# A CINEMATOGRAPHICAL ANALYSIS OF MECHANICAL DIFFERENCES IN THE VERTICAL JUMP THAT OCCUR THROUGH LEARNING

by

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DEDICATED TO

My Parents and Family

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## Chapter 1

## INTRODUCTION

There seems to be inherent pleasure in doing something well or seeing something done well. To most people efficiency and effectiveness characteristic of a skilled performance are intriguing. How then, are these qualities acquired? Efficiency and effectiveness of a movement are obtained and improved through the analysis and evaluation of the movement by either internal or external feedback. Internal feedback is provided kinesthetically, the way the movement "feels" to the performer. External feedback can be provided in various ways, the most common of which is that provided by another individual's observations.

There are several limitations encountered when dealing with external feedback. Human beings have an inability to perceive rapidly moving objects or distinguish each phase and bodily part of a movement pattern, especially when the movement is performed with speed. They also have an inability to accurately and permanently record the movement that is taking place. To facilitate human observation and evaluation, and to make it more meaningful, some type of media is often employed. A useful instrument for studying man in motion is cinematography. Cinematography, or motion pictures as they are more commonly known, is a medium that professionals in sports have employed for years to evaluate performance. It is a method that is now being utilized extensively, even to the junior high school level, where "game films" are taken to aid coaches in their individual and team evaluations. From a more scientific basis, the camera provides a means of obtaining an extremely informative record of the human body in motion from which various parameters of motion can be derived. From the scientific standpoint, a camera that runs at a high rate of speed is more advantageous than the camera that runs at normal or slow speeds. A faster camera speed will provide additional frames per second giving a more comprehensive picture of the action. In addition, image blurring is deleted, or at least minimized. Cinematography then, can provide and is a means of obtaining accurate and permanent feedback information, allowing extensive study of the movement.

Differences in performance occur as an individual moves from initial learning of a skill to mastery of that skill. Changes occur as weaknesses are found and corrected by the performer, as timing and coordination of the various components are obtained, and as the movement pattern becomes clearer and more automatic. These changes that are brought about through learning affect both the quality and quantity of the movement pattern. "Unfortunately for many of our aesthetic interests, this significance to perform with the highest degree of efficiency is often measured in quantitative terms, and thus in terms of winning or losing" (25:311). In other words, most people tend to use the quantity of the movement, for instance in terms of distance or time, as the criterion measure of a "good" or a "poor" performance instead of looking at the quality, or how correct mechanically the movement pattern was executed.

Emphasis should be placed on the quality of movement, especially in the early phases of learning. It is in the early phases of skill acquisition that poor and improper techniques are often embedded as part of the movement response. These inappropriate responses become resistant and more difficult to change as time elapses. An individual may be able to achieve an "accepted" quantity performance even though the skill is done incorrectly. This brings two important questions to mind. First, what would be the achievement level of the performer if the skill was done with correct mechanics? Secondly, will the performer be able to progress normally and continue to improve his quantity performance or will the incorrect mechanics of the skill limit or retard his future progress?

Quality of movement is obviously important to the individual who wishes to compete at a top level. His efficiency in movement dictates many times whether he will win or lose in his endeavors. But what about the individual who participates in an activity just for the pleasure of being active? How is quality of movement important to him? In this respect, quality movement allows a person to move at the level of which he is truly capable. It enables him to move more effectively and efficiently and to derive a higher degree of satisfaction from his participation.

By accepting the quantity rather than the quality performance, especially in the early stages of learning, poor technique is reinforced. This can cause frustration and other problems later as normal progress is hampered. Certainly, the quality of a movement should be a major priority whether learning a new skill or improving old ones.

## STATEMENT OF THE PROBLEM

The problem of this study was whether quality or quantity of movement should be stressed in the teaching and learning of skills. In our society today, quantity is stressed over quality by a large number of coaches, parents, teachers, and peers. These people judge the success or failure of a performance on quantitative results. To be successful, the learner tends to disregard the correct movement pattern and rely on any means possible to obtain the desired quantity. This can be detrimental to the learner, especially while the skill is still new to him.

The quality of movement is instrumental in allowing the performer to move with efficiency and ease. It allows the performer to progress through the skill normally, without having to break bad habits that have been acquired and relearn new movement patterns. The question is which is most important in teaching, the process, the way that a person gets to where he's going, or the end product of the individual's endeavors.

## PURPOSE OF THE STUDY

The purpose of this study was to cinematographically analyze mechanical differences, both qualitatively and quantitatively, that occur in a movement pattern as a result of practice and subsequent learning. More specifically, the purpose of this study was to: 1) analyze through motion picture photography mechanical changes that occur from initial learning of a vertical jump, through a learning phase, to mastery of the skill and, 2) to determine if quantitative changes accompany changes in the quality of movement in vertical jumping.

## DELIMITATIONS OF THE STUDY

Due to the nature of this type of study, the following delimitations were selected and incorporated into the procedures.

1. The subjects participating in this study were eight voluntary Caucasian nine-year-old boys selected from the Manhattan, Kansas area.

2. A vertical jump was the skill taught, filmed, and analyzed for the study.

3. The subjects were restricted to performing with their dominent side adjacent to the jumpboard.

## LIMITATIONS OF THE STUDY

Several limitations were present in this study. These limitations were uncontrollable by the investigator due primarily to time, space, and a lack of equipment.

1. A small sample size, consisting of eight boys, may have biased the results to some degree.

2. Filming was restricted to the saggital plane of each of the subjects.

3. Some measurement and computational errors were unavoidable when marking and reading film, enlarging film images, and transferring data.

4. The study was limited by the speed, accuracy, and quality of the camera used for filming. Some image blurring occurred leading to inaccurate locations of some joint centers and bodily parts.

5. Performance in the presence of a filming environment was different than it would have been in an actual setting, especially when it involved children.

6. The results of the study were dependent on the ability of the subject to do his potential best at any one given time.

7. There was a relatively short learning-training period.

## DEFINITIONS OF TERMS

Acceleration

A rate of change in velocity; it may or may not be uniform and may be positive or negative.

Center of Gravity

Within every mass there is a point about which the gravitational forces on one side will equal those on the other side. This balance point, determined in three planes of the mass, is the center of gravity (8:165).

Cinematography

A term used to describe motion pictures.

Segmental Method

A method used to locate the center of gravity of a body, especially when that body is in motion.[1]

Quality

The correctness of mechanical performance as determined by film analysis.[2]

Quantity

The magnitude of an event. Here quantity refers to the actual vertical jump height measured in inches.

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[1]See Appendix A for further explanation.

[2]For details, refer to Chapter 3.

## Chapter 2

## REVIEW OF LITERATURE

The review of literature was divided into five basic areas. The first area of discussion dealt with the quality of movement versus the quantity of movement. Philosophies of individuals primarily in the field of physical education are given for each case. The second section briefly outlined some physical characteristics of nine-year-old boys pertinent to this investigation. The third section dealt with the vertical jump. Research supporting and rejecting the use of the vertical jump was given. Research dealing with the mechanical aspects of the vertical jump was also presented. The final section dealt with the findings of research pertaining to the methods used in gathering data.

### QUALITY VERSUS QUANTITY

Various opinions have been generated in the field of physical education concerning the quality versus quantity of performance. Quality movement deals primarily with subjective parameters, the process, or "how" a skill is executed. Quantity movement is objectively based and gives concrete answers to the magnitude of a skill performance. Quantity is based on the end result.

In a review of the literature, there were many who expressed through their writing the importance of quality movement. Johnson and

Nelson believe that students, parents, and administrators understand objective measures more readily than subjective measures, and consequently, they are more easily defended. However, they believe that the physical education teacher can never divorce himself from subjective evaluation, nor should he try. "It is a simple fact that certain performances require qualitative, rather than quantitative, evaluation" (24:5). Corbin states that "evaluation is more than measurement. While measurement is the quantitative assessment of what is, evaluation is the qualitative assessment or judgement of what is" (10:330). Raw measurements, or the quantitative products, are frequently meaningless in assessing the total student performance (10). There are others (12) (18) (31) (32) who agree with the basic idea that although objective tests have their place, the subjective tests of student progress are just as, or more, important than the objective tests.

On the other hand, there are those who profess that subjective evaluation is not the answer. To these people, objective testing is the only accurate, concrete way to evaluate performance. Barrow and McGee approach the subject by saying that there are definite disadvantages to the subjective evaluation. Their comments are that the instructor has to know the abilities of his group to use subjective evaluation and that the "knowledge is hardly feasible early in the school year, since the instructor will not have had enough time to acquaint himself sufficiently with the abilities of students" (3:424). Further, their belief is that subjective evaluation is difficult and most unreliable and that without an acceptable degree of objectivity, subjective results do not have great value. "It is probably due to this apparent subjectivity of observations that many persons question its validity" (3:138). One point they expressed was that "if physical education is to be accepted in the academic family, then its grades must be reports of measures of status" (3:442). By "status" they meant the quantitative assessment of the performance. Another individual who strongly believes in objective testing is Sheehan. He points out that before constructing any type of skills test, the physical educator must resolve the problem of whether the process or the product is most important. He states that:

> Without demeaning the relative merits of the way (process) in which motor acts are performed it can be stated that the most reliable measurement comes from the product of the act. This is especially true for the public school physical educator who must measure with only the use of his unaided eye... Success in a motor-skill task may be defined through the terminal behavior objectives as being able to accomplish the end product of the task so many times out of so many tasks. 'How' the pupil arrives at the product is another way of stating process. This is largely a subjective observational procedure and, as a result, is subject to observational error. (40:204, 205-206)

Johnson and Nelson believe differently. They profess that there is another point of philosophical contemplation and that is whether to consider a student's future growth and development or to consider only his present status. Their philosophy is that education should be fundamentally interested in the student's future growth and development. Children are sent to school for future preparation. Stressing quality performance of skills, or the process, prepares them best for the future use of those skills (24).

There is a persistent problem that occurs with beginners. The fact that good results at the beginning do not always shape the responses that will be conducive to improvement later on must be considered. "There can be, and is in many cases, a correct way to perform the skill; and there also are certain undesirable elements which should be avoidable" (12:135). Dauer says that at the beginning level form is a consideration but the learner needs time to explore the movement. The teacher must be careful that the learner does not acquire a poor habit which will cause him difficulty later on. As the learner progresses, "the quality in movement is of greater importance than quantity of movement. Emphasis should be on doing things as well as possible, but this must not become an overriding consideration" (12:135). It must be remembered that establishing quality is the vital part of movement education and without this aspect, movement is mere activity (12). Schurr points out that most children have some experience with a skill before they come to a physical education class. Through the class they should gain assistance in detecting and eliminating errors, especially during the early stages of learning. The child is the focal point and all evaluation should center around him. "His status and progress must be evaluated in terms of the primary goal of physical education; that is, for each child to develop into his fullest capacity" (38:119).

A beginner tends to adopt a gross framework to his own abilities by making adjustments in terms of ease and success. "If the learner gets the general idea and is motivated to practice, he will gradually adjust his performance to his own individuality as a result of his feedback of practice results" (27:55). For example:

> The young basketball player may have to adopt a rather unique form in order to generate enough force to shoot the ball up to a 10-foot-high basket. In a trial and

> error situation the intrinsic information feedback (making or missing the shot) for this youngster might shape a response that will not be very useful when he gets older and wants to compete at higher levels of skill. (34:60)

An individual will tend to adopt strategies that bring about a desired result even if these strategies are not in the direction of correct skill performance. A further problem is created in these situations because once an inappropriate strategy is learned it becomes resistant to change (34). Relating to this, Felshin (18) states that both the quality and quantity of prior experience will influence future performance. If the quality is not first-rate, then the individual will be unable to perform a first-rate movement consistently later on. Previous experiences do affect later outcomes. For this reason, poor quality performance should not be acceptable except in the experimental stages (38) (18). In The Learning of Physical Skills, Lawther points out the difficulty in changing and replacing a less efficient performance-habit by a more effective one.

> He the performer continues the same inefficient aspect, tries harder to succeed, but merely thrusts the error deeper into the unconsciousness of automaticity. These handicap him for higher level performance. (27:60)

It is important then that the focus when learning and developing motor skills be on bodily control rather than maximum performance (26).

From the literature presented, the importance of quality in skill acquisition and performance can be seen. But how is the desired quality determined? Broer, a leader in the field of kinesiology, says that

> ...good form has been determined by analyzing the performance of an individual, or individuals who have been unusually successful in a particular activity. The concept

> of good form has changed from time to time because of the fact that an individual who looked different from the accepted model demonstrated even greater success. There has been a failure to consider the possibility than an individual may be having success despite certain incorrect mechanics by compensation and extra expenditure of energy, or that an individual who uses his body well mechanically may have certain mannerisms which, while they do not necessarily detract from his success, are not the reason for it. (5:20)

Those components that help make movement more efficient and effective are the quality components that should be incorporated into the skill.

Most test and measurement books in the field of physical education contain a number of tests that are all based on quantitative results, with relatively few tests and forms for qualitative evaluations. For example, visualize the softball throw or the running broad jump. In the books reviewed, without exception, the evaluation of performance for these two tests was based on quantitative results: how far the ball was thrown, or how far the individual jumped. No mention was made for any type of criteria for qualitative evaluation. Only the end product is scored, compared, and finally given a grade. Quantitative tests are the bases of most physical education textbooks. (3) (12) (24) (27) (34)

## PHYSICAL CHARACTERISTICS

Nine-year-old boys are characteristically becoming more aware of the capabilities of their bodies in skill acquisition. Consequently, their body control is improving. Their height and weight are steadily increasing with a gradual growth in body breadth, body depth, heart size, lung capacity, and muscle strength. There is a definite increase in motor performance which could be a result of more strength, more speed of movement, better balance, and better coordination (4) (17) (32) (38).

Jumping was the skill required of the subjects for this study. As such, jumping was found to be an appropriate activity for boys of this age group. "After the age of nine years the earlier development of thigh and trunk flexibility in boys becomes evident in the superiority of their jumping ability" (17:44). "A long jump is attempted by some individual children from five years on. From six years, ability in such stunts as high jump and broad jump improves rapidly" (4:315). Nagel (32) suggests that jumping and reaching activities be an integral part of the nine-year-old's skill vocabulary.

## THE VERTICAL JUMP

In 1921, Sargent (36) presented his "Physical Test of a Man" in the form of a vertical jump. Since that time the vertical jump, or variations of it, has been extensively used as a test item of power and motor ability. McCloy points out that the Sargent Jump "does not test all the elements of general motor ability...but measures only the ability to develop power and does not measure motor educability or agility" (29:241, 242). The Sargent Jump is a test of the ability of the body to develop power relative to the weight of the individual himself, "...the jump is a measure of the way in which force can combine with the highest possible contraction-velocity of the muscles so as to project the body upward to a maximum height" (29:236). McCloy points out further that if this jump is done slowly, the body will not leave the ground. Therefore, the test is a measure of how fast one can work.

Several studies (1) (7) (15) (29) (41) (42) have been directed toward studying the relationship of leg strength to jumping ability. All studies reviewed showed the same conclusion: that leg strength was not a factor in the ability of the legs to generate power. However, it must be pointed out that the majority of these studies were performed by college-age subjects which means that these findings may not apply to the age group of which this study centered. One study done with college men found that "speed has a considerable similarity to power and little to strength and that the latter two factors appeared reasonably separate entities" (42:558).

The reliability of the vertical jump has been found to be good. Johnson and Nelson (24) reported in their text the reliability to be as high as 0.93, while Gray, Start, and Glencross (20) found through investigation the vertical jump to have a test-retest correlation of 0.985 and a coefficient of objectivity of 0.981. They concluded that "the vertical jump would seem valid as a test of genuine power developed by the legs" (20:50). In a later study Glencross (19) used 85 college students and came up with a reliability of 0.9263 for the jump and reach. However, he concluded his study by stating that the jump and reach had limited application as a valid measure of muscular power as measured by the power lever as the criterion. Van Dalen found that "the highest correlations will be obtained when these events are practiced frequently enough that one's best possible performance is produced" (43:112). Another study said that "both practice and fatigue seem to influence the reliability of the Sargent jump" (21:28).

Form seems to be closely related to test performance (43) (21). Form in all activities is based on an understanding of two fundamental principles: "(1) how to conserve energy by proper use of the body and its parts, and (2) how to expend energy intelligently and efficiently to accomplish a given purpose" (30:5). The following studies will elaborate on the technique and form that has been researched on the vertical jump.

The position of the head during the movement is an important consideration since head position and direction go together. In the study by Henry (21), subject's gaze was fixed upon a reference point to keep the head position up, and keep the subject oriented frontally.

The arm swing of the subject in the performance of the vertical jump is exceedingly important (5) (20) (22) (43). The momentum of the arm swing is transferred to the upper body and if timed with the leg extension adds force to the jump (5). Higgins performed a cinematographic analysis of the vertical jump. In his analyzation, he found that the poorest jump by each subject in every case resulted when the arms were not swung back as far in the preparatory position. He concluded that an "increase in the range of arm motion would appear to be conductive to attaining maximum height during the jump" (22:6795A).

Several additional parameters may affect the performance of the vertical jump. A study in 1924, right after the introduction of the Sargent jump studied the effects of size of dip, height, and weight, and reported that jumping performance was independent of these factors (37). McCloy (29), in his instructions on performing the vertical jump, has the performer bend the knees to a 90 degree angle and then pause in this position before continuing. Mechanically speaking, a slight flex of the knee and hip permits a more forceful action of the muscles that control these joints. The amount of flexion will depend on the strength of the muscles. Those with weak leg muscles should not have as much flexion as those with strong leg muscles (5) (6). An interesting study was done by Martin on various knee angles and foot spacing combinations. He found that a knee angle of 90 degrees resulted in better performance in the vertical jump than did a knee angle of 65 degrees, and that a knee angle of 115 degrees resulted in better performance in the vertical jump than did a knee angle of either 65 degrees or 90 degrees. In addition, his study showed that lateral foot spacings of five and ten inches resulted in better vertical jump performances than did lateral foot spacings of zero and fifteen inches. An anterior-posterior foot spacing of five inches was best for vertical jumping performance (28: 327-329). Bangester in 1968 on the basis of his study found that "either knee extensors, hip extensors, or the combination of the two contribute to the vertical jump while plantar flexors contribute very little, if at all" (2:436).

Higgin's mechanical analysis of angular measures of the elbow, shoulder, hip, knee, ankle, and body lean, and the velocities of the arms, hip extension, knee extension, and plantar flexion yielded the following, in addition to what has already been mentioned. The poorest jump of each subject when compared to his best jump showed that there was less shoulder flexion at the take-off and at the apex of the jumps. The knees, hips, and ankles had less than or equal extension at the point of take-off while the angle of body lean was greater than or equal. The "poor" jumps exhibited a lower elevation of the arms, a greater body lean, less extension of the hips, the knees, and the ankles, and a faster rate of arm velocity. From Higgin's investigations, one can see that the arms, the body velocities, and the acceleration of the hip and knee extensions must all function together in the performance of a vertical jump (22).

The angle of take-off is extremely important to the purpose of the jump. "All force and movement should be directed as nearly vertical as possible. The more nearly vertical all forces are directed, the greater will be the effective force for the jump" (6:248). For example, any sideward swing of the free arm will waste a part of the forces exerted.

The position of the center of gravity in man in any movement is important as this is where the effective weight of the body is centered. In jumping, "the direction of the force applied by the push-off of the toes is determined by the relationship of the center of gravity to the toes at the moment of take-off" (5:73). The position of the feet at take-off determines the direction of the movement of the knees and hips (8).

> In jumping for height, the desired direction of movement is straight upward and therefore, the center of gravity should be directly above the feet at take-off. The forward lean of the trunk which accompanies the bending of the legs should therefore, be kept to a minimum. (5:154)

The center of gravity of the body through the air is determined by the magnitude of the force exerted at take-off and the angle of projection (5) (6). "Once the subject's feet leave the ground the legs are no longer capable of exerting any thrust against the floor and thus can do no further work in propelling the body upwards against gravity" (20:46). Once a body has lost contact with the projecting surface, no movement of the various body segments can alter the path followed by the center-of-gravity (5) (6).

> However, the center of gravity in relation to the body can be lowered after the jump by changing the position of the body, i.e., lowering the arms from overhead. By thus lowering the center of gravity, the body will be projected higher into the air; this is an important principle in all jumping activities where height is the objective. (17:25)

## CINEMATOGRAPHY AND THE SEGMENTAL METHOD

Cinematography is being extensively used in the field of physical education for the study of human movement. It has become an invaluable aid to the researcher, teacher, and coach, allowing for an objective approach to the precise and accurate determination of quality performance.

The primary objective of cinematography in the study of motion is to supplement the visual process. One way the visual apparatus is supplemented is through time magnification. "Time magnification is achieved by taking motion pictures of an action at a picture repetition rate (in frames per second) greater than the frame rate used in projecting the films" (23:2). In this way, the movement is slowed down or stopped and in all actuality, a moving body is made to appear stationary.

Only when a rapid motion is slowed down or stopped can it be effectively evaluated. The characteristics of human vision limit the observer's ability to discern rapidly moving objects. As the velocity of the movement becomes greater, visual contact becomes difficult to maintain and the retinal image lapses into a blur (16) (23). For example, blurring occurs frequently when observing a human body in motion. The trunk and head are usually easily observed but the legs and arms, because of their faster speed, appear as a blur. The fingers and feet, which move even faster, often times seem to "disappear." The faster a movement occurs, the more difficult it becomes to see each phase. "If an event takes place too rapidly, only the effects before and after are usually recorded" (23:8). Image blurring may still occur when filming a body in motion and is a result of the film speed being slower than the speed of the movement. However, this problem can be eliminated, or at least decreased by filming the motion at a speed that is as fast or faster than the movement itself (35).

Another "critical shortcoming of the eye in the comparative study of motion is the lack of permanency of the visual record" (23:8). Cinematography gives a permanence to the movement allowing for a more scientific evaluation. For instance, it would be impossible for the eye to directly compare two events that did not occur simultaneously. With the two or more events recorded on film it is possible to objectively compare and evaluate them.

Once the film of a particular movement is made, the investigator is faced with the interpretation of that film. Data reduction of motion picture film is a routine, straight forward operation but is extremely tedious when a large number of frames comprises the sequence to be analyzed. "For this reason the analytical procedure should be patterned to fit the degree of accuracy required in the resulting numerical data" (23:482). Depending on the film speed and the degree of accuracy desired, it is not necessary that each frame in the sequence be analyzed.

Possibly the most widely used method for obtaining the location of the center of gravity of a body in motion is the segmental technique. By finding the locations of the center of gravity for each of the major body segments with respect to a predetermined X, Y axis, along with the respective proportional segment weights, it is possible to determine the coordinate location of the center of gravity of the total body (23). Davis performed a study recently to determine the reliability, objectivity, and validity of the segmental method. His findings indicate that the reliability of determining the X-Y coordinates of the center of gravity was $R_x = 0.9682$, $R_y = 0.9443$. The objectivity of the plotters in identifying consistently the same center of gravity varied significantly. He drew the following conclusion from his study: the reliability of the segmental method is acceptable but the objectivity of the method is valid for kinematic analysis[1] but not for kinetic analysis[2] (13). By marking the joint centers of each subject prior to filming, the objectivity of the segmental method can be greatly increased.

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[1]Kinematic analysis deals with pure motion without reference to mass or cause. It involves the mechanical aspects of converting one kind of motion into another.

[2]Kinetic analysis deals with the action of forces in producing or changing the motion of masses.

## SUMMARY

A review of the literature indicates that research dealing with the quality of human movement desperately needs to be conducted. Instead of personal philosophies, concrete evidence either for or against stressing quality movement needs to be presented.

One method that allows for the objective determination of quality movement is cinematography. It is a technique that will continue to play a large role in the biomechanical investigations of human movement.

## Chapter 3

## PROCEDURES

All filming and instruction for this study took place at Kansas State University and the Biomechanics Lab at Kansas State University. The following pages contain a descriptive step-by-step account of the procedures adhered to for this study. In terms of organization, the procedures were divided into four basic categories: preliminary investigation, general procedures, specific procedures, and analysis procedures.

### PRELIMINARY INVESTIGATION

A preliminary investigation using the proposed procedures for the study was performed by the experimenter in order to become acquainted with the Bolex camera and other filming equipment, to check through the procedures before actual filming, and to insure that everything being filmed was what the investigator wished to record. Revisions in procedures were then made where appropriate.

### GENERAL PROCEDURES

Subjects were selected for the study and assembled at the Biomechanics Lab at Kansas State University. A pre-test involving the filming of a standing reach and two vertical jump trials for each subject was done. After each subject had been filmed, subjects were matched according to leg length and divided into two groups. Group One subjects received instruction on how to perform a vertical jump and then performed 60 practice trials over a three day period. Group Two subjects received the same number of trials, but with no instruction. A post-test was then performed on each subject which involved the same procedures as the pre-test. The film was then analyzed. Comparisons and general tendencies of the performances were noted.

## Subjects and Their Preparation

Eight nine-year-old boys from the Manhattan, Kansas area volunteered to serve as subjects for investigation. All but one of the subjects attended Lee Elementary School. Subjects were attired in regular gym shorts for all filming. To facilitate film analysis, joint centers were marked as described below with white pieces of tape marked with a black "X" on the tape and this "X" placed as close to the desired reference point as possible. Marking the joint centers this way increased the objectivity of the segmental method. Subjects were marked with tape on the left side of the body at the following places: acromion process, lateral epicondyle of the humerus, styloid process of the ulna, greater trochanter of the femur, lateral epicondyle of the femur, and the lateral malleolus of the fibula. On the right side of the body, the subjects were marked at the lateral epicondyle of the humerus, styloid process of the ulna, tips of the middle three fingers, the medial epicondyle of the femur and the medial malleolus of the tibia.

## Equipment and Its Placement

A jumpboard, 28 inches by 45 inches, was constructed from black poster board marked with white horizontal lines one inch apart. The jumpboard was tacked to a wall four feet above a mat. The mat was placed on the floor to prevent slipping. A rectangle was marked with tape on the mat eight inches from the wall. The rectangle was 10 inches by 12 inches as measured on the inside of the tape. A reference point was marked in the middle of the rectangle and from this point the distance and placement of the lights and camera were determined.

All filming was done with a Bolex H-16 RX5 manual movie camera with a C-mount lens. The camera was equipped with a variable film speed control which was set at 64 frames per second and remained at that setting for the entirity of the study. The film used was 100 foot rolls of black and white Kodak Tri-X Reversal 7278 film with an indoor ASA number of 160.

The film was loaded in the camera, and the camera then placed on a heavy-duty tripod. The tripod was positioned so that the camera was filming perpendicular to the wall. The distance from the reference point on the mat to the camera opening was 17 feet. Height of the camera from the floor to the middle of the lens apperature was 42 inches. A level was used to insure that the camera itself was level with the ground.

A clock, readable to 1/100 of a second accuracy, was placed within the photographic field next to the jumpboard. Even though the camera speed was set at 64 frames per second, which is a time of 1/64th of a second between each frame, a manual camera requires time to speed up, and when turning the camera off, it again slows down. Therefore, to attain a higher degree of accuracy in determining time intervals between succeeding or intermitten frames, the clock was used.

In addition to the overhead lighting of the room, two lights were employed. These lights were 1100 watt quartz lights with 39,000 lumens each. They were placed on top of a light tripod 40 inches high and set at right angles to each other with the reference point on the mat as the vertex of the angle. There was a distance of 10 feet from the reference point to the lights. Heavy duty extension cords connected the lights to the electrical source.

Each subject was assigned a number according to his order of testing and his trial number. These identification numbers appeared in the bottom left-hand corner of the filming environment to facilitate subject identification. A visual representation of the filming set-up is provided in Figure 1 on page 27.

## SPECIFIC PROCEDURES

After the test filming, all adjustments in procedures were made. The subjects for the study were then selected on a voluntary basis. An informed consent form shown in Appendix B was sent home with each subject explaining the nature of the test and requiring parental consent.

The lab was set up according to Figure 1 and as described previously. The film was loaded into the camera. The camera was then attached to a heavy duty tripod and adjusted so that it was level with the ground and set at right angles to the filming environment. A true horizontal was determined at the intersection of the wall and mat.

The camera was set at 64 frames per second with the lens set on automatic. The manual spring-driven camera was wound tight prior

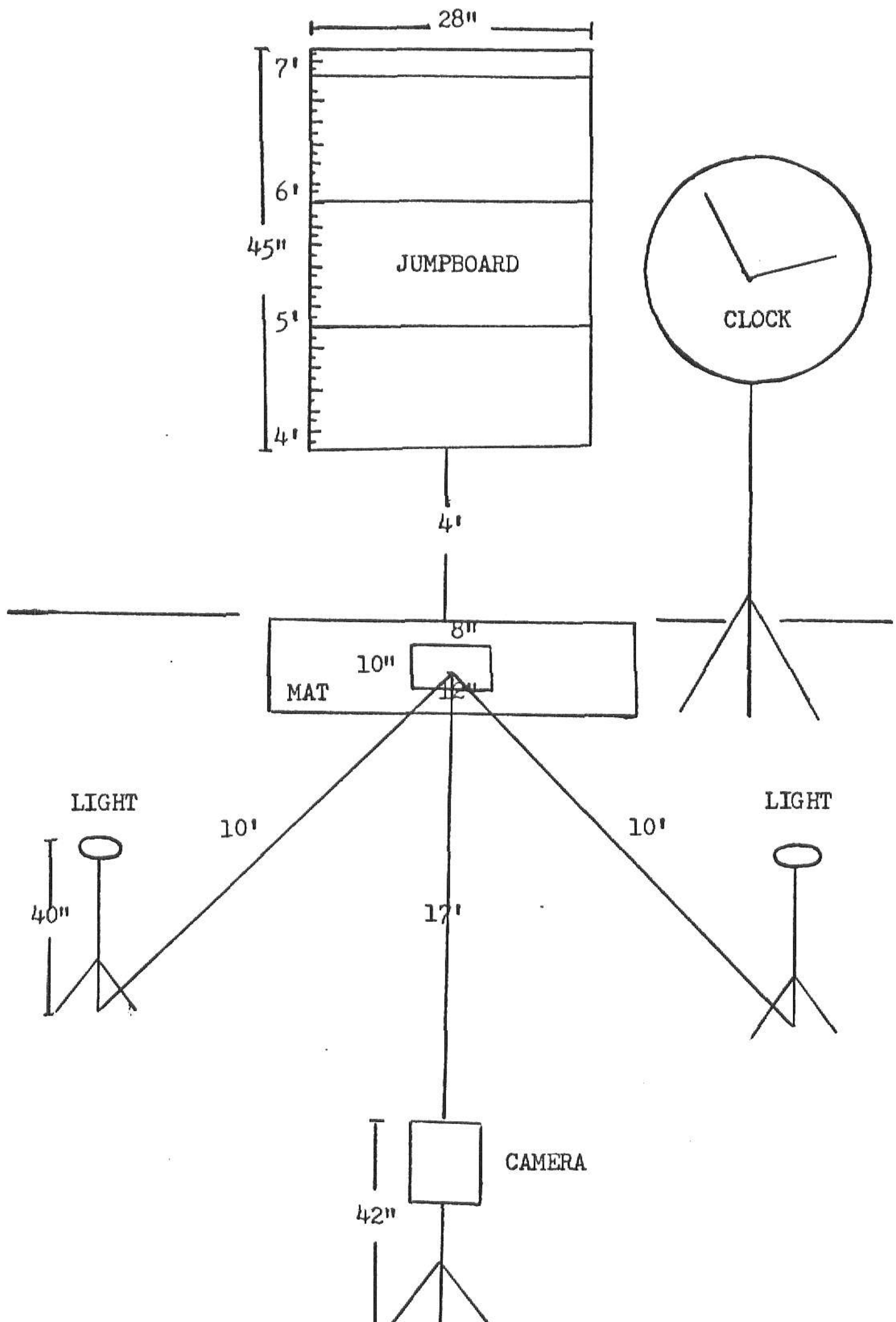


Figure 1. Diagrammatical Representation of the Laboratory Set-Up During the Filming of the Vertical Jump.

to the filming of the subject's standing reach, prior to the first attempt of the vertical jump, and then again before the second attempt of the vertical jump. This procedure was followed in both the pre-filming and the post-filming. This was a necessity in keeping the tension of the camera spring as constant as possible.

Pre-test filming was done on a Tuesday afternoon beginning at 3:30 P.M. Subjects were assembled and brought to the Biomechanics Lab at Kansas State University. All subjects were shown the set-up and then taken into the hallway and given instructions. They were told that they would each have to perform a vertical jump. To do this jump, they were to stand in the box that was marked with tape on the floor in the Biomechanics Lab with their dominant side next to the wall. Subjects were asked as to which was their dominant side, and all responded that they were right-handed. In order to perform a vertical jump, they were then told to swing their arms back, bend at the knees, then jump up in a straight line and reach as high as they could with their right hand and touch the wall with the right fingertips. The subjects were then allowed one practice trial in the hallway.

The testing order for each subject was done at random. The first subject was taken into the Biomechanics Lab for filming. The experimenter and one assistant remained in the room during the filming of the first subject and each of the remaining subjects in turn. The following procedures were adhered to for each of the subjects as they came in to be filmed. The subject entered the lab and removed all clothing except his gym shorts. His height, to the nearest $\frac{1}{2}$ inch, and weight, to the nearest pound, were taken. Square pieces of white tape with a black "X" were placed at various joint centers and reference points as described earlier. Measurements of segment length, determined by the distance between the pieces of tape, were then measured and recorded on a personal data sheet, along with all other personal data regarding the subject, including height and weight. A copy of the personal data sheet is shown in Appendix C. The subject was then shown where to stand for the filming and which way to face. The subject's identification number was placed in the left-hand corner of the filming environment. The camera was wound tight and the filming lights turned on. The subject was instructed to stand straight with his right side adjacent to the jumpboard, heels flat on the floor, and reach up as high as he could and touch the jumpboard with his right fingertips. At this time the camera was turned on, recording the standing reach of the subject. The camera was again wound tight and the subject's trial number placed alongside his identification number. When the camera was ready, the subjects were asked if they were ready. When the subject answered "yes," he was then told to "begin" at which time he commenced jumping. The first attempt in the actual filming situation was a practice trial for the subject and was not filmed, but was included to acquaint the subject with the procedures and filming environment. The subject then performed a vertical jump following the procedures of the practice trial except that the camera was turned on a moment before the word "begin" and continued filming until the subject had regained his balance upon landing. The trial number for the subject was changed and the Bolex camera wound tight once again. A third performance was then attempted by the subject and recorded on film. There was an approximate two minute rest period between each trial. The camera speed was set at 64 frames per second for the entirity of the study. At the conclusion of his pre-test filming, the subject was told that "he had done a good job." The above procedures were then followed in turn for each subject, with one exception. Due to an oversight, the timing clock was not started for Subject One's first two filming attempts. Consequently, he was permitted to execute two additional trials. The camera was wound tight prior to each jumping attempt.

After each had gone through the above procedures, the subjects were matched according to leg length and randomly assigned to one of two groups. Subjects in Group One were to receive instruction on vertical jump performance, while Group Two was to receive no instruction. Each group was allowed twenty practice trials following the initial filming. Group Two was isolated from Group One with an assistant who counted the trials for the subjects. In Group One, the experimenter gave instructions verbally on how to perform a vertical jump. Subjects were instructed to swing the arms downward and backward, inclining the body slightly forward, bending the knees to about a hundred and fifteen degree angle, and raising the heels slightly off the floor. They were then told to forcefully swing the arms forward and upward and to jump as high as possible. Just prior to the highest point of their jump, subjects were told to bring their left arm down to their side and to reach with the right hand as high as they could and stretch. They were instructed to jump as close to the vertical as possible for any deviations from a vertical trajectory would cause a loss of height. The subjects were told to look up to where they were jumping in hopes that this would allow the forehead to be the highest point on the head. Group One was then given twenty practice trials as the experimenter recorded the number of trials and offered group suggestions concerning their performance.

The following day subjects were assembled at 3:30 P.M. in the Biomechanics Lab. The subjects were divided into their same two groups. Each group was allowed twenty practice trials. Group Two received no instruction or verbal encouragement. Group One was given verbal instructions once again, then allowed twenty practice trials. Correct technique was stressed during their performances.

On day three, subjects followed the procedures as outlined for day two. Thus, subjects received a total of sixty practice trials in the three days.

On the fourth day, subjects were again filmed. The equipment was placed according to the positions established during the first filming. The testing order of the subjects followed the order of the first filming. The experimenter and one assistant remained in the room during each subject's filming. The procedures followed were the same as the procedures of the first filming.

## ANALYSIS PROCEDURES

Upon its return from processing, the film was projected with a Lafayette Analyzer Projector onto a screen. Each trial for each of the subjects was viewed a number of times to thoroughly acquaint the investigator with the contents of the film. The pre-test and post-test trials to be analyzed were then selected. The following criteria were used to determine which trial this would be: the height of the reaching fingertips, the height of the head, and the height of the left hip mark. The trial with the highest combination of the three was selected for analyzation.

The film was then taken to a 16 mm Recordak Film Analyzer. The Recordak provides for the image to be projected onto a ground glass screen and thus provide a magnification of the frame size. This magnified image was projected onto graph paper readable to the nearest millimeter. Filming constants were determined to be the line formed by the base of the jumpboard and the vertical line formed by the side of the jumpboard. This permitted both vertical and horizontal reference points. An X-Y coordinate system was then devised so that the projected image remained within the positive quadrant to facilitate mathematical computations. The image was projected onto the X-Y coordinate system and the two reference lines assigned an X-Y coordinate which then remained constant throughout the analyzation. The position of each marked joint and reference point appeared as a single point on the grid. It was a little more difficult determining the coordinates of those joints and reference points of the body that were hidden from view by other parts of the body. The experimenter made a conscientious effort to plot these as accurately and consistently as possible. All coordinates were determined and recorded for those joints and reference points needed to determine the center of gravity by the segmental method.

The following analysis procedures were carried out on each subject for both the pre-test and the post-test. First, a single frame of the standing reach of the subject was projected and analyzed. All necessary coordinates to determine the center of gravity were recorded. A sample recording sheet is given in Appendix D.

For each vertical jump, every fourth frame was analyzed. To avoid "missing" the highest point of the filmed jump, the frame with the greatest height was marked. From there the investigator counted back every fourth frame until the subject's first positive action of the jump. This frame was designated as the second frame for analyzation. The investigator went back four more frames to the "first" frame for analyzation. This allowed for one analyzation before the subject began his positive action of the jump.

After recording the X-Y coordinates on each subject, the raw data was then fed through an Olivetti Underwood Programma 101 desktop computer to determine the center of gravity of the total body for each analyzed frame. The X-Y coordinate of the center of gravity of the body was then multiplied by 3.158, the film-to-life-size constant.

The center of gravity of each subject was the basis of comparison for most of the data collected. Using the center of gravity, a t-test for related samples was used to determine individual improvement in performance following the sixty practice trials. A student's t-test was then utilized to compare Group One to Group Two on the amount of change in each trial undergone by the center of gravity of the body.

The position of the center of gravity of the foot in relation to the gravitational line of the body was then determined. The frame in which the toes of the foot were still in contact with the floor, but the heels had already been elevated just prior to take-off was used to make this comparison. The center of gravity of the foot at this point was compared to the gravitational line of the total body at this same point.

The next item to be evaluated was that of the velocity of the center of gravity at take-off. For each of the subjects, this velocity was measured between the frame prior to take-off when the heels were raised but the toes still in contact with the floor, and the following frame in which the toes had lost contact. The distance was calculated, the time interval determined, and the velocity obtained by the formula $V = d/t$.

Angles of projection were determined by plotting the position of the center of gravity in the frame just prior to take-off and plotting its position according to the frame just after take-off. By connecting these two points and using a protractor, the angle of projection from the vertical was determined and recorded.

The degree of hip flexion, knee flexion, and ankle flexion were all determined in the frame of which the center of gravity was at its lowest point. In this frame, the angle of hip flexion was measured between the shoulder, hip, and knee. The angle of knee flexion between the hip, knee, and ankle. The angle of ankle flexion between the knee, ankle, and the toes.

A short checklist was then developed to rate each subject on head position, preliminary arm swing, arm lift, and thrusting of the left arm down just prior to the high point of the jump. Each subject was rated according to this checklist.

# SUMMARY

A preliminary investigation was performed by the experimenter in order to become familiar with the equipment and procedures used for the study. Revisions in procedures were made where appropriate.

Eight nine-year-old boys volunteered to serve as subjects for investigation. All filming and training took place at Kansas State University. A pre-test involving the filming of a standing reach and two vertical jump trials for each subject was done. After each subject had been filmed, subjects were matched according to leg length and divided into two groups. Group One subjects received instruction on how to perform a vertical jump and then performed 60 practice trials over a three day period. Group Two subjects received the same number of trials, but with no instruction. A post-test was then performed on each subject which involved the same procedures as the pre-test.

Every fourth frame of the film was analyzed using a 16 mm Recordak Film Analyzer. Various comparisons, measurements, and evaluations were made based on the information gained from the pre-test and post-test films.

## Chapter 4

## RESULTS AND DISCUSSION

The results of this study were divided into several categories or subheadings, depending upon the nature of the results. The main divisions were: the center of gravity, angle measures, and quality movement. All results were given and discussed under one of these major headings.

### CENTER OF GRAVITY

The center of gravity of a body does not remain in a fixed position. Rather, the center of gravity will change within a body depending on the motion of that body. Figure 2 illustrates the changing position of the center of gravity during one trial of a vertical jump. The figure depicts Subject One during the first trial of the post-test jump. Subject One was a member of Group One which received instruction during the practice trials of the vertical jump. In Position One of the Figure, the center of gravity was forward in the pelvic region. This was due mostly to the forward position of the arms and head. Note how far forward and upward the center of gravity moved as the subject crouches down in the second position. The reader can see from this that it was the position of the center of gravity that caused the heels to be raised off the floor and was not due to the muscle action of the legs. At this point, the subject was less stable than before because of his smaller base of support and the forward position of the center of gravity. If

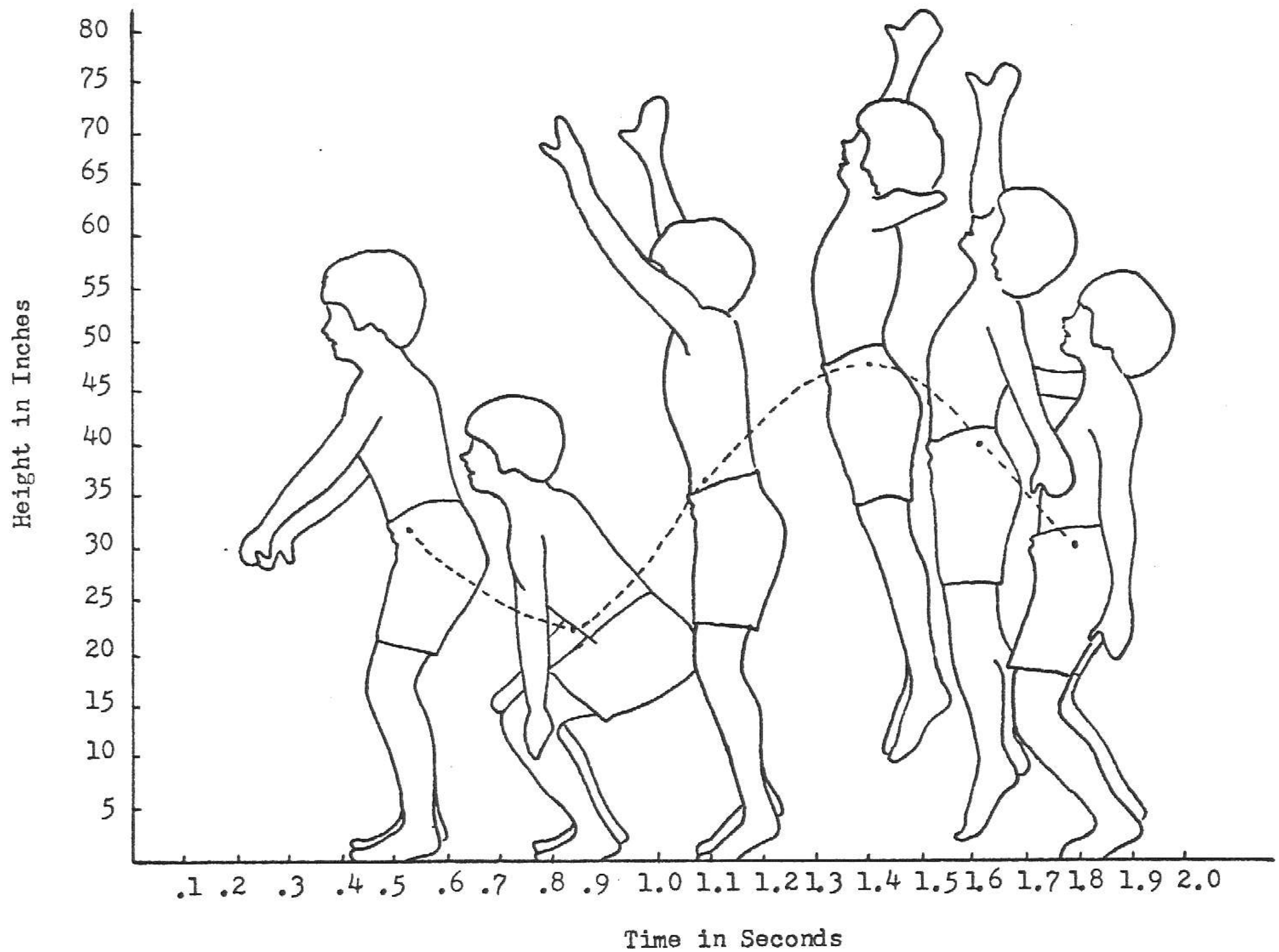


Figure 2. Outline of the Body and Tracing of the Center of Gravity of Subject One During His Third Filmed Trial of the Vertical Jump.

the subject wished to go forward at this point, he would allow the center of gravity to continue moving forward until it was outside the base of support thus causing him to lose equilibrium. However, since the subject in this study wanted to rise vertically upward, the center of gravity was moved back within the body and over the base of support as shown in Position Three.

Once contact is broken with the floor, the path of the center of gravity is determined by the velocity and direction imparted to it at take-off and by gravitational pull. The body now acts as a projectile and as such, the center of gravity will travel in a parabolic path (6). In a total perspective of Figure 2, observe that the center of gravity did travel in a parabolic path even though the movement in this illustration has been spread out. Related to this is the principle that states that no movement of a body can alter the path of the center of gravity once it has become airborn (6) (8) (35). However, as this illustration points out, the relationship of the body to its center of gravity can be changed. There was "more" of the body above the center of gravity in Position Four than in Position Three due for the most part to the lowering of the left arm. This allowed the subject a higher reach with his right hand.

The center of gravity of the best pre-test jump for each of the subjects was compared with the center of gravity of his best post-test jump. The purpose of such a comparison was to determine improvement in performance following sixty practice trials of the vertical jump. The differences between these two jumps are presented in Table 1. A two-tailed t-test for related samples was used to make the comparison.

According to this test, there was no significant improvement in the jumps after sixty practice trials at the .05 level.

Table 1

Peak Heights, In Inches, of the Center of Gravity of the Eight Subjects During Their Performance of the Pre-Test and Post-Test Vertical Jumps

| | Instruction Group | | | | Non-Instruction Group | | | |
|---|---|---|---|---|---|---|---|---|
| Subject | 1 | 3 | 4 | 7 | 2 | 5 | 6 | 8 |
| Pre-Test | 48.2 | 46.3 | 42.7 | 47.2 | 43.1 | 46.6 | 43.6 | 46.9 |
| Post-Test | 48.0 | 46.6 | 42.3 | 49.0 | 43.5 | 46.7 | 42.4 | 49.4 |
| Difference | -0.2 | 0.3 | -0.4 | 1.8 | 0.4 | 0.1 | -1.1 | 2.5 |

Notice from the table that not all subjects improved their jumps following the practice trials as would be expected after being subjected to a practice period. In fact, three of the eight subjects decreased in the height they attained. Two of these subjects were from the instruction group. A possible explanation is that these subjects were so conscious of the mechanics involved that they were unable to perform the movement as a smooth integrated unit. In addition, sixty practice trials over a three day period may not have allowed enough time for the movement pattern to become automatic and ingrained within the individual without conscious attention to details.

The difference in the position of the center of gravity from the standing reach to its position at the peak of the jump was computed for each of the subjects. This was done to show how much change in the center of gravity can be attributed to the application of the forces developed in the jump. A second difference was then found between the subject's pre-test height difference and his post-test height difference. Each subject who received instruction was then compared on this height difference with the matched subject from Group Two who received no instruction. A two-tailed students' t-test at the .05 level was used to ascertain any significant differences. According to the results of this test, there were no significant differences between the two groups. Table 2 lists the center of gravity change from the standing reach to the peak of the jump. The difference in this change from pre-test to post-test is also listed.

Table 2

Difference, in Inches, in the Center of Gravity of the Eight Subjects From Their Standing Reach to the Height of Their Jump During the Pre-Test and Post-Test Vertical Jumps

| | Instruction Group | | | | Non-Instruction Group | | | |
|---|---|---|---|---|---|---|---|---|
| Subjects | 1 | 3 | 4 | 7 | 2 | 5 | 6 | 8 |
| Pre-Test | 14.7 | 13.7 | 12.6 | 13.0 | 10.7 | 12.9 | 11.6 | 12.3 |
| Post-Test | 14.1 | 13.1 | 12.1 | 15.2 | 11.5 | 12.9 | 10.2 | 14.3 |
| Difference | -0.6 | -0.6 | -0.5 | 2.2 | 0.8 | 0.0 | -1.4 | 2.0 |

The table shows that three of the subjects in the instruction group decreased in the height that their center of gravity reached, while only one subject from the non-instruction group decreased. It might be pointed out here that a standing reach was filmed on each of the subjects in both the pre-test and post-test and that the heights of the center of gravity of these reaches did not correspond as would be expected. In fact, the standing reach center of gravity was higher in the post-test for all subjects but two. This was due possibly to the fact that the subjects were more aware of the skill and stretched higher by further extension of the shoulder. Referring to Table 1 and then comparing it to Table 2, one can see that the actual difference in the jumps was not as much as when the center of gravity of the standing reach was involved. These differences obviously affect the results presented in Table 2.

Force should be applied as directly as possible in the direction of the intended motion so that all the forces can be effectively utilized (6). In vertical jumping, the desired direction of movement is straight upward. Since the direction of the combined forces of the body applied by the push-off of the toes is determined by the relationship of the center of gravity to the toes at the moment of take-off, the center of gravity should be directly above the feet at push-off for the body to rise vertically. This relationship was explored in this study by measuring the horizontal distance between the gravitational line of the body and the center of gravity of the left foot. Measurements were taken by finding the center of gravity of the left foot with the heel raised and the toes still in contact with the floor just prior to the toes pushing off. The reader should refer to Figure 2, Position Three which depicts Subject One in this particular position. The reader should also observe from Figure 2 the difference in the horizontal distance of the center of gravity of the body and the center of gravity of the foot. The closer this measurement was to zero, the more nearly vertical the body should have risen. Table 3 shows the horizontal difference in the position of the center of gravity of the foot to the gravitational line of the body at the same moment for each of the eight subjects in the pre-test and post-test jumps.

Table 3

Horizontal Distance, in Inches, of the Center of Gravity of the Foot to the Gravitational Line of the Body for the Eight Subjects During Their Performance of the Vertical Jump

| | Instruction Group | | | | Non-Instruction Group | | | |
|---|---|---|---|---|---|---|---|---|
| Subject | 1 | 3 | 4 | 7 | 2 | 5 | 6 | 8 |
| Pre-Test | 2.1* | 1.9 | 2.8 | 0.9 | 0.3 | 1.0 | 1.8* | 2.3 |
| Post-Test | 2.4 | 1.2* | 1.5* | 1.8* | 1.7* | 3.4* | 2.5 | 1.1* |

*The highest jump for each subject.

Five of the subjects' best jumps occurred when the gravitational line of the body was closer to the center of gravity of the foot. There appeared to be no real differences between the instruction group and the non-instruction group on this comparison. None of the subjects' center of gravity was directly over the foot at take-off. In fact, all subjects were found to have their gravitational line to the front of the center of gravity of the foot at take-off. This could in part be accounted for by the fact that both arms were extended in front of the body at this time in their swinging action. Another reason was that this helped to make the subject less stable which made it easier for him to move.

The velocity of the center of gravity of the body at take-off was then determined. "A measure of the velocity of the center of gravity is rarely made; yet this is the most valid evaluation of the force developed in the take-off" (8:230).

The velocity of the center of gravity for each of the subjects was measured between the frame prior to take-off when the heels were raised but the toes were still in contact with the floor, and the following frame when the toes had lost contact. Table 4 lists the velocities in feet per second for each of the subjects.

Table 4

Velocities, in Feet per Second, of the Center of Gravity at Take-Off for Each of the Eight Subjects During Their Performance of the Vertical Jump

| | Instruction Group | | | | Non-Instruction Group | | | |
|---|---|---|---|---|---|---|---|---|
| Subject | 1 | 3 | 4 | 7 | 2 | 5 | 6 | 8 |
| Pre-Test | 8.07* | 5.97 | 6.86 | 5.91 | 6.99 | 5.51 | 7.19* | 6.09 |
| Post-Test | 7.14 | 7.13* | 7.04* | 7.50* | 6.72* | 7.27* | 5.93 | 6.34* |

*The highest jump for each subject.

In all but one instance, the highest jump for each subject was the jump in which he had the greatest velocity at take-off. This was logical since the more force generated and imparted to the subject as he became airborn, the longer it will take the force of gravity to overcome his forces. Thus, the subject can continue on his projected path for a longer time and can reach a greater height if he has a greater velocity at take-off, as long as the angle of projection remains the same.

Summary

The investigator found that Subject One was in a fairly unstable position as shown in Figure 2, Position Three, due in part to the small base of support. This was because the smaller the base of support, the less stable the body. In addition, his center of gravity was close to the edge of his base of support making him less stable forward since stability in a given direction is directly proportional to the horizontal distance of the center of gravity from the edge of the base toward the given direction of movement (6).

Subject One's center of gravity was traced and found to travel in a parabolic path once he became airborn. This conforms to basic principles of projectiles. This parabolic path cannot be changed by movement of the body but the position of the center of gravity within the body can be changed by various body movements, and parts of the body may be raised or lowered above the floor by this changing position of the center of gravity within the body (6). This phenomenon was noticeable in the drawing of Figure 2.

There were no significant improvements in the vertical jumps for the eight subjects following 60 practice trials. The 60 practice trials were probably not enough for measurable differences to occur in the subjects' performances.

There was no significant difference between the group which received instruction and the group that did not receive instruction in a comparison of the center of gravity from the standing reach to the height of their jumps during the pre-test and post-test. The reliability of the standing reach measure used in this comparison was thought to be very poor and it did have some bearing on the outcome of this comparison.

Measurement of the horizontal distance of the center of gravity of the foot to the gravitational line of the body for the eight subjects during their performance of the vertical jump found that in every case, the gravitational line was forward of the center of gravity of the foot at take-off. There were no differences between the groups.

The highest jumps occurred when the subjects had the greatest velocity at take-off. This was logical since the more force generated and imparted to the subject as he became airborn, the longer it took the force of gravity to overcome his forces.

## ANGLE MEASURES

The angle of projection is an important factor to consider. Unless all forces are channeled in the desired direction, the resultant outcome will be ineffective. One should be aware that in vertical jumping "...all force and movement should be directed as nearly vertical as possible. The more nearly vertical all forces are directed, the greater will be the effective force of the jump" (6:248).

The angles of projection were found for each of the subjects and are presented in Table 5. These angles were measured between the frame just before take-off and the frame just after take-off. All measures are in degrees from the vertical.

From the pre-test to the post-test, all but one subject improved or remained the same in his projection angle. Although jumping as vertical as possible was a point stressed by the experimenter to the subjects in Group One, it can be seen from Table 5 that Group Two improved just as much as the subjects in Group One.

Table 5

Angles of Projection, in Degrees From the Vertical, of the Center of Gravity of the Eight Subjects During Their Performance of the Vertical Jump

| | Instruction Group | | | | Non-Instruction Group | | | |
|---|---|---|---|---|---|---|---|---|
| Subject | 1 | 3 | 4 | 7 | 2 | 5 | 6 | 8 |
| Pre-Test | 7* | 5 | 16 | 4 | 4 | 8 | 3* | 1 |
| Post-Test | 9 | 0* | 4* | 1* | 2* | 7* | 1 | 1* |

*The highest jump for each subject.

In all but one instance, the best jump between the pre-test and post-test was when the angle of projection was nearer the vertical. Recalling that once contact is broken with the floor, the path of the center of gravity is determined by the velocity and the direction imparted to it at take-off and by gravitational pull (6). Referring to Table 4 and then comparing it to Table 5, the reader can see that for each of the eight subjects, their highest jumps occurred when they had the greatest velocity, an angle of projection nearer the vertical, or as in most of the cases, a combination of the two.

The degree of knee flexion, ankle flexion, and body lean in the preparatory phase of the vertical jump will greatly influence the amount of force that can be generated for the jump. Although no attempt was made to compare these measures between the two groups, the various angles are summarized for the reader in Table 6. All measures were taken in the frame in which the center of gravity of the body was at its lowest point.

Table 6

Degree of Ankle, Knee, and Hip Flexion as Measured on the Eight Subjects During Their Performance of the Vertical Jump

| | Instruction Group | | | | Non-Instruction Group | | | |
|---|---|---|---|---|---|---|---|---|
| Subject | 1 | 3 | 4 | 7 | 2 | 5 | 6 | 8 |
| Ankle | | | | | | | | |
| Pre-Test | 64* | 73 | 71 | 69 | 54 | 71 | 78* | 77 |
| Post-Test | 68 | 85* | 85* | 67* | 63* | 70* | 84 | 61* |
| Knee | | | | | | | | |
| Pre-Test | 94* | 103 | 106 | 97 | 91 | 102 | 99* | 105 |
| Post-Test | 90 | 115* | 128* | 96* | 80* | 100* | 110 | 110* |
| Hip | | | | | | | | |
| Pre-Test | 91* | 61 | 83 | 111 | 114 | 96 | 97* | 114 |
| Post-Test | 73 | 103* | 103* | 81* | 82* | 78* | 101 | 105* |

*The highest jump for each of the subjects.

The degree of knee flexion is very important and according to Martin (28) when testing college-age students, this angle should be around 115°. However, because of the lack of research, it is difficult to ascertain that 115° is the best angle for nine-year-old boys. From the table, it can be seen that only one subject actually attained this angle.

### Summary

In all but one instance, the best jump between the pre-test and the post-test was when the angle of projection was nearer the vertical. A combination of the angle of projection nearer the vertical and a greater velocity at take-off resulted in the best jumps. This was expected since the velocity and angle of projection of the subject at take-off will determine the path of the center of gravity. There was no difference as far as one group jumping closer to the vertical than the other.

The degree of knee flexion, ankle flexion, and body lean influence the amount of force that can be generated in vertical jumping. The results of these measures were presented in Table 6. However, no attempt was made to compare the measures between the two groups.

## QUALITY MOVEMENT

There were certain qualities involved in the vertical jump that did not lend themselves to direct measurement because of the subjects and/or time involved. Presented here is a checklist of observable qualities that do affect vertical jumping. The first of these was the head position. This was an important consideration since head position and direction go together.

The arm swing was even more important since it can add a great deal of force to the jump. The arm swing was divided into two phases in the checklist since the subjects were observed to begin the arm swing, but many of them did not swing or lift both arms above chest level.

The thrusting of the left arm down was included in the checklist because of its importance in gaining additional height with the fingertips. This was a characteristic that was easily observable since the subject either brought his arm down or did not bring it down.

It was quite obvious that certain individuals were doing the mechanics of these checklist items correctly, while others were not. Table 7 presents the results of this evaluation while Appendix E provides the description of how these points were determined.

As a group, it can be seen that Group One improved a total of 10 points while Group Two improved three points. On these particular items, one can see that the subjects in the group that received instruction during their practice trials were able to perform with better quality than the subjects that did not receive instruction during the practice trials.

It was believed that there would be a direct relationship between the quality of movement and the quantity of movement. That is, that if the quality of movement was improved, then the quantity of the movement would also improve. However, comparing Table 1 with Table 7, it was found that this was not necessarily the case. For example, all the subjects in the instruction group improved the quality of their jumps from the pre-test to the post-test. Yet, not all of these same

Table 7

Checklist of Quality Aspects for the Eight Subjects Performing the Vertical Jump

| | Instruction Group | | | | Non-Instruction Group | | | |
|---|---|---|---|---|---|---|---|---|
| Subject | 1 | 3 | 4 | 7 | 2 | 5 | 6 | 8 |
| Head Position | | | | | | | | |
| Pre-Test | 1 | 3 | 1 | 2 | 2 | 1 | 2 | 2 |
| Post-Test | 3 | 3 | 2 | 3 | 1 | 2 | 2 | 2 |
| Prelim. Arm Swing | | | | | | | | |
| Pre-Test | 1 | 1 | 3 | 1 | 1 | 3 | 1 | 1 |
| Post-Test | 3 | 3 | 3 | 1 | 1 | 3 | 1 | 1 |
| Arm Lift | | | | | | | | |
| Pre-Test | 3 | 2 | 2 | 1 | 1 | 1 | 2 | 1 |
| Post-Test | 3 | 3 | 3 | 1 | 1 | 1 | 2 | 3 |
| Left Arm Down | | | | | | | | |
| Pre-Test | 3 | 1 | 2 | 1 | 1 | 1 | 2 | 2 |
| Post-Test | 3 | 2 | 2 | 2 | 1 | 1 | 2 | 3 |
| Totals | | | | | | | | |
| Pre-Test / Post-Test | 8/12 | 7/11 | 8/10 | 5/7 | 5/4 | 6/7 | 7/7 | 6/9 |

subjects improved the heights of their jumps from the pre-test to the post-test. The author believes again that this was a result of the vertical jump not being overlearned by the subjects. The instruction group did not perform the jumps as smooth integrated wholes but rather in parts due to their conscious attention to details. When the highest speed possible is desired at the moment of take-off, the speed of each successive member should be faster than that of its predecessor, and ultimately in the direction of the objective (6). When an individual is thinking of each part of a movement pattern, he loses the timing between successive parts and thus decreases the efficiency of his movement which ultimately affects the outcome or quantity of his performance.

Summary

The subjects in the instruction group improved the quality of their performance as compared to the subjects in the non-instruction group. The data did not support however, the belief that there was a direct relationship between the quality of movement and the quantity of movement and that if the quality of movement improved, then the quantity would also improve.

## SUMMARY

In the investigations that dealt with the center of gravity of the body, the author found the center of gravity does travel in a parabolic path once the subject becomes airborn. It was also shown that changes in the position of the center of gravity during flight can aid the subject in gaining more height with his reach.

It was found that there were no significant improvements in the vertical jumps for the eight subjects following 60 practice trials. There was also no significant difference between the group which received instruction and the group that did not receive instruction in a comparison of the center of gravity from the standing reach to the heights of their jumps. However, the investigator found the standing reach measure was not a reliable measure on which to base the vertical jump.

In a comparison of the center of gravity of the foot to the gravitational line of the body, it was found that in every case, the gravitational line was forward of the center of gravity of the foot at take-off. There was no difference between the groups.

The best jumps for each of the subjects occurred when they had the greatest velocity and an angle of projection nearer the vertical. There was no difference between groups in these measures. The degree of knee flexion, ankle flexion, and body lean influence the amount of force that can be generated in vertical jumping. However, no attempt was made to compare these measures between the two groups.

The subjects in the instruction group improved the quality of their performance over the subjects in the non-instruction group. However, the data did not support the belief that there was a direct relationship between the quality of movement and the quantity of movement and that if the quality of movement improved, then the quantity would also improve.

## Chapter 5

## SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A brief summary of the thesis is given first, stating the problem, the purpose, and the basic procedures followed. After the summary will be a list of the general findings of the study followed by conclusions based on these general findings. Recommendations for further study are then made by the author.

### SUMMARY

The problem of this study was whether quality or quantity of movement should be stressed in the teaching and learning of skills. The purpose of this study was to: (1) analyze through motion picture photography mechanical changes that occur from initial learning of a vertical jump, through a learning phase, to mastery of the skill, and (2) to determine if quantitative changes accompany changes in the quality of movement in vertical jumping.

A total of eight nine-year-old boys served as subjects for investigation. A pre-test consisting of the filming of a standing reach and two vertical jump trials for each subject was carried out. The subjects were then divided into two groups. Group One subjects received instruction during practice on how to perform a vertical jump, while Group Two subjects received no instruction during practice.

A post-test filming was then carried out which involved the same procedures as the pre-test.

After the film had been processed, every fourth frame of the film was analyzed using a 16 mm Recordak Film Analyzer. Various comparisons, measurements, and evaluations were made based on the information gained from the analyzation. These findings are listed below.

## FINDINGS

The following is a list of findings based on the analyzation of the pre-test and the post-test films of the eight subjects performing the vertical jump.

1. There were no significant improvements in the vertical jumps for the eight subjects following 60 practice trials.

2. There were no significant differences between the group which received instruction and the group that did not receive instruction in a comparison of the center of gravity from the standing reach to the height of their jumps during the pre-test and post-test.

3. The standing reach measure was not a reliable measure upon which to base height gains.

4. Measurement of the horizontal distance of the center of gravity of the foot to the gravitational line of the body for the eight subjects during their performance of the vertical jump showed that in every case, the gravitational line was forward of the center of gravity of the foot at take-off.

5. The highest jumps occurred when the subjects had the greatest velocity at take-off.

6. In all but one instance, the best jump between the pre-test and the post-test was when the angle of projection was nearer the vertical.

7. A combination of the angle of projection nearer the vertical and a greater velocity at take-off resulted in the best jumps.

8. The subjects in the instruction group improved the quality of their performance over the subjects in the non-instruction group.

9. The data did not support the belief that there was a direct relationship between the quality of movement and the quantity of movement and that if the quality of movement improved, then the quantity of movement would also improve.

10. The sixty practice trials performed by the subjects in this study did not allow the subjects adequate time to respond consistently and automatically when performing the vertical jump.

## CONCLUSIONS

The following conclusions are based on the findings of this study:

1. It is possible to gain accurate information through the analyzation of motion picture film involving both qualitative measurement and quantitative measurement.

2. Quantity changes in movement do not necessarily accompany changes in the quality of movement in vertical jumping.

# RECOMMENDATIONS

The following recommendations were based on the review of literature, the results, and the conclusions of this study.

1. Simultaneous filming in a second or third plane of the body would aid in gathering data. This is especially true when the subject exhibits rotation about a body axis. Possibly the placement of mirrors could provide for multiple plane pictures.

2. Filming at a faster speed than the 64 frames per second used in this study would decrease the amount of image blurring that would occur.

3. A force platform could be used to obtain immediate data on the amount of force that each subject was able to generate at the take-off point.

4. Electrogoniometers attached at the elbow joints, hip joints, knee joints, and ankle joints would yield accurate data on the joint actions, the range of movement, and the speed of the movement.

5. Measurements recorded on computer cards and fed through the computer would speed up the analyzation process.

6. The learning design should be changed to include: more practice trials, more time between practice trials so that the subjects will have time for some rest and some mental practice, the practice periods spread over a three or four week period instead of a three day period, and that more individualized feedback be given to the subjects concerning their performances since each subject has his own unique problems and learning rate.

7. The subjects should practice in a situation that is very similar to the filming environment so that they become at ease with the situation.

8. A study like this should be done, but it should include a larger sample size so that meaningful statistical comparisons can be made.

9. It would be advantageous to film possibly one or two times between the initial filming and final filming, especially if the training-learning period was lengthened to at least three or four weeks. This would help in tracing the learning that is taking place.

10. It would be interesting to include female subjects as a part of the study to determine mechanical differences that might exist because of male/female differences.

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# REFERENCES


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# APPENDICES

# APPENDIX A

## The Segmental Method

The segmental method is a method used to determine the center of gravity of a total body, especially when that body is in motion. To use the segmental method, the following information is needed: the percentage of the total body weight of each segment; the location of the center of gravity of each segment; the horizontal distance of each center of gravity from a vertical line; and, the vertical distance of each center of gravity from a horizontal line. (8:172)

Each body segment was defined as listed below:

Trunk - The top of the sternum to the crotch.
Head and Neck - the targus of the ear to the top of the sternum.
Right Thigh - the greater trochanter of the right femur to the lateral condyle of the tibia.
Right Lower Leg - lateral condyle of the tibia to the lateral malleolus of the fibula.
Right Foot - the lateral malleolus of the fibula to the end of the great toe of the right foot.
Left Thigh - the greater trochanter of the left femur to the lateral condyle of the tibia.
Left Lower Leg - the lateral condyle of the left tibia to the lateral malleolus of the left fibula.
Left Foot - the lateral malleolus of the left fibula to the end of the great toe of the left foot.
Right Upper Arm - the acromion process of the right scapula to the lateral epicondyle of the humerous.
Right Lower Arm - the lateral epicondyle of the right humerous to the styloid process of the right ulna.
Right Hand - the styloid process of the right ulna to the tip of the middle finger.
Left Upper Arm - the acrimion process of the left scapula to the lateral epicondyle of the humerous.
Left Lower Arm - the lateral epicondyle of the left humerous to the styloid process of the left ulna.
Left Hand - the styloid process of the left ulna to the tip of the middle finger of the left hand.

Given next is a list of the body segment, the percentage of the segment that its center of gravity is located, and the proportion that the segment contributes to the total body weight.

| Body Segment | % Segment | Prop. Body Weight |
|---|---|---|
| Trunk | .4500 | .5140 |
| Head and Neck | .5000 | .0790 |
| Right Thigh | .4330 | .0965 |
| Right Lower Leg | .4330 | .0450 |
| Right Foot | .4290 | .0140 |
| Left Thigh | .4330 | .0965 |
| Left Lower Leg | .4330 | .0450 |
| Left Foot | .4290 | .0140 |
| Right Upper Arm | .4360 | .0265 |
| Right Lower Arm | .4300 | .0155 |
| Right Hand | .5060 | .0060 |
| Left Upper Arm | .4360 | .0265 |
| Left Lower Arm | .4300 | .0155 |
| Left Hand | .5060 | .0060 |

By knowing the X-Y coordinates of each segment, the center of gravity of the total body can be located. To find the X coordinate, the proximal X coordinate of the segment is subtracted from the distal X-coordinate. This difference is then multiplied by the percent of the segment. This product is added back to the proximal X-coordinate for the center of gravity of the segment. Then to find the center of gravity of the total body, each X-coordinate for the center of gravity of the segment is multiplied by its proportion of body weight and then all of these segment products are added together to yield the X-coordinate of the center of gravity for the total body. The same procedure is followed to obtain the Y-coordinate of the center of gravity of the total body.

APPENDIX B

Subject Participation Consent Form

BIOMECHANICS RESEARCH
Department of Health, Physical
Education, and Recreation
Kansas State University
Manhattan, Kansas

Date ______________

I ______________ have volunteered as a subject for a research study that will utilize motion pictures in the analysis of mechanical differences in performance of a vertical jump for boys. The study will also be concerned with the quality as well as the quantity of the performance. I understand that all this study requires of me is the following:

1) to be marked with tape at various joint centers in order to facilitate film analysis,
2) to participate on four different days the following:

Day 1 - perform initial vertical jump for filming and perform twenty practice trials.
Day 2 - perform twenty practice trials of the vertical jump.
Day 3 - perform twenty practice trials of the vertical jump.
Day 4 - final filming of the vertical jump.

In consideration of the instructions furnished to me, I hold harmless any and all personnel of Kansas State University for claims and demands resulting from participation in the testing program described above. I fully understand the nature of the testing procedures described and desire to participate.

______________________ Date ______________
Subject's Signature

I ______________________, guardian of ____________________ agree to the participation of my son in the research project described above and conducted by Karen Wallace. I waive any possibility of damage which may occur to him which may be blamed upon the program and accept the responsibility for him being in this study.

____________________________ ____________________ Date ______________

Guardian's Signature Phone Number

# APPENDIX C

## Personal Data Sheet

Name ______________________________ Subject no. __________
Address ___________________________ Phone ______________
Age __________ Birthdate ________________
Height __________ Weight ____________

Group assigned to: ______________________________

Upper leg length ________________
Lower leg length ________________
Lower arm length ________________
Upper arm length ________________
Foot length ________________

Measurement constants:

Specific markings:

Movement description:

Camera settings:
shutter:
ASA number :
Focal setting:

Distance of camera from subject:

Height of camera:

Distance of lights from subject:

Other information:

# APPENDIX D

## Recording Sheet for X - Y Coordinates

Subject __________
Trial __________

Frame

| | | stand. reach | | 1 | 5 | 9 | 13 | 17 | 21 | 25 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| crotch | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| sternum | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| ear | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| rt. hip | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| rt. knee | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| rt. ankle | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| rt. foot | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| l. hip | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| l. knee | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| l. ankle | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| l. foot | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| rt. shou. | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| rt. elbow | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| rt. wrist | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| rt. fing. | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| l. shou. | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| l. elbow | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| l. wrist | x | | | | | | | | | | |
| | y | | | | | | | | | | |
| l. fing. | x | | | | | | | | | | |
| | y | | | | | | | | | | |

# APPENDIX E

## Checklist for Quality Movement

### Head Position

#### Superior Quality-3

The head alignment begins forward. The eyes continue to follow the hand so that the subject is watching where he contacts the board.

#### Average Quality-2

The head alignment begins forward. The subject continues to watch the same spot on the wall so that the head alignment does not change.

#### Poor Quality-1

The head alignment begins forward or down. As the subject executes his jump, the head alignment remains in a downward position.

### Preliminary Arm Swing

#### Superior Quality-3

The subject begins with the arms at his sides, swings the arms up to approximately shoulder height, then backward, then forward again. Both arms swing together.

#### Average Quality-2

Begins with the arms at the sides. The subject swings the arms back, then forward. He swings both arms, but they are not swung together.

#### Poor Quality-1

The subject may or may not begin with his arms at the sides. Subject does not swing one or both arms.

### Arm Lift

#### Superior Quality-3

Subject lifts with both arms all the way up. He stretches his arms overhead. There is good pendulum action and the swing contributes to the lift.

Average Quality-2

The subject lifts with both arms to at least shoulder height, but does not lift all the way up. There is not a good stretch or pendulum action with the arms.

Poor Quality-1

The subject lifts with only one arm or with both arms but the arms never go above chest height. There is no stretch or pendulum action.

Thrusting of Left Arm Down

Superior Quality-3

Just prior to the highest point of the jump, the left arm is thrusted downward. The arm is lowered in a smooth and coordinated action.

Average Quality-2

The arm is above shoulder height and is lowered sometime during the pre-flight but not just prior to the high point of the jump.

Poor Quality-1

The arm remains up or it never reached at least chest height. Therefore, there is no thrusting of the left arm downwards.

# A CINEMATOGRAPHICAL ANALYSIS OF MECHANICAL DIFFERENCES IN THE VERTICAL JUMP THAT OCCUR THROUGH LEARNING

by

KAREN E. WALLACE

B. S., Eastern New Mexico University, 1973

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AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

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1974

Most people tend to use the quantitative outcome of a movement as the criterion measure of a good or a poor performance instead of looking at the quality of the movement itself. However, quality movement is very important as it allows the individual to move more effectively and efficiently. It enables him to move at the performance level of which he is truly capable.

The purpose of this study was to cinematographically analyze mechanical changes that occur from initial learning of a vertical jump, through a learning phase, to mastery of the skill and then, to determine if quantitative changes accompany changes in the quality of movement in vertical jumping.

A total of eight nine-year-old boys served as subjects for the study. A pre-test consisting of the filming of a standing reach and two vertical jump trials for each subject was carried out. The subjects were then matched according to leg length and divided into two groups. A practice period consisting of sixty practice trials over a three-day period was then administered to each of the groups. Group One subjects received instruction during practice on how to perform a vertical jump, while Group Two subjects received no instruction during practice. A post-test filming was then done which involved the same procedures as the pre-test.

Results were obtained by film analysis of the pre-test and post-test films. Comparisons were done on the results through the use of the t-test for related samples and the student's t-test. The statistical treatments revealed that there were no significant differences in the two groups as to the height they were able to jump. Other results showed no significant differences in the two groups concerning the position of the center-of-gravity of the body in relation to the foot position at take-off, velocities of the center-of-gravity, angles of projection, and degrees of ankle, knee, and hip flexion.