that sound foundation in the fundamental sport skill of shooting free throws.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The purpose of this study was to analyze the mechanics of the basketball free throw as performed by 13 seventh grade boys under four environmental conditions. The environmental conditions included: (a) shooting with a regulation sized basketball at a regulation basket height of 10 ft, (b) shooting with a regulation sized basketball at a basket lowered to a height of 8 ft, (c) shooting with an intermediate sized basketball at a regulation height basket of 10 ft, and (d) shooting with an intermediate sized basketball at a basket lowered to a height of 8 ft.

Film records of the frontal and sagittal views of the basketball free throw were obtained with the use of two LoCam model 51, 16 mm, pin-registered, high speed, cameras each operating at a film transport speed of 100 fps. The subjects were filmed on two consecutive days, one day shooting free throws with each ball size at the 8-foot basket and the next day shooting free throws with each ball size at the 10-foot basket. The subjects were provided with as much practice time as they felt necessary prior to the start of the filming session. No coaching was provided for the subject during either the practice or the filming session. Approximately 10 free throws per subject under each of the four environmental conditions were filmed. The order of presentation of the environmental conditions was alternated within and across subjects. Each free throw attempt was coded according to the system suggested by Pangman (1982). The coding system was later used in identifying and selecting the appropriate trials to be analyzed.

The film records were projected onto a horizontal surface. Software written by Richards and Wilkerson (1984) in combination with a Numonics 1224 digitizer interfaced to an Apple II+ microcomputer were used to digitize 19 body landmarks and the basketball. A statistical analysis was conducted on the following four kinematic parameters: (a) the angle of projection of the basketball, (b) the release angle of the shoulder, (c) the starting angle of the elbow, and (d) the forearm in relation to the vertical at ball release. A descriptive analysis was conducted on the following six kinematic parameters: (a) the linear velocity of the basketball at release, (b) the displacement and path of the body's center of gravity, (c) the point of release of the basketball in relation to the height of the body's center of gravity, (d) the angle of trunk inclination, (e) the timing and coordination of the joint actions of the upper and lower body, and (f) the angular velocity of the wrist joint.

An ANOVA with repeated measures revealed significant differences in the angle of projection of the basketball among the subjects ($p=.0001$) and for the main effect of basket height ($p=.0001$) across the four environmental conditions. A MANOVA with repeated measures revealed simultaneous significant differences in the release angle of the shoulder, the starting angle of the elbow, and the forearm in relation to the vertical at ball release among the subjects ($p<.0001$) and for the main effect of basket height ($p=.0001$) across the four environmental conditions. Subsequent post hoc ANOVA's of each angular measurement revealed the following significant interaction effects in addition to the significant differences revealed by the MANOVA: (a) a significant interaction between subject and basket height ($p=.03$) for the release angle of the shoulder, (b) a significant interaction between basket height and ball size ($p=.01$), between subject and basket height ($p=.0001$), and between subject and ball size ($p=.002$) for the starting angle of the elbow, and (c) a significant interaction between subject and basket height ($p=.0003$) and between subject, basket height, and ball size ($p=.02$) for the forearm in relation to the vertical at ball release.

Similar mean linear velocities of the basketball at release under the four environmental conditions were found ($7.00\ m \cdot s^{-1}$ for the regulation environmental condition). A higher mean angle of projection of the basketball occurred under the environmental conditions that involved the 10-foot basket (50.64°) than under those that involved the 8-foot basket (45.02°); similar mean angles of projection occurred under the environmental conditions that involved the regulation sized basketball (47.84°) and the intermediate sized basketball, (47.82°). The strongest relationship between the subjects' standing height and average angle of projection of the basketball ($r=-.80$) occurred when the subjects used the regulation sized basketball at the 8-foot basket; the weakest relationship ($r=-.25$) occurred when the subjects used the intermediate sized basketball at the 10-foot basket.

The mean displacement of the total body center of gravity under the three modified environmental conditions was 11.5 cm horizontally and 29.5 cm vertically from the start of the free throw shooting motion through ball release; under the regulation environmental condition, the mean displacement was 19 cm horizontally and 32 cm vertically. The ball was released before the mean center of gravity had reached its highest vertical position under each of the four environmental conditions. The lowest vertical displacement of the mean center of gravity in preparation for the free throw occurred when the subjects were shooting at the 10-foot basket; whereas, the highest vertical displacement at ball release occurred when the subjects were shooting with the regulation sized basketball.

Similar mean angles of trunk inclination were noted for the subjects across the four environmental conditions. At ball release, the trunk was flexed +.03 rad under the modified environmental conditions and +.02 rad under the regulation environmental condition. The mean timing and coordination of the right wrist, elbow, shoulder, and knee angles showed similar sequencing of the joint actions across the four environmental conditions. Under the regulation environmental condition, the right shoulder began to flex .34 s prior to ball release, followed by knee extension .24 s prior to ball release, right elbow extension .18 s prior to ball release, and wrist flexion .08 s prior to ball release. The angular velocities of the right wrist were similar across the four environmental conditions; the greatest angular wrist velocity at ball release (38.5 $rad \cdot s^{-1}$) occurred with the intermediate sized basketball at the 8-foot basket.

Conclusions

Based on the results of this investigation, the following conclusions can be drawn.

1. The main effect of basket height revealed statistically significant differences ($p<.05$) in the angle of projection of the basketball, the release angle of the shoulder, the starting angle of the elbow, and the forearm in relation to the vertical at ball release.

2. The main effect of ball size did not reveal statistically significant differences ($p>.05$) for the angle of projection of the basketball, the release angle of the shoulder, the starting angle of the elbow, nor for the forearm in relation to the vertical at ball release.

3. The low correlation between the subjects' standing height and average projection angle when shooting with the intermediate sized basketball at the 10-foot basket ($r=-.25$) suggested that the projection angle needed to successfully shoot a free throw at a basket of regulation height was relatively unrelated to the subject's standing height if he used a basketball that was smaller and lighter than one of regulation size.

4. Increased horizontal displacement of the mean center of gravity under the regulation environmental condition suggested that the subjects gained additional momentum needed to project the basketball under the regulation environmental condition that was not needed under the three modified environmental conditions.

5. Releasing the ball before the mean center of gravity had reached its highest vertical position under all four environmental conditions suggested that the subjects gained momentum that was needed to successfully shoot the free throw by releasing the ball early in the

shooting motion, regardless of modification of the ball size and/or adjustment of the basket height.

6. Differences in the magnitudes of the joint angles and the range of motion of the identified joints across the environmental conditions reflected changes in the amount of momentum needed to project the successful free throw rather than changes in the timing and coordination of selected joint actions in the skill of free throw shooting.

Recommendations for Future Study

The results of this investigation suggest the following for future study.

1. Replicate this study with a different sample of seventh grade boys.

2. Replicate this study with girls as the subjects of the investigation.

3. Replicate this study with subjects of different chronological ages, but of the same biological age.

4. Analyze the kinetic parameters of the basketball free throw under the changing environmental conditions to better interpret the kinematic results of this analysis.

5. Replicate this study with high skilled male performers using a regulation sized basketball at the 10-foot basket and/or high skilled female performers using the women's sized basketball at the 10-foot basket to establish a criterion measure against which the sequencing of the joint angles reported in this investigation can be compared.

6. Perform a longitudinal study in which fifth and sixth grade children are taught to shoot free throws with reduced size basketballs at lower basket heights. Compare the kinematic parameters of this group of children to a control group of children who have not been taught with the reduced size equipment as they perform free throws under the regulation sized conditions for their sex, i.e. with the regulation sized basketball for the boys and the women's sized basketball for the girls, in the eighth grade, tenth grade, and twelfth grade.

7. Compare the selected kinematic parameters of this investigation between the successful and unsuccessful free throw attempts across the four environmental conditions.

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APPENDIX A

INDIVIDUAL SUBJECT DESCRIPTIVE DATA

INDIVIDUAL SUBJECT DESCRIPTIVE DATA

Subject Number	Age (yrs)	Date Filmed	Birth Date	Ht (cm)	Wt (N)	Finger Span (cm)
1	12.92	Jan 5-6	2-11-72	166.4	476.1	21.2
2	12.17		11-13-72	168.9	431.6	19.5
3	12.58		6-08-72	166.4	500.5	20.2
4	12.92		2-08-72	174.0	567.3	22.9
5	12.25	Jan 12-13	10-09-72	144.8	284.7	17.7
6	12.33		9-03-72	151.1	458.3	19.0
7	12.92		2-24-72	181.6	645.1	21.7
8	13.08		12-02-71	160.0	431.6	19.3
9	13.00		12-21-71	160.0	444.9	18.5
10	13.92	Feb 16-17	3-04-71	168.9	525.0	22.9
11	12.92		3-22-72	152.4	396.0	18.3
12	13.08		1-17-72	175.3	580.6	19.3
13	13.08		1-17-72	168.9	507.2	19.6
M	12.86			164.51	480.68	20.00
SE	.13			3.03	26.32	.49

APPENDIX B

INFORMED CONSENT FORM

INFORMED CONSENT FORM *

I understand that the purpose of this study/project is

to analyze biomechanically the free throw in basketball as performed by 12-13 year old boys (7th grade) under four environmental conditions: shooting with regulation sized ball at basket heights of 8 ft and 10 ft, intermediate sized ball at basket heights of 8 ft and 10 ft

I confirm that my participation is entirely voluntary. No coercion of any kind has been used to obtain my cooperation.

I understand that I may withdraw my consent and terminate my participation at any time during the project.

I have been informed of the procedures that will be used in the project and understand what will be required of me as a subject.

I understand that all of my responses, written/oral/task, will remain completely anonymous.

I understand that a summary of the results of the project will be made available to me at the completion of the study if I so request.

I wish to give my voluntary cooperation as a participant.

Signature of Participant

Signature of Parent

Address

Date

*Adapted from L. F. Locke and W. W. Spirduso. Proposals that work. New York: Teachers College, Columbia University, 1976, p. 237.

APPENDIX C

ORIENTATION LETTER

ORIENTATION LETTER

Thank you for agreeing to participate in this study on the basketball free throw as performed by 7th grade boys.

You are scheduled to be filmed on the following days at the listed time:

____

The filming will take place at Craft Recreation Center, 3911 Yanceyville Street in Greensboro. A map to the recreation center is attached.

Please wear shorts, a tee shirt, basketball or gym shoes, and socks. Upon entering the recreation center, you will be greeted by a person who will first take your height and weight and then will measure your finger span from the little finger to the thumb of your right hand. This person will then place adhesive markers over the joints of your arms and legs. During the filming you will be asked to remove your shirt. This will help the investigator in later identifying the body parts that are necessary to complete the analysis of this study of the free throw.

Upon entering the gymnasium, you will be given as much practice time as you feel necessary to be comfortable with the skill to be filmed. When ready, you will perform 5 free throws at the testing condition that <u>will not</u> be filmed, followed by 10 more free throws that <u>will</u> be filmed, and then 5 more free throws that <u>will not</u> be filmed. You will then be given a short rest period if you want one. Following the rest period, you will be given a basketball of a different size than the one just used. You will be allowed to practice with it as you did before. When ready, the same sequence will be repeated as with the first ball.

On the following day, the procedure to be followed will be the same. You will not be measured again, but joint markers will again be placed on the joints of your arms and legs. You will again be filmed shooting free throws with two different ball sizes, but the height of the basket will be different than it was on the first day.

I am looking forward to seeing you on the above days at the scheduled times. Please feel free to call me if you have any questions. Please be assured that your participation in this study will be completely voluntary and that the results when presented will be anonymous. A summary of the results will be provided to each participant in this study.

Miriam Satern, Graduate Student
School of Health, Physical
Education, Recreation & Dance

APPENDIX D

POINTS DIGITIZED

POINTS DIGITIZED

Center of gravity was determined using software by Richards and Wilkerson (1984) based on Dempster's (1955) segmental data. The points were digitized in the following order:

1. right hand
2. right wrist
3. right elbow
4. right shoulder
5. left shoulder
6. left elbow
7. left wrist
8. left hand
9. right toe
10. right ankle
11. right knee
12. right hip
13. left hip
14. left knee
15. left ankle
16. left toe
17. top of head
18. sternal notch
19. crotch
20. basketball
21. stationary reference point

APPENDIX E

INDIVIDUAL ANGLES OF PROJECTION

INDIVIDUAL ANGLES OF PROJECTION (degrees)

	Environmental Condition			
Subject	8 - I	8 - R	10 - I	10 - R
1	49.78	41.87	+51.05	+49.44
	53.06	45.48	+54.92	+55.27
2	44.39	47.17	67.30	*55.70
	44.71	39.92	$-----	40.12
@3	#44.49	45.69	*46.05	48.64
	#38.03	52.42	50.90	51.66
4	+#37.17	+#46.77	+55.16	+50.96
	+#42.73	+#42.44	+51.85	+53.22
5	+47.11	+50.21	+61.07	+70.24
	+56.28	+54.45	+56.53	+54.06
6	+42.05	+49.63	+52.46	+52.70
	+43.20	+51.14	+51.47	+49.29
7	+41.60	+36.01	+37.27	+43.52
	+42.52	+34.35	+41.77	+44.68
8	53.07	51.69	54.42	50.21
	43.40	46.05	57.63	51.59
9	+48.37	+47.80	+52.24	+54.28
	+45.54	+51.65	+48.78	+54.44
@10	+ 39.36	+44.34	+43.73	+54.17
	+32.47	+38.81	+51.09	+46.47
11	43.49	48.95	42.00	56.21
	44.44	43.25	42.01	39.05
@12	38.83	39.22	48.58	37.83
	$-----	30.55	46.19	44.97
13	51.66	45.98	*53.08	57.90
	52.80	49.52	52.87	45.84
M	44.82	45.21	50.82	50.48
SE	1.14	1.17	1.32	1.33

Note. @ = players who used a two-handed shooting motion
\+ = baskets shot in which the players jumped
* = baskets scored a "3"
\# = baskets scored a "2"
$ = projection angle could not be determined

APPENDIX F

RELEASE ANGLE OF THE SHOULDER, STARTING ANGLE OF THE ELBOW, AND FOREARM IN RELATION TO THE VERTICAL AT BALL RELEASE

RELEASE ANGLE OF THE SHOULDER (rad)

	Environmental Condition			
Subject	8 - I	8 - R	10 - I	10 - R
1	2.17	2.11	2.20	2.18
	2.05	2.00	2.27	2.25
2	1.84	1.79	1.76	1.76
	1.90	1.79	2.05	1.83
4	1.98	1.82	2.04	2.08
	1.78	1.91	1.97	2.03
5	1.85	1.81	1.94	2.06
	1.89	2.09	1.88	2.18
6	2.44	2.36	2.48	2.61
	2.46	2.49	2.40	2.48
7	1.93	1.94	2.21	2.21
	1.96	1.99	2.13	2.16
8	1.96	1.93	2.14	2.20
	1.87	1.85	2.19	2.28
9	2.39	2.12	2.45	2.31
	2.17	2.21	2.41	2.45
11	2.12	1.92	2.24	2.24
	2.15	2.20	2.24	2.20
13	1.96	1.98	1.98	2.08
	1.99	2.01	1.95	2.08
M	2.04	2.02	2.15	2.18
SE	.04	.04	.04	.04

Note. Subjects 3, 10, and 12 used a two-handed shooting motion; therefore, the angular measures for these subjects were not included in this analysis.

STARTING ANGLE OF THE ELBOW (rad)

	Environmental Condition			
Subject	8 - I	8 - R	10 - I	10 - R
1	.85	.91	.80	.79
	.91	.79	.92	.77
2	.83	.87	.78	.84
	.70	.85	.67	.73
4	.87	.79	.92	.96
	.90	.86	.89	.95
5	1.15	.82	.72	.78
	.95	.91	.80	.82
6	.47	.03	.12	.01
	.40	.12	.00	.02
7	1.43	1.35	1.10	1.24
	1.21	1.26	1.22	1.25
8	1.10	1.09	1.26	1.15
	1.01	1.09	1.08	1.15
9	.87	.85	.79	.78
	.87	.84	.83	.76
11	.76	.79	.40	.51
	.71	.77	.51	.62
13	1.15	1.04	1.04	1.04
	1.14	1.06	1.05	.98
M	.91	.85	.80	.81
SE	.05	.07	.07	.08

Note. Subjects 3, 10, and 12 used a two-handed shooting motion; therefore, the angular measures for these subjects were not included in this analysis.

FOREARM IN RELATION TO THE VERTICAL AT BALL RELEASE (rad)

	Environmental Condition			
Subject	8 - I	8 - R	10 - I	10 - R
1	-.17	-.22	-.15	-.10
	-.21	-.14	-.11	-.06
2	-.39	-.36	-.29	-.29
	-.33	-.41	-.29	-.29
4	-.34	-.31	-.32	-.31
	-.38	-.33	-.17	-.39
5	*----	*----	-.13	-.14
	*----	*----	$----	-.13
6	-.05	-.15	-.00	+.07
	-.09	-.14	-.11	+.02
7	-.31	-.30	-.19	-.22
	-.37	-.35	-.17	-.21
8	-.39	-.36	-.33	-.32
	-.31	-.36	-.37	-.32
9	*----	*----	-.26	-.26
	*----	*----	-.24	-.22
11	+.07	+.02	+.00	+.03
	+.07	+.13	+.01	-.04
13	-.24	-.22	-.24	-.31
	-.29	-.27	-.24	-.24
M	-.23	-.24	-.19	-.19
SE	.04	.04	.03	.03

Note. Subjects 3, 10, and 12 used a two-handed shooting motion; therefore, the angular measures for these subjects were not included in this analysis.

* = equipment malfunction during filming prevented calculation of this angular measure

$ = this angular measure could not be determined

APPENDIX G

INDIVIDUAL LINEAR BALL VELOCITIES AT RELEASE

INDIVIDUAL LINEAR BALL VELOCITIES AT RELEASE ($m \cdot s^{-1}$)

	Environmental Condition			
Subject	8 - I	8 - R	10 - I	10 - R
1	8.35	8.52	8.22	7.90
	8.84	7.24	8.31	7.85
2	7.68	8.22	7.66	6.63
	7.80	6.86	*----	7.15
3	8.80	8.47	7.57	7.97
	7.64	7.40	7.02	8.35
4	7.38	7.59	7.13	6.95
	7.09	7.70	7.20	7.30
5	6.89	7.35	7.09	7.04
	4.94	7.69	7.43	6.53
6	6.66	6.75	6.72	7.20
	6.97	7.28	6.94	7.08
7	6.84	7.08	6.35	7.28
	7.12	6.32	6.60	6.47
8	6.82	6.13	7.04	7.21
	6.70	6.80	7.05	7.18
9	7.00	6.92	7.01	6.53
	6.21	7.04	6.88	6.23
10	6.98	6.16	8.02	6.71
	6.80	6.40	6.16	7.21
11	7.11	7.30	7.43	5.42
	7.22	7.17	5.15	8.42
12	5.67	5.74	6.60	6.60
	*----	7.19	6.30	6.23
13	6.34	6.45	6.04	6.24
	5.88	6.11	6.89	6.27
M	7.03	7.07	6.99	7.00
SE	.18	.14	.14	.14

Note: * = projection velocity could not be determined

APPENDIX H

SUBJECT'S STANDIDNG HEIGHT AND AVERAGE PROJECTION ANGLE

SUBJECT'S STANDING HEIGHT (cm)

AND AVERAGE PROJECTION ANGLE (degrees)

		Environmental Condition			
Subject	Height	8 - I	8 - R	10 - I	10 - R
1	166.4	51.42	43.68	52.99	52.36
2	168.9	44.55	43.55	67.30	47.91
3	166.4	41.26	49.06	48.48	50.15
4	174.0	39.95	44.61	53.51	52.09
5	144.8	51.70	52.33	58.80	62.15
6	151.1	42.63	50.39	51.97	51.00
7	181.6	42.06	35.18	39.52	44.10
8	160.0	48.24	48.87	56.03	50.90
9	160.0	46.96	49.73	50.51	54.36
10	168.9	35.92	41.58	47.41	50.32
11	152.4	43.97	46.10	42.01	47.63
12	175.3	38.83	34.89	47.39	41.40
13	168.9	52.23	47.75	52.98	51.87
M	164.51	44.59	45.21	51.45	50.48
SE	3.03	1.50	1.58	2.06	1.44

APPENDIX I

INDIVIDUAL SUBJECT SHOOTING PERCENTAGES

INDIVIDUAL SUBJECT SHOOTING PERCENTAGES

	Environmental Condition			
Subject	8 - I	8 - R	10 - I	10 - R
1	45%	40%	20%	50%
2	50%	25%	50%	50%
3	13%	40%	16%	40%
4	40%	26%	35%	35%
5	25%	25%	25%	40%
6	19%	25%	45%	25%
7	45%	20%	25%	40%
8	45%	65%	35%	35%
9	55%	75%	85%	65%
10	25%	25%	30%	30%
11	20%	16%	25%	35%
12	45%	45%	40%	50%
13	95%	60%	45%	35%
Overall Percentage	39.77%	36.59%	36.06%	40.77%