A STUDY OF THE INTERRELATIONSHIPS OF SELECTED MECHANICAL, SKELETAL, AND ANTHROPOMETRIC VARIABLES, AND SKILLED PERFORMANCE IN THE STANDING LONG JUMP FOR THREE AND ONE HALF YEAR OLD GIRLS

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This is to certify that the

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Mary Lou Stewart

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[signature]
Major professor

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ABSTRACT

A STUDY OF THE INTERRELATIONSHIPS OF SELECTED MECHANICAL, SKELETAL, AND ANTHROPOMETRIC VARIABLES, AND SKILLED PERFORMANCE IN THE STANDING LONG JUMP FOR THREE AND ONE HALF YEAR OLD GIRLS

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The purposes of the study were threefold: (1) to delineate the mechanical, skeletal and anthropometric variables most highly associated with and divergent from skilled performance through cinematographical analysis of the entire standing long jump; (2) to examine the interrelationships of these variables; (3) to present descriptive information pertinent to the development of skilled performance in the standing long jump in childhood education.

The research subjects were 19 Caucasian girls, chronological ages 40 to 44 months, from the upper socio-economic level of society. Testing procedures were completed in 1966 at the Merrill Palmer Institute in Detroit, Michigan. Eight anthropometric measurements were made; an Xray of the left hand was taken and assessed for individual bone age and skeletal age by Dr. S. Idell Pyle; a Walker Compliance Rating, reflecting motivation, was assigned; pediatric histories of each girl were obtained from the family physician; and measurements of 35 selected mechanical variables were completed. Comparison was made between the research subjects and the Wisconsin

criterion subjects (the skilled performers) on mechanical variables. This comparison (rank with criterion) was included as a variable.

Complete data which met the standards of the investigation were available for nine of the 19 girls tested. Three matrices were developed: mechanical, skeletal, and anthropometric. Distance jumped, Walker Compliance Rating, and rank with criterion were included in each matrix as variables. An elementary linkage analysis was completed for each matrix, then 33 variables were selected from the three matrices so a final elementary linkage analysis could be developed. The data and film record were also analyzed by inspection.

The major findings of the study, presented within the context of the limitations of the design, were:

1. Similarities in movement patterns between the research subjects and the Wisconsin criterion subjects were more pronounced than differences. Except for take-off angle of the shoulder, angular measurements in the lower segments of the body were similar for the two groups as were average angular velocity measurements of the lower segments, the trunk and the head.
2. Movement patterns which approached skilled performance appeared to associate with greater physical maturity in terms of an increase in developmental age of specific bones, and an increase in weight, length and girth measurements.
3. The mechanical variables related to the skeletal and the anthropometric variables, but the skeletal and the anthropometric variables did not interrelate.
4. Throughout the analyses, a decrease in time spent in force

application and an increase in average angular velocity of the thigh during that time associated with skilled performance.

5. Generally, differences found in performance patterns between the research subjects and the Wisconsin criterion subjects were arm pattern relationships that could be discerned at the time of filming.

There are two major implications for structuring teaching and learning experiences in early childhood education. First, it is recommended that achievement standards of performance: (a) reflect variability of individual difference; (b) be constructed in percentile charts; (c) serve as diagnostic tools for teacher evaluation of specific developmental levels achieved by an individual child; (d) form the basis for programming specific activities for the individual child based on his level of development. Second, it is recommended that learning experiences be structured for the child to sequentially develop skilled performance. Using the diagnostic tools described above to assess status, the teacher would recognize the next sequence of development of skilled performance. A model of sequential development of form for the fundamental motor skills needs to be designed. A suggested model is presented. The beginning stages, occurring during early childhood education, would be primarily descriptive. Namely, the experiences would be structured around such questions as, first, "Can you jump quickly?", and secondly, "How did you move your arms?". The use of equipment has been suggested.

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Dr. Candace Roell was a constant source of moral support.

My brother and his wife gave financial assistance and warm encouragement over the years.

This is a study of children. Ethics dictate that they and their parents remain anonymous, but without their interest and cooperation, there could have been no investigation.

The author is in great debt to these people.

DEDICATION

This study is dedicated with deep affection and admiration to the memory of Ruby M. Reebel and A. Earl Brant, M.D. They were fine people who hoped to see this investigation completed. Both of them loved all children, especially those in their families, and devoted their lives to them.

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CHAPTER I

THE PROBLEM OF THE RESEARCH

Introduction

Man, in large measure, expresses himself in terms of overt motor behavior or movement patterns. The development of motor behavior is complex and interesting. As Stott (68) has aptly stated, motor or overt behavior undergoes great developmental changes during infancy and early childhood. The child must learn what motor skills he possesses or can possess.

It is through the human achievement of standing and walking against the force of gravity that the baby, relatively immobile at birth, becomes an autonomously mobile individual. Once the child has mastered the skill of walking, other locomotor patterns develop. They include the run, leap, hop, jump and gallop. The child moves from milestone to milestone as he progresses from one motor skill achievement to another.

During the 1920's and 1930's, the child growth and development specialists documented, in terms of normative patterns, the key age ranges for accomplishment of the tasks enumerated above. However, their documentation focused on achievement per se rather than quality of movement. For example, in the Bayley (5) scale of motor development, the milestones were represented by succinct achievement standards: pulls self to feet, walks on tip toes, jumps with both feet. Another difficulty present in earlier investigations was disregard, at times, for possible contributing variables such as sex, developmental age, length and girth measurement, and social-cultural status.

One cannot negate the contributions made by the early investigators. The need now is for an extension of their work in terms of appraising the neuromuscular efficiency of the child and his degree of skill in performing the task. Hellebrandt *et. al*. (43:23) have summarized the problem as follows:

> Much of the motor growth and development information available in the literature is descriptive. Furthermore, the picture is drawn with broad strokes that present changes in the form and character of performance in the most general terms. Too little consideration has been given to the evolution of those spatial and sequential components of neuromuscular patterning which grant to purposeful movement the qualities so readily recognized a skill....

One technique which presents opportunities for detailed analysis of the quality of movement by yielding quantitative data is that of cinematographical analysis of the mechanics of movement. In many ways movement in the human body, which operates largely as a third class lever system, is analogous to that of a machine. The laws of physics can be applied to human motion both on a theoretical and a practical basis. In the latter case, film records can be obtained of performance and a frame by frame mechanical analysis can be conducted on the cinematographical data. Bunn (12:275) has explained the procedure.

> The direction of movement, related body movements, sequence of movements, speed, force, distance, angles, conditions of equilibrium and so forth may be determined directly or indirectly by means of the analysis of motion pictures.

The present study has focused on one aspect of human movement, the development of a specific motor pattern, jumping, in young girls. The jump was selected for study for a variety of reasons. Jumping is recognized as one of the fundamental locomotor activities in physical education; elementary games, team sports, stunts, tumbling, gymnastics, dance, diving, and track and field demand jumping skill. Investigations of jumping represent an extensive area of inquiry. Studies such as the present one must of necessity be delimited in scope. The standing long jump, a structured form of jumping, was selected for filming at an age shortly following inchoation.

From the practical point of view, the action in this skill occurs in the sagittal plane and lends itself to filming with one camera. The standing long jump is a complex, developmental motor task involving the projection of the center of gravity through space. Because of its complexity, this activity offers opportunities for differentiating distinct skill components, such as velocity of levers; these can be related to such selected developmental factors as bone age.

The standing long jump has been included in many physical fitness and motor ability tests from first grade through college. A partial listing would include the American Association for Health, Physical Education and Recreation Youth Fitness Tests, the Army Air Force Physical Fitness Test, the Cozen's Test of General Athletic Ability and McCloy's General Motor Ability Test (52). Carpenter (13) reported a coefficient of correlation of .80 between the standing long jump and eight other tests of motor ability for primary age girls. The standing long jump was one of three measures which became the basis for her general motor ability test in the first three grades. In

Fleishman's words: (29:73)

> ....it is encouraging that our results confirm the superiority of many widely used tests (Broad [Long] Jump, Pull Ups, Softball Throw).

Little information exists concerning emerging movement patterns in the standing long jump. The lack of information extends to the interrelationships of the motor patterns and the developmental, anthropometric, and social-cultural variables in this basis motor skill.

Statement of the Problem

This study was designed to investigate the interrelationships of selected mechanical, skeletal, and anthropometric variables, and skilled performance in the standing long jump for three and one half year old girls. The purposes of the study were threefold: (1) to delineate the mechanical, skeletal, and anthropometric variables most highly associated with and divergent from skilled performance; (2) to examine the interrelationships of these variables; (3) to present descriptive information pertinent to the development of skilled performance in the standing long jump in early childhood education.

Limitations

1. Sample size. An effort has been made in this exploratory study to carefully control variables that could affect performance results and determination of physical developmental status. Chronological age, sex, race, socio-economic classification, investigation

of health history and ability to execute a bipedal take-off were considered and controlled; this resulted in a limitation of the sample size to nine children.

2. Cross sectional research. In cross sectional research, a child is measured (or filmed) once and comparison usually is made against a mean value. "Such studies cannot, however, give us the information we need when it is change or velocity in development which we wish to investigate (27:17).

3. Mechanical variable measurement. Limitations exist in the measurement techniques of mechanical analysis. Measurement technique has not been standardized. When movement out of the sagittal plane occurred to a marked degree in his study, analysis was based on inspection. Determination of segmental inclination, on which average angular velocity is based, was difficult at times because of the roundness of body contours and the impediment of clothing. If variations in movement of the right and left side of the body were evident, the body segment closest to the camera was measured; no body part obscured another to the extent that measurement could not be made. Ossification of the bone landmarks is not complete at three and one half years of age and as close an approximation as possible was made in delineating bone landmarks.

4. Anthropometric measurement. Anthropometric measurement techniques should be based on internationally accepted standards, and in so far as possible, this was done. The children could not be measured nude and five of the eight measurements were made over clothing. This probably contributed to measurement error. Determination of degrees

of pronation and inward rotation of the patella was subjectively based on appraisal by the investigator.

5. Motivation. Dammann (18) found attitude in the completion of a stair-climbing task was related to chronological age. Since motivation may affect performance, the Walker Compliance Rating was included as a variable in this study to reflect motivation in terms of reaction to and enjoyment of the total testing situation. One never knows if a child refuses to participate because he cannot or will not perform. Walker (71) discussed the necessity of specifying difficulties encountered with childhood negativism in reporting research. In the present study, five children irrevocably refused to cooperate and could not be recalled for testing. Their scores are not included in the Walker Compliance Rating.[1] This rating was administered by the investigator without the corroboration of another adult.

6. Power/Strength measurments. Theoretically, Bunn (12) and Broer (9) have specified the importance of leg strength in the standing long jump. The measurement of strength presents problems. Fleishman (29) identified four strength factors: dynamic, static, explosive and trunk strength. The factor loading of the standing long jump on dynamic strength was .35; on explosive strength, .66. Explosive strength was defined as the "ability to expend a maximum of energy in one explosive act." (29:64-67) One important finding was that explosive strength is independent of particular muscle groups. Strength tests were excluded from the present investigation for two

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[1]The Walker Compliance Rating Scale can be found in Chapter III.

reasons: the lack of instrumentation like Metheny's (59) "Dyna: The Hungry Duck" that would appeal to children and the difficulty of measuring explosive strength with a tensiometer. The design of strength measurement techniques for use with young children represents an extensive area of inquiry in itself.

7. Statistical treatment of the data. A cluster analysis was developed from an intercorrelation matrix based on one sample. One should expect some degree of significance of correlation coefficients to be caused by chance alone (42:576). Hays also says: (42:510)

> A related problem with the value of r_{xy} in a sample has to do with selection of cases to appear in the sample, and in particular with systematic restriction of range of X (or Y) values that appear. This introduces a bias in the value of r_{xy}.... the absolute value of the correlation coefficient tends to be lowered by the introduction of such systematic selection.

Definition of Terms

Growth represents "observable increments in general body size including changes in length and weight of the body or body segments, alterations in the tissue components, and changes in the internal organs." (63:442)

Development refers to those "manifestations of physical growth reflected in the expanding functional powers and adjustment capacities of the growing organism." (63:442)

Maturation is a process representing attainment of maximum functional capacity of the various body systems.

Standing long jump denotes a structured form of the skill of jumping in which the individual stands with his feet together on a mat and on a signal projects his entire body through space, for distance, by pushing off with both feet simultaneously. The bipedal take-off from the supporting surface differentiates the jump from the hop and the leap.

Mechanical analysis or cinematographical analysis refers to the process of frame by frame film appraisal in which measurements and computations are made of the position of various body segments and the body as a whole as it moves through space, in time, with direction and force. In this pragmatic approach, one deals with an actual film record and obtains interval data.

Theoretical mechanical analysis is the application of the laws of mechanical physics to human motion in the standing long jump.

Distance jumped, the measurement of achievement in the standing long jump, is measured on the film record and represents the shortest distance between the take-off mark and the point of contact with the mat of the body segment landing closest to the take-off mark.

Criterion measure or skilled performance is the filmed record of standing long jump performance showing the component movement patterns of two, skilled, sixth grade girls in the jump. Determination of degree of skill is based on comparison of distance jumped with national norms (29).

Key reference point frames are specific frames in the motion picture film record. They include the following:

1. Initial standing position frame is the last frame in which the angles at the hip and knee stay constant before decreasing as action begins.

2. Depth of crouch frame is the frame in which the distance between parallel lines on a grid passing through the top of the head and the bottom of the feet is the shortest as the child crouches in preparatory action for power application. If more than one frame shows the same measurement, the reference frame is the one in which the sum of the angles at the hip, knee and ankle are the smallest.

3. Take-off frame is the last frame in which any part of the foot is in contact with the mat before flight through the air begins.

4. Height of parabola frame is the frame in which the "center of gravity" mark on the crest of the ilium reaches its highest point during flight through the air.

5. Landing frame is the first frame in which some segment of the body contacts the mat following flight through the air.

Phases are the divisions of one standing long jump into specific groupings of film frames. The groupings are:

1. Phase I includes the frames from the initial standing position frame to and including the frame immediately preceding depth of crouch frame.

2. Phase II includes the frames from the depth of crouch frame to and including the take-off frame.

3. Phase III includes the frames from that immediately following take-off frame to and including the landing frame

Mechanical variables represent the measurements and computations made from the film record at specific reference point frames in the performance of the standing long jump. They include:

1. Angular measurements at the shoulder, hip, knee, and ankle.

2. Average angular velocities of the arm, trunk, thigh, leg, foot and head.

3. Acceleration,force, angle of projection, and velocity of projection of the total body at take-off. These variables are computed by measuring changes in the center of gravity of the body which is located slightly higher in three year olds than in adults. "Center of gravity" in the present study is a point in the sagittal plane on the crest of the ilium just slightly anterior to the midpoint of the child's body.

4. Time factors: ratios of various phase times to total jump time; time before take-off when the lower arm reaches its maximum vertical height; time of maximum angular velocity of the lower arm before take-off; and time airborne.

5. Ratio of depth of crouch height to initial standing height.

6. Distance jumped.

A complete listing of the mechanical variables can be found in Appendix A.

A maturity indicator in the broad sense is "an identifiable point or stage in the development of a structure (or function) which occupies a fixed position in a series." (68:72-73) In the skeletal system, maturity indicators are the "regular series of changes in form that characterize successive stages of [a bone's] progress toward maturity." (37:34)

Skeletal assessment is the process by which a roentgenogram of a particular child is compared to a radiographic standard of reference for the purpose of determining bone age.

The Greulich and Pyle Radiographic Standard of Reference is based on a series of roentgenograms of the hand and wrist of about 1000 healthy children from Cleveland, Ohio. All were white. While this population of children came from a variety of socioeconomic levels, the majority of them were from comfortable homes and better than average health circumstances. This standard (37) consists of two series of films: the male hand and wrist and the female hand and wrist, respectively. Each film represents the median skeletal developmental level in a particular chronological age array of 100 films which do not vary by more than two percent, chronologically speaking. Since the median is obtained by ranking osseous features of bones individually, for further specificity, the authors have named each standard film the "anatomical mode."

Skeletal age or bone age represents the arithmetical average of the assessed ages of each individual bone of the hand and wrist showing ossification in the roentgenograms of the hands of the girls participating in the study. Determination is based on comparison with the Greulich and Pyle (1959) Standard of Reference. Individual bone ages in this study are the assessments of Dr. S. Idell Pyle.

Skeletal variables are the assessed ages of each bone in the hand and wrist showing ossification in the roentgenograms of the hands of the girls participating in the study. Skeletal age is also included as a skeletal variable.

Anthropometry is the "systematized measurement of man." (61:146) and is based on internationally accepted standards.

Anthropometric variables are the following length, girth weight measurements and foot and leg deviations of the girls in the present study:

1. Standing height
2. Weight
3. Erect sitting height
4. Bicristal width
5. Knee height
6. Thigh length
7. Degrees of inward rotation of the femur viewed at the patella
8. Degrees of pronation of the foot

CHAPTER II

THE RELATED LITERATURE

The review of literature related to the present study will be presented under six headings: (a) jumping, (b) cinematographical analysis of the standing long jump, (c) sex differences in jumping, (d) skeletal assessment, (e) anthropometry, (f) social-cultural factors.

Jumping

In the jump, the body is projected upward or forward into space by a bipedal thrust against the supporting surface. The landing can be made on one or both feet. Previous to the time a child learns to jump, all his efforts have been directed at the propulsion of pushing of one foot against the supporting surface and landing on the opposite foot as in the walk and run. Since the jump involves momentary suspension in the air, some investigators believe it is closely related to the ability to descend stairs (43, 14, 26).

To jump, two concepts must be developed by the child and integrated into the motor system: a bipedal take-off and suspension in the air. Espenschade and Eckert (26) consider the standing long jump with its two foot take-off and landing the most difficult form of jumping. In the present investigation, girls who were unable to jump did a leap. The concept of suspension in the air was present but that of the simultaneous push with both feet was not. Film analysis has shown another factor is involved in skilled performance of the standing long jump: the deliberate move toward imbalance just prior to take-off caused by the thrust of the center of gravity of the total body beyond the base of support.

As the ability to jump emerges in a child's motor skill repertory, many forms of jumping can be observed: in place, off an elevation, over an obstacle, and for attainment of distance.

The early studies focused on achievement based on the abilito to perform the activity and the skill in attaining a specified distance. Several purposes were implied in the design of the investigations. One intent was the consideration of jumping ability as a parameter which could be compared with other parameters such as intelligence and physical growth. Cunningham (17) organized an experimental series of motor tasks with the purpose of viewing gross motor coordination as distinct from general intelligence and physical growth. In the group of 100 children, ages 12 to 42 months, it was noted that more than 50 percent could execute bipedal jumps from an elevation eight inches high by 36 months of age.

Another category of studies was directed at specification of scales and "curves" based on chronological age to show normal range of achievement in various motor skills, including jumping ability. "Motor milestones" or sequence of stages of motor achievement could be identified following development of the scales of age. The scales could also be the basis for appraising a child's total functioning ability and/or determining a particular child's variance from the "norm" performance.

> Neuromuscular functioning does indeed involve the whole person.... Piaget (1952), in tracing the development of mentality in children, refers to the first 18 months to 24 months of life as the "sensorimotor period". During this period the child's activity becomes progressively more complicated, more controlled, deliberate.... The baby's reaching for and grasping of an object held before him involve cognitive awareness. Such acts obviously are directed visually and with awareness and intent. The level of his mental development, however, is judged objectively in terms of the outcome -- the quality of his motor performance. (68:120)

The hurdle jump was designed by Cowan and Pratt (15) as a developmental diagnostic test of motor achievement. The researchers believed maturation was the determining factor in influencing the height achieved in the jump. In order to attain a specific score, a child had to take-off and land with both feet together while performing a standing long jump over a bamboo pole which rested on high jump standards. Cowan and Pratt found, in developing a scale similar to the Gesell Grading System, that at 48 months of age, a child would score below C, and could be considered retarded in motor development if he was unable to jump over the pole at the height of three and one half inches.

The California Scale of Motor Development, consisting of 76 items arranged in order of difficulty, each with its age placement, was developed by Bayley in 1935. The Scale included such abilities as: walks sideways, stands on one foot alone, jumps from a chair. The Scale is now out of print and is presently being revised (7). In scoring, cumulative points are obtained for what the child passes and each child's score is related to the mean and standard deviation of points attained by children the same age. The jump sequence and age placement, adapted from Bayley (5) is as follows:

1.	Jumps off floor, both feet	28. mo.
2.	Jumps from chair	32.1 mo.
3.	Jumps from height of 30 cm.	37.1 mo.
4.	Distance jump, 36 to 60 cm.	39.7 mo.
5.	Jumps over rope less than 20 cm. high	41.5 mo.
6.	Distance jump, 60 to 85 cm.	48.4 mo.

Another Motor Age Scale was developed by McCaskill and Wellman (53). Specific activities were grouped into four main divisions: steps and ladders; ball activities; jumping; hopping and skipping. Motor Age represented the median or point at which 50 percent of the children achieved a given score on a battery. Scores were assigned to various stages of each skill according to the percentage of children at each age who passed them. For example, in the jumping group, jumping 18 inches, alone, with feet together at 37 months of age was assigned a score of 3.

Gesell and Amatruda (35) set the "norm" for the jump with both feet in place at 30 months of age on the Developmental Schedule.

Recently Frankenburg and Dodds (31) published their Denver Developmental Screening Test designed for early detection of delayed development in children. One hundred five test items were finally selected from a battery of 12 developmental and preschool intelligence tests, and were administered to 1036 Denver children between the ages of two weeks and 6.4 years in an effort to find the percentage of children in each age group passing each item. In the standing long jump, the percentile achievements were as follows: 25 to 50 percent of the boys and girls could long jump at 24 to 33 months of age; 75 percent could achieve the skill by 36 months and 90 percent were successful by 39 months.

An additional category in the early investigations involved detailed study of the effects of special practice. In 1935, McGraw published her well known study of Jimmy and Johnny. In the years following the investigation it was found the boys were not monozygotic twins. Under careful experimental conditions, one baby, Johnny, acted as the control and was restricted in activity. Jimmy was stimulated at frequest intervals in the activities he was capable of performing at the time. The program began at age 20 days. The practice of jumping off a pedestal to a mat was instituted when Jimmy was about 14 months old. At approximately 17 months of age he could jump spontaneously off a stool 14½ inches high. Johnny never jumped during the experiment but instead cried intensely as he stood on the stool.

The last category of the early investigations includes, to the author's knowledge, one study. The Gutteridge (38) research was based on direct observation of children in a natural setting as the youngsters engaged in their usual play occupations. Gutteridge found that jumping from a high to a low level was in evidence from 24 months of age on. At three years of age, 42 percent of the children were rated as jumping well which meant their movements were well co-ordinated; there was evidence of accuracy, poise, grace and display of satisfaction. The ratings were based on observations of jumping from heights and over obstacles 12 to 36 inches high.

It is hoped this review of literature has not given the impression that the ages for accomplishment mentioned thus far were to represent rigid, inflexible standards. The above named researchers were well versed in knowledge of children and probably would have subscribed to the interpretation of Gesell and Ilg (36) who called specific tasks like "jumps with both feet in place", growth gradients.

> The gradients are intended to show the overall developmental sequences of behavior rather than rigid standards of expectancy. Individual differences are too great to permit rigid standards rigidly applied. Generous allowances should be made for age variations. (36:221-223)

Cinematographical Analysis of the Standing Long Jump

Pragmatic investigation

As defined in the first chapter, the mechanical or cinematographical analysis of the standing long jump can be appraised from two points of view, the pragmatic and the theoretical. Both approaches have provided bases for selection of mechanical variables in the present study. Variables and measurement techniques are mentioned in the following review of literature.

The first of the analytical studies of the jumping of young children was that of Wilson in 1945. Fewer than ten four year olds were included in this study, an investigation of the three forms of jumping: the running jump, the standing long jump and the vertical jump for children ages four through 12. Wilson used cinematography in her investigation. The camera, with telephoto lens, was positioned 150 feet from the subject; the children were filmed at 24 frames per second and wore outdoor clothing; the investigator resorted to observation to determine arm action. Five angular measurements at each of four reference points (crouch, take-off, crest of flight and landing) comprised the mechanical analysis.

At the time of the Wilson research, measurement techniques were not as refined as later nor was individual segmental position specified to the extent observed in later studies. Optimum depth of crouch "angle" was given in the results without designation of which articulations were included. Take-off angle was measured with the vertical at the back of the hips. These limitations can be understood since this investigation represented a pioneering effort. Wilson found no particular pattern at the crest of flight peculiar to the best or poorest jumpers. She also advanced the theory that any difference in jumping ability among the more highly skilled above the five year age level could be attributed to differences in strength and explosive power rather than movement pattern (76:56).

In Halverson's study (39) as reported in Dissertation Abstracts, five year olds were filmed performing the standing long jump. The 32 kindergarten children were put into age and sex groupings. Each sex group was then further divided into two skill groups on the basis of jumping ability. Each skill division was randomly assigned to practice and non practice groups. Films were taken of the standing long jump before and after a two week practice period in which each practice subject was given 20 minutes of guided practice on five occasions.

Significant differences for the following variables were found between ability groups on initial and final filming: total distance jumped; range and speed of the movement of the knee just prior to take-off; angle of the trunk with the horizontal at thigh perpendicular; and position of the trunk and thigh at take-off. Velocity and angle of projection of the center of gravity distinguished between groups in the initial film record only. The angle of projection of the center of gravity for both groups was below a theoretical best angle. As skill increased, angle of projection decreased.

Hellebrandt, et. al. (43) filmed six preschool boys in their study of the standing long jump. Frame by frame performance of these boys was studied by inspection from films covering a period of four to seven consecutive months. Records of three of the preschool boys were reported. The youngest boy was 14 months old when observation began. Detailed analyses for the other two boys were presented for ages ranging from 30 to 43 months. The first halting efforts of one boy's jumping which involved a step off an elevation, were directed toward maintaining balance. "At 21 months of age, this child could move the center of gravity of the body as a whole sufficiently forward to evoke autonomous ankle joint extension before take-off from a low stool." (43:16)

Hellebrandt, et. al., essentially stressed three characteristics observed in the early phases of jumping. The first was the ability of the boy to restore balance following flight so the integrity of the weight bearing segments could be maintained. Degree of propulsive force engendered was dependent on this ability to restore balance.

The second was the progression in arm motion. Initially the arms and shoulders were retracted during take-off and flight. This became a "full blown 'winging' pattern as the arms were moved behind the body to shoulder height, reaching culmination in one child's performance at 41 months." (43:18-19) At 43 months of age, this same boy first attempted to swing his arms forward during force application.

The researchers also inspected the films taken by Halverson (39) of kindergarten children and found the arms were used as "equilibrators": "abduction at the glenohumeral joint was common and often more marked than humeral advancement." (43:19) In addition, the investigators inspected the films from the Longitudinal Study conducted by the Department of Physical Education for Women at the University of Wisconsin. The investigators found the pattern of using the arms as stabilizers persisted through the elementary school years in most of the performances analyzed. Some "winging" also appeared in these years. The forceful, upward, adult male arm swing involving complete elbow extension and shoulder joint flexion at force application was not found in elementary school aged boys although one skilled boy closely approximated this pattern.

The third characteristic component observed in preschool aged boys was that of head motion. This motion consisted of dorsiflexion during preparatory crouch and ventroflexion as the legs extended for take-off once the concept of jumping for distance was established. At the crest of flight, the "chin in" reached maximum position. The head then dorsiflexed slightly to expedite leg flexion which absorbed landing jar. The purpose of the head motion, according to the researchers, was to "expedite the limb positioning which is most advantageous" by "secondarily evoking the tonic neck reflexes." (43:20)

These researchers discussed the necessity of differentiating between a simple execution of the standing long jump and the forceful projection of the body through space for horizontal distance. The latter, for them, "implied exercise of will and a desire to put forth maximal effort." (43:23) This is a crucial point and differentiation is difficult to assess. Their conclusions were:

> There is nothing in our study which proves that the increasingly efficient utilization of the arms to add momentum to the jump is a learned modification of a more elemental response, proceding under cortical direction. It may be no more than the last of a series of spontaneous changes unfolding in response to endogeneous directional forces but affected to a significant degree by opportunities for practice. It remains for us to determine what aspects of the neuromuscular patterning associated with the execution of so called willed or purposive movement are amenable to modification other than the autonomous modulation induced by gradation in the severity of the effort. (43:24)

More recently, Waterland (72) focused her research on this problem in studying the autonomous head and shoulder girdle patterning in the standing long jump. Waterland defined this patterning as supportive phenomena in the conjecture that skilled movement results from the integration of willed and supportive processes where stress, causing increased sensory input, might be the agent responsible for evoking the mechanism.

Waterland (72) compared five highly skilled and five unskilled college freshmen women in the standing long jump. The measurement technique involved multiple light chronocyclegraph photography supplemented by one stroboscopic picture during filming. The skilled subjects performed three maximal, three moderate and three minimal jumps. The minimal jumps of the skilled women and of the unskilled women were remarkably similar. In general, it was noted that limited mobility of all body segments was present; the arms were held close to the body with a hint of the "winging" pattern discussed previously; the head and shoulder girdle (a supportive component) showed only minimal changes; a marked asymmetrical positioning of the extremities included one footed take-offs. "The skilled subjects suppressed the supportive components of willed movement." (72:21)

Eckert (25) studied the interrelationships of strength and angular measurements during the power application phase of the standing long jump of elementary school boys. She found statistically significant relationships existed at the hip between isometric extensor strength and angular velocity at the point of maximal angular acceleration and at the point of maximal angular velocity.

Zimmerman (78) and Felton (28) each compared the standing long jump performances of highly skilled and unskilled college women. Ten students were in each category in the Zimmerman investigation, five in the Felton research. Zimmerman analyzed the entire standing long jump and divided it into phases. Phase time for each jumper was recorded. Zimmerman observed greater joint action throughout the jump at the ankle, hip, knee and shoulder among the skilled. The results reported by Felton substantiated those of Zimmerman. The skilled women had greater speed of projection developed by greater range and speed of joint action during force application; a lower angle of projection because of greater lean at take-off (21^{o}); a more horizontal leg position on landing; and a lower position at landing permitting longer time in flight.

Theoretical basis

Theoretical mechanical analysis represents an application of the principles of mechanical physics to human movement. In the standing long jump, the principles have been well defined.

> ....The problem is not only to produce sufficient force to overcome the inertia of the body and gravity's pull, but also to control the angle at which this force is applied so that the desired purpose is fulfilled. The force that projects the body into space must be exerted by the muscles of the body. It is produced by quick contraction of the extensors of the legs aided by a forceful arm swing (9:152).

Bunn (12) and Broer (9) discussed the factors influencing the depth of crouch at the height of the preliminary backswing of the arms. Bunn believed the bend of the knees in the preparatory motions should not be extreme and should be in direct proportion to the strength of the leg muscles (12:118). Broer concurred with additional explanation:

> A deeper crouch puts the extensor muscles on stretch and gives a greater distance over which acceleration is possible. However, since the body must be lifted through the distance that it is lowered, more work is done when a low crouch is used, and the angle of muscle pull is also changed. The optimal depth of crouch, therefore, depends upon the strength of the leg muscles. (9:152)

The purpose of the preliminary backswing of the arms is to put the arms in such a position that the swing forward can be executed through as long an arc as possible thus transferring to the body the momentum of the arms (12:117). The arm swing also helps control the take-off angle of the center of gravity which should move in front of the feet as they thrust down and back (9:155).

Proper leg and foot alignment is necessary to insure instability in the forward direction only and to provide force exertion that passes straight through the joint. The legs should be placed hip width apart and the toes should be pointed straight ahead to avoid inward and outward components of force application (9:154-155).

During the action of the standing long jump, the body is projected through the air and is subject to the laws governing projectiles. The objective is attainment of distance and the following formula should apply:

$$R = \frac{V_o \sin 2\theta}{g} \quad (12:28)$$

This formula for distance is not really applicable since the center of gravity of the body drops below take-off level in landing. Bunn's correction (12:33) does not completely solve the problem since it is based on the distance between the foot and the center of gravity remaining constant for both take-off and landing. Take-off velocity of the center of gravity, angle of projection of the center of gravity, and the acceleration of gravity, a constant for a specific place, are the keys to skilled performance according to the formula.

With these limitations, the optimum take-off angle specified by Bunn (12:34) is 40 degrees; by Broer, 45 degrees (9:155). Tricker and Tricker (69) have discussed the fallacy of the 45 degree angle recommendation:

> The one thing which is certain is that the 45 [degree] angle for maximum range of elementary mechanics textbooks has nothing to do with the case. This theory is worked out on the assumption that the velocity of projection remains constant as the angle of projection is varied and this will manifestly not be the case in the long jump... as the angle of projection is increased the velocity of projection will decrease since the body muscles have then to act against the pull of gravity.(69:228).

The authors go on to say that the optimum angle may vary from person to person.

Velocity of projection of the center of gravity can be computed by using the formula, $V_o = \sqrt{\frac{dg}{2 \sin\theta}}$ once distance (d) has been measured on the film. As Cooper and Glassow point out (14:157), the importance of knowing V_o is its value in computing the force developed at take-off.

This force is dependent in part on the nature of the supporting surface and the coefficient of friction between the feet and that surface. The reaction of a mat to the thrust of the feet would not be as great as the reaction of a beatboard to the thrust of the feet. Frictional force on a mat, however, might be greater. One of the limitations of theoretical analysis is the inability to determine mass of separate body segments, mass being a necessary variable in the computation of angular momentum.

Once the body is airborne in the standing long jump, the law of conservation of angular momentum can be applied.

> Once the [jumper] has left the ground there is nothing he can do to increase his forward acceleration, but he can affect the distance achieved by changing the configuration of his body and the relative position of the partial masses.... movements may rotate the hips backward and give greater forward reach with the legs (64:395).

Tricker and Tricker (69:229) state the neuromuscular task involved:

> The problem the long jumper.... has to face is that of getting his heels as far forward as possible on landing, without entailing his having to sit down in the pit.

The feet, behind the hips on take-off, must be swung forward to catch the body weight on landing (9:156). Theoretically, a backward swing of the arms while airborne would assist in the leg swing forward, and on landing, the arms could then be swung forward to add momentum as the trunk moves forward over the feet. Broer says: (9:156)

> This is a difficult co-ordination to perform in the short time available and it is questionable whether any but the most highly skilled will be successful in its use.

The distance in the jump can be increased by extending the reach of the legs just before landing. Cooper and Glassow (14:157) believe the key to the leg reach is the position of the thigh on landing: the more horizontal the thigh, the more skilled the jumper. For safety, kinetic energy (1/2 mv^2) must be lost gradually to prevent injury. This is accomplished by landing on the balls of the feet on a soft surface followed by immediate flexion in the ankle, knee and hip (74:505). Stability is maintained by swinging the center of gravity up over a sufficiently large base of support.

Sex Differences in Jumping

No statistically significant difference was reported in the literature regarding sex differences in the jumping ability of young children. Cowan and Pratt (15) found the existing difference, which was slight, favored girls up to age seven in the hurdle jump. In the standing long jump, Hartman (41) found girls were slightly superior and Wilson (76) reported the median distance jumped by girls was greater than that by boys.

At ages five, six and seven years, Jenkins (46) reported the mean distance jumped by boys was greater than that of girls at the same chronological age but less than that of girls of the next older age group. Halverson (39) noted that five year old boys tended to have a slightly better mean score on distance jumped but in few cases was it statistically significant. However, in skeletal growth, girls mature at a faster rate than boys. On this basis, rather than performance, sample selection in this study was restricted to girls.

Skeletal Assessment

If one is interested in knowing how motor patterns change with age as the child grows and develops, age becomes a key factor. Considerable disparity between individuals may exist within a chronological age because different children have different maturational rates. In the determination of physical development, or the assessment of what is basically an internal phenomenon in the human body, the difficulty is especially acute in the United States.

> As a people we are very heterogenous in national, and to some degree, in racial origin.... In addition, and perhaps more important, there is almost every possible mixture between these and numerous other strains that compose the population of the United States.... There is another factor which makes it difficult to determine the developmental status of children from their age, height and weight alone. The existence of early maturing as well as late maturing strains in our population makes for wide difference in the age at onset of puberty (37:1-2).

Skeletal assessment was included in this investigation so children in the study could be placed on as definitive a yardstick of physical development as possible. Also, association could be established between physical development and neuromuscular skill on a basis other than that provided by age, height and weight.

In 1904, shortly after the development of radiology, J. W. Pryor published his studies of Xrays of children's hands. He believed bones in the female ossify in advance of those in the male; ossification is bilaterally symmetrical; variation in ossification can be genetically determined. The latter point still represents an area of controversy in skeletal assessment today (1:466). In 1909,

T. M. Rotch, after working with Pryor and analyzing 1,000 cases, advanced his theory that the wrist may be accepted as a fairly accurate index of general development (1:466).

If the wrist can be considered to include the hand, subsequent research has generally substantiated the earlier conjectures except for the one regarding genetic determination. In the hand, fusion in distal phalanx II in the female occurs very near the date of menarche and can be substituted for iliac crest ossification (11). Based on a computer programmed intercorrelation matrix of data from the Fels Research Institute longitudinal study, Garn (33) reported that for males the bone of greatest utility, yielding the most information on present or future skeletal status, is the epiphysis of distal phalanx V of the hand. Garn's report was based on onset of ossification - the time of first appearance of the particle of hard bone in the cartilaginous bone model and includes study of 73 bones. In females, the epiphysis of metacarpal III has the third greatest information value; the patella and epiphysis of the distal segment of the first toe are first and second,respectively

Cost, expense, and time are diminished if a roentgenogram of the wrist can be substituted for a series of Xrays of various sections of the body. They can be further decreased if bilateral symmetrical development occurs. Dreizen, _et_. _al_. (23) found that the difference between the skeletal ages of the two hands exceeded three months in only 13 percent of the 450 children studied and more than six months in only 1.5 percent of the cases. Baer and Durkatz (2) reported the same bones are involved when either the right or left hand is maturationally advanced. Specific centers of ossification did not exhibit different bilateral trends.

Following World War I, attempts were made to relate the calcification process as viewed in roentgenograms to chronological age. In the words of Acheson: (1:467)

> the bones themselves were the yardstick, a yardstick of biological stages to which time was related as a dependent variable.

It was T. W. Todd, perhaps with insight from the work of Hellman, who achieved the major breakthrough in skeletal assessment. The first step in his work involved recognition of determinators of maturity, later called maturity indicators[1] by Greulich and Pyle (37). Secondly, in an extensive, carefully controlled longitudinal study, Todd related the maturity indicators experimentally to a population of normal children in Cleveland, Ohio.

The basic procedure involved sequential arrangement of the films in increasing order of maturity for each sex and each chronological age group of 100 healthy children. Chronological age and examination date did not vary in these children by more than two percent. The films chosen as a standard were most representative of the anatomical mode of the particular array. The standard film was then assigned a skeletal age so that time between skeletal ages was comparable to time between chronological ages (37:31-32).

Acheson (1:470) has indicated his measure of respect for the "Cleveland Atlases" which have been twice revised since their original publication by Todd:

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[1] Maturity indicators were defined in Chapter 1.

> Because of the care and thought that have gone into [the] compilation of [the Atlases] and the expertise of their authors--in particular Dr. Idell Pyle, who was a pupil of Todd's and who has made the preparation and publication of these atlases her life's work--they hold a place among standards of reference in child development that is unlikely to be challenged.

Other skeletal assessment procedures exist. Two of the best known are the Oxford Method and the Tanner-Whitehouse-Healy Method. Both are essentially based on the concept of maturity indicators and each attempts to weigh the contribution of various ossification centers through the development of a specified scoring system. Detailed description of these methods is considered to be outside the scope of this paper.

Acheson (1) also has expressed criticism of the "Cleveland Atlases"; one criticism has direct bearing on the present investigation. In the actual process of skeletal assessment, the film of a child is compared to a standard film and subjectively rated. Interpolations must usually be made in determining bone age. Each bone is considered separately. Skeletal age represents the arithmetical average of the ages of all bones in which ossification has begun. Absence of a center is not acknowledged in computation of skeletal age since bones "not present" are rated o. Dr. Pyle has long been cognizant of this problem. In the preparatory phases of the present study, she recommended the author read a series of films for bone age. The series read were partially longitudinal and were taken from the Brush Foundation collection. Dr. Pyle also reread these films. Figure 2.1 shows individual bone ages of two girls chosen at random from this series. Comparison has been made against the standard (37). The bone ages, read according

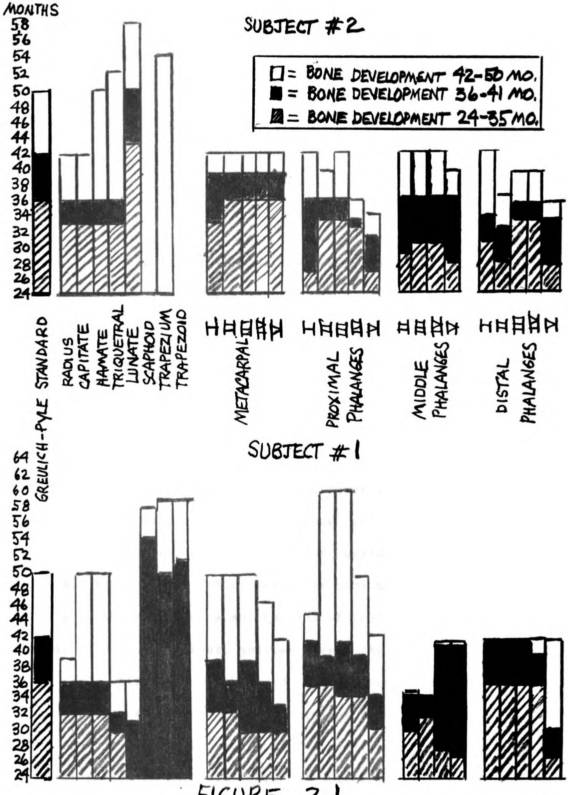

FIGURE 2.1

INDIVIDUAL BONE AGES COMPARED TO GREULICH PYLE (1959) STANDARDS FOR 2 BRUSH FOUNDATION FEMALE LONGITUDINAL SUBJECTS FILMED AT 36, 42, 48 MONTHS OF AGE.

to this standard of reference, indicated that individual differences in progress of ossification were characteristic for the bones in the hands and wrists of these girls. On this basis, it seemed most logical to use the individual bones ages as well as skeletal age as individual variables.

Anthropometry

Garn and Shamir (32:35) discussed the role of anthropometry in past studies of physical growth.

> Anthropometric measurements have played a long and honorable role in studies of physical growth. In fact, the routine caliper and anthropometer measurements beloved of classical physical anthropologists have been the mainstay of most growth investigators.

Anthropometry representing measurement for measurements sake may lack value; hence reasons for including anthropometric data must be clarified. Variables like weight, lever length, bicristal width, foot and leg deviations might influence performance in the standing long jump. Theoretically, a basis for consideration of lever length exists. If two levers of different lengths move through identical angles in the same time span, the end of the longer lever has greater linear velocity. However, shorter levers can be moved at a faster rate (14). Bicristal width could assume importance since the weight of the body must be projected through space in the standing long jump and the center of gravity of the total body is located in the general region of the hips, slightly higher in three year olds than adults. Dissipation of force can occur in the power phase of the standing broad jump unless the child can point the toes straight ahead and bend the knees straight forward over the toes (9:155).

In 1921, Baldwin was Research Professor of Educational Psychology and Director of the Iowa Child Welfare Research Station. At that time he published (3) one of the most extensive reports ever written of anthropometric techniques and measurements conducted on a wide variety of American children of all ages. His annotated summary covers the period between 1875 and 1910. One of the early comprehensive studies which Baldwin cites is that of 24,000 Boston boys and girls made by Bowditch in 1875. Other researchers cited by Baldwin included Peckham, Greenwood, Boaz, Jackson, Barnes, Gardiner and others. Consequently, by 1910, considerable data had been gathered for American children living in various sections of the country. Some 30 years following the Baldwin (3) report, Krogman (50) published an extensive appraisal of anthropometric studies.

However, a problem existing in the early anthropometric studies had not been resolved; measarement techniques had not been standardized. Previous to 1870, the French methods of Broca were followed. A German school developed at the time of the Frankfort Agreement in 1882. Regulation and standardization of measurement became a necessity in anthropometry. Without it, little replication of studies or comparisons could be made. At Monaco in 1906 and at Geneva in 1912, international agreements were reached and anthropometric measurement was standardized (24). Hrdlička was the representative of the United States at both these conventions and the specifications given in his books (44, 45) generally followed the International Agreements. Hrdlička, however, accepted the standards of Martin (51) in definition of measurements not considered precise enough in the International Agreements.

Hrdlička spent one week at the Iowa Child Welfare Research Station and assisted in formulating procedures for the anthropometric investigations of Baldwin (3). By 1936, McCloy, (54) working within the historical context just described, made additional modifications in commonly used techniques to further refine measurement and provide even more rigid standardization.

The McCloy techniques were followed in the present investigation in measurement of erect sitting height and bicristal width. McCloy did not define measurement techniques for determining knee height. The specification of Simmons (67) was the basis of the method used in the present study, although some modification was necessary. At the time of data collection, the measurement techniques followed in the National Health Survey, authorized by Public Law 652, 84th Congress, had not been published.

Cowan and Pratt (15) were the only investigators who reported findings on the interrelationship of height, weight and jumping ability in preschool aged children. They found weight and the ratio of height to weight were not important in hurdle jump skill. The effect of height was negligible in achievement in jumping the hurdle.

The evidence relating height and weight in the elementary school aged child to standing long jump ability, represented by distance jumped, is confusing. Flynn (30) observed a high multiple correlation coefficient of .917 in 12 year old boys when distance jumped was multiplied by body weight and used as the dependent variable in a multiple regression equation with weight, strength index and skinfold total. Degutis (21) reported a multiple correlation coefficient of .408 when distance jumped was correlated with body weight, leg length and lung capacity in boys of the same age.

Wyrick (77) found no significant relationships between performance in the standing long jump and height or weight in 10 to 13 year olds who represented various nationality groups. Seils (66) reported the following partial correlations for first grade girls: standing long jump performance with weight (age held constant), .16; standing long jump performance with height (age held constant), .18; standing long jump performance with weight (height held constant), .10. Despite the fact these low correlations have been reported in the literature, height and weight were included as variables in the present study, which is exploratory in nature.

Social-Cultural Factors

No studies were found relating socio-economic status and race to standing long jump ability in three year old girls. Hellebrandt, et.al. (43) considers the leg action in the standing long jump phylogenetic. Frankenburg and Dodds (31) included the long jump in their Denver Developmental Screening Test which was designed for early detection of delayed development in young children. If jumping ability is inherent in the organism and emerges naturally as a motor skill in normal, healthy children, it could be affected by the same variables that influence other motor skills which appear at the same relative time on the continuum.

The investigation of the literature in this section was undertaken to ascertain first, the influence of race, and secondly, the aspects of socio-economic and family status which affect gross motor skill.

In the United States, specification of race presents problems. Over 30 years ago, McGraw (55:91-92) discussed the difficulties.

> ....Studies concerning racial characteristics of the American Negro, more properly the American amalgam, suggest the following inferences:
>
> 1. The American Negro is the product of White and Negro miscegenation.... Herskovits [has estimated] that about 80 percent of the American Negro population has some white blood in its heritage....
>
> . . . .
>
> 4. Results of studies of Negro racial characteristics in America have been clouded by two very serious experimental handicaps: (a) the degree of admixture of white blood and (b) the effect of environmental factors upon the performances of Negroes.

In 1931, McGraw found a difference in sitting unsupported which favored the Negro baby on the Hetzer Wolf Baby Tests, but the difference was not significant. In 61 white infants, Bayley and Jones (8) reported more rapid early mental and motor development in children from low socio-economic groups. Brožek (10) and Gerber (34) reported a remarkable superiority of African children in psychomotor skills. Gerber defined specific child rearing practices which she thought might have accounted for precocity on all aspects of the Gesell Schedule and Thomas Tests.

In a 1953 study, Negro babies were superior to white in gross motor behavior on the Gesell Schedule up to age two (48). Williams and Scott (75), in a further delineation of this finding, compared Negro babies from upper and lower socio-economic levels. The mean Development Quotient based on the Gesell Schedule was higher for the lower group. An interview schedule was conducted in which Williams and Scott discerned a significant biserial correlation between Developmental Quotient and child rearing practice which they acknowledged was difficult to assess. Permissiveness, flexibility and lack of restriction enhanced motor development on the Gesell Developmental Schedule.

On a 12 step neuromuscular scale, Scott, _et_. _al_. (65) reported similarity between white and Negro babies whose physicians were engaged in private practice. This pattern persisted until 30 weeks of age when the Negro mother usually returned to work. Then the Negro baby who had a private physician began to approximate the Negro baby who attended the clinic. On the Revised California Infant Scale of Motor Development, in a representative United States sample, the Negro baby scored consistently above the white on the Motor Scale (6). Bayley attributed this difference to a genetic factor because no differences for educational subgroups were observed. Finally, in 1966, Knobloch and Pasamanick (49) reported that the Negro and white baby were equal in motor development on the Gesell Schedule and motor performance was accelerated over the norms reported a decade or two ago.

Maternal (sensory) deprivation apparently influences motor performance. Provence and Lipton (62) found that phylogenetic activities of the first few weeks were not affected by institutionalization. But sitting, creeping, standing and walking were retarded perhaps because of lack of sensory stimulation. Patton and Gardner (60) reported marked retardation in children, ages 13 to 36 months, who came from seriously disrupted environments. No child in their study was walking. In both these investigations, deviant motor behavior like excessive rocking was noted.

The evidence regarding the influence of special practice on motor skill achievement is sparse and controversial. McGraw (56) did not find extra practice influenced motor skills of the first year of life except for the assumption of erect posture. However, additional practice did affect performance in jumping off a stool. Dennis and Dennis (22) observed no difference in age of walking for Hopi Indians who had been cradled as opposed to those who had not.

The applicability of the findings cited above is dependent on knowledge of degree of specificity in gross motor skill in the first years of life. Cratty (16:198) stated that "after the age of two, ... motor abilities, which had been more closely related during infancy, tend to become more specific, a trend which continue(s) into adulthood." Bayley (6:409) wrote that there is "ample evidence that within normal limits, developmental status in the first year of life is a poor predictor of later mental and motor functioning." Whether or not the principle of specificity is characteristic of jumping at three and one half years is questionable.

The weight of the evidence cited in this section seemed to dictate that the sample in the present investigation should be restricted to girls of one race from home environments in a specific socio-economic level of society.

Summary

The review of related literature which has been presented in Chapter II suggests:

1. The ability to jump for distance emerges in the motor skill repertory of most children sometime between two and four years of age. However, only two studies have been directed at observation of the components of the total skill pattern in the standing long jump during this age period. Analysis in one study was on inspection. In the other study, the camera, filming at 24 frames per second, was positioned 150 feet from the performers who wore outdoor clothing.
2. Cinematographical analysis can be approached from pragmatic and theoretical points of view. To the author's knowledge, no study has attempted to include all the apparently pertinent mechanical analysis variables involved in the standing long jump.
3. The evidence regarding sex differences in jumping ability is controversial indicating need for restriction of the sample to children of one sex.
4. Extended efforts have been directed at the development of skeletal assessment as a more accurate indicator of physiological maturity than age, height and weight. The Cleveland Atlases are recognized as an excellent standard of reference

in this area. In skeletal assessment the hand can be accepted as a fairly accurate index of skeletal development and specific ossification centers do not show bilateral trends. Finally, justification exists for analysis of individual bone ages in the hand.

5. To the author's knowledge, no studies have been conducted for preschool children which included the effects of lever length, bicristal width, leg and foot position on standing long jump performance. Nor is there evidence regarding the interrelationship of height, weight and skill in this motor activity at this age. Also, anthropometric measurement techniques should be based, in as far as possible, on internationally accepted standards.

6. Much of the research concerning gross motor skill development in the first four years of life has been done by specialists in child growth and development. They have also studied the interrelationship between motor skill and child rearing practice, race and socio-economic status. The weight of the evidence provides justification for the restriction of these factors in sample selection.

CHAPTER III

METHODS

Overview

This study was designed to investigate the interrelationships of selected mechanical, skeletal and anthropometric variables and skilled performance in the standing long jump for three and one half year old girls.

Selection of the Total Group of Subjects

This investigation was conducted at the Merrill Palmer Institute in Detroit, Michigan, during the winter of 1966. Permission was given to the investigator to contact the parents of the girls of the white race, chronological ages 40 to 44 months,[1] who were enrolled in the Merrill Palmer Institute Nursery School. Alumnae of the Merrill Palmer Institute who operated nursery schools in the suburban Detroit area, the Director of the Wayne State University Nursery School, and interested staff at the Merrill Palmer Institute assisted the investigator in obtaining

[1] Hellebrandt and her associates (43) had observed complete neuromuscular patterning including movement of the arms forward during force application in the standing long jump performance of a boy 43 months of age. On this basis, 42 months, or three and one half years, was selected for study in the present investigation.

names of parents from the upper socio-economic class[1] with eligible girls.

Letters were sent to 21 parents explaining the purpose of the research and the procedures involved.[2] After a lapse of a few days, the investigator called the parents on the telephone to ascertain their decision regarding particpation in the study. If the parent consented, arrangements were made for a filming appointment. At least one parent accompanied each of the 19 girls who actually came to the Merrill Palmer Institute to participate in the investigation.

General Procedures

The filming of the standing long jump, the anthropometric measurements, and the roentgenogram on the hand were all done in the basement of the Program Building at the Merrill Palmer Institute. The girls wore stretch pants and a T shirt under their winter snowsuits so it was unnecessary to change clothing for the testing. Some of the girls were apprehensive about removing their shoes and they were permitted to keep them on. The parent(s) remained in the room while the girl was measured and filmed. During that time,

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[1]Two studies were the basis for selection of the demographic characteristics for socio-economic level of classification. Bayley (6) included race, sex, sibling status, education of the parents, and geographic residence. The National Health Survey (70) designated place, age, sex, race, marital status, educational level, occupation, and income.

[2]A copy of the initial letter sent to the parents explaining the study and the procedures involved can be found in Appendix C.

a secretary worked with the parent(s) and recorded the data for the Parental Record Form and the Parental Permission Form.[1] The investigator recorded information on the Child's Record Form[2] as the girl was tested.

Measurement Procedures

Anthropometric

Anthropometric data were obtained first. They are listed in Table 3.1 along with the specification of the technique followed.

Cinematographical

Next, three trials of the standing long jump were filmed.[3] Each girl was given an opportunity to practice one jump and to push the shutter on the camera so she could hear it run. A 16 mm. Bell and Howell camera was used. It was placed on a tripod and was equipped with a Hokuto f2.7, 17mm. lens. The camera was operated at 64 frames per second and was loaded with Kodax Tri X black and white reversal film. Figure 3.1a shows the camera and light placement in relationship to the mat. Figure 3.1b shows the wall markings in reference to the girl's position as she stood

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[1]Copies of the Parental Record Form and the Parental Permission Form can be found in Appendices D and E.

[2]Copies of the Child's Record Form can be found in Appendix F.

[3]The following results have been reported on the reliability of the standing broad jump: (a) 1 trial on a 2 footed hop with hop 2 weeks later in 3 year olds: .98 ± .004 (73); (b) Between second and third jump of 3 trials, 4 year olds: ± .849 (76).

TABLE 3.1--Anthropometric Data Collected and Specification of Measurement Technique Employed

Anthropometric Data Collected	Measurement Technique
Standing height (inches)	Damon (19)
Weight (pounds)	Girl was weighted with shoes, slacks, shirt on.
Erect sitting height (inches)	McCloy (54)
Bicristal width (inches)	McCloy (54)
Thigh length (inches)	Derived measurement. For computation, erect sitting height was subtracted from the sum of standing height and knee height.
Knee height (inches)	Variation of Simmons (67) Measurement was made with an anthropometer from the top of the sole of the shoe to the joint space of the knee, lateral aspect of leg.
Degrees, pronation (1, 2, or 3)	Subjective rating. A score of 3 represented marked deviation.
Degrees, inward rotation patella (1, 2, or 3)	Subjective rating. This deviation occurs at the hip but was observed at the knee. A score of 3 represented marked deviation.

ready to jump.

The girl was placed on the mat in the initial standing position with her toes touching the toe mark. No take-off board was used. The acromion process of the scapula and the crest of the ilium just in front of the midpoint were marked by sticking a 1/4 inch square piece of mystic tape on the girl's clothing at these

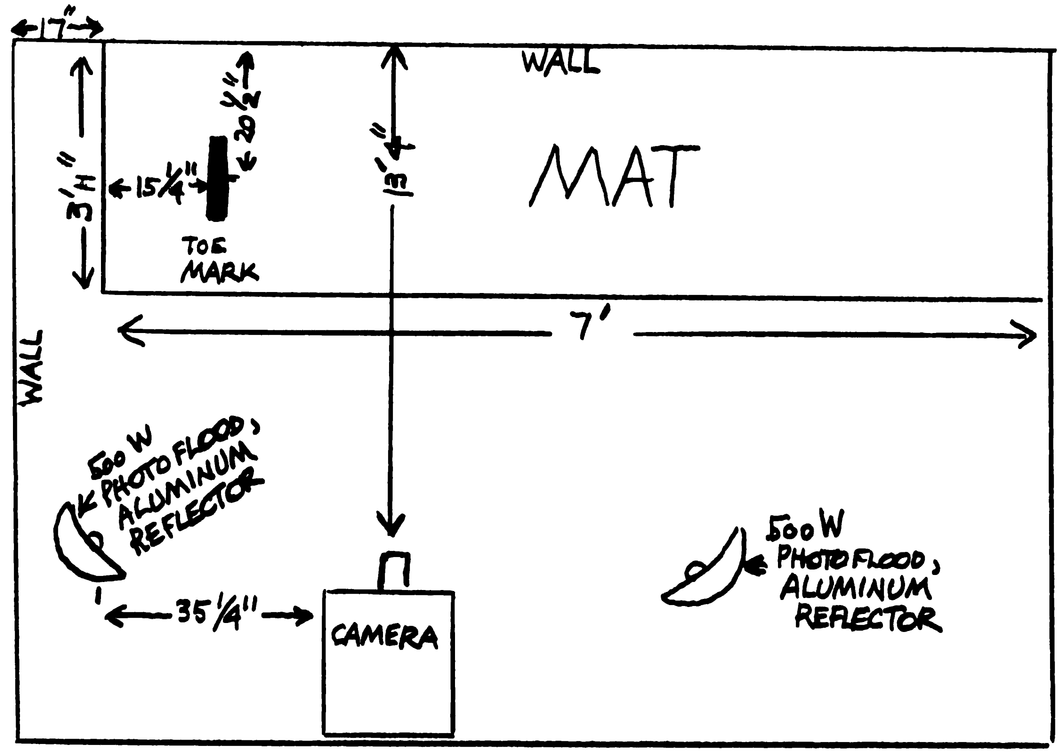

FIGURE 3.1a CAMERA AND LIGHT PLACEMENT FOR FILMING

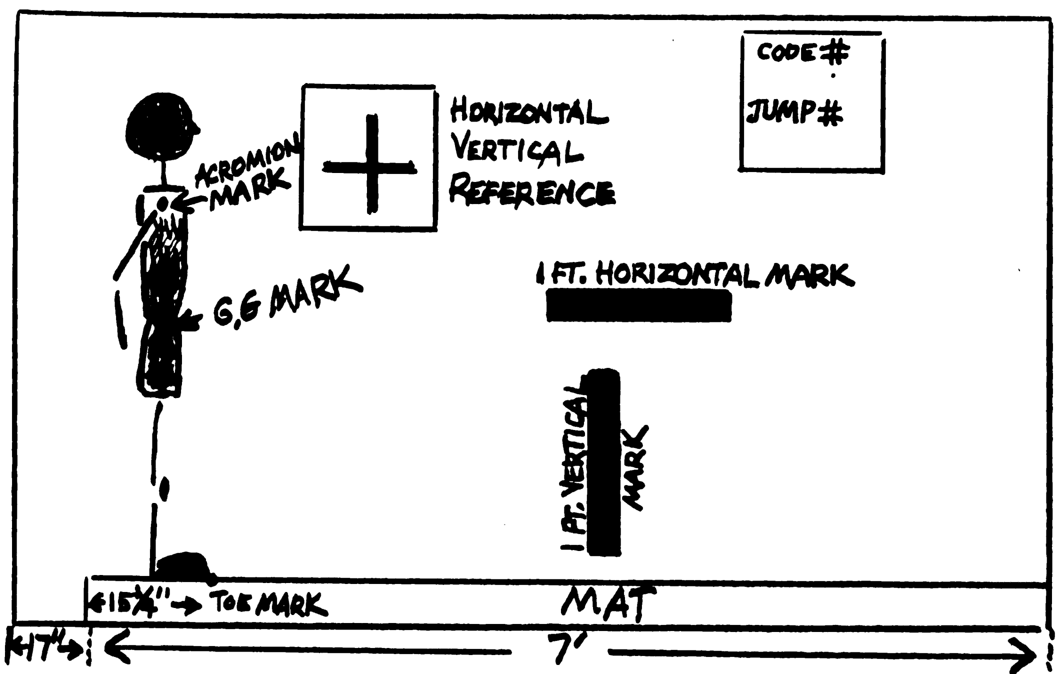

FIGURE 3.1b WALL MARKINGS FOR FILMING

points.

The investigator then stood beside the girl on the mat as if she too were preparing to jump. The following standardized directions were given to each girl:

"I'll say, 'Ready' then you will hear the camera run. Then I'll say 'Jump' and you will jump just as far out on the mat as you can."

Following one practice trial, the lights were turned on. The camera was rewound previous to each jump including the practice trial. The girl was praised and encouraged after each jump.

"That is fine. Let us see if you can jump a little further."

If the girl did a leap or run, she was still encouraged but a suggestion for correct skill performance was given:

"That is fine. Next time try to push off with both feet."

No actual demonstration of the jump was given. All of the girls knew what the word, "jump", meant and most were aware of the difference between a leap and a jump. Subjects #12 and #13 came together for the testing and saw each other perform. It was necessary for subject #15 to see her brother, age five, jump before she would attempt it for the investigator.

Skeletal procedures and the Walker Compliance Rating

If the girl was able to execute at least one jump, testing was continued and an Xray was taken of the left hand in the Xray room at the Merrill Palmer Institute. The Xray was the last measurement taken of the girl and represented the end of the testing procedure. As soon as the girl and her parent(s) left the building, the investigator completed the Walker Compliance Rating.

Motivation was reflected in the Walker Compliance Rating. This rating scale was developed by Walker (71) in his somatotype study of preschool children. The specific scale follows: (71:30)

1. Real enjoyment of the situation
2. Active co-operation, mild pleasure
3. Unresisting co-operation
4. Compliance with traces of uneasiness: moody, coy, embarrassed.
5. Compliance expressing mild dislike
6. Compliance expressing definite dislike or partial compliance
7. Refusal on initial performance, level six on subsequent one
8. Complete refusal

The Walker Compliance Ratings in the present investigation do not give a complete picture of the total group response since some of the subjects were excluded from the data analysis because of failure to co-operate. These girls could not be recalled for testing. The ratings made by the investigator can be found in Appendix I. The Walker Compliance Rating was variable # 69 in the data analysis.

The hand and wrist Xray for each girl was processed by the author using the equipment at the Merrill Palmer Institute. Xrays of the left hand of sufficient quality to be read for bone age with reliability and validity were obtained for nine of the 19 subjects. No Xray was attempted for three of the 19 girls. These roentgenograms were appraised by Dr. S. Idell Pyle. Each bone on each Xray was assessed through comparison with the Greulich and Pyle (37) Standard of Reference. The individual bone age readings can be found in Appendix I. The assessments for the lunate, scaphoid, trapezoid and trapezium were not included in the data analysis as individual variables. Onset of ossification had not begun in these four bones in all of the girls. The lunate was "absent" in two girls; the scaphoid, in seven; the trapezoid, in seven; and the trapezium, in five.

Pediatric history

A few days after the girl had been tested, a letter was sent to the family physician explaining the purpose of the research and requesting that the Physicians Certification Form be completed.[1] This was a necessary adjunct to the design since research was restricted to jumping patterns in "well, healthy" children who had not suffered accidents or illness that would be detrimental to neuromuscular or physical growth. The doctor was also given a copy of the signed Parental Permission Form. The physicians were most cooperative in returning a medical report on the health histories of the girls. However, many of the doctors were unable to provide developmental data from their files regarding birth weight and length, and first age of sitting and walking unsupported. This developmental data was not included in the statistical analysis for this reason. A summary of the physician's report for each girl can be found in Appendix H.

Mechanical Analysis of the Cinematographical Data

The first step in the cinematographical analysis was the

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[1]A copy of the Physicians Certification Form can be found in Appendix G.

selection of one jump for study for each girl. Inability to execute a bipedal take-off, a determination made from the film record, resulted in the discounting of a child's performance in that trial. Subjects # 6, # 13, and # 15 completed only one successful jump out of three trials.

The processed film for two subjects was run through a Federal Enlarger equipped with a condenser system and an Elgeet f 4.5, 51mm. lens. Tracings were made of the projected image of each frame in Phase II in each of the three trials of the standing long jump for these subjects. Take-off angle was determined for each child by superimposing the tracings of the center of gravity mark for the take-off frame and the two following frames so a line could be drawn between the center of gravity marks. The angle formed by the intersection of this line with a horizontal line on a grid represented take-off angle. Figure 3.2 shows the process of measurement of take-off angle in graphic form. The jump in which take-off angle most closely approximated Bunn's theoretical best angle of 40 degrees (12:34) was selected for study.

It soon became apparent the cooling system in the Federal Enlarger was inadequate. The film for the remaining subjects was run through an Omegalite D Enlarger equipped with a Kodak f4.5, 75mm. lens.

The take-off angles for the nine research subjects are summarized in Table 3.2. The rationale for the selection of these nine girls as research subjects will be explained in the last section of this chapter because final determination was based on initial statistical treatment of the data.

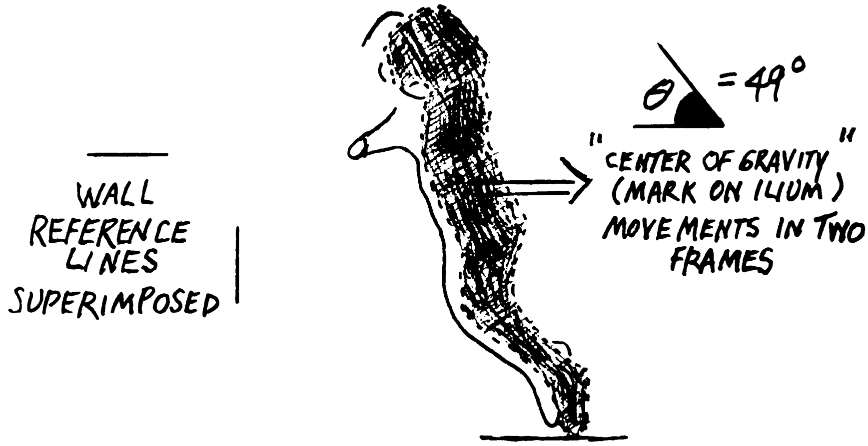

FIGURE 3.2 Determination of Angle of Projection, Center of Gravity, by Superimposing Consecutive Frames.

Dotted and shaded figure = take-off frame

Solid line and clear figure = take-off frame plus one frame

After the jump was selected, frame by frame tracings were made of the entire jump from beginning to end for each girl. Key reference point frames were determined according to the definitions specified in Chapter I. The reference point frames were the initial standing position frame, depth of crouch frame, take-off frame, height of parabola frame, landing frame and the frame representing the landing plus seven additional frames.

In order to determine linear measurement on the film, Cureton's correction factor was used (12:178). For example, if the twelve inch horizontal wall mark measured 1.4 centimeters on the film, each centimeter on the film represented 8.6 inches, the multi-

TABLE 3.2.--Take-Off Angles of the Valid Standing Long Jumps for the Nine Research Subjects

Subject	Jump #1	Jump #2	Jump #3
5	77°	*77°	55° (Bipedal take-off in doubt)
6	*16°		
7	*41°	54°	51°
8	*43°	47°	
9	90°	86°	*65°
12	69°	*45°	63°
13	*53°		
15			*66°
16	*36°	52°	

*Represents the standing long jump selected for study.

plier, or correction factor. This had to be determined anew for each girl's film tracings because of possible variation in enlarger position.

The camera used in the present study had a spring wind mechanism. To determine frame time, the drop of a four pound bowling ball was filmed three times in succession. Since $S = 1/2\ gt^2$, time could be calculated for each ball drop. 32.2 feet per second^2 was the value used for g in the formula. Time for the ball drop was divided by the frames of film consumed for the drop. The average of the three frame times was selected as final frame time. That time was .0165 seconds.

In the design of this study, 35 mechanical variables were finally selected for inclusion. Choice was based on the research which had been cited in Chapter II. For example, Halverson (39) and Eckert (25) focused on specific measurements in the power application phase of the jump; Wilson (76) measured angles at variour reference points; and Zimmerman (78) divided the jump into phases. The present investigation represents an attempt to evaluate the standing long jump in its entirety, amalgamating the measurements used in previous studies in this area. The 35 mechanical variables are listed in Appendix A; the cinematographical analysis results for each of the nine research subjects can be found in Appendix I. Tracings for the nine research subjects at each of the six key reference point frames can be found in Appendix J. These tracings must be regarded as close approximations since they have been "processed" a number of times in the production of this paper.

One major problem in mechanical analysis is that measurement technique has not been standardized. Both horizontal and vertical reference lines have been used in past studies in measuring segmental inclination, the basis for computing average angular velocity. Such a measuring system does not take into account the fact some levers move more than 180 degrees in the standing long jump. An additional consideration was posed in the present investigation. The particular segmental movement patterns which, in essence, are natural variations during progress of young girls (or boys) toward mature performance of the mammalian standing long jump were unknown. Segmental inclination was measured using a circular protractor. This is described in Appendix B.

Determination of angle size and average angular velocity, which is based on segmental inclination, have been important measurements in cinematographic analysis (14). In the present study, angles of the hip, knee, ankle and shoulder were measured at depth of crouch, take-off and landing. Angular measurement technique can be found in Appendix B.

Average angular velocities were determined for Phase I for the upper arm, lower arm, trunk, thigh, leg, and head. In Phase II of the jump, average angular velocities were computed for the upper arm, trunk, thigh, leg, head, and foot. Plus and minus values were assigned to angular velocity measurements to show direction of movement of levers so patterns could be related to mature performance. The specific technique of assignment is explained in Appendix B.

In the Waterland (72) study, head motion was measured as the "angle formed by the intersection of a line joining the head and clavicle light with a line from the clavicle light to the light on the greater trochanter of the femur." (72:17) Defibaugh (20) reviewed the methods of measuring head motion and designed a head gonimeter using the plane of the lower surface of the upper teeth as the constant. The measurement technique for head inclination used in the present study is defined in Appendix B, Measurement Technique A, Step 2.

Three measurements related to the application of power between depth of crouch and take-off were included. Ratio of depth of crouch height to standing height represented one mechanical variable (#8). Inclusion of the time of maximum angular velocity of the lower arm during power application was suggested by Eckert (25) and incorporation of the time before take-off when maximum vertical height of the lower arm was reached was suggested by the work of Cooper and Glassow (14).

In the theoretical formula for projectiles ($D= \frac{V_o^2 \text{ Sin } 2\theta}{g}$) velocity and angle of projection of the center of gravity assume key importance as they relate to distance jumped. In the present investigation, velocity of the projection of the center of gravity was computed using the formula $V_o=\sqrt{\frac{dg}{\text{Sin } 2\theta}}$. This formula is based on the center of gravity of a particular projectile taking off and landing at identical heights. This does not occur in the standing long jump.

Force was determined from the formula, Ft=mv, with time represented by the time the feet were in contact with the ground in Phase II. Consequently the value of t varied for each subject. Acceleration was calculated from F = ma.

The basic purpose of the standing long jump is the attempted achievement of horizontal distance over a surface while the body is projected through space. Hence, distance jumped has been the key measurement of skill in countless investigations of this activity in physical education. Distance jumped is variable #34 in the present study.

Finally, three time factors were included in the data analysis, each representing a separate variable: the percentage of total jump time encompassed by Phase I and that for Phase II, and the time airborne. The first two time variables were suggested by the research of Zimmerman (78) and the last by the investigation of Felton (28).

Criterion

Skilled performance was selected as the criterion in the present investigation. Halverson (40) defined skilled adult performance of a fundamental motor activity as the mature stage of the activity. The film of the standing long jump of a highly skilled college woman could have been chosen. However, physical changes in body structure, especially hip width following menarche, could cloud the issue. A decision was made that skilled performance, based on the distance jumped of two skilled, sixth grade girls, should be the criterion measure.

The criterion data was provided through the generosity of Miss Ruth B. Glassow, Dr. Lolas Halverson, and Dr. Elizabeth Roberts of the University of Wisconsin. Miss Glassow selected the films of two, skilled, sixth grade girls who had participated in the Longitudinal Study conducted by the Department of Physical Education for Women at the University of Wisconsin. Film records of performance in the standing long jump were taken for both these girls in the second and through the sixth grades. The girls had a physical education program of two class periods per week in their elementary school throughout these years but no guidance in administration of that program was provided by the staff of the University of Wisconsin.

One girl was 10 years, 9 months of age, and the other 11 years, 7 months of age, at the time performance was filmed in 1959 when they were in the sixth grade. The distance they jumped was measured on the film. The 10 year old girl jumped 72.4 inches, and the 11 year old, 83.8 inches. With this achievement, the younger girl would be placed in the upper tenth percentile, and the older girl in the upper first percentile, on the Fleishman (29) norms for 13 to 15 year old girls.

The sixth grade film record for these Wisconsin criterion subjects was projected through an Eastman Recordak in the Women's Physical Education Department at the University of Wisconsin. Tracings were made of each frame of the standing long jump performance of each girl. There was only one filmed jump for the criterion subjects at the sixth grade level. Measurement technique used to obtain the data for the criterion subjects were identical to those used for the nine research subjects of this study. The scores for the two criterion subjects on each of the mechanical variables were then averaged. This average score ($\bar{x}$) became the criterion for each mechanical variable except those of force and acceleration which could not be computed since weight for the Wisconsin subjects was unknown. The raw scores of the Wisconsin subjects are included in Appendix I and film tracings of them at the six key reference point frames are in Appendix J.

In order to arrive at a composite score for each of the nine research subjects, comparison was made with the criterion for each mechanical variable. If a research subject's score was equal to or closest to the criterion, the girl received a point on that particular variable. For example, Wisconsin subject #124 had a take-off angle of eight degrees, and Wisconsin subject #122, 28 degrees.

The average ($\bar{x}$) of the two performances was 18 degrees. Research subject #6 had a take-off angle of 16 degrees, the value closest to 18 degrees in the group of three and one half year old girls; subject #6 received a point for that mechanical variable. Points accumulated by each of the research subjects for all 35 mechanical variables were then totaled. The total point scores for the nine research subjects were then ranked. This ranking became variable #70 in the study, rank with criterion. Scores for the 35 mechanical variables and consequent rank with criterion for each research subject are shown in Table 3.3.

TABLE 3.3.--Comparison of the Nine Research Subjects with the Criterion

Subjects	Total Points Accumulated in Comparison with Criterion.	Rank with criterion
5	4	4
6	7	2
7	2	6.5
8	2	6.5
9	3	5
12	7	2
13	1	8.5
15	1	8.5
16	7	2

Statistical Treatment of the Data

The first major decision affecting procedural sequence in the statistical treatment of the data was determination of the size of the final research sample. Complete data which met the standards of this investigation were available for nine subjects. However, there was still some question regarding the medical histories for two of the nine girls, subjects #8 and #13, even though the family physician had stated these girls were "essentialy normal" and "well and healthy", respectively.

The family physician of subject #8 had written that the mother, by history, had reported that in labor, fetal heart tones were decreased. The girl was delivered vaginally. The girl had asphyxia at birth and was in an incubator a few days. There was some jaundice but no Rh problem. The physican went on to report that the girl was essentially normal with one degree allergies affecting the respiratory system. The father of subject #13 was a physician and had certified that his daughter was "well and healthy." However, in the Xray of the hand and wrist of this girl, a distinct line of arrested growth was found on the radium 13 mm. proximal to the metaphysis. The implications of this finding are taken from Greulich and Pyle: (37:19)

> The carpals and the epiphyses are not the only skeletal structures the development of which is affected by severe illness and other adverse influences. The growing ends of the shafts of the long bones sometimes contain striking and even more permanent evidences of such misadventure. These evidences take the form of transverse lines or bands of increased density in that portion of the shaft which was contiguous with the epiphyseal carilage when the illness or other causative incident occurred.

In order to evaluate the effect of these adverse medical histories, the computer was programmed to develop two groups of three intercorrelation matrices each (mechanical, skeletal, and anthropometric). The first group of three intercorrelation matrices was based on the data for the sample of seven children with subjects

#8 and #13 excluded. No question existed concerning the data for these seven subjects. The second group of three matrices included identical data for all nine subjects.

Since the basic purpose of this study was determination of variable interrelationships, the computer was programmed to yield descriptive information--means and standard deviations of each of the 70 variables in addition to the intercorrelation matrices[1]. The intercorrelation matrices were developed as follows:

1. The mechanical variable matrix included the 35 mechanical variables and variables #69, Walker Compliance Rating, and #70, rank with criterion.

2. The skeletal variable matrix included 23 individual bone ages (variables #36 through #58); variable #59, skeletal age; variable #60, chronological age; variable #34, distance jumped; variable #69, Walker Compliance Rating and variable #70, rank with criterion.

3. The anthropometric matrix included eight anthropometric variables (variables #61 through #68); variable #60, chronological age; variable #34, distance jumped; variable #69, Walker Compliance Rating and variable #70, rank with criterion.

The mechanical, skeletal and anthropometric matrices for the sample of seven subjects can be found in Appendix L; the matrices for nine subjects, in Appendix M. Means and standard deviations for all of the variables based on data for nine subjects are listed in Appendix K.

An elementary linkage analysis, or cluster analysis, (57) was completed for each matrix in each of the two sample size groupings.

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[1]Hays (42:510) explains that "it is not necessary to make any assumptions at all about the form of the distribution, the variability of Y scores within X columns... or the true level of measurement represented by the scores in order to employ linear regression and correlation indices to describe a given set of data."

> Elementary linkage analysis is a method of clustering. It can be used to cluster either people or items, or any objects, for that matter, which have distinctive cluster-characteristics... linkage analysis seeks a typal structure... A type is here defined as a category of persons of such a nature that everyone in the category is in some way more like some other person in the category than he is like anyone not in the category. In terms of coefficients of correlation between persons, every person in a type would have a higher correlation with some other person in the type than he would with anyone not in the type. (57:207-213)

Types in elementary linkage analysis correspond to factors in factor analysis, except that a typal structure is achieved rather than a simple structure as in factor analysis (57). The linkage is defined as the "largest index of association which a variable has with any or all of the other variables... every variable is assigned to a cluster in terms of its highest degree of association." (57:208) "Each cluster contains one and only one reciprocal pair." (58:442)

The present investigation is exploratory and represents an attempt to discern constructs (factors, types) within and between mechanical, skeletal and anthropometric variable groupings.

> [Definition of constructs] serves the cause of scientific parsimony.... it limits the variables with which the scientist must cope. It also (hopefully) helps the scientist to locate and identify unities or fundamental properties underlying tests and measures. (47:650)

Replication of the elementary linkage analyses for seven and nine subjects on each of the three intercorrelation matrices (mechanical, skeletal and anthropometric) was necessary to determine if the adverse medical histories reported for subjects #8 and #13 influenced cluster composition. Despite the fact sample size had been increased by some 23 percent in the matrices for nine subjects, no marked dissimilarities between sample size groupings appeared in the elementary linkage analyses. The decision was made that the statistical analysis should include all nine subjects.

The last step in the statistical treatment of the data was the development of a final intercorrelation matrix and a final cluster analysis which could show the relationships between mechanical, skeletal and anthropometric variable groupings for the nine subjects. First, the number of variables in each grouping was reduced.[1] Since this was an important process, the following guidelines were established:

1. Clusters composed only of reciprocal pairs of variables were examined. If the degree of association was quite high (a correlation coefficient greater than ± .80), one variable of the pair was eliminated.[2] Variable #13 (r= -.78) was also eliminated.

2. All variables which associated with different variables in different clusters in the analyses for seven and nine subjects were eliminated.

3. In many investigations, developmental status has been, and probably will be, determined by chronological age, height and weight. These variables along with erect sitting height, bicristal width, and distance jumped were retained. In physical development studies, skeletal age rather than individual bone ages has been a key variable; it was also included.

4. Rank with criterion and the Walker Compliance Rating, variables which were a part of each matrix, were retained.

5. If the degree of association between the first and second and between the second and third variables was almost the same in a variable grouping of three, two of the three variables were excluded. (If A=B and B=C, then A=C)

---

[1]Hays (42:577) points out that in an intercorrelation matrix of K variables, "the average of the $\binom{K}{2}$ intercorrelations among these variables must be greater than (or equal to) -1/(K-1).... given the values of some of the intercorrelations, the average lower limit for all the other correlations is not -1 but some number greater than -1. The larger K is, the closer this lower limit comes to 0."

[2]Hays (42:503) explains that "as long as we are talking about the correlation coefficient alone, it is immaterial which we designate as the independent and which the dependent variable; the measure of possible linear prediction is the same."

6. Variable #32, a second cousin (McQuitty's terminology) showing low association, and variable #2, average angular velocity of the lower arm, Phase I, were eliminated.

The final intercorrelation matrix included 33 variables.

Reasons for Rejecting Subjects

The general results of the testing procedures for the 19 children who came to the Merrill Palmer Institute for a filming appointment can be found in Appendix H. Of the 19 children, nine were included in the final statistical analysis. The reasoning for this decision has just been presented in the preceding section of this chapter. Some subjects were excluded for more than one reason. The reasons for the exclusion of 10 of the subjects follow:

1. The child was not Caucasian (2).
2. The child was unable to execute a bipedal take-off (2).
3. The child refused to remove outer clothing and/or to participate (5).
4. The developed Xray film was below the quality needed for valid skeletal assessment (6).
5. Abnormalities and/or anomalies were found in the Xray film (2).
6. The child had suffered an accident or illness which might be detrimental to physical or neuromuscular growth (1).

CHAPTER IV

RESULTS OF THE STUDY

Analysis Based on Inspection

Demographic characteristics of the nine research subjects

Table 4.1 summarizes the demographic information for the nine research subjects. The girls in this study represent a relatively homogeneous group from the upper socio-economic level of society. Each girl lived with her mother and father in a home in the suburbs of Detroit, Michigan. All but one girl had been in nursery school for periods ranging from five to 13 months. The fathers of these children were all college graduates with occupations in the executive and professional class. All of the mothers except one had received college education, and four had graduate education. Two of the mothers were teaching at the time of the investigation; the rest were at home with their children. One couple had adopted their daughter. Each girl in the study had been given periodical medical examinations from the time of prenatal development.

To façilitate presentation in the chart, sibling status has been converted to a numerical score of three digits. The first digit signifies birth rank in the family; for example, a

Table 4.1. Demographic Information for the Nine Research Subjects

Code Number	Occupation		Age at Birth of Child		Educational Attainment		Nursery School Attendance	Sibling Status
	Father	Mother	Father	Mother	Father	Mother		
5	Dentist	Teacher	27	26	20	16	13 months	111
6	Teacher	Teacher	31	27	17	17	13 months	110
7	Salesman	Housewife	39*	36*	16	13	7 months	111
8	Advertising Writer	Housewife	27	28	16	17	12 months	210
9	Accountant	Housewife	47	42	16	12	6 months	210
12	Research Chemist	Housewife	26	25	19	17	5 months	111
13	Physician	Housewife	35	32	20	16	5 months	310
15	Biology Professor	Housewife	32	30	19	16	None	211
16	Teacher	Housewife	31	32	17	17	7 months	111

* = Adopted child

number two denotes the girl in the study was the second child born in the family. The middle number signifies birth rank of the girls in the family. All of the research subjects were first born girls. The last digit represents the number of siblings younger than the research subject; there was just one "only" child in the sample.

Subject #16 had an interesting family background. The mother had been a nursery school teacher and was aware of studies like Gerbers (34) which discussed the interrelationship of motor ability and child rearing practice. The child's mother had deliberately provided experiences that various researchers had thought might contribute to advanced development in the motor as well as other areas. For example, her child, subject #16, was breast fed until she was 18 months old. This girl had always shown remarkable motor ability. She was able to stand at six months, walk unsupported at eight and one half months and could turn a somersault at 12 months. At the time of the filming, the girl could skip and polka with ease. In the present investigation this girl jumped the greatest distance and tied for first ranking with the criterion.

Mechanical factors

Eight of the 19 children filmed in the present study were able to execute the standing long jump in all three trials. The following other performance records were observed:

1. The child was able to execute the jump, but under duress and only after refusing to remove outer clothing (2).
2. The child completely refused to even attempt the skill. It is not known whether these children could nor or would not perform (3).

3. The child was willing to attempt the skill, but with evidence of running and leaping patterns in all three trials which was discerned at the time of filming (1).

4. The child appeared to be insecure and jumped with affected style like a "jack in the box." (1)

5. At take-off, the child placed one foot before the other on either one or two of the trials of the standing long jump. Some of these walk and leap patterns could be discerned at the time of testing. It was necessary to consult the film record for verification in many cases (4).

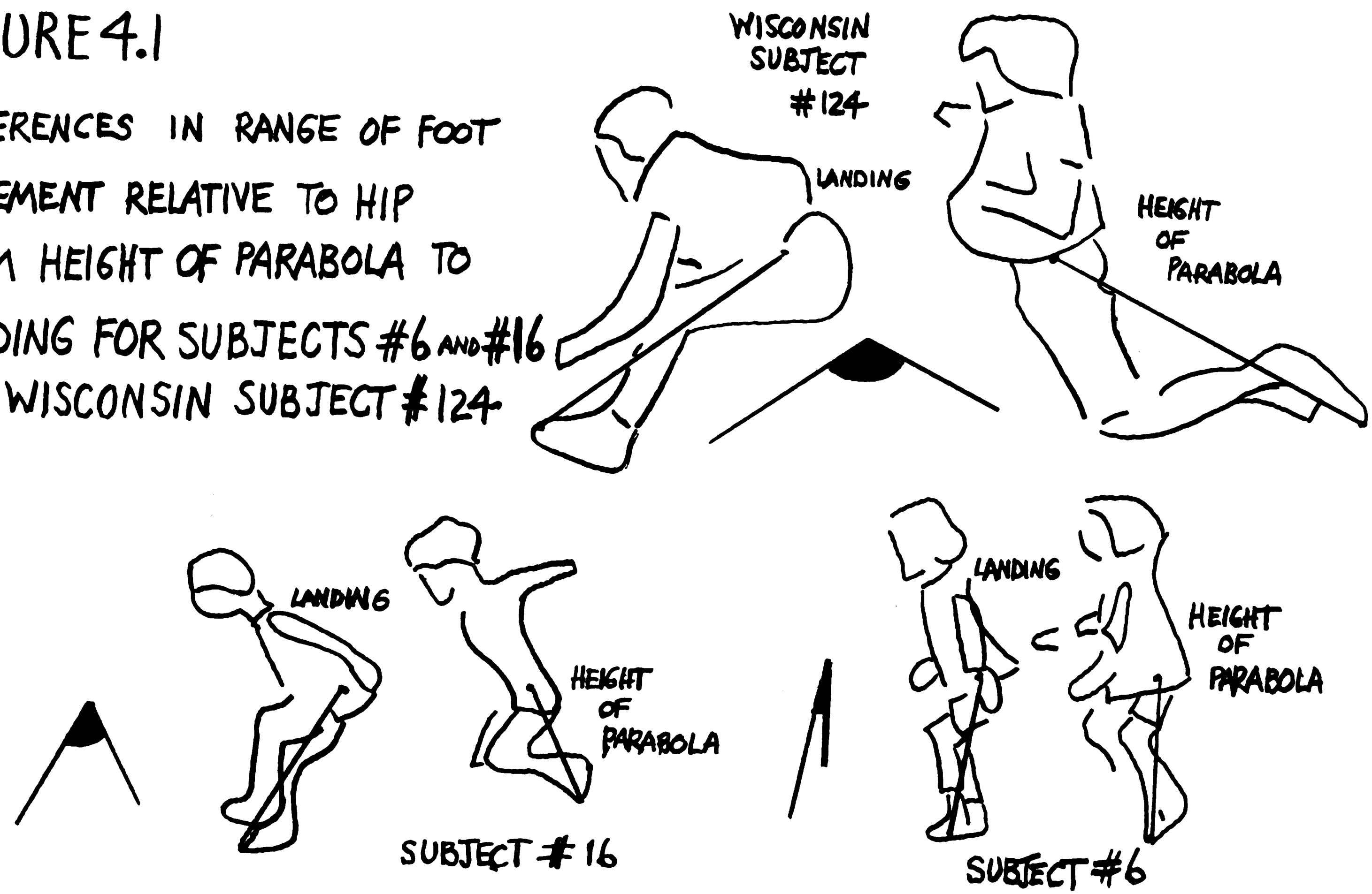
The Wisconsin criterion subjects were able to execute a preliminary backswing of the arms at depth of crouch. In the group of nine research subjects, only one girl, subject #13, placed her arms behind the midline of her body at this point in the jump. This same subject was the only girl who showed the "winging" arm pattern.

Considerable difference in range of movement of the toes relative to the hips was found between the Wisconsin criterion subjects and the nine research subjects during flight through the air. Figure 4.1 shows graphically the difference in body positions at the height of the parabola and landing for Wisconsin criterion subject #124, who jumped 83.8 inches; subject #16, who jumped 34.4 inches; and subject #6, who jumped 6.02 inches. In the figure, a line has been drawn between the approximate center of the hip and the tip of the toes in the two reference frames. The difference in range of movement of the toes relative to the hips is readily apparent despite the difference in lever length, change of hip position in space, and variance in time airborne.

In general, the directional movements of body levers were the same for the research subjects and the Wisconsin criterion subjects. Figure 4.2 shows graphically the average angular velocities

FIGURE 4.1

DIFFERENCES IN RANGE OF FOOT MOVEMENT RELATIVE TO HIP FROM HEIGHT OF PARABOLA TO LANDING FOR SUBJECTS #6 AND #16 AND WISCONSIN SUBJECT #124



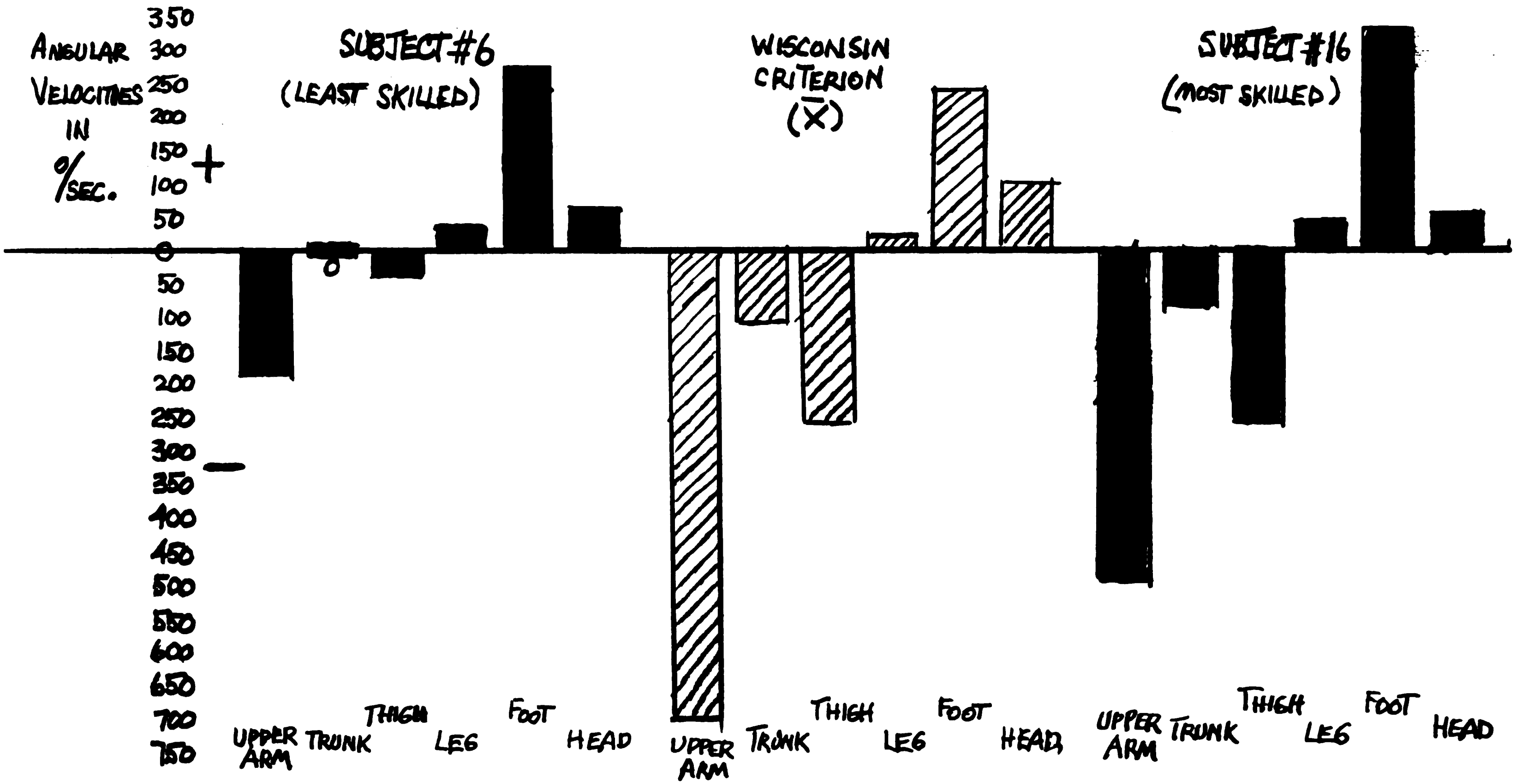


FIGURE 4.2 ANGULAR VELOCITIES, PHASE II, FOR MOST SKILLED AND LEAST SKILLED JUMPERS (BASED ON DISTANCE JUMPED) COMPARED WITH CRITERION.

for Phase II for the most skilled and the least skilled jumpers (based on distance jumped) in the present study. Comparison of average angular velocites is made with the performance of the Wisconsin criterion ($\bar{x}$). Direction of lever movement, reflected as a + or - score, was the same for all of the subjects whose performance is portrayed in Figure 4.2, but timing, or range of movement within specified phase time, differed. The average angular velocities shown by subject #16, the most skilled in the research group, more closely approximated the angular velocities for each of the levers of the Wisconsin criterion ($\bar{x}$) than did those of subject #6, the least skilled in the research group. The greatest difference in angular velocity measurement between research subject #6 and the Wisconsin criterion ($\bar{x}$) occurred in movements of the upper arm, trunk, and thigh.

If the leg pattern in the standing long jump is phylogenetic and the arm pattern, ontogenetic, one might expect greater variance in the latter. Figure 4.3 is a graphic representation of the segmental inclinations of the upper arm, lower arm, trunk, thigh, leg and foot for the nine research subjects and the Wisconsin criterion ($\bar{x}$) in the take-off frame. Measurement of segmental inclination was the basis for determination of average angular velocity in the present study. However, raw scores for segmental inclination were not listed in Appendix I since they were not included as variables in the statistical analysis.

In Figure 4.3, all lines in the drawing, which represent lever inclinations, extend from a central point which denotes a bone landmark in the human body, designated as Point S Placement in the measure-

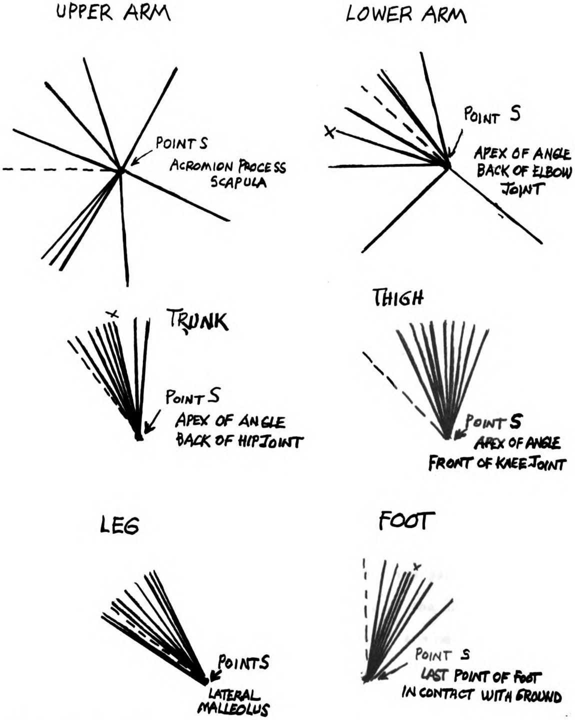


FIGURE 4.3 VARIATION IN SEGMENTAL INCLINATION OF LEVERS IN TAKE-OFF FRAME.
DOTTED LINE = INCLINATION OF WISCONSIN CRITERION ($\bar{X}$)
SOLID LINE = INCLINATION OF A RESEARCH SUBJECT
X = MORE THAN ONE CHILD SHOWED SAME INCLINATION

ment techniques used in the present investigation (see Appendix B). Each solid, lever line extension denotes the segmental inclination exhibited by one research subject. The dotted line represents the segmental inclination of the average of the two Wisconsin criterion scores ($\bar{x}$). The greater variability in segmental inclination of the arms, compared to the other levers, which is evident in the drawing, was found at each of the six key reference point frames.

It was impossible to measure average angular velocity of the arms during Phase III of the standing long jump in this investigation because many of the children moved their arms out of the sagittal plane during flight through the air. Since the arm motion during this section of the jump might be an important consideration, a joint motion analysis of the humerus at the shoulder was completed for the nine research subjects and the Wisconsin criterion subjects for Phase III of the standing long jump. The terminology used was derived from Wells (74). The results of the joint motion analysis are summarized in Table 4.2.

The skilled arm patterns of the Wisconsin criterion subjects varied in timing and, slightly, in direction but the joint action was one of flexion and extension of the humerus at the shoulder. It is difficult to categorize the wide variety of arm motions demonstrated by the three and one half year olds. Excluding the "wing" pattern of subject #13, the following humeral action was generally observed:

I. Joint motion at take-off relative to the anatomical position:

A. Flexion and horizontal extension (2)
B. Flexion (2)

Table 4.2.--Joint Motions of the Humerus at the Shoulder During Phase III for the Nine Research Subjects and the Wisconsin Criterion Subjects. (Terminology is derived from Wells (74))

Subject	Joint Motion at Take-Off Relative to the Anatomical Position	Joint Motion from Take-Off to the Height of the Parabola	Joint Motion from the Height of the Parabola through the Landing
Wisconsin Subject #124	Flexion to less than 90° with slight abduction.	Flexion for four frames then extension at shoulder begins, and continues to height of parabola plus six frames. In extension, humerus returns to anatomical position.	Flexion begins at the height of the parabola plus six frames and continues through landing plus seven frames. At this point flexion of almost 90° is reached.
Wisconsin Subject #122	Flexion to about 135°.	Arms basically remain suspended in space although a very slight extension of two degrees occurs.	At height of parabola plus one frame, extension begins. At landing plus two frames, arms reach anatomical position.
#5	Flexion to a position of almost 90°. Five frames before take-off, horizontal extension begins and reaches a position behind the midline of the body.	Adduction.	Adduction with slight flexion to the anatomical position.

Table 4.2--Continued

Subject	Joint Motion at Take-Off Relative to the Anatomical Position	Joint Motion from Take-Off to the Height of the Parabola	Joint Motion from the Height of the Parabola through the Landing
#6	Flexion to a position of almost 90°.	Extension.	Extension to a position of hyperextension just behind the midline of the body.
#7	Flexion to a position of almost 90° with slight abduction. Position reached seven frames before take-off and held to take-off.	Adduction with slight hyperextension.	Continued adduction with slight hyperextension to a position just behind the mid-line of the body.
#8	Flexion to a position of almost 180°.	Continuation of arms around be-hind body in "windmill" fashion through hyperflexion into a position at shoulder height of almost 90° horizontal exten-sion.	Flexion through hyperexten-sion with abduction. At landing, arms hyperextended just behind midline of body.
#9	Flexion to a position of about 90°. Seven frames be-fore take-off, horizontal extension begins with slight adduction to a posi-tion even with midline of body.	Adduction with hyperextension.	Continued hyperextension to a position about 45° behind the midline of the body.

Table 4.2--Continued

Subject	Joint Motion at Take-Off Relative to the Anatomical Position	Joint Motion from Take-Off to the Height of the Parabola	Joint Motion from the Height of the Parabola through the Landing
#12	Abduction to a position at shoulder height even with midline of body.	Adduction with very slight horizontal extension.	Adduction with slight flexion. Arms at landing abducted about 45°.
#13	Hyperextension to more than 45° behind the midline of the body.	Continuation of slight hyperextension.	Flexion to a position of about 45° hyperextension behind the midline of the body.
#15	Flexion to 180° with slight abduction.	Adduction.	Continued adduction. At landing, arms are abducted more than 45°.
#16	Flexion to about 135° with slight abduction.	Continuation of arms around behind the body in "windmill" fashion through hyperflexion to a position of horizontal extension of more than 90°.	Flexion through hyper-extension. At landing, arms are about 45° behind midline of body.

C. Flexion and abduction (3)
D. Abduction (1)

II. Joint motion from take-off to the height of the parabola:

A. Adduction (3)
B. Extension (1)
C. "Windmill" (2) (See Table 4.2 for specification of pattern)
D. Adduction and horizontal extension (2)

III. Joint motion from the height of the parabola through landings:

A. Adduction (3)
B. Extension (1)
C. Flexion (2)
D. Horizontal extension (1)
E. Adduction with flexion (1)

In this study no girl lost her balance following flight through the air. At times the landing of a jump represented the preparatory motion for another jump which immediately followed, and in several cases the girl landed with one foot in front of the other and immediately moved into a walk or run pattern. It appeared that these activities represented the means of maintaining balance and controlling kinetic energy.

There was considerable difference between the research subjects and the Wisconsin subjects in body configuration at the reference point of landing plus seven additional frames. Both Wisconsin subjects were in a position of a deep squat at this point with the hips low, behind the feet, and with the arms raised forward as a counter-balance. Although all of the three and one half year olds showed some flexion at the hip, knee and ankle at landing plus seven additional frames, no girl had the hips below knee level, and for each one, the upper arm was held quite close to the body, and slightly anterior or posterior to the anatomical position.

Skeletal and anthropometric factors

Skeletal age, which represents an arithmetical average of the bones showing ossification in the hand, ranged from 33 months to 50 months of age for the nine subjects. Figure 4.4 represents in graphic form the individual bone ages for two of the research subjects and includes an overall comparison with chronological age. In subject #12, four of the metacarpals did not quite achieve an assessment equal to chronological age. In subject #15, only the triquetral was advanced over chronological age.

In this study, when the bones of the hand were grouped for any particular girl into five categories (carpals, metacarpals, proximal phalanges, middle phalanges, distal phalanges), ossification appeared fairly even except for the carpals. In subject #7, metacarpal I was considerably advanced in age over the other metacarpals. This same pattern, though not to as great a degree, was evident in subject #8. In subject #5, middle phalanx V was advanced. Statistical appraisal of the skeletal assessment will be considered in the next section of this chapter. Bone age and skeletal age readings for the research subjects can be found in Appendix I.

The chronological age range for the children in the present investigation was from 40 to 44 months. With this homogeneity, no great discrepancies were found between subjects in the anthropometric measurements which are listed in Appendix I. Weight of the nine research subjects ranged from 33 to 43.3 pounds, and height, from 38.1 to 41.7 inches. When plotted on the Bayer and Gray (4) Graphic Growth Record Charts for Girls, all of the research subjects except

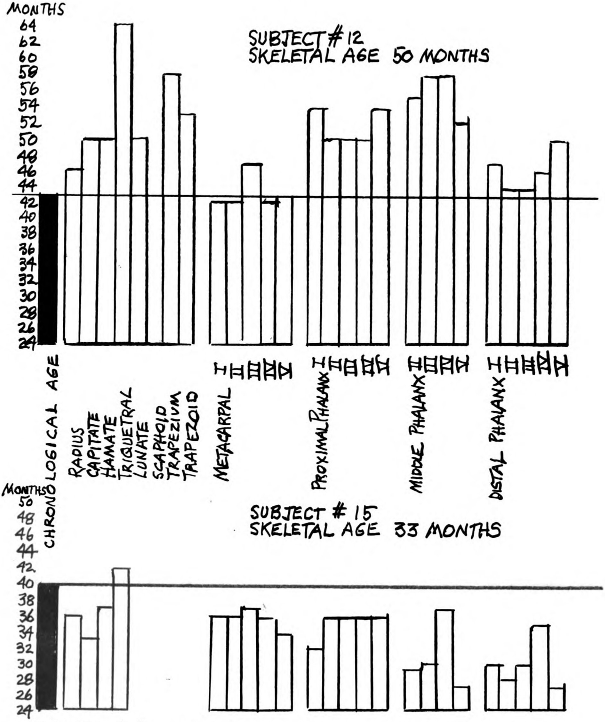


FIGURE 4.4 INDIVIDUAL BONE AGES COMPARED WITH CHRONOLOGICAL AGE FOR CHILDREN WITH HIGHEST AND LOWEST SKELETAL AGE.

two fell within the average maturational rate range between three and four years of age. Subjects #7 and #16 were accelerated in maturational rate; their scores fell in the range between four and five years of age on the Bayer and Gray Charts.

Elementary Linkage Analysis

Various complexities are involved in the interpretation of the elementary linkage analyses which follows. These complexities were caused by the rather large number of variables (70) considered; the fact cluster analyses were completed for sample sizes of both seven and nine subjects,[1] the appearance of inverse relationships between variables which developed out of the measurement techniques used in obtaining mechanical variable data; and diversification of cluster composition. Several procedures have been developed to facilitate presentation.

Average angular velocity will, from now on, be designated by the symbol, $\bar{w}$. The "construction of hypothetical entities" (47:680) or the naming of clusters, would be an impossible task. No attempt will be made to label factors.

Interrelationships between skilled performance patterns and the various variables in the mechanical, skeletal and anthropometric groupings will be discussed. Skilled performance, as defined in Chapter I, refers to the filmed execution of the standing long jump by the two sixth grade girls, the Wisconsin criterion subjects.

[1]The mechanical, skeletal and anthropometric elementary linkage analyses for N=7 can be found in Appendix N.

Several bases exist for comparison of the skilled performance patterns of these girls with the performance patterns of the nine research subjects. The first basis is variable #70, rank with criterion, which represents a comparison of individual mechanical variables in all phases of the standing long jump between the research subjects and the average ($\bar{x}$) of the two Wisconsin performances. A low numerical rank with criterion score represents a higher ranking, a performance more closely approximating the criterion for individual mechanical variables. The second basis of comparison is visual inspection of the filmed performance. These results were reported in the first section of this chapter. The third basis is $\bar{w}$ score. In the mechanical analysis of the data, plus and minus values were assigned to $\bar{w}$ of levers depending on whether the body segment moved clockwise or counterclockwise so a comparison could be made between the research subjects and the Wisconsin criterion subjects. A limitation exists in this comparison; specification of direction of lever movement does not indicate optimal timing. For example, the Wisconsin average score ($\bar{x}$) for $\bar{w}$ of the thigh, Phase I, was + 40 degrees per second, representing clockwise movement (+) toward a deeper crouch position. This $\bar{w}$ score of + 40 degrees per second was derived, as an average, from $\bar{w}$ scores of +73 degrees per second and + 6 degrees per second. In the research group, the $\bar{w}$ of the thigh, Phase I, ranged from - 19 degrees per second (counterclockwise movement) to + 104 degrees per second. The raw data scores represent the fourth basis of comparison between the Wisconsin criterion subjects and the research subjects.

Elementary Linkage Analysis Within Variable Groupings: Mechanical

General

Figure 4.5 shows the elementary linkage analysis based on the intercorrelation matrix for mechanical variables. Eleven clusters were found. In general, the cluster composition showed that all phases of the standing long jump were interrelated, and that lever movement and position in the preparatory motions were associated with movement and position during power application and landing.

In several cases, lever movements in the upper part of the body tended to interrelate. This was also true for segments in the lower part of the body. In one cluster, angular measurements grouped together but in general, $\bar{w}$ and angular measurements were associated.

Projection of the body through space

The first three clusters, containing variables showing the highest degree of association, were related to projection of the body through space and the results of that projection. Force and acceleration formed the first cluster with a coefficient of correlation of .98. It should be recalled that linkage, by definition, represents the "largest index of association which a variable has with any or all the other variables." (57:208). In elementary linkage analysis, degree of association is the only determinant responsible for variable position in the first cluster. In computation, the value of acceleration (a=F/m) was found once force was known (Ft= mv) which could account for the high relationship.

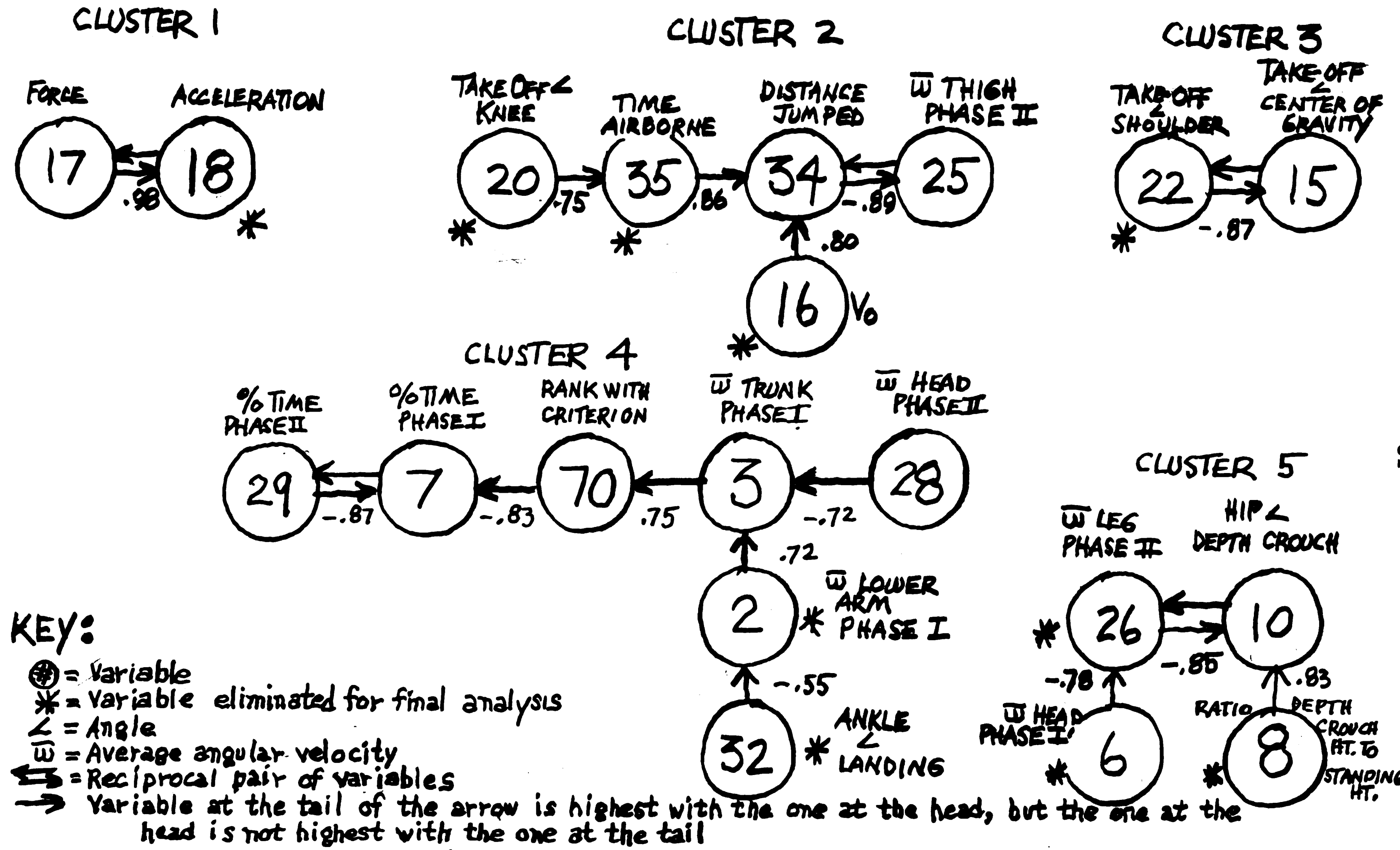


FIGURE 4.5 CLUSTER ANALYSIS FOR MECHANICAL VARIABLES N=9

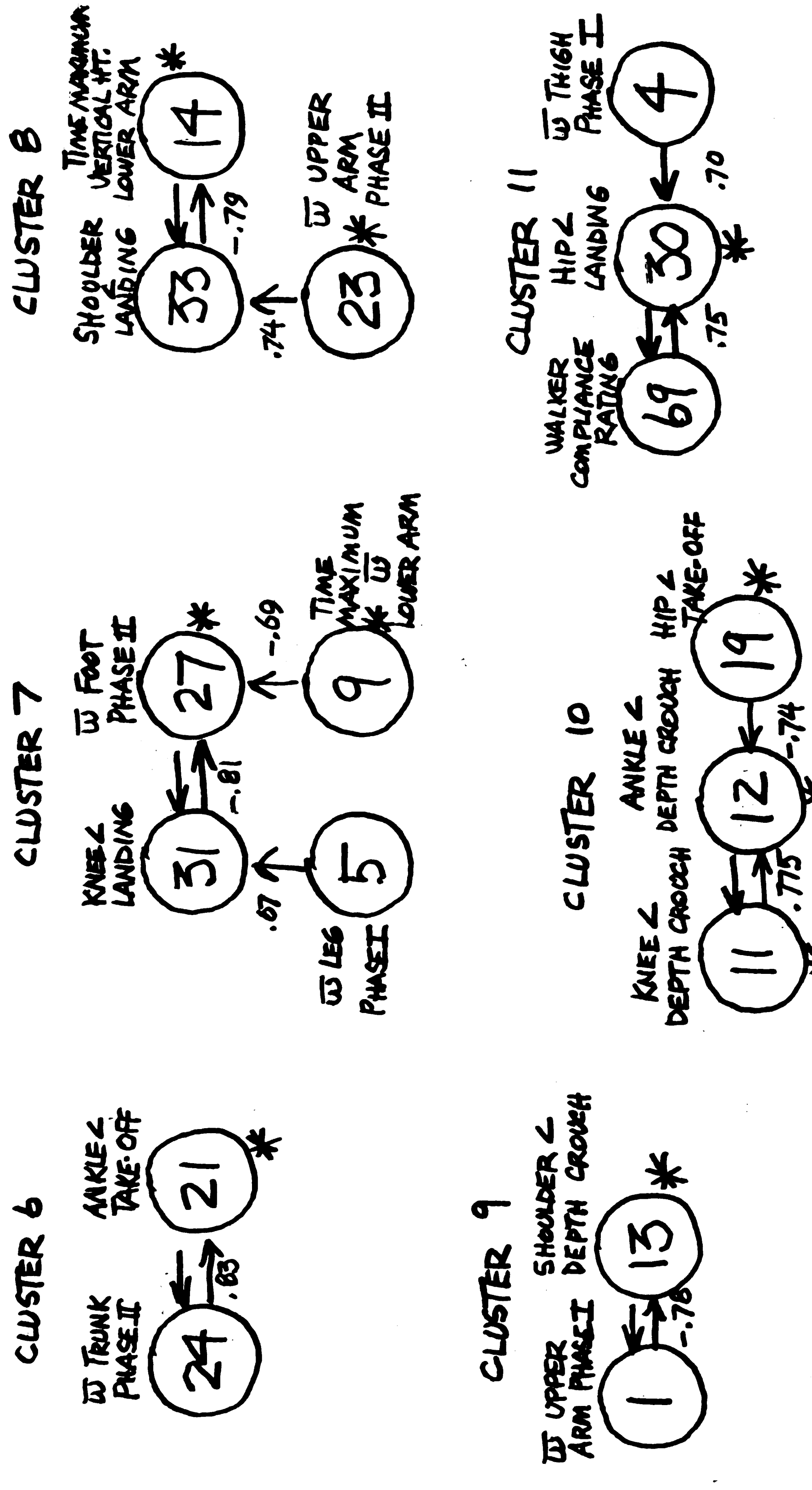


FIGURE 4.5 CONTINUED

Distance jumped was found in the second cluster. It was one of a reciprocal pair with $\bar{w}$ of the thigh during power application (r= -.89). Measurement techniques used in the study are responsible for many of the inverse relationships found in the elementary linkage analyses. For example, a minus (-) value was assigned to $\bar{w}$ of the thigh when the lever moved counterclockwise. Consequently, as the thigh moved with greater $\bar{w}$, counterclockwise, during power application, distance jumped increased. The thigh moved in this same direction in the skilled performance of the two Wisconsin criterion subjects.

V_o and time airborne also related to distance jumped with correlation coefficients of .80 and .86 respectively. As V_o increased and time airborne increased, distance jumped increased. In turn, as time airborne increased, take-off angle of the knee (r= .75) increased, reflecting extension at this articulation at the moment of projection. In summary, in the research group, the mechanical variables related most highly to achievement represented by distance jumped, were, in relative order of association: $\bar{w}$, thigh, Phase II; time airborne; V_o; and take-off angle of the knee.

The third cluster was composed of two variables, a reciprocal pair: take-off angle of the center of gravity and take-off angle of the shoulder (r= -.874). Take-off angle of the center of gravity was arbitrarily selected in this study. As take-off angle of the center of gravity decreased, the arms, in the take-off frame, were positioned at a greater angle away from the trunk in the sagittal plane (for example, a shoulder flexion of about 90 degrees). The Wisconsin criterion subjects did not move the arms to a position of complete shoulder flexion overhead at take-off, but some research subjects moved them to an overhead position.

Relationship of mechanical variables with skilled performance

Rank with criterion, variable #70, represented one basis of comparing performance in the research group with that of the Wisconsin criterion subjects. Rank with criterion was determined by comparing the individual mechanical variable scores of the research subjects with the average score of the Wisconsin criterion subjects ($\bar{x}$) on each mechanical variable. The mechanical variables associating most highly with rank with criterion were time ratio determinations. As a child earned a higher rank with criterion score (low numerical score), the percentage of total jump time spent in power application (Phase II) decreased and the percentage of total jump time spent in preparatory motions (Phase I) increased. The specific coefficients of correlation involved in these interrelationships can be found in Figure 4.5. Based on the average of the two performances, the Wisconsin criterion subjects spent almost 1/2 (.46) of the total jump time in preparatory action (Phase I) and roughly 1/4 (.22) in power application (Phase II).

In the cluster analysis for mechanical variables, a number of interrelationships were found that showed the movement patterns for the research subjects (three and one half years olds) were approaching the skilled performance patterns of the Wisconsin criterion subjects in terms of direction of lever movement. These interrelationships are presented in tabular form in Table 4.3. In general, similarities in directional movement pattern and lever position between the research subjects and the Wisconsin criterion subjects in all phases of standing long jump performance were more pronounced than differences in pattern. Specifically, with the two exceptions of take-off angles of the shoulder and the center of gravity, the angular measurements in the lower segments of the body were similar for the two groups as were the $\bar{w}$ measurements of the lower segments, the trunk, and the head.

On the other hand, differences were evident only in the preparatory and landing phases of the jump. Major differences were clearly apparent in shoulder angle measurement at depth of crouch and landing and in $\bar{w}$ of the lower arm, Phase I. The specific interrelationships involving the arm pattersn were:

1. $\bar{w}$ of the upper arm, Phase I, increased counterclockwise (+), in the "right" direction, as shoulder angle at depth of crouch decreased (r= -.73)

2. $\bar{w}$ of the upper arm, Phase II, increased in a clockwise (-) "right" direction as shoulder angle at landing decreased (r= .74).

3. As the trunk moved with less $\bar{w}$ in the "right" direction, counterclockwise (+), into the depth of crouch during Phase I, the $\bar{w}$ of the lower arm during the same phase increased in the "wrong" direction to a position near the body.

The research subjects held their arms closer to their bodies, anterior or posterior, at depth of crouch and landing, and moved their arms in the "wrong" direction toward a position near the body during the preparatory motions.

Table 4.3.--Mechanical Variable Relationships That Show Movement Patterns for the Research Subjects Approaching the Skilled Performance Pattern of the Wisconsin Criterion Subjects in Terms of Direction of Lever Movement.

Associated Variables	Coefficient of Correlation	Explanation
$\bar{w}$, head, Phase I $\bar{w}$, leg, Phase II Hip angle, depth crouch	-.78 -.85	As the leg moves counterclockwise (+) with greater $\bar{w}$ during force application, the chin drops and the head moves in ventroflexion in Phase I. The Wisconsin criterion ($\bar{x}$) is slight ventroflexion (-3^{o}). At the same time, hip angle at depth of crouch position decreases.
Rank with criterion $\bar{w}$, trunk, Phase I $\bar{w}$, head, Phase II	-.75 -.72	A higher rank with criterion score (low numerical score) is associated with less $\bar{w}$ in trunk movement counterclockwise (+) toward the depth of crouch position. At the same time, movement of the head occurs with greater $\bar{w}$ in the direction of dorsal flexion during power application.
$\bar{w}$, leg, Phase I Knee angle on landing $\bar{w}$, foot, Phase II	.67 -.81	As knee angle on landing decreases to greater flexion reflecting a more horizontal position of the thigh, $\bar{w}$ of the foot, moving toward a vertical position with the mat at take-off, increases. At the same time, the leg, Phase I, moves with less $\bar{w}$ counterclockwise (+) toward the crouch position.

Table 4.3.--Continued.

Associated Variables	Coefficient of Correlation	Explanation
$\bar{w}$, thigh, Phase II Distance jumped Time airborne } and V_o Take-off angle, knee	-.89 .86 and .80 .75	As distance jumped increases, the thigh moves with greater $\bar{w}$ counterclockwise (-) during force application and V_o and time airborne increase. As time airborne increases, take-off angle of the knee increases reflecting extension at this articulation at take-off.
Knee angle, depth crouch Ankle angle, depth crouch Hip angle, take-off	.775 -.74	As knee angle at depth of crouch decreases, ankle angle at depth of crouch also decreases reflecting a deeper preparatory crouch position. At the same time, hip angle at take-off increases as extension at the hip joint occurs when the body leans forward at the moment of projection.
Walker Compliance Rating Hip angle, landing $\bar{w}$, thigh, Phase I	.75 .70	As hip angle on landing decreases and flexion at this articulation occurs, motivation reflected in the Walker Compliance Rating increases (a low numerical score indicates higher motivation). At the same time, the thigh moves with less $\bar{w}$ in a clockwise (+) direction to a position of deeper crouch in the preparatory motions of Phase I.

Table 4.3--Continued.

Associated Variables	Coefficient of Correlation	Explanation
$\bar{w}$, trunk, Phase II Take-off angle, ankle	.83	The trunk during power application moves with less $\bar{w}$ in a clockwise direction (-) as take-off angle of the ankle increases.
Take-off angle, center of gravity Take-off angle, shoulder	-.87	As take-off angle of the center of gravity decreases, take-off angle of the shoulder increases as the arms are positioned away from the trunk in the sagittal plane.

Elementary Linkage Analysis Within Variable Groupings: Skeletal

General

Figure 4.6 is a graphic representation of the results of the elementary linkage analysis based on the intercorrelation matrix of skeletal variables for nine subjects. The same number of clusters (eight) appeared in the analyses for seven and nine children. Nineteen of the 23 bones maintained the same relationships in the analyses for seven and nine children.

The coefficients of correlation between reciprocal pairs were high, ranging from .98 between the capitate and hamate in cluster 1 to .907 between distal phalanges II and III in cluster eight. In general, bones tended to group in clusters relative to bone position in the hand. Cluster one was composed of carpals. Clusters two and three included bones largely from the middle of the hand: middle phalanges II, III and IV; proximal phalanges III and IV and meta-carpal V. Bones on the "little finger side of the hand" were found in cluster five; proximal phalanx V, middle phalanx V and distal phalanges IV and V. The "thumb side of the hand" was represented in cluster seven: proximal phalanges I and II and metacarpal I.

Skeletal age and chronological age associated more highly with each other than they did with either distance jumped or rank with criterion. Skeletal age and chronological age each related to the bone age of distal phalanx I with coefficients of correlation of .942 and .76, respectively.

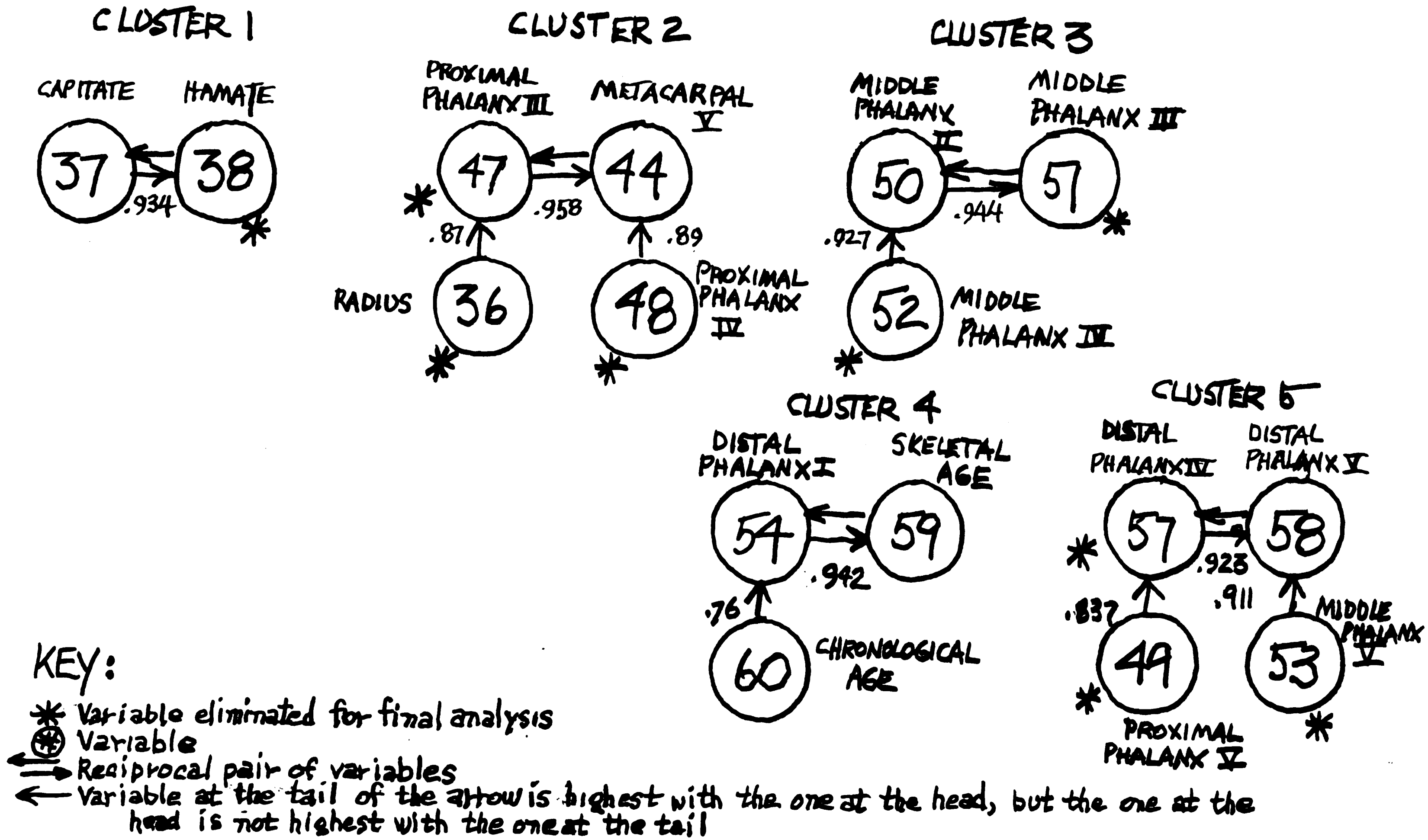


FIGURE 4.6 CLUSTER ANALYSIS FOR SKELETAL VARIABLES N=9

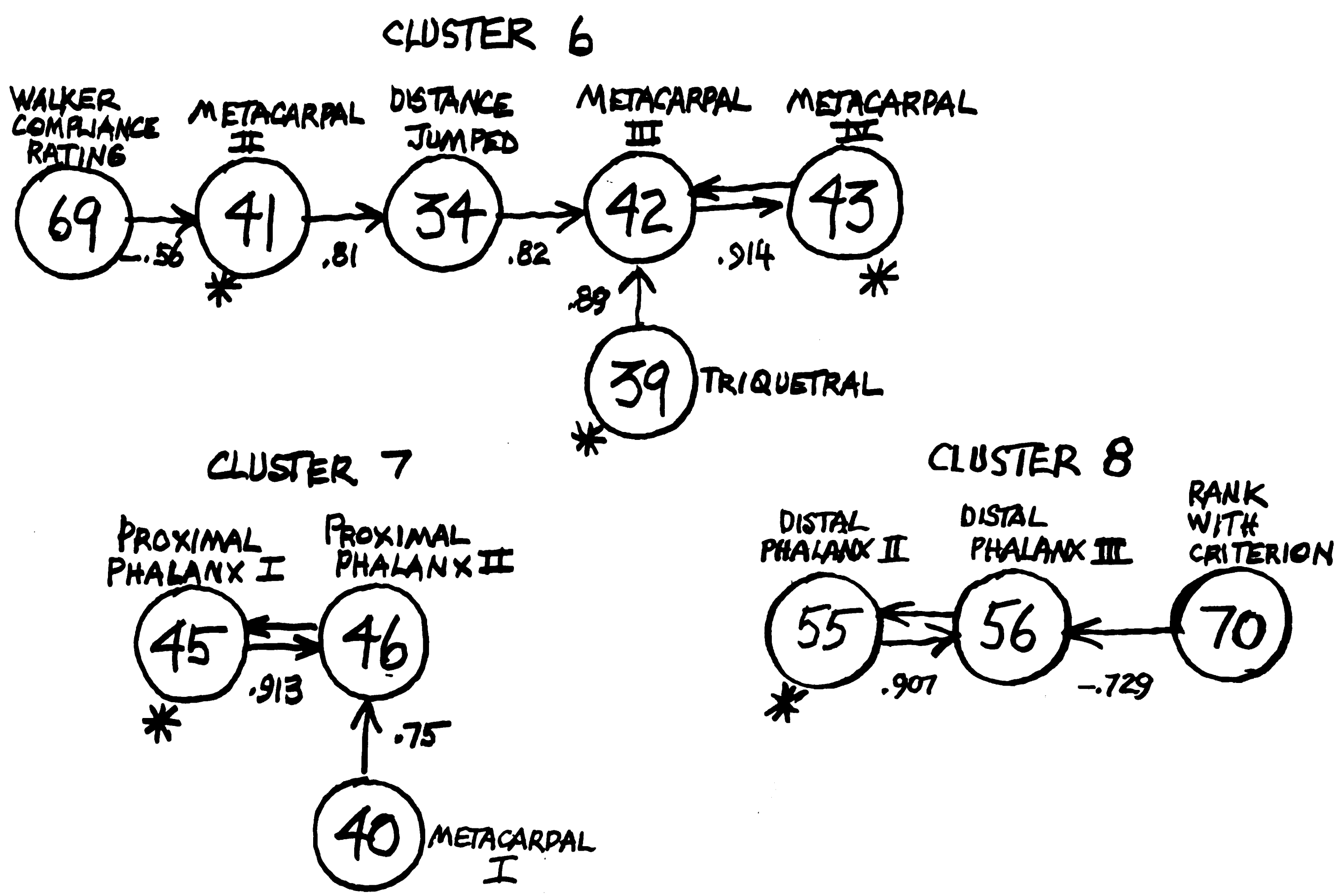


FIGURE 4.6 CONTINUED

The Walker Compliance Rating was inversely related to metacarpal II (r= -.56) in cluster six. As metacarpal II became developmentally older, the child was rated higher in motivation (low numerical score) as reflected in the Walker Compliance Rating.

Interrelationships of skeletal variables, achievement, and skilled performance

Distance jumped fell in cluster six in association with metacarpal III (r= .82) and metacarpal II (r = .81). As metacarpal III and metacarpal II became developmentally older, distance jumped increased: the "older" children jumped further.

Rank with criterion was found in cluster eight; rank with criterion became higher (low numerical score) as distal phalanx III became developmentally older (r = -.73). The "older" children, based on the bone age of distal phalanx III, were more like the Wisconsin criterion subjects ($\bar{x}$) in the components of movement in the standing long jump.

The relationship was low (r = -.26) between distance jumped and rank with criterion. Distance jumped and rank with criterion each related to the increase in developmental age of specific bones more than they related to each other.

Elementary Linkage Analysis Within Variable Groupings: Anthropometric

General

Figure 4.7 gives the graphic representation of the results of

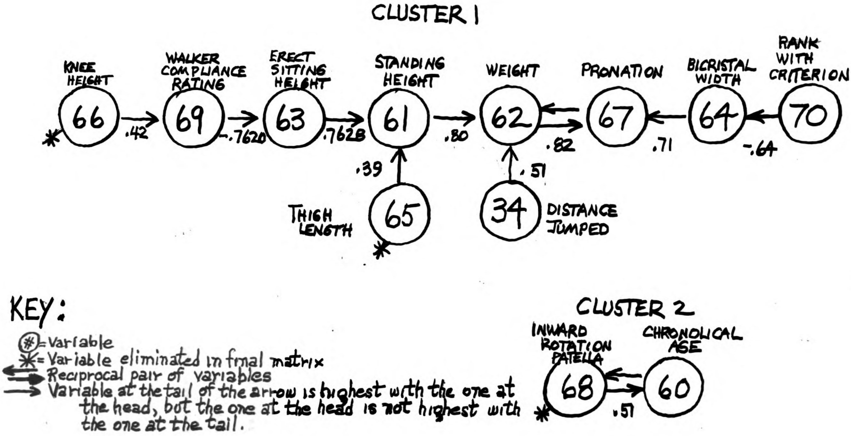


FIGURE 4.7 CLUSTER ANALYSIS FOR ANTHROPOMETRIC VARIABLES N=9

the elementary linkage analysis based on the intercorrelation matrix of anthropometric variables for nine subjects. There were 12 variables in the matrix and eight were anthropometric measurements. Two clusters resulted from the analysis. In terms of cluster analysis, the relationship of variables in the first cluster was linear with first, second, third and fourth cousins (McQuitty's terminology). Ten of the twelve variables fell in this cluster showing that all the variables except chronological age and inward rotation of the patella, which were found in the second cluster, were highly interrelated. The heavier children tended to show more pronation, had greater bicristal width, and were taller in terms of erect sitting and standing height. Children who showed higher motivation (lower numerical Walker Compliance Rating score) were taller as reflected in erect sitting height and standing height, but they had less knee height.

Interrelationship of anthropometric variables, achievement and skilled performance.

Distance jumped was related to weight, although the relationship was not high (r= .51). As weight increased, distance jumped increased. Rank with criterion, one method of comparing anthropometric variables with skilled performance, was associated with bicristal width (r= -.64) in the first cluster. As a girl's performance approached that of the skilled performer, bicristal width increased.

Elementary Linkage Analysis Between Variable Groupings: Mechanical Skeletal and Anthropometric

Figure 4.8 shows the final cluster analysis for the 33 selected mechanical, skeletal and anthropometric variables included in the final intercorrelation matrix. The 37 variables which were excluded from the final matrix have been designated by an asterisk (*) in Figures 4.5, 4.6, 4.7.

Six clusters appeared in the final elementary linkage analysis. In general, variables tended to associate with other variables from the same grouping: mechanical, skeletal and anthropometric. Mechanical variables, exclusively, were found in clusters four and five; skeletal, in cluster three. The last cluster, six, contained all of the anthropometric variables. Anthropometric variables related in clusters to mechanical variables, and mechanical variables, to skeletal, but skeletal and anthropometric variables did not associate with each other in clusters. Mechanical variables remained associated with distance jumped and rank with criterion.

A number of cluster relationships found in the separate mechanical, skeletal and anthropometric analyses were replicated in the final elementary linkage analysis. Several "new" interrelationships of variables were found which indicated that as the research subjects matured physically, their standing long jump performance, as reflected by the mechanical variables, approached that of the Wisconsin criterion subjects. The new interrelationships were as follows:

1. As knee angle on landing decreased to greater flexion, reflecting a more horizontal position of the thigh at this reference

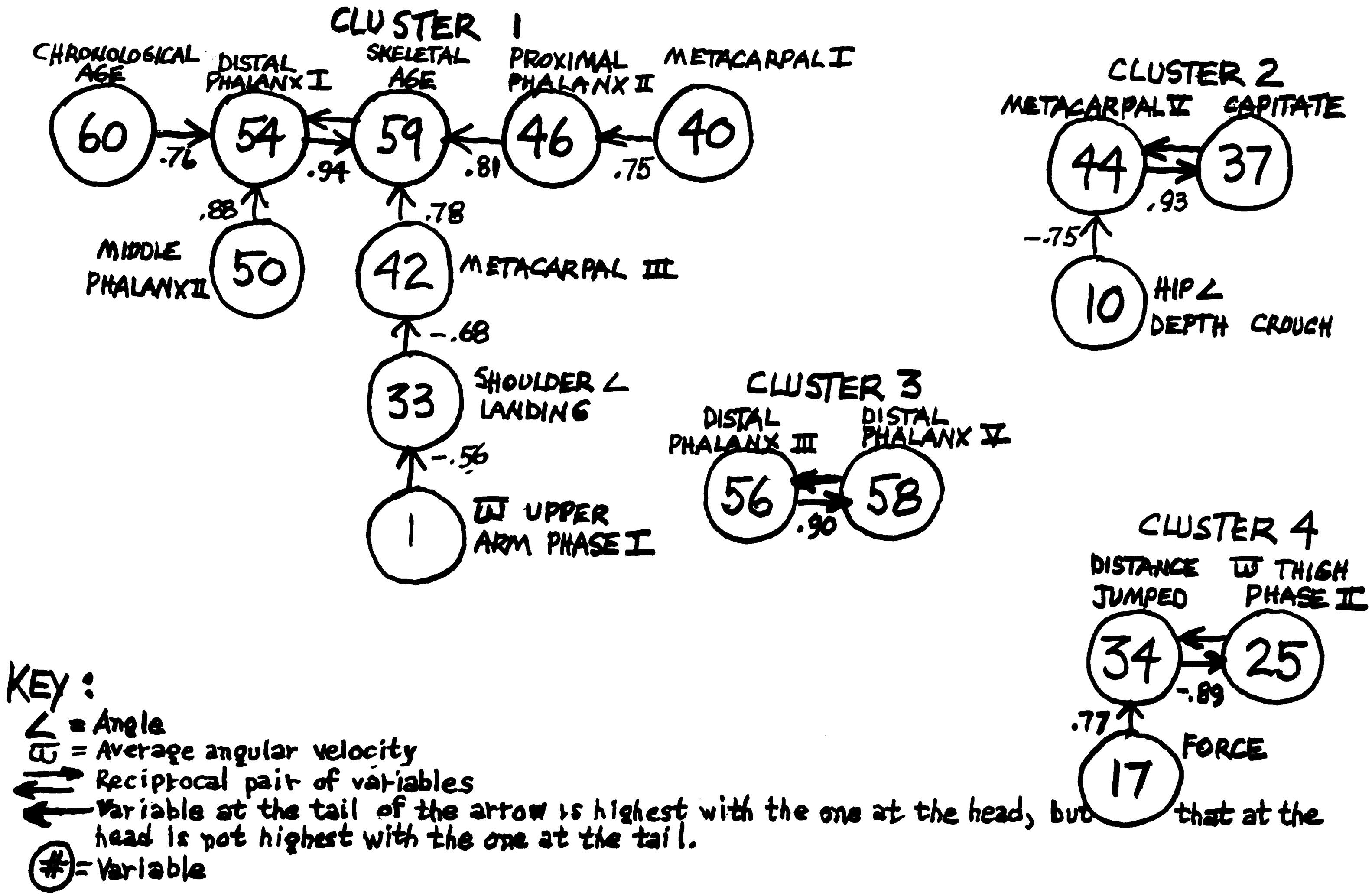


FIGURE 4.8 FINAL CLUSTER ANALYSIS FOR FINAL 33 VARIABLES

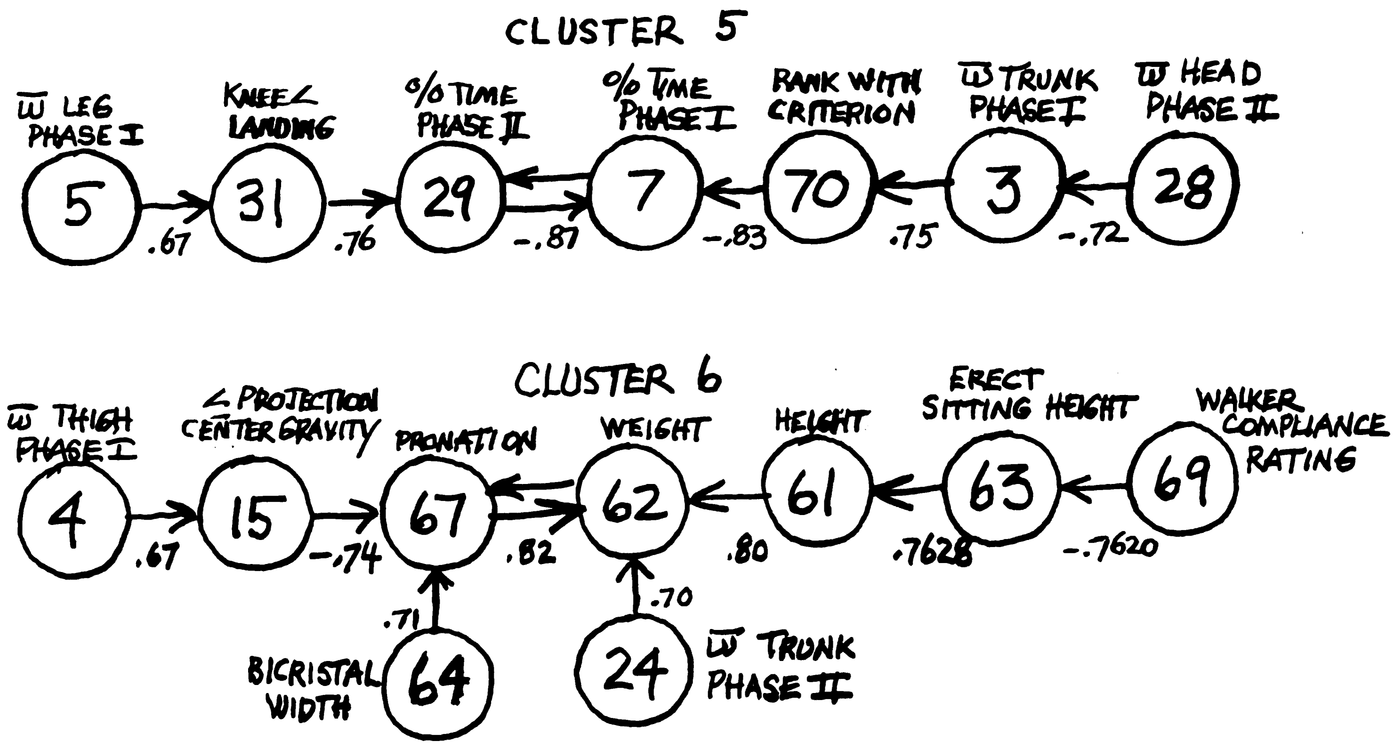


FIGURE 4.8 CONTINUED

point frame, ratio of time spent in force application in the jump decreased.

2. As force increased, distance jumped increased.

3. As the angle of projection of the center of gravity decreased, pronation increased and the thigh moved with less $\bar{w}$ in a clockwise (+) direction to a position of deeper crouch in the preparatory motions.

4. As weight increased, the trunk moved with less $\bar{w}$ counterclockwise (-) in the "right" direction during force application.

5. As metacarpal V became developmentally older, hip angle at depth of crouch decreased.

One relationship found in the final cluster analysis showed a difference in performance pattern between the research subjects and the Wisconsin criterion subjects. As the upper arm moved in the "right" direction, counterclockwise (+), toward a position behind the body during the preparatory action of Phase I, shoulder angle at landing decreased.

Summary of the Elementary Linkage Analyses

The summary of the interrelationships of all the variables and the skilled performance patterns will be described according to their similarities and differences. Figure 4.9 presents the similarities in graphic form. The basis of selection was the delineation of the mechanical variables associated with skilled performance. These mechanical variables were:

Angular measurements:
- At depth of crouch: hip
- At take-off: knee, shoulder and ankle
- At landing· knee and hip

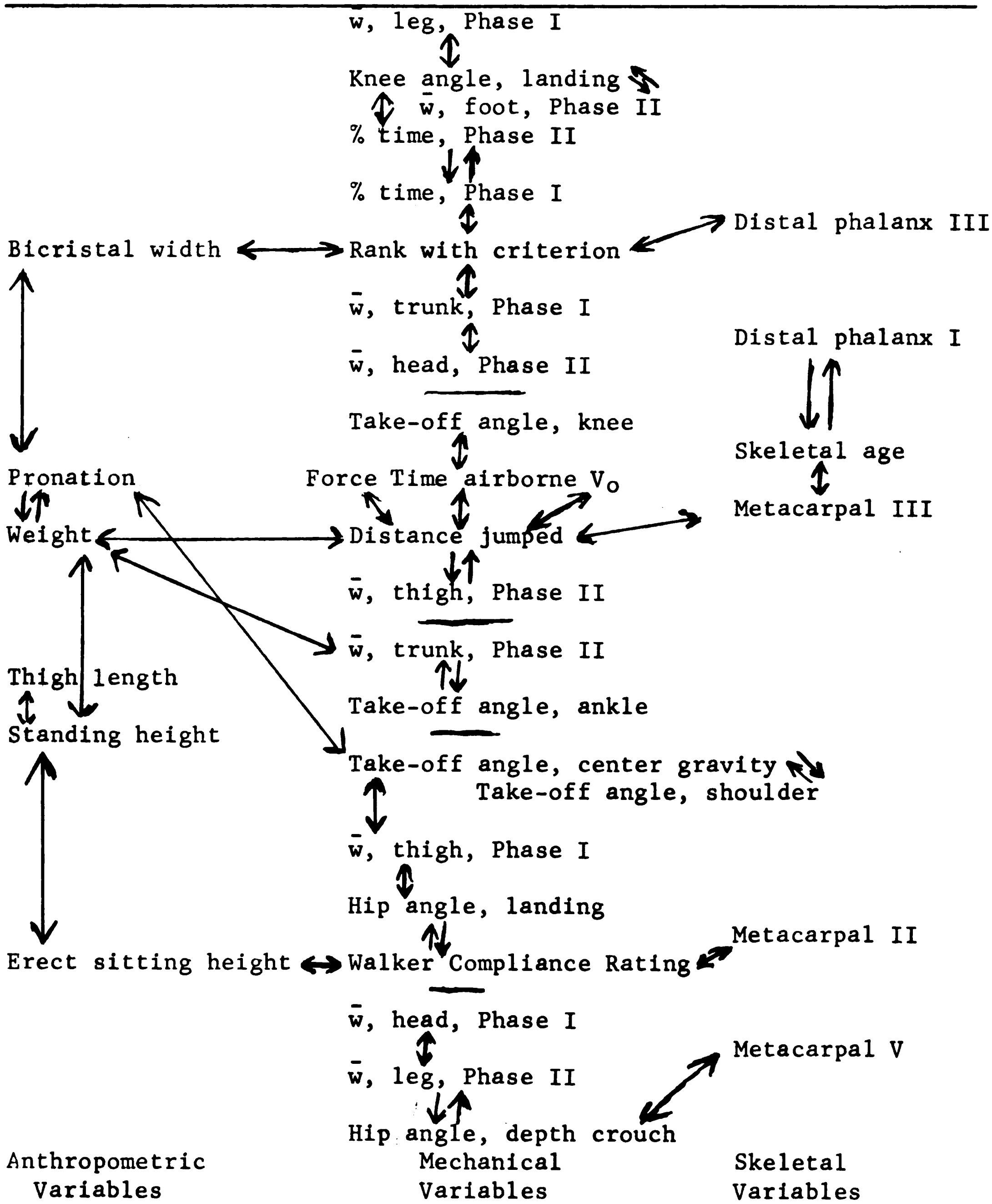
$\bar{w}$ measurements:
- Phase I: head, trunk, thigh, leg
- Phase II: head, trunk, thigh, leg, foot

Figure 4.9.--Interrelationship of Variables Most Highly Associated with Skilled Performance.

(⇄ = Variables correlate as a reciprocal pair)

(↔ = Variables correlate)

An Increase in Anthropometric Measurements Shows the Child Becomes Heavier and Taller AS............	Motivation Increases and the Mechanical Variables Approach Patterns of Skilled Performance AS..	Age of the Following Bones Increases



Time determinations:
- Time airborne
- Percentage of jump time spent in Phase I and Phase II

Force, angle of projection, velocity of projection of the total body at take-off

The anthropometric and skeletal variables which related to these mechanical variables were specified from the cluster analyses. The anthropometric and skeletal variables were:

Anthropometric variables:
- Bicristal width
- Pronation
- Weight
- Thigh length
- Standing height
- Erect sitting height

Skeletal variables:
- Distal phalanx III
- Metacarpal II
- Metacarpal III
- Metacarpal V
- Skeletal age
- Distal phalanx I

In addition, Walker Compliance Rating and rank with criterion, which associated with skilled performance, were included. On examination of Figure 4.9, it would appear that movement patterns which approach skilled performance are associated with greater physical maturity and higher motivation.

The variables that reflected movement patterns divergent from skilled performance were determined in the following manner. In the elementary linkage analyses, five coefficients of correlation, involving five pairs of variables in association with each other in clusters, were found which showed a difference in performance between the research subjects and the Wisconsin criterion subjects. For example, the coefficient of correlation between the $\bar{w}$ of the upper arm, Phase I, and shoulder angle on landing was -.56. An increase in $\bar{w}$ of the upper arm in a counterclockwise (+) direction to a position behind the body in the preparatory motion of Phase I represented a skilled performance pattern. Decrease in shoulder angle on landing was not representative of skilled performance. All of the research subjects had a shoulder angle on landing smaller than the criterion average ($\bar{x}$) of 62 degrees. The five pairs of associations have been listed below so the first variable mentioned represents movement comparable to skilled performance; the aberration is the second variable.

1. $\bar{w}$, upper arm, Phase I, moved counterclockwise (+) as shoulder angle at depth of crouch decreased.

2. $\bar{w}$, upper arm, Phase I, moved counterclockwise (+) as shoulder angle at landing decreased.

3. $\bar{w}$, upper arm, Phase II, moved clockwise (-) as shoulder angle at landing decreased.

4. The trunk in Phase I moved with less $\bar{w}$, counterclockwise (+), as the lower arm in Phase I moved clockwise (-).

5. Walker Compliance Rating decreased (higher motivation) as knee height decreased.

In summary, examination of the coefficients of correlation, the raw data, and the interrelationships of Figure 4.9 showed only one of the variables in each of the five pairs failed to associate with skilled performance. Through this process, three mechanical variables were found to represent divergence from skilled performance in arm pattern relationship. The variables were:

$\bar{w}$ measurement:
Phase I: lower arm

Angular measurements:
Shoulder angle at depth of crouch and landing

Discussion

General considerations

It was reported in Chapter II that Frankenburg and Dodds (31) found all of the children in their study could perform the standing long jump by 39 months of age. In the present investigation, only eight of the 19 girls, chronological ages 40 to 44 months, who came to the Merrill Palmer Institute for a filming appointment were able to execute the standing long jump in all three trials. Childhood negativism was a factor in performance failure in five cases. Running and leaping patterns were in evidence in one, two or all of the trials for five subjects; it was necessary to consult the film record for final verification of the bipedal thrust. In observation of the performance of the standing long jump, it might be difficult at times to discern the necessary simultaneous push with both feet.

In the initial standing position frame, the Wisconsin criterion subjects stood in a semi-crouched position (see Appendix J), looking ahead in the direction of the jump. The research subjects generally stood upright, and many looked at the investigator; some flexion was apparent at the hip and knee. The Wisconsin criterion subjects did not have to move the trunk, thigh and leg very far to arrive at depth of crouch position. For example, the average ($\bar{x}$) score for the Wisconsin criterion subjects for $\bar{w}$ of the trunk during this preparatory motion (Phase I) was + 40 degrees per second. The average $\bar{w}$ of the trunk, Phase I, for the research subjects was + 59 degrees per second with a range of from + 21 degrees per second to + 106 degrees per second. Every research subject moved her trunk counterclockwise (+) in the same directional movement shown by the skilled performers.

This difference in initial standing position has been considered in the interpretation of $\bar{w}$ relationships for the trunk, thigh and leg in Phase I, and for the $\bar{w}$ of the trunk, Phase II, which was affected by what happened to the trunk in Phase I. For example, the coefficient of correlation between $\bar{w}$, trunk, Phase I and $\bar{w}$, head, Phase II, in the elementary linkage analysis for mechanical variables was -.72. This association has been described as follows in the study: as movement of the head occurs with greater $\bar{w}$ in the direction of dorsal flexion during power application (Phase II), the trunk moves with less $\bar{w}$ counterclockwise (+) toward the depth of crouch position. One girl moved her thigh the "wrong" direction during Phase I, and another girl moved her leg the "wrong" direction at this time; two subjects moved their trunks in the "wrong" direction in Phase II. Otherwise direction of movement was the same for the research subjects and the Wisconsin criterion subjects.

Hellebrandt, _et_. _al_. (43) discussed the differentiation of a simple execution of the standing long jump from the forceful projection of the body through space for horizontal distance. The latter, for them, "implied exercise of will and desire to put forth maximal effort." (43:23) This is a crucial point and differentiation is difficult to ascertain. No attempt was made to do so in the present investigation. The Walker Compliance Rating, which indicated motivation, was based on the girl's reaction to and enjoyment of the total situation.

Specification of race in American society presents problems. McGraw (55) discussed these difficulties some 35 years ago. Her inferences were given in Chapter II. In the present study, one child, who appeared to be Caucasian, came for a filming appointment. The mother was predominantly Negro. If the child had been seen alone, the investigator probably would have classified this girl as white.

Specific consideration: theoretical mechanics

In the analysis by inspection and in the elementary linkage analyses sections of this chapter, motor patterns of the research subjects which were similar to and divergent from skilled performance were specified. Focus will now be placed on these motor patterns.

Evidence in the present investigation tends to indicate that the principles of mechanical physics can be applied to human movement. Bunn (12) and Broer (9) have stated that the preliminary backswing of the arms at depth of crouch puts the arms in such a position that the forward swing can be executed through a long arc thus transferring the momentum of the arms to the body. The Wisconsin criterion subjects were able to execute a preliminary backswing of the arms at depth of crouch, but only one research subject, the girl who showed the "winging" arm pattern, placed her arms behind the midline of her body at this point in the jump. The armswing also helps control the take-off angle of the center of gravity which should move in front of the feet as they thrust down and back at take-off.

The evidence regarding the relationship of V_o, projection angle of the center of gravity and distance jumped in this intestigation does not completely substantiate the theoretical formula for projectiles: $D = \frac{V^2 \sin 2\theta}{g}$. V_o did relate to distance jumped (r= .80) in the elementary linkage analysis for mechanical variables for nine subjects; as V_o increased, the girl assumed a deeper crouch position in the preparatory motions of the standing long jump. But V_o correlated inversely (r= -.90) with ratio of depth of crouch height to standing height in the cluster analysis for seven subjects. Tricker and Tricker (69) stated that optimum take-off angle should be less than 45 degrees and might vary from person to person. The standing long jump selected for study in the present investigation was based on Bunn's (12) theoretical "best" angle of a 40 degree projection of the center of gravity. This arbitrary selection might account for the lack of association between distance jumped and angle of projection of the center of gravity in any cluster of the analyses of the present study. Halverson (39) had reported that as skill increased in the kindergarten children studied, angle of projection decreased and was below a theoretical best angle. Felton (28) found skilled college women had a 21 degree projection angle. In the present study, the average ($\bar{x}$) take-off angle of the center of gravity of the Wisconsin criterion subjects was 18 degrees and 28 degrees. Normative data is needed regarding optimum center of gravity take-off angles of skilled jumpers of various ages in standing long jump performance.

An increase in $\bar{w}$ of the thigh during force application correlated with distance jumped throughout the anlyses of the present investigation. Broer (9) stated that the force required for projection of the body through space is derived from a quick contraction of the extensors of the leg. In the Halverson (39) study, support for this theoretical position was also reported. Halverson found a significant difference between ability groups in speed and range of movement of the knee just prior to take-off.

In Chapter II, the theoretical position regarding the application of the law of the conservation of angular momentum to the body once it is airborne was stated. Distance can be affected by "changing the configuration of the body and the relative position of the partial masses." (64:395) The problem is one of getting the heels as far forward as possible on landing without loss of balance. Differences were found between the Wisconsin criterion subjects and the research subjects in range of movement of the toes relative to the hips from the height of the parabola to landing. Subject #6 jumped 6.02 inches and the range of movement of her toes relative to her hips was about 10 degrees. Between the same key reference point frames, this range was about 120 degrees for Wisconsin criterion subject #124 who jumped 83.8 inches.

In this study, as knee angle on landing decreased, reflecting a more horizontal position of the thigh at this reference frame, performance in the research group approached that of the Wisconsin criterion subjects in terms of direction of lever movement. Felton (28) had reported the unskilled women in her study had a more horizontal leg position on landing and Cooper and Glassow (14) believed that the more horizontal the thigh position on landing was associated with greater skill in jumping.

Specific consideration: prāgmatic mechanical investigation

Hellebrandt and her associates (43) had observed, in the boys studied, a progression in arm motion in the standing long jump. Initially the arms and shoulders were retracted during flight and take-off. This becamse a "full blown 'winging' pattern as the arms were moved behind the body to shoulder height, reaching culmination in one [boy's] performance at 41 months." (43:18-19) This same boy first attempted to swing his arms forward during force application at 43 months. The "winging'pattern was exhibited by one one girl, subject #13, in the present study. This girl, in terms of chronological age, was one of the youngest(40 months); her skeletal age (37 months) was below the average of 41 months, but she was not the "youngest" subject in terms of skeletal age. The skeletal age of the "youngest" girl was 33 months.

The next step in the arm progression observed in the Hellebrandt research was the use of the arms as stabilizers: "abduction at the glonohumeral joint was common and often more marked than humeral advancement." (43:19) This arm motion was found in kindergarten children, and the pattern persisted throughout the elementary years. In the analysis by inspection in the present study, the results of a joint motion analysis of the humerus at the shoulder were given. A wide variety of arm motions was demonstrated by the three and one half year old subjects. Basically the arm pattern observed was that of the stabilization which Hellebrandt and her associates had found in the kindergarten children studied. The skilled arm patterns of the Wisconsin criterion subjects varied in timing, and slightly, in direction, but the joint action was primarily one of flexion and extension of the humerus at the shoulder. Hellebrandt and her coresearchers described this arm action as "augmentation" (43:24); it represents the last step in arm pattern progression.

Another characteristic described in the Hellebrandt (43) research was that of head motion. This motion consisted of dorsiflexion during preparatory crouch and ventroflexion as the legs extended for take-off once the objective of jumping for distance was established. It is difficult to ascertain precisely head motion from this verbal description, but Hellebrandt and her associates included an explanatory drawing in their reported research. The head action was one of dorsiflexion during force application (Phase II); ventroflexion began at take-off. This same head motion was exhibited by the research subjects in this investigation.

In their investigation, Hellebrandt et. al. (43) reported the following regarding the phylogeny-ontogeny factors in the standing long jump:

> By the time central nervous system maturation progresses sufficiently to permit the jump to be evoked, the leg pattern appears in stereotyped form. It has all the earmarks of a phylogenetic acquisition--not so the arms.... The integration of the arms with the lower extremities to add momentum to a purposive movement is a learned skill which makes a comparatively late and hesitant appearance. (43:14)

Their conclusions were:

> There is nothing in our study which proves the increasingly efficient utilization of the arms to add momentum to the jump is a learned modification of a more elemental response, proceeding under a cortical direction. It may be no more than the last of a series of spontaneous changes unfolding in response to endogenous directional forces but affected to a significant degree by opportunities for practice. (43:24)

If the leg pattern is phylogenetic and the arm pattern ontogenetic, one might expect greater variability in the latter. In this study in the analysis by inspection greater variability in segmental inclination of the arms relative to the trunk, thigh, leg and foot was found for the research group at each of the six key reference frames. In addition, in the elementary linkage analyses, the variables that were representative of differences in movement patterns between the three and one half year olds and the Wisconsin criterion subjects were arm pattern relationships.

Finally, Hellebrandt and her associates (43) found the boys studied were able to restore balance following flight through the air so the integrity of the weight bearing segments could be maintained. Degree of propulsive force engendered was dependent on this ability to restore balance. No girl in the present investigation lost her balance following flight through the air.

Specific considerations: skeletal

In the skeletal assessment section of Chapter II, Garn's (33) findings were reported. Garn stated that, for the female, in the hand and wrist, the epiphysis of metacarpal III was the bone of greatest utility, yielding the most information on present or future skeletal status. Garn's report was based on onset of ossification; he found that by 1.94 years of age, onset of ossification had occurred in the epiphysis of metacarpal III in 95 percent of the girls studied. In the Greulich and Pyle Standard of Reference (37), onset of ossification in this bone appears between the ages of nine and 12 months in females, some 30 months in time previous to the ages of the research subjects. In this investigation, metacarpal III was a key individual bone which associated with achievement as represented by distance jumped (r= .82) in the cluster analysis for skeletal variables and with shoulder angle on landing (r= -.68) in the final elementary linkage analysis.

In the same section of Chapter II, the problem inherent in the computation of skeletal age for preschool aged children was discussed. Skeletal age represents an arithmetical average of the bone ages of all the bones in the hand and wrist in which ossification has begun. Bones not present are rated 0. Because of this problem, a partially longitudinal series of Xrays of preschool aged girls from the Brush Foundation Collection were read in the preliminary phases of this study. Individual differences in progress of ossification were characteristic for the bones in the hands and wrists of the Brush Foundation girls; consequently, individual bone age, as well as skeletal age, was included as individual variables in the present investigation. Distance jumped, rank with criterion, and Walker Compliance Rating all related to individual bone ages: metacarpal III, distal phalanx III and metacarpal II. Skeletal age and chronological age related to distal phalanx I with coefficients of correlation of .942 and .76, respectively.

Specific consideration: anthropometric

In Chapter II, it was explained that variables like lever length, bicristal width, foot and leg deviations might influence performance in the standing long jump. The theoretical basis for inclusion of these anthropometric variables was presented. The elementary linkage analyses indicated that the heavier girls tended to show more pronation, had greater bicristal width, and were taller in terms of erect sitting height and standing height. Higher motivation was related to an increase in erect sitting height and standing height; and as weight increased, distance jumped increased. As this gain in physical maturity, reflected by the greater length, girth, and weight measurements, occurred, motor patterns for the research subjects in the standing long jump approached those of the skilled performers.

Cowan and Pratt (15), Seils (66), and Wyrick (77) all reported low correlation coefficients between distance jumped and height, and between distance jumped and weight. The results of this study tend to support their findings. A moderate coefficient of correlation was found between distance jumped and weight ($r = .51$) and a low coefficient of correlation between distance jumped and height ($r = .32$).

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

This study was designed to investigate the interrelationships of selected mechanical, skeletal, and anthropometric variables, and skilled performance in the standing long jump for three and one half year old girls.

Nineteen Caucasian girls, chronological age 40 to 44 months, from highly favorable homes in the upper socio-economic level of society, came to the Merrill Palmer Institute in Detroit, Michigan during the winter of 1966 for a filming appointment. First, eight anthropometric measurements were made, then the girl was filmed as she performed three trials of the standing long jump on a mat. A 16 mm. Bell and Howell camera operated at 64 frames per second was used. If the girl was able to execute at least one jump, an Xray was taken of the left hand to determine bone age. Ratings based on the Walker Compliance Rating scale were completed to reflect movivation as the last step in the testing procedure.

The processed Xray film was appraised for bone age by Dr. S. Idell Pyle. Each bone on each Xray was assessed through comparison with the Greulich and Pyle (37) Standard of Reference. Letters were sent to the family physician requesting information on pediatric history.

A cinematographical analysis was completed on the filmed record of the standing long jump. The jump selected for study was the one in which take-off angle of the "center of gravity" mark on the ilium most closely approximated Bunn's (12) theoretical best angle of 40 degrees. Thirty-five mechanical variables were selected for study. Choice was based on the research which has been cited in Chapter II. Measurements and computations were made from the film record at six specific reference point frames: initial standing position, depth of crouch, take-off, height of parabola, landing, and landing plus seven additional frames. The variables included: angular measurements; average angular velocities; time determinations; ratio of depth of crouch height to initial standing height; acceleration, force, angle of projection, and velocity of projection of the total body at take-off; and distance jumped. Plus and minus values were assigned to average angular velocity measurements to show direction of movement of levers so patterns could be related to mature performance.

The criterion measure was the filmed record of the skilled performance of two sixth grade girls. Degree of skill was determined by comparison of the distance jumped by these girls with records in published normative studies. This data was provided by Miss Ruth Glassow and her associates at the University of Wisconsin. The three and one half year olds were compared to the Wisconsin criterion subjects on an individual, mechanical variable basis. Total points accumulated by the three and one half year olds in the comparison were ranked. This ranking (rank with criterion) was included as a variable.

The data for this investigation consisted of mechanical variables, skeletal variables (individual bone ages and skeletal age), anthropometric variables, Walker Compliance Rating, and rank with criterion. Complete data which met the standards of this investigation were available for nine of the 19 girls who came to the Merrill Palmer Institute for a filming appointment. Some question still existed regarding the medical histories of two of the nine subjects. Final determination of sample size was based on initial statistical treatment of the data. The data was submitted to a computer which was programmed to develop two groups of three matrices each: mechanical, skeletal and anthropometric. One group of matrices was based on the data for seven subjects; the other, on the data for nine subjects. Rank with criterion, Walker Compliance Rating, and distance jumped were included in each matrix as variables.

An elementary linkage analysis, or cluster analysis (57) was completed on each matrix. The analysis focused on delineation of typal or cluster structure and observation of variable relationships within mechanical, skeletal and anthropometric groupings. No marked dissimilarities appeared in the composition of clusters for the two sample sizes. A final decision was made that the statistical analysis should include all nine subjects.

On the basis of association within clusters and degree of stability of variables in the analyses for seven and nine subjects, selection was made of 33 variables from the mechanical, skeletal and anthropometric matrices. A final intercorrelation matrix was developed and a final elementary linkage analysis was completed for these variables to ascertain interrelationships between variable groupings. The data and the film record were also analyzed by inspection.

The findings of this investigation, presented within the context of the limitations imposed by the design of the study, were:

I. Eight of the 19 girls, chronological ages 40 to 44 months, who were filmed while performing the standing long jump were able to execute the skill in all three trials; examination of the film record was necessary for verification of the simultaneous thrust with both feet.

II. Variables tended to cluster with variables from within the same grouping: mechanical, skeletal and anthropometric. Anthropometric variables related in clusters to mechanical variables and mechanical variables, to skeletal, but skeletal and anthropometric variables did not associate with each other in clusters.

III. All phases of the standing long jump were related: lever movement and position during the preparatory motions associated with movement and position during power application and landing.

IV. In general, similarities in directional movement pattern and lever position between the research subjects and the Wisconsin criterien subjects in all phases of standing long jump performance were more pronounced than differences in pattern. Movement patterns which approached skilled performance appeared to be associated with greater physical maturity and higher motivation. The mechanical variables associated with skilled performance were:

Angular measurements:
- At depth of crouch: hip
- At take-off: shoulder, knee, ankle
- At landing: knee, hip

$\bar{w}$ measurements:
- Phase I: head, trunk, thigh, leg
- Phase II: head, trunk, thigh, leg, foot

Time determinations:
- Time airborne
- Percentage of jump time spent in Phase I and Phase II

Force, angle of projection, velocity of projection of the total body at take-off.

In general, individual bones tended to group in clusters relative to bone position in the hand. High coefficients of correlation were found between reciprocal pairs in the cluster analysis for skeletal variables. An increase in developmental age of the following bones and an increase in skeletal age associated with skilled performance.

Distal phalanx I
Distal phalanx III
Metacarpal II
Metacarpal III
Metacarpal V

Anthropometric variables were highly interrelated. The girls who weighed more showed greater pronation, had greater bicristal width, and were taller in terms of erect sitting and standing height. This increase in physical maturity associated with skilled performance. The anthropometric variables involved were:

Bicristal width
Pronation
Weight
Thigh length
Standing height
Erect sitting height

Walker Compliance Rating, the measurement of motivation, and rank with criterion, one method of comparing performance between the research subjects and the Wisconsin criterion subjects on an individual, mechanical variable basis, also associated with skilled performance.

V. Differences in performance were found between the research subjects and the Wisconsin criterion subjects. The research subjects tended to:

A. move the lower arm clockwise toward the body in assuming the depth of crouch position.

B. hold their arms closer to their bodies, anterior or posterior, at depth of crouch and landing.

C. use the arms as frontal plane stabilizers instead of augmentors of movement at take-off and flight through the air.

D. show less range of movement of the leg relative to the hip during flight through the air.

E. have the hips above knee level seven frames following landing.

These differences could be representative of ontogenetic or late appearing phylogentic patterns.

VI. Greater variance was observed in segmental inclination of the arms relative to the trunk, thigh, leg and foot in the research group at all the six key reference point frames.

VII. Throughout the analyses, the average angular velocity ($\bar{w}$) of the thigh during force application associated most highly with achievement as measured by distance jumped. Velocity of projection of the center of gravity was related to distance jumped, but projection angle of the center of gravity was not. Moderate relationship (r = .51) was found between distance jumped and weight, and low relationship (r = .32), between distance jumped and height.

VIII. Rank with criterion related throughout the analyses to time ratio determinations: as less time was spent in power application, and more in preparatory action, rank with criterion increased. Distance jumped and rank with criterion each related to the increased developmental age of specific bones more than they related to each other.

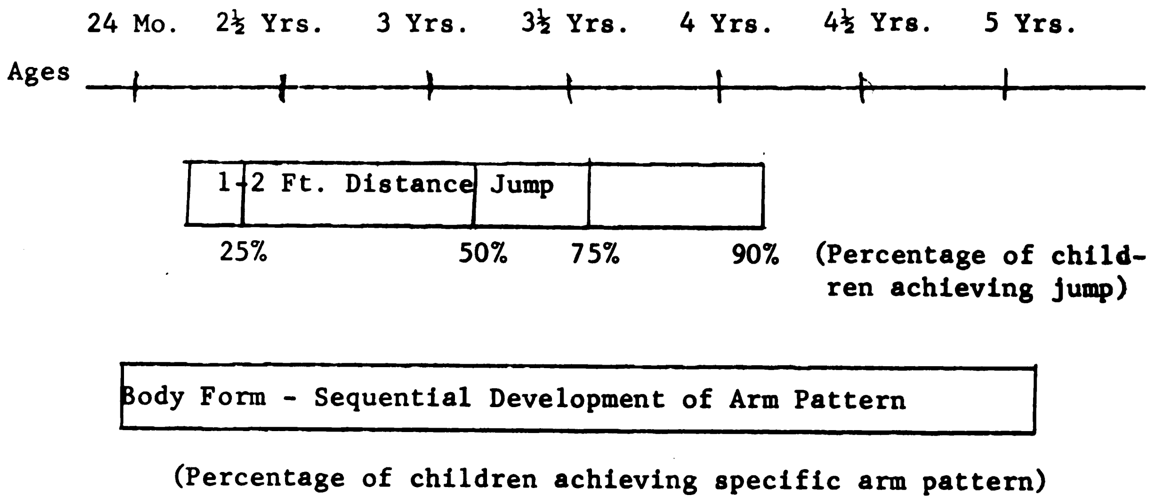
IX. Skeletal age and chronological age associated in clusters with each other, but not with distance jumped, rank with criterion, height or weight. Skeletal age and chronological age each related to the bone age of distal phalanx I, but more variance was accounted for in the association of skeletal age and distal phalanx I.

X. Distance jumped, rank with criterion, and the Walker Compliance Rating each related to physical maturation as evidenced by an increase in developmental age of individual bones: metacarpal II, metacarpal III, and distal phalanx III. The bone age of metacarpal III was related to shoulder angle on landing, distance jumped, and skeletal age.

Implications for Childhood Education

There are two major implications of this investigation for structuring and teaching learning experiences in physical activity in early childhood education.

First, it is recommended achievement standards of performance should reflect variability of individual difference. It is suggested that these be constructed in percentiles such as the Denver Developmental Screening Test which indicates no absolutes for variability of performance. The following chart is an adaptation of the Denver percentile charts (31:185):



The evaluation tool for form could be subjectively appraised through visual inspection by the teacher. Movies or still pictures taken from movies depicting sequential movement of body form is the recommended format for visual inspection. These developmental standards will serve as diagnostic tools for the teacher to evaluate the specific developmental level achieved by an individual child. As such, the diagnostic tools will serve two vital functions· (1) programming the specific activities for the individual child based on his level of development, (2) evaluating changes occurring in the learning situation.

Second, it is recommended that the learning experiences be structured for the child to sequentially develop skilled performance. His present status would be evaluated using the diagnostic tool described above. Thus, the individual's present level of development would be diagnosed, and the next sequence of development for attaining skill performance, recognized by the teacher. A complete sequential development of form for the fundamental motor skills (run, hop, leap, throw, catch, and so forth) for the teacher is not to be found in the literature. An example of a suggested model that would be helpful for the teacher would be as follows:

Stage 1	Stage 2	Stage 3	Stage 4
Attempts activity, but seeks help or support. (38:172-173)	Efforts directed at general body control.	Trunk, leg patterns emerge. Arms assist in balance in specific skill.	Trunk, leg patterns more refined, but unnecessary movements still evident.

Under each stage, sequential pictures would be presented, showing the motor patterns thought necessary before structuring experiences for the next stage.

Specific examples for the teacher in structuring learning experiences in the standing long jump for sequential skill development might be as follows. The beginning stages, occurring during early childhood education would be primarily descriptive, such as:

"Can you:

jump over this little brook or over this wider one?"
(achieve jumps of greater distance)

squat way down and make yourself very small; then, when the drum sounds, jump as far as you can?"
(develop a deeper preparatory crouch position)

swing your arms up high as you jump?"
(use the arms to augment movement)

jump quickly?"
(decrease the time spent in force application)

"How do you:

move your arms when you jump?"

land when you jump?"

get ready to jump?"

In addition, equipment can be designed, or if existing equipment is available, it can be utilized to enlarge opportunities for the child to experience jumping in many different situations. The basic skills of dropping into a deeper crouch and jumping quickly could be learned on a flexible board or a mini-trampoline. To insure success in the beginning stages, the adult could hold the child's hands. A gentle lifting of the arms during flight through the air might show the child how the arms could be used to augment movement.

Implications for Further Research

Areas for further research suggested by the findings of study include the following topics:

1. Measurement technique in cinematographical analysis needs to be standardized.

2. The design of this study could be replicated with a larger sample representing other socio-economic groups and other races.

Improved filming techniques should be incorporated in the procedures so all body planes can be recorded on the film record. Markings to show rotation in body levers need to be developed.

3. The performance of subject # 16 in this study suggests that investigation of the interrelationships between child rearing practice and development of specific motor skills such as jumping should be undertaken.

4. Specification of direction of lever movement does not indicate optimal timing. Normative data of the actual average angular velocities exhibited by skilled performers in the standing long jump are needed as criteria.

5. The factors affecting motivation in the performance of the standing long jump at various ages should be studied.

6. Techniques for measuring explosive strength in young children need to be developed.

LITERATURE CITED

1. Acheson, Roy M. "Maturation of the Skeleton." Chapter 16 in Falkner, Frank. Human Development. Philadelphia: Saunders, 1966.

2. Baer, Melvyn and Durkatz, Josephine. "Bilateral Asymmetry In In Skeletal Maturation of the Hand and Wrist: A Roentgenographic Analysis." American Journal of Physical Anthropology, 15: 81-196, June, 1957.

3. Baldwin, Bird T. "The Physical Growth of Children from Birth to Maturity." Iowa City, Iowa: University of Iowa Studies in Child Welfare, Vol. 1, No. 1, 1921.

4. Bayer and Gray Graphic Growth Record Chart for Girls from Bayer and Gray, "Plotting of a Graphic Record of Growth for Children Aged One to Nineteen Years." American Journal of Diseases of Children, Vol. 50:1408-1417, 1935.

5. Bayley, Nancy. "The Development of Motor Abilities During the First Three Years." Monographs of the Society for Research in Child Development, Vol. I, No. 1: 1-26, 1935.

6. Bayley, Nancy. "Comparisons of Mental and Motor Test Scores for Ages 1-15 Months by Sex, Birth Order, Race, Geographic Location and Education of Parents." Child Development, 36: 379-412, June, 1965.

7. Bayley, Nancy. "Psychological Development of the Child. Part III: Mental Measurement." Chapter 12 in Falkner, Frank. Human Development. Philadelphia: Saunders, 1966.

8. Bayley, Nancy and Jones, Harold E. "Environmental Correlates of Mental and Motor Development: A Cumulative Study Infancy to Six Years." Child Development, 8: 329-341, 1937.

9. Broer, Marion R. Efficiency of Human Movement. Second Edition. Saunders: Philadelphia, 1966.

10. Brožek, Josef. Body Measurements and Human Nutrition. Detroit, Michigan: Wayne University Press, 1956.

11. Buehl, Clara C. and Pyle, S. Idell. "Use of Age at First Appearance of Three Ossification Centers in Determining The Skeletal Status of Children." Journal of Pediatrics, 21: 335-342, September, 1942.

12. Bunn, John C. Scientific Principles of Coaching. Englewood Cliffs, New Jersey: Prentice Hall, 1962.

13. Carpenter, Aileen. "The Measurement of General Motor Capacity and General Motor Ability in the First Three Grades." Research Quarterly, 13: 444-465, December, 1942.

14. Cooper, John B. and Glassow, Ruth B. Kinesiology. St. Louis: C. V. Mosby, 1963.

15. Cowan, Edwina A. and Pratt, Bertha M. "The Hurdle Jump as a Developmental Diagnostic Test of Motor Co-ordination for Children from Three to Twelve Years of Age." Child Development, 5: 107-121, 1934.

16. Cratty, Bryant J. Movement Behavior and Motor Learning. Philadelphia: Lea and Febiger, 1964.

17. Cunningham, B. V. "An Experiment in Measuring Gross Motor Development of Infants and Young Children." Journal of Educational Psychology, 18: 458-464, 1927.

18. Dammann, Vera T. "Developmental Changes in Attitude as One Factor Determining Energy Output in a Motor Performance." Child Development, 12: 241-246, 1941.

19. Damon, Albert. "Notes on Anthropometric Technique I: Stature Against a Wall and Standing Free." American Journal of Physical Anthropology, 22: 73-77, March, 1964.

20. Defibaugh, Joseph J. "Measurement of Head Motion. Part I: A Review of Methods of Measuring Joint Motion." Journal of the American Physical Therapy Association, 45: 157-163, March, 1964.

21. Degutis, Ernest W. Relationship Between Standing Broad Jump and Various Maturity, Structural and Strength Measures of 12 Year Old Boys. Unpublished masters thesis. University of Oregon, 1959.

22. Dennis, Wayne and Dennis, Marsena G. "The Effect of Cradling Practices Upon the Onset of Walking in Hopi Children." Journal of Genetic Psychology, 56: 77-86, 1940.

23. Dreizen, S.; Snodgrasse, R. M.; Webb-Peplow, H.; Parker, G. G.; Spies, T. D. "Bilateral Symmetry of Skeletal Maturation in the Human Hand and Wrist." American Journal of Diseases of Children, 93:122-127, 1957.

24. Duckworth, W.L.H. "Report of the Commission Appointed by the XIVth International Congress of Prehistoris Anthropology and Archeology at Geneva (1912)." The Anthropological Laboratory of the University, New Museums, Cambridge, October 30, 1912.

25. Eckert, Helen M. "Linear Relationships of Isometric Strength to Propulsive Force, Angular Velocity, Angular Acceleration in the Standing Broad Jump." Research Quarterly, Vol. 35, No. 3, Pt. I: 298-306, October, 1964.

26. Espenschade, Anna A. and Eckert, Helen M. Motor Development. Columbus, Ohio: Charles E. Merrill Books, Inc., 1967.

27. Falkner, Frank. "General Considerations in Human Development." Chapter 2 in Falkner, Frank. Human Development. Philadelphia: Saunders, 1966.

28. Felton, Elvira. A Kinesiological Comparison of Good and Poor Jumpers in the Standing Broad Jump. Unpublished masters thesis. University of Wisconsin, 1960.

29. Fleishman, Edwin A. The Structure and Measurement of Physical Fitness. Englewood Cliffs, New Jersey: Prentice Hall, 1964.

30. Flynn, Kenneth W. Relationships Between Various Standing Broad Jump Measures and Strength, Speed, Body Size and Physique Measures of Twelve Year Old Boys. Unpublished masters thesis. University of Oregon, 1966.

31. Frankenburg, William K. and Dodds, Josiah B. "The Denver Developmental Screening Test." Journal of Pediatrics, Vol. 71, No. 2: 181-191, 1967.

32. Garn, Stanley M. and Shamir, Zvi. Methods for Research in Human Growth. Springfield, Illinois: Charles C. Thomas, 1958.

33. Garn, Stanley: Rohman, Cristobel G.; Silverman, Frederic N. "Radiographic Standards for Postnatal Ossification and Tooth Calcification." Eastman Kodak Company. Medical Radiography and Photography, Vol. 43, No. 2, November 2, 1967.

34. Geber, Marcelle. "The Psychomotor Development of African Children in the First Year and the Influence of Maternal Behavior." Journal of Social Psychology, 47: 185-195, 1958.

35. Gesell, Arnold and Amatruda, Catherine. Developmental Diagnosis: Normal and Abnormal Child Development. New York: Harper, 1941

36. Gesell, Arnold and Ilg, Frances. The Child from Five to Ten. New York: Harper and Brothers, 1946.

37. Greulich, W. W. and Pyle, S. Idell. Radiographic Atlas of Skeletal Development of the Hand and Wrist. Stanford California: Stanford University Press, 1959.

38. Gutteridge, Mary V. "A Study of Motor Achievements in Young Children." Archives of Psychology, 34: 1-178 (#244), 1939.

39. Halverson, Lolas E. A Comparison of Performance of Kindergarten Children in the Take-Off Phase of the Standing Broad Jump. Unpublished doctoral dissertation. University of Wisconsin, 1958.

40. Halverson, Lolas E. "Development of Motor Patterns in Young Children." Quest, VI: 44-53, May, 1966.

41. Hartman, Doris M. "The Hurdle Jump as a Measure of Motor Proficiency of Young Children." Child Development, 14: 201-211, 1943.

42. Hays, William L. Statistics for Psychologists. New York: Holt, Rinehart, Winston, 1963.

43. Hellebrandt, F.A.; Rarick, G.L; Glassow, R.; Carns, M. L. "Physiological Analysis of Basic Motor Skills: I Growth and Development of Jumping." American Journal of Physical Medicine, 40: 14-25, 1961.

44. Hrdlička, Aleš. Anthropometry. Philadelphia: Wistar Institute of Anatomy and Biology, 1920.

45. Hrdlička, Aleš. Practical Anthropometry. Philadelphia: Wistar Institute of Anatomy and Biology, 1939.

46. Jenkins, Lulu Marie. "A Comparative Study of Motor Achievements of Children of Five, Six and Seven Years of Age." New York: Columbia University Contributions to Education, No. 414, 1930.

47. Kerlinger, Fred N. Foundations of Behavioral Research. New York: Holt, Rinehart and Winston, 1964.

48. Knobloch, Hilda and Pasamanick, Benjamin. "Further Observations on the Behavioral Development of Negro Children." Journal of Genetic Psychology, 83: 137-157, 1953.

49. Knobloch, Hilda and Pasamanick, Benjamin. "Prospective Studies on the Epidemiology of Reproductive Casualty: Methods, Findings and Some Implication." Merrill Palmer Quarterly Vol. 12, No. 1: 27-43, January, 1966.

50. Krogman, Wilton Marion. "The Physical Growth of Children: An Appraisal of Studies 1950-1955." Monographs, Society for Research in Child Development, Vol. XX, No. 1, Lafayette, Indiana: Purdue University, 1955.

51. Martin, Rudolph. (As quoted in Hrdlička, Practical Anthropometry, 1939) Lehrbuch der Anthropologie, Second Edition. 3 Vol. in 8^{o}, Jena, 1928.

52. Mathews, Donald K. Measurement in Physical Education. Second Edition. Philadelphia; Saunders, 1963.

53. McCaskell, Carra L. and Wellman, Beth L. "A Study of Common Motor Achievements at the Pre School Ages." Child Development, 9: 141-150, 1938.

54. McCloy, Charles H. "Appraising Physical Status: The Selection of Measurements." Iowa City, Iowa: University of Iowa Studies in Child Welfare, Vol. XII, No. 2, 1936.

55. McGraw, Myrtle B. "A Comparative Study of a Group of Southern White and Negro Infants." Genetic Psychology Monographs, 10: 1-105, 1931.

56. McGraw, Myrtle B. Growth: A Study of Jimmy and Johnny. New York: Appleton-Century, 1935.

57. McQuitty, Louis L. "Elementary Linkage Analysis for Isolating Orthogonal and Oblique Types and Typal Relevancies." Educational and Psychological Measurement, Vol. 17, No. 2: 207-229, 1957.

58. McQuitty, Louis L. "Capabilities and Improvements of Linkage Analysis as a Clustering Method." Educational and Psychological Measurement, Vol. XXIV, No. 3: 441-456, 1964.

59. Metheny, Eleanor. "Breathing Capacity and Grip Strength of Preschool Children." Iowa City, Iowa: University of Iowa Studies in Child Welfare, Vol. 18, No. 2, 1941.

60. Patton, Robert Gray and Gardner, Lytt I. Growth Failure in Maternal Deprivation. Springfield, Illinois: Charles Thomas, 1963.

61. Poley, Margaret; Kelly, Ellen; Meredith, Howard V. "Anthropometry and Body Mechanics Research Methods." Chapter 7 in American Association for Health, Physical Education and Recreation. Research Methods Applied to Health, Physical Education, Recreation. Washington, D.C.: N.E.A. Publication, 1949.

62. Provence, Sally and Lipton, Rose C. Infants in Institutions; A Comparison of Their Development with Family Reared Infants During the First Year of Life. New York: International Universities Press, 1962.

63. Rarick, G. Lawrence. "Exercise and Growth." Chapter 23 in Johnson, Warren R. Science and Medicine of Exercise and Sports. New York: Harper, 1960.

64. Rasch, Philip J. and Burke, Roger K. Kinesiology and Applied Anatomy. Third Edition. Philadelphia: Lea and Febiger, 1967.

65. Scott, Roland B.; Ferguson, Angella; Jenkins, Melvin; Cutter, Fred. "Growth and Development of Negro Infants: V Neuromuscular Patterns of Behavior During the First Year of Life." Pediatrics, 16: 24-30, 1955.

66. Seils, LeRoy G. "The Relationship Between Measures of Physical Growth and Gross Motor Performance of Primary Grade Children." Research Quarterly, 22: 244, May, 1951.

67. Simmons, Katherine. "Brush Foundation Study of Growth and Development." Monographs, Society for Research in Child Development, Vol. 9, No. 1, 1944.

68. Stott, Leland H. Child Development: An Individual Longitudinal Approach. Chicago: Holt, Rinehart and Winston, Inc., 1967.

69. Tricker, R.A.R. and Tricker, B.J.K. The Science of Movement. New York: American Elsevier Publishing Company, 1967.

70. United States, Department of Health Education and Welfare, Public Health Service, Cycle I of the Health Examination Survey: Sample and Response, United States, 1960-62. Washington, D. C.: Superintendent of Documents, April, 1964.

71. Walker, Richard N. "Body Build and Behavior in Young Children: I, Body Build and Nursery School Teacher' Ratings." Monographs, Society for Research in Child Development, Vol. 27, No. 3, 1962.

72. Waterland, Joan C. "The Effect of Force Gradation on Motor Patterning: Standing Broad Jump." Quest, VIII: 15-25, May, 1967.

73. Wellman, Beth L. "Motor Achievments of Pre School Children." Childhood Education, 13: 311-316, March, 1937.

74. Wells, Katherine. Kinesiology. Fourth Edition. Philadelphia: Saunders, 1966.

75. Williams, J.R. and Scott, R.B. "Growth and Development of Negro Infants: Motor Development and Its Relationship to Child Rearing Practices in Two Groups of Negro Infants." Child Development, 24: 103-131, 1953.

76. Wilson, Marjorie U. Development of Jumping Skill in Children: Unpublished doctoral dissertation. State University of Iowa, 1945.

77. Wyrick, Mary Dell Leisenberg. The Relationship of Selected Factors to Performance Made by Elementary School Children in the Standing Broad Jump. Unpublished masters' thesis, University of Colorado, 1960.

78. Zimmerman, Helen M. "Characteristic Likenesses and Differences Between Skilled and Non Skilled Performance of Standing Broad Jump." Research Quarterly, 27: 352-362, October, 1956.

APPENDIX A

LISTING OF VARIABLES INCLUDED IN THE DATA ANALYSIS

Variable Number	Variable
1.	Average angular velocity of upper arm, Phase I Measurement Technique: A. Point S Placement: Acromion process of scapula
2.	Average angular velocity of lower arm, Phase I Measurement Technique: A. Point S Placement: Apex of angle, back of elbow joint
3.	Average angular velocity of trunk, Phase I Measurement Technique: A. Point S Placement: Apex of angle, back of hip joint
4.	Average angular velocity of thigh, Phase I Measurement Technique: A. Point S Placement: Apex of angle, front knee joint
5.	Average angular velocity of leg, Phase I Measurement Technique: A. Point S Placement: Lateral malleolus
6.	Average angular velocity of head, Phase I Measurement Technique: A. (See Appendix B)
7.	Percentage of total jump time Phase I consumes
8.	Ratio (in percentage) of depth of crouch height to initial standing height
9.	Time (in seconds) before take off when maximum angular velocity of lower arms occurs, Phase II, (Take 1/2 of time between the two adjacent frames in which this maximum angular velocity occurs)
10.	Size of angle at the hip between the trunk and thigh, depth of crouch frame Measurement Technique: B
11.	Size of angle at the knee between the thigh and leg, depth of crouch frame Measurement Technique: B

12. Size of angle at the ankle between the leg and foot, depth of crouch frame
    Measurement Technique: B

13. Size of the angle at the shoulder between the humerus and trunk, depth of crouch frame
    Measurement Technique: B

14. Time in seconds before take off when arms (lower arm) reaches maximum vertical height, Phase II

15. Angle of projection of the center of gravity mark with the horizontal (Measurement of the movement of the center of gravity mark taken from the grid using both horizontal and vertical reference points. Measured in take off frame + 2 frames)

16. Vo computation (Velocity of projection of center of gravity)

17. Computation of force (time = time feet are in contact with mat, Phase II) Ft = mv

18. Computation of acceleration at take off using F = ma formula

19. Size of angle at the hip between trunk and thigh, take off frame
    Measurement Technique: B

20. Size of angle at the knee between thigh and leg, take off frame
    Measurement Technique: B

21. Size of angle at the ankle between leg and foot, take off frame
    Measurement Technique: B

22. Size of angle at the shoulder between humerus and trunk, take off frame
    Measurement Technique: B

23. Average angular velocity of upper arm, Phase II
    Measurement Technique: A. Point S Placement: Acromion process of scapula

24. Average angular velocity of trunk, Phase II
    Measurement Technique: A. Point S Placement: Apex of angle, back of hip joint

25. Average angular velocity of thigh, Phase II
    Measurement Technique: A. Point S Placement: Apex of angle, front of knee joint

26. Average angular velocity of leg, Phase II
    Measurement Technique: A. Point S Placement: Lateral malleolus

27. Average angular velocity of foot, Phase II
    Measurement Technique: A. Point S Placement: Tip of toes

28. Average angular velocity of head, Phase II
    Measurement Technique: A

29. Percentage of total jump time Phase II consumes

30. Size of angle at the hip between trunk and thigh, landing frame
    Measurement Technique: B

31. Size of angle at the knee between thigh and leg, landing frame
    Measurement Technique: B

32. Size of angle at the ankle, between leg and foot, landing frame
    Measurement Technique: B

33. Size of angle at the shoulder between humerus and trunk, landing frame
    Measurement Technique: B

34. Distance jumped

35. Time in seconds child is airborne

36. Bone age, radius

37. Bone age, capitate

38. Bone age, hamate

39. Bone age, triquetral

40. Bone age, metacarpal I

41. Bone age, metacarpal II

42. Bone age, metacarpal III

43. Bone age, metacarpal IV

44. Bone age, metacarpal V

45. Bone age, proximal phalanx I

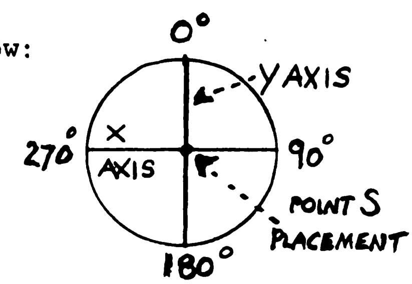
46. Bone age, proximal phalanx II
47. Bone age, proximal phalanx III
48. Bone age, proximal phalanx IV
49. Bone age, proximal phalanx V
50. Bone age, middle phalanx II
51. Bone age, middle phalanx III
52. Bone age, middle phalanx IV
53. Bone age, middle phalanx V
54. Bone age, distal phalanx I
55. Bone age, distal phalanx II
56. Bone age, distal phalanx III
57. Bone age, distal phalanx IV
58. Bone age, distal phalanx V
59. Skeletal age
60. Chronological age
61. Standing height
62. Weight
63. Erect sitting height
64. Bicristal width
65. Thigh length
66. Knee height
67. Degrees, pronation in the foot
68. Degrees, inward rotation, patella
69. Walker Compliance Rating
70. Rank with criterion

APPENDIX B

MEASUREMENT TECHNIQUES, MECHANICAL VARIABLES

MEASUREMENT TECHNIQUE A: AVERAGE ANGULAR VELOCITY OF A SEGMENT

Step 1: For determination of segmental inclination a circular protractor was placed over the traced image so the X axis was parallel to the mat surface and the Y axis, perpendicular to the mat. 0 degrees pointed up, toward the child's head. Point S was placed on the anatomical landmark specified in the variable description. The degree at which the center of the other end of the segment (lever) intersected the circle represented the measurement. The positioning of the circular protractor is shown in the drawing below:



Step 2: For measurement of head inclination, a line was drawn from the tragus of the ear to the apex of the chin. Point S was placed on the tragus of the ear. The measurement represented the degree at which the extended line intersected the circle using the circular protractor described above.

Step 3: Average angular velocity of a segment was then determined as follows:

1. The degrees the distal end of the humerus ,radius, ulna, and head moved was measured.

2. The degrees the proximal end of the trunk, thigh, leg, foot moved was measured.

3. The difference in degrees was measured between the position of the lever in the two frames specified in the definition of phases. That value was divided by the time that elapsed between the two lever positions to obtain the average angular velocity measured in degrees per second.

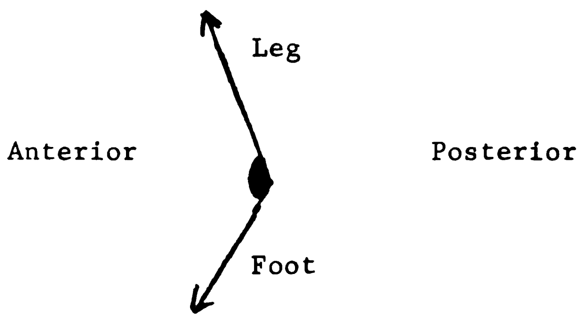
4. Plus or minus values were assigned as follows:

A. When the humerus, radius and ulna, trunk, leg, foot moved CLOCKWISE, a minus (-) value was assigned; COUNTER-CLOCKWISE, a plus (+) value was assigned.

B. When the thigh and head moved CLOCKWISE, a plus (+) value was assigned; COUNTERCLOCKWISE, a minus (-) value was assigned.

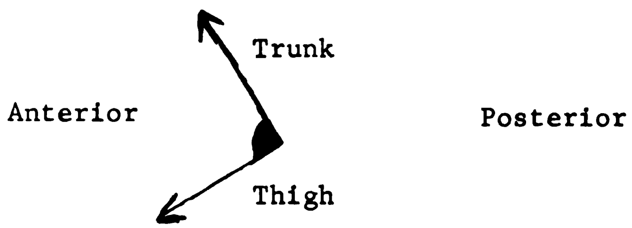
MEASUREMENT TECHNIQUE B: ANGULAR MEASUREMENT

Foot: A line was drawn through the center of the leg parallel to the long axis of the tibia and through the foot from the toe to the heel along the sole. The following angle represented the measurement:

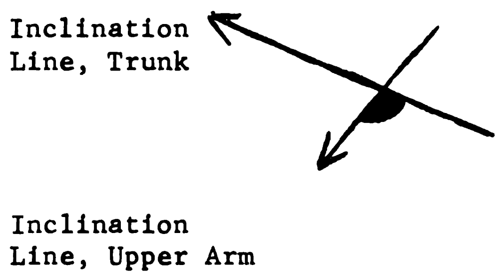


Knee: A line was drawn through the center of the thigh parallel to the long axis of the femur and through the center of the leg parallel to the long axis of the tibia. The following angle at the intersection of these lines represented the measurement:

Hip: A line was drawn through the center of the trunk parallel to the long axis of the spine and through the center of the thigh parallel to the long axis of the femur. The following angle at the intersection of these lines represented the measurement:



Shoulder: A line was drawn through the center of the trunk parallel to the long axis of the spine and through the center of the upper arm parallel to the humerus. The following angle at the intersection of these lines represented the measurement:



APPENDIX C

INITIAL LETTER SENT TO PARENTS

Dear (Parent's Name):

This letter concerns a research study on the development of locomotor skills that I am conducting at the Merrill Palmer Institute. Mrs. . . . . director of . . . . Nursery School suggested you be contacted.

The problem is that children of a specific age are needed for this study. As you know, research studies have to be carefully controlled. In the present research design, girls, ages 3 years, 4 months, through 3 years, 8 months, who are free from physical disabilities will be included. All of the children presently enrolled in the Merrill Palmer Institute who are eligible are participating.

The basic objective of the research is the investigation of normative patterns in locomotor skills, and the procedure would involve your bringing your child to the Merrill Palmer Institute. The actual data collection would consist of three parts and will take <u>only</u> 45 minutes.

First, we will take measurements like height, weight, and hip width. Secondly, a motion picture film will be taken of the child performing some locomotor skills. Thirdly, an Xray will be taken of the hands to determine the child's level of physical maturation. The Xray at Merrill Palmer Institute has been licensed and will be operated by the qualified technician with the child wearing proper protective equipment.

If you are interested, we would like to include your child in this study. I will call you in a few days and get your final decision. At that time, if you are willing to participate, final arrangements can be made.

Thank you for your consideration of this matter.

Sincerely,

Mary Lou Stewart
Doctoral Candidate
Merrill Palmer Institute

APPENDIX D

PARENTAL RECORD FORM

CODE # ____________

CHILD'S NAME: ________________ ________________ ________________
Last First Middle

ADDRESS: ________________________________ CHILD'S BIRTHDATE: _____ ___ _____
Number Street City Zip Month Day Year

FATHER: ________________ ________________ ________________ AGE AT BIRTH OF CHILD: ________
Last Name First Name Middle Name

OCCUPATION: ____________________ PLACE OF EMPLOYMENT: ____________________

PLACE OF BIRTH: ____________________ EDUCATION: ______ LAST SCHOOL ATTENDED: ________
Grade

MOTHER: ________________ ________________ ________________ AGE AT BIRTH OF CHILD: ________
Last Name First Name Middle Name

OCCUPATION: ____________________ PLACE OF EMPLOYMENT: ____________________

PLACE OF BIRTH: ____________________ EDUCATION: ______ LAST SCHOOL ATTENDED: ________
Grade

BIRTHPLACE OF CHILD: ____________________ NURSERY, CHURCH SCHOOL, DAY CARE CENTER ATTENDANCE: ________ ________
Name Months

HAS THE CHILD LIVED WITH OTHER RELATIVES: ________ ________ SIBLINGS: ________ ________
Yes, No How Long?

________ ________

________ ________

APPENDIX E

PARENTAL PERMISSION FORM

I HEREBY GIVE PERMISSION FOR MY CHILD: ____________________________

A) TO BE PHOTOGRAPHED
B) TO HAVE A SKELETAL XRAY (1) TAKEN OF THE HANDS ON A SINGLE FILM

IN THE MOTOR DEVELOPMENT STUDY OF PRESCHOOL GIRLS CONDUCTED BY MARY LOU STEWART, A GRADUATE STUDENT AT THE MERRILL PALMER INSTITUTE, DETROIT, MICHIGAN.

MISS STEWART ALSO HAS PERMISSION TO CONTACT OUR FAMILY PHYSICIAN CONCERNING THE PHYSICAL STATUS OF THIS CHILD.

OUR FAMILY PHYSICIAN'S NAME: ____________________________

HIS ADDRESS: ____

I FURTHER AGREE THAT THE PHOTOGRAPHS TAKEN IN THIS STUDY MAY BE PUBLISHED IN PROFESSIONAL JOURNALS WITH THE UNDERSTANDING THAT THE NAME AND PICTURE OF THE CHILD WILL BE ANONYMOUS.

PARENT'S SIGNATURE: ____________________________________

PARENT'S ADDRESS: ______________________________________

DATE: ________________________________

APPENDIX F
CHILD'S RECORD FORM

CODE # ____________

CHILD'S NAME: ______________ Last ______________ First ______________ Middle

CHILD'S BIRTHDATE: _____ Month ____ Day _____ Year

CHILD'S ADDRESS: ______________ Number Street ______________ City ______________ Zip

CHILD'S C.A. AT FILMING _____ Yrs., _____ Mos., _____ Days

ANTHROPOMETRIC DATA:

______________ Height (inches)

______________ Weight (pounds) Shoes, clothes on

______________ Erect Sitting Height (inches) (McCloy)

______________ Bench Height (inches)

______________ Bicristal Width (inches) (McCloy)

______________ Thigh Length (Derived: inches)

______________ Knee Height (inches) (Simmons)

Variation: Top of sole of shoe to joint space of knee, lateral aspect of leg

Degrees, Pronation: 1 2 3
3 = marked deviation

Degrees, inward rotation, patella: 1 2 3
3 = marked deviation

FILMING DATA:

Child jumps willingly: _____ Yes _____ No

Demonstration jump needed: _____ Yes _____ No

Bipedal take off correction needed: _____ Yes _____ No

Correction for upright landing needed: _____ Yes _____ No

WALKER COMPLIANCE RATING __________

MEAN SKELETAL AGE: (Greulich & Pyle, 1959) _______ Right hand _______ Left hand

APPENDIX G

PHYSICIAN'S CERTIFICATION FORM

Dear Dr. ____________________________.

The following child, ____________________________, one of your patients, has participated in a motor development study conducted at the Merrill Palmer Institute.

The child's mother, ______________________, has consented to this request for information. In this study, it is important that we ascertain that this child is "well and healthy" and has not suffered accidents or illness that would be detrimental to neuromuscular or physical growth. It would also be very helpful if you could provide some developmental data on this child from your records.

Would you fill in the chart below? A stamped, addressed envelope is enclosed for convenience in returning this letter. Your assistance would be greatly appreciated. Thank you.

Mary Lou Stewart
Doctoral Candidate
Merrill Palmer Institute

I (can) ____(cannot)____certify that _______________________, one of my patients, is to the best of my knowledge "well and healthy" and has not suffered accidents or illness that would be detrimental to neuromuscular or physical growth.

The reason(s) I cannot certify to the above:

I (can)____(cannot)____provide the following developmental data:

Birth weight ________________ Birth length ____________

Age at which this child first sat unsupported ____________

Age at which child first walked unassisted ______________

Physician's signature: __________________

Date: ____________________

APPENDIX H

GENERAL RESULTS OF THE TESTING PROCEDURES FOR THE ENTIRE GROUP OF 19 SUBJECTS

(An asterisk [*] indicates the data for that subject was included in the final statistical analysis)

Code Number	Race	Standing Long Jump Results	Skeletal Xray Results	Physician's Certification
1	White	Child refused to change her clothing for filming. Dress obscured trunk on film record.	Child moved left hand while Xray was being taken.	None requested.
2	White	Good jumps recorded in all three trials.	Xray film difficult to read. Dr. Pyle recommends data should not be included in the statistical analysis.	"Well and healthy".
3	Negro	Running and leaping pattern appeared in all three trials.	Xray film difficult to read.	None requested.
4	Negro	Good jumps recorded in all three trials.	Xray film difficult to read. Damaged diaphyseal growth cartilage plate, bilateral, in middle V phalanx and in middle II phalanx, left hand.	"Well and healthy".

Code Number	Race	Standing Long Jump Results	Skeletal Xray Results	Physician's Certification
--	White	Child refused to participate.	No Xray taken	None requested
5*	White	Good jumps recorded in all three trials.	Xray film good. No abnormalities or anomalies.	"Well and healthy".
6*	White	Trial # 1 = Jump Trial # 2 = Walk Trial # 3 = Walk	Xray film good. No abnormalities or anomalies.	Physician did not take over medical care of child until she was 2½ years old. Previous record unavailable. Physician believes child is "well and healthy".
7*	White Adopted Child	Good jumps recorded in all three trials.	Xray film good. No abnormalities or anomalies.	"Well and healthy".
8*	White	Good jumps recorded in all three trials.	Xray film good. No abnormalities or anomalies.	By history, mother reported that in labor fetal heart tones were decreased, but child delivered vaginally. Child had asphyxia at birth; in incubator a few days. Some jaundice, but not Rh. Physican reports child essentially normal with 1^{o} allergies affecting respiratory system.

Code Number	Race	Standing Long Jump Results	Skeletal Xray Results	Physician's Certification
9*	White	Good jumps recorded in all three trials.	Slight tendency, short middle V phalanx. No abnormal growth, diaphyseal growth cartilage plate.	"Well and healthy".
--	White	Child refused to participate.	No Xray taken.	None requested.
10	White	Child refused to take off her dress. Dress obscured trunk on film record.	Xray did not "turn out". Wrong film used in holder.	None requested.
11	White	Good jumps recorded in all three trials.	Xray did not "turn out". Wrong film used in holder.	"Well and healthy".
--	White	Child refused to participate.	No Xray taken.	None requested.
12*	White	Good jumps recorded in all three trials.	Xray film good. No abnormalities or anomalies.	"Well and healthy".
13*	White	Trial # 1 = Jump Trial # 2 = Leap Trial # 3 = Leap	Distinct line of arrested growth in radius 13mm. proximal to metaphysis.	"Well and healthy".

Code Number	Race	Standing Long Jump Results	Skeletal Xray Results	Physician's Certification
14	White	Affected jump pattern resembling a "Jack in the Box".	Short middle V phalanx with damaged diaphyseal growth cartilage plate. Line of arrested growth in radius indicating an "environmental" problem six to nine months previous to filming.	Knee laceration seven mos. previous to filming. Infection followed suturing. Some soft tissue damage to knee but normal functioning apparent and Xrays of knee normal.
15*	White	Trial # 1 = Child partially faced camera. Trial # 2 = Walk Trial # 3 = Jump	Xray film good. No abnormalities or anomalies.	"Well and healthy".
16*	White	Trial # 1 = Jump Trial # 2 = Jump Trial # 3 = Leap	Xray film good. Fingers spread so widely, dorsal surface of radius does not show.	"Well and healthy".

APPENDIX I

SCORES OF THE NINE RESEARCH SUBJECTS FOR THE 70 VARIABLES INCLUDED IN THE DESIGN

SUBJECTS	VARIABLE						
	1	2	3	4	5	6	7
	ANGULAR VELOCITES PHASE I						% Time Phase I
	Upper Arm	Lower Arm	Trunk	Thigh	Leg	Head	
5	-10^{o}/sec	$+24^{o}$/sec	$+54^{o}$/sec	$+100^{o}$/sec	$+66^{o}$/sec	-65^{o}/sec	.42
6	-15^{o}/sec	$+16^{o}$/sec	* $+29^{o}$/sec	* $+ 27^{o}$/sec	$- 4^{o}$/sec	-64^{o}/sec	.47
7	$+27^{o}$/sec	$+152^{o}$/sec	$+61^{o}$/sec	$+104^{o}$/sec	$+74^{o}$/sec	* $- 9^{o}$/sec	.25
8	-35^{o}/sec	$+52^{o}$/sec	$+52^{o}$/sec	$+ 9^{o}$/sec	$+13^{o}$/sec	-74^{o}/sec	.23
9	-196^{o}/sec	-227^{o}/sec	$+54^{o}$/sec	$+104^{o}$/sec	$+12^{o}$/sec	$+62^{o}$/sec	.30
12	* $+41^{o}$/sec	* $+168^{o}$/sec	$+70^{o}$/sec	$+ 26^{o}$/sec	* $+38^{o}$/sec	-41^{o}/sec	* .46
13	$+39^{o}$/sec	$+104^{o}$/sec	$+81^{o}$/sec	$+ 92^{o}$/sec	0^{o}/sec	-19^{o}/sec	.34
15	-12^{o}/sec	$+471^{o}$/sec	$+106^{o}$/sec	$+100^{o}$/sec	$+71^{o}$/sec	$+53^{o}$/sec	.23
16	-109^{o}/sec	-10^{o}/sec	$+21^{o}$/sec	$- 19^{o}$/sec	$+ 8^{o}$/sec	-10^{o}/sec	.41
* = EQUAL TO OR CLOSEST TO WISCONSIN CRITERION ($\bar{X}$)							
Wisc. 124	$+405^{o}$/sec	$+441^{o}$/sec	$+50^{o}$/sec	$+73^{o}$/sec	$+57^{o}$/sec	$+ 4^{o}$/sec	.33
Wisc. 122	$+92^{o}$/sec	$+127^{o}$/sec	$+30^{o}$/sec	$+ 6^{o}$/sec	$+26^{o}$/sec	$- 9^{o}$/sec	.59
Wisc. $\bar{X}$	$+249^{o}$/sec	$+284^{o}$/sec	$+40^{o}$/sec	$+40^{o}$/sec	$+42^{o}$/sec	$- 3^{o}$/sec	.46

SUBJECTS	VARIABLE						
	8	9	10	11	12	13	14
	Ratio Depth Crouch to Standing Ht.	Time Maximum w Arm	ANGLES, DEPTH OF CROUCH FRAME				Time Maximum Vertical Ht. Arm
			Hip	Knee	Ankle	Shoulder	
5	* .78	.11 sec	97°	112°	58°	31°	.03 sec
6	.92	* .14 sec	128°	126°	68°	38°	.07 sec
7	.84	* .14 sec	118°	133°	65°	2°	.05 sec
8	.81	.26 sec	* 96°	* 96°	54°	10°	.05 sec
9	.89	.11 sec	129°	113°	55°	* 57°	* .00 sec
12	.84	.26 sec	103°	111°	65°	4°	.03 sec
13	.84	.008 sec	109°	119°	70°	24°	.02 sec
15	.90	.09 sec	116°	130°	72°	32°	.02 sec
16	.80	.06 sec	110°	105°	* 58°	40°	.03 sec
* = EQUAL TO OR CLOSEST TO WISCONSIN CRITERION ($\bar{X}$)							
Wisc. 124	.58	.16 sec	.29°	.86°	.53°	.100°	.00 sec
Wisc. 122	.81	.14 sec	.94°	.107°	.64°	.31°	.00 sec
Wisc. $\bar{X}$	.70	.15 sec	.62°	.97°	.59°	.66°	.00 sec

SUBJECTS	VARIABLE						
	15	16	17	18	19	20	21
	Angle Projection Center Gravity	V_o	Force	Acceleration	ANGLES TAKE-OFF Hip	Knee	Ankle
5	77°	* 10.2 ft/sec	38 lbs	35 ft/sec^2	173°	119°	113°
6	* 16°	5.6 ft/sec	30 lbs	27 ft/sec^2	143°	127°	117°
7	41°	7.7 ft/sec	34 lbs	26 ft/sec^2	177°	155°	116°
8	43°	7.9 ft/sec	25 lbs	24 ft/sec^2	176°	144°	111°
9	65°	5.5 ft/sec	22 lbs	22 ft/sec^2	177°	155°	110°
12	45°	7.0 ft/sec	27 lbs	27 ft/sec^2	172°	139°	108°
13	53°	4.4 ft/sec	22 lbs.	22 ft/sec^2	139°	128°	* 128°
15	66°	7.3 ft/sec	32 lbs	28 ft/sec^2	158°	146°	124°
16	36°	9.95 ft/sec	59 lbs	48 ft/sec^2	* 175°	* 153°	117°
* = EQUAL TO OR CLOSEST TO WISCONSIN CRITERION ($\bar{x}$)							
Wisc. 124	8°	28.3 ft/sec	Mass not known	Mass not known	169°	169°	127°
Wisc. 122	28°	15.3 ft/sec	Mass not known	Mass not known	180°	174°	132°
Wisc. $\bar{x}$	18°	21.8 ft/sec	---	---	175°	172°	130°

SUBJECTS	VARIABLE						
	22	23	24	25	26	27	28
	Take Off Angle	ANGULAR VELOCITIES PHASE II					
	Shoulder	Upper Arm	Trunk	Thigh	Leg	Foot	Head
5	2°	0°/sec	-154°/sec	-121°/sec	+82°/sec	+293°/sec	* +104°/sec
6	* 60°	-186°/sec	0°/sec	- 43°/sec	* +29°/sec	+267°/sec	+ 57°/sec
7	48°	-237°/sec	+ 83°/sec	-130°/sec	+57°/sec	+230°/sec	+ 7°/sec
8	27°	-521°/sec	- 88°/sec	-203°/sec	+88°/sec	+215°/sec	+ 30°/sec
9	26°	+320°/sec	- 84°/sec	-132°/sec	-36°/sec	+184°/sec	+ 24°/sec
12	41°	* -735°/sec	* -100°/sec	-177°/sec	+65°/sec	+214°/sec	+ 7°/sec
13	46°	+ 50°/sec	- 70°/sec	- 95°/sec	+45°/sec	+350°/sec	+ 15°/sec
15	5°	-615°/sec	- 69°/sec	- 92°/sec	+31°/sec	* +238°/sec	- 42°/sec
16	57°	-500°/sec	- 95°/sec	* -267°/sec	+38°/sec	+324°/sec	+ 52°/sec
* = EQUAL TO OR CLOSEST TO WISCONSIN CRITERION ($\bar{X}$)							
Wisc. 124	97°	-629°/sec	-163°/sec	-274°/sec	+42°/sec	+225°/sec	+ 73°/sec
Wisc. 122	37°	-792°/sec	- 69°/sec	-258°/sec	+ 4°/sec	+258°/sec	+112°/sec
Wisc. $\bar{X}$	66°	-711°/sec	-116°/sec	-266°/sec	+23°/sec	+242°/sec	+ 93°/sec

SUBJECTS	VARIABLE						
	29	30	31	32	33	34	35
	% Time Phase II	ANGLES IN LANDING FRAME				Distance Jumped	Time Airborne
		Hip	Knee	Ankle	Shoulder		
5	.28	139°	138°	* 92°	14°	16.5 in.	.17 sec
6	* .22	116°	121°	78°	5°	6.02 in	.17 sec
7	.33	124°	169°	115°	8°	21.5 in	.26 sec
8	.34	110°	150°	90°	5°	23.2 in	.26 sec
9	.29	140°	159°	98°	* 51°	8.6 in	.23 sec
12	.23	123°	* 139°	78°	1°	17.2 in	.21 sec
13	.26	98°	107°	114°	38°	6.9 in	.15 sec
15	.35	136°	160°	53°	20°	13.8 in	.18 sec
16	.18	* 74°	120°	98°	15°	* 34.4 in	* .33 sec
* = EQUAL TO OR CLOSEST TO WISCONSIN CRITERION ($\bar{X}$)							
Wisc. 124	.28	49°	124°	91°	62°	83.8 in	.41 sec
Wisc. 122	.15	67°	156°	92°	62°	72.4 in	.36 sec
Wisc. $\bar{X}$	.22	58°	140°	92°	62°	78.1 in	.39 sec

SUBJECTS	VARIABLE 36	37	38	39	40	41	42
	BONE AGES (MONTHS)						
	Radius	Capitate	Hamate	Triquetral	Metacarpal I	Metacarpal II	Metacarpal III
5	34	38	38	56	41	36	42
6	36	30	33	28	33	34	30
7	42	39	39	50	62	42	42
8	55	54	54	52	54	35	40
9	36	36	37	43	42	35	30
12	46	50	50	64	42	42	47
13	33	36	36	42	37	33	30
15	36	33	37	42	36	36	37
16	32	48	50	57	41	46	40

SUBJECTS	VARIABLE						
	43	44	45	46	47	48	49
	BONE AGE (MONTHS)						
	Metacarpal IV	Metacarpal V	Proximal Phalanx I	Proximal Phalanx II	Proximal Phalanx III	Proximal Phalanx IV	Proximal Phalanx V
5	38	36	38	36	37	33	42
6	32	33	42	36	36	33	42
7	37	37	54	51	42	38	37
8	40	42	42	45	50	42	45
9	33	33	36	34	34	34	33
12	42	43	54	50	50	50	54
13	32	36	33	34	36	34	34
15	36	34	32	36	36	36	36
16	41	38	39	36	40	41	40

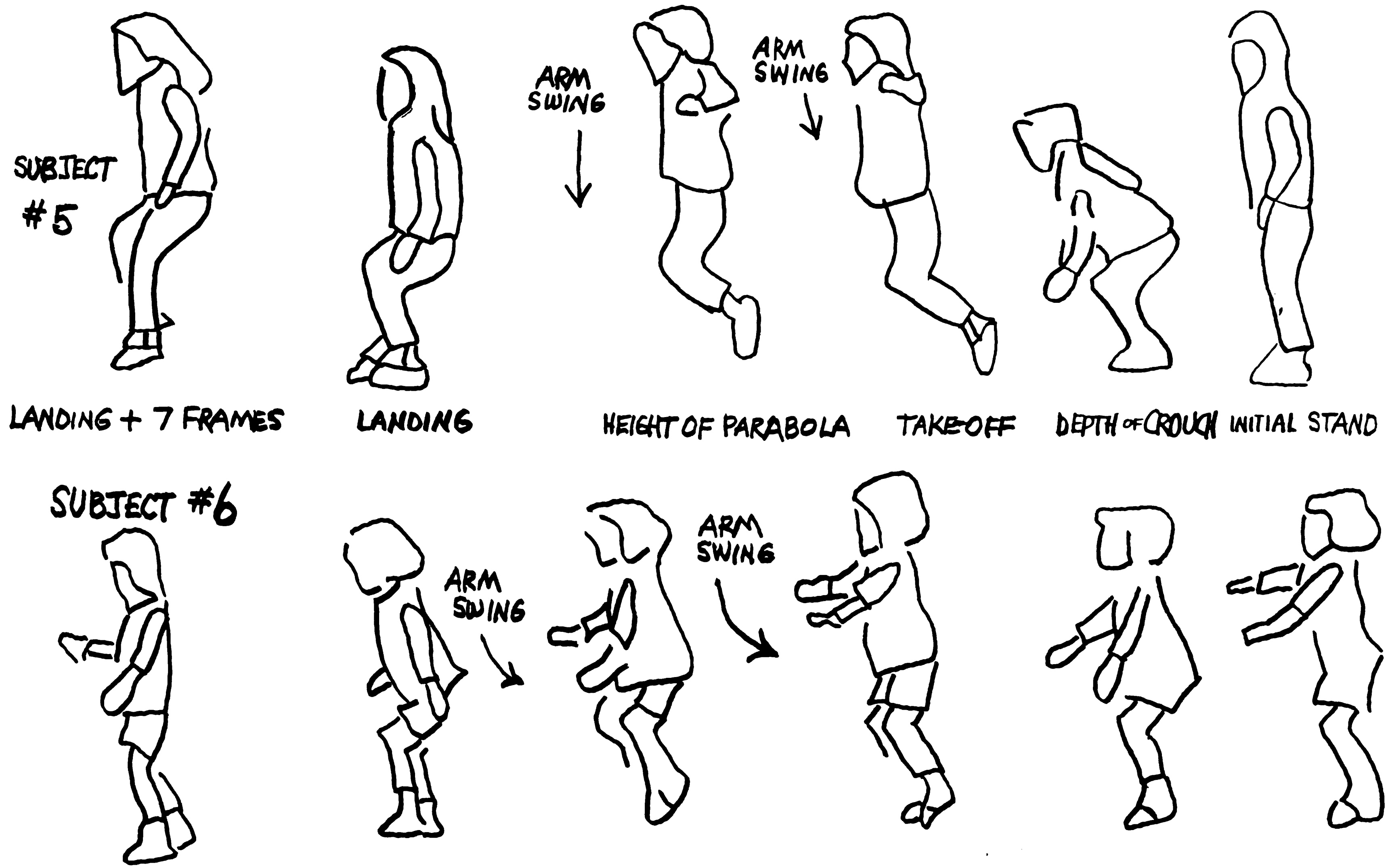
SUBJECTS	VARIABLE						
	50	51	52	53	54	55	56
	BONE AGES (MONTHS)						
	Middle Phalanx II	Middle Phalanx III	Middle Phalanx IV	Middle Phalanx V	Distal Phalanx I	Distal Phalanx II	Distal Phalanx III
5	42	42	48	60	40	40	42
6	42	45	44	48	38	40	42
7	42	42	43	44	42	39	38
8	36	42	42	44	41	39	41
9	42	42	42	42	38	40	38
12	55	58	58	52	47	44	44
13	36	42	42	43	36	39	40
15	29	30	37	27	30	28	30
16	36	38	42	45	37	39	43

SUBJECTS	VARIABLE						
	57	58	59	60	61	62	63
	BONE AGES (MONTHS)		Skeletal Age (Months)	Chronological Age (Months)	Height (Inches)	Weight (Pounds)	Erect Sitting Ht. (Inches)
	Distal Phalanx IV	Distal Phalanx V					
5	42	50	42	44	38.1	33.5	21.4
6	42	47	38	42	39.5	36.7	23.2
7	38	37	44	44	41.7	42.9	24.1
8	41	44	45	44	38.9	34	22.9
9	38	36	37	42	40.1	33	23.9
12	46	50	50	43	39.7	32.7	21.9
13	40	43	37	40	39	32.7	22.9
15	35	27	33	40	40.7	37.3	23.1
16	41	40	41	41	40.7	40.1	24.4

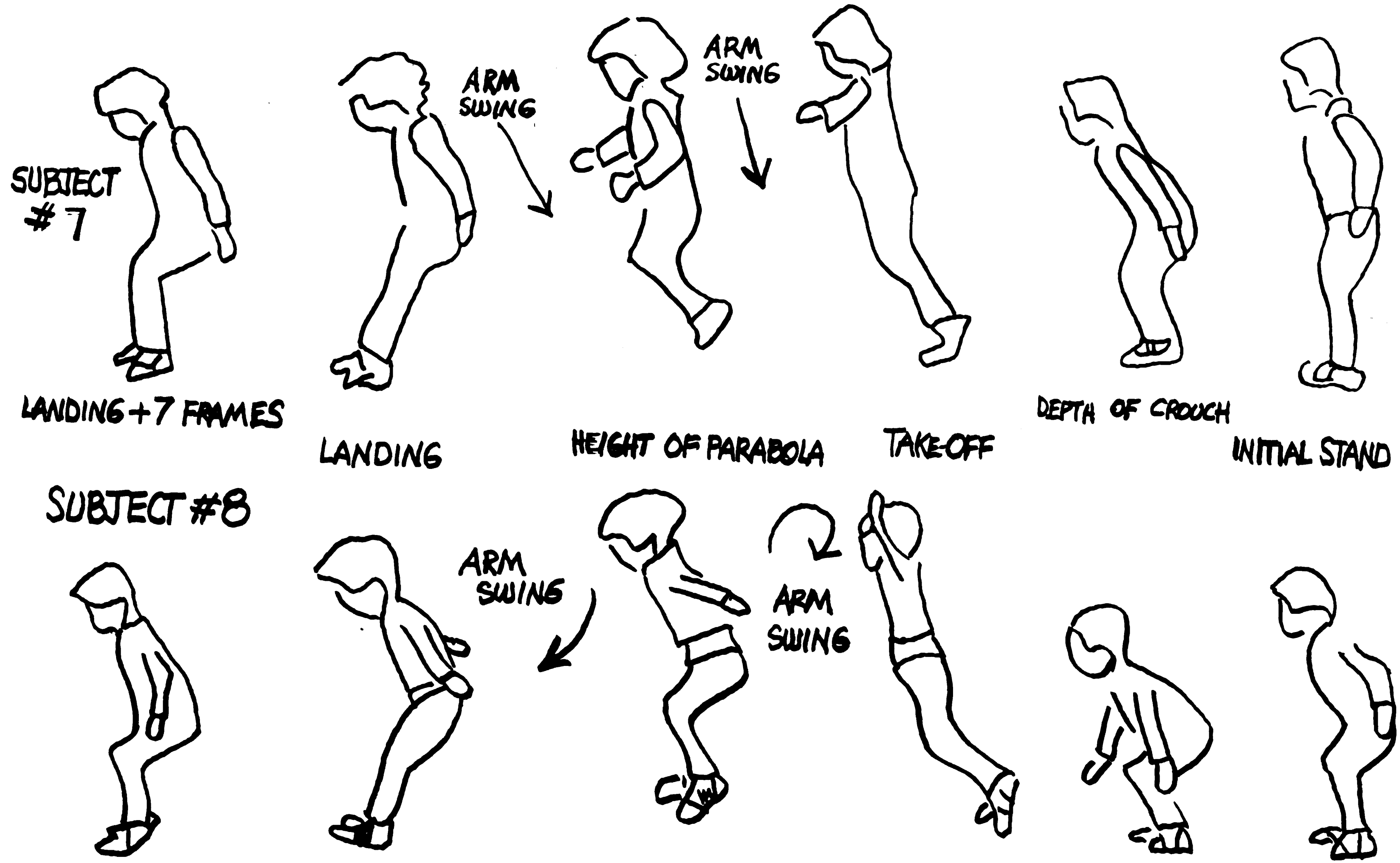
SUBJECTS	VARIABLE						
	64 Bicristal Width (Inches)	65 Thigh Length (Inches)	66 Knee Height (Inches)	67 Degrees Pronation	68 Degrees, Inward Rotation Patella	69 Walker Compliance Rating	70 Rank with Criterion
5	7.3	6.3	10.4	1	1	3	4
6	8	6.5	9.8	2	1	2	2
7	7.6	7	10.6	2	2	2	6.5
8	6.9	6.3	9.7	1	2	2	6.5
9	7.5	6.1	10.2	1	2	2	5
12	7.1	8.1	9.8	1	1	2	2
13	6.5	6.1	10.1	1	1	2	8.5
15	6.9	7.5	10.1	1	1	2	8.5
16	7.4	6.5	9.9	2	1	1	2

APPENDIX J

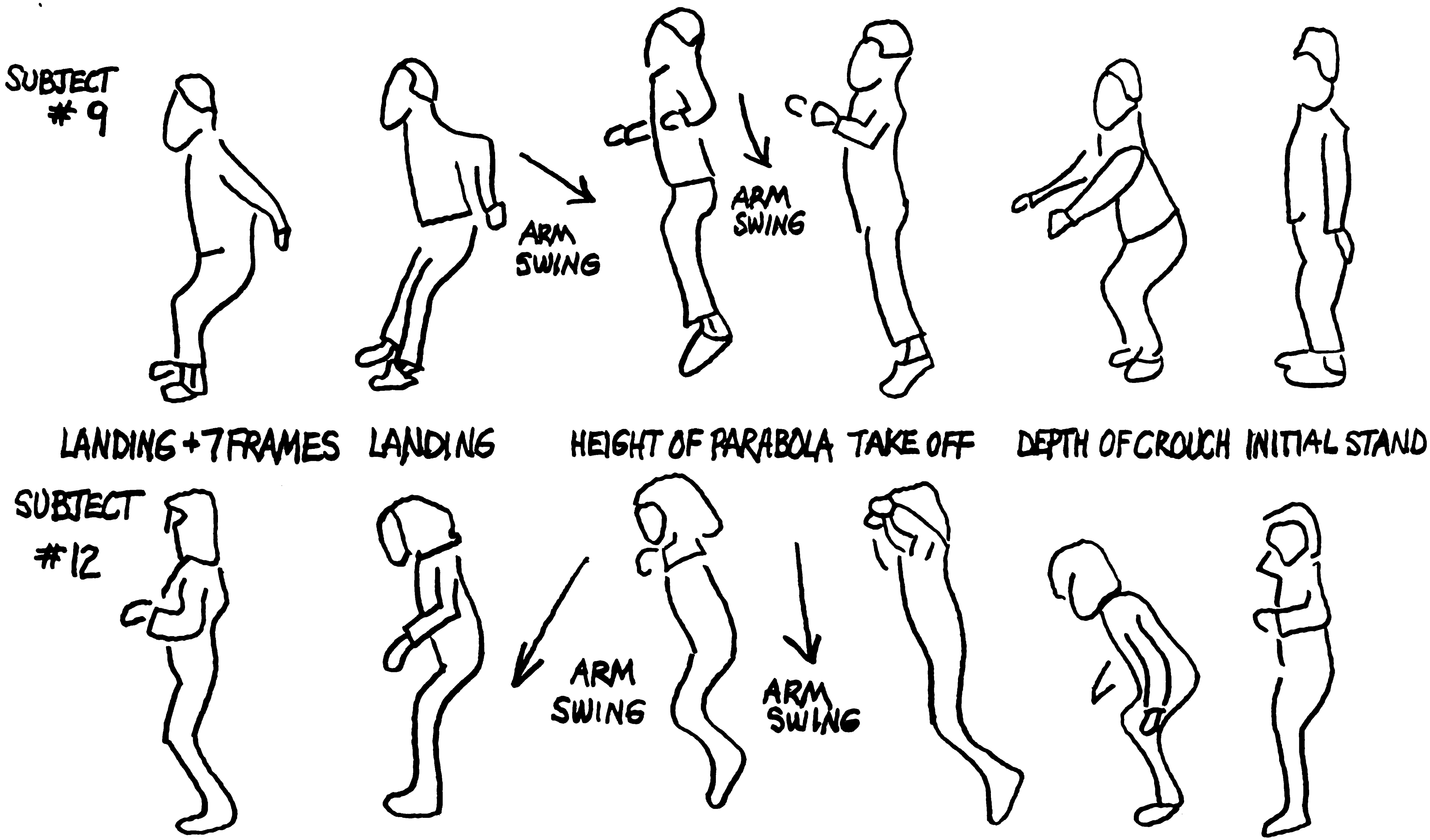
FILM TRACINGS OF THE NINE RESEARCH SUBJECTS AND THE TWO WISCONSIN CRITERION SUBJECTS AT THE SIX KEY REFERENCE POINT FRAMES



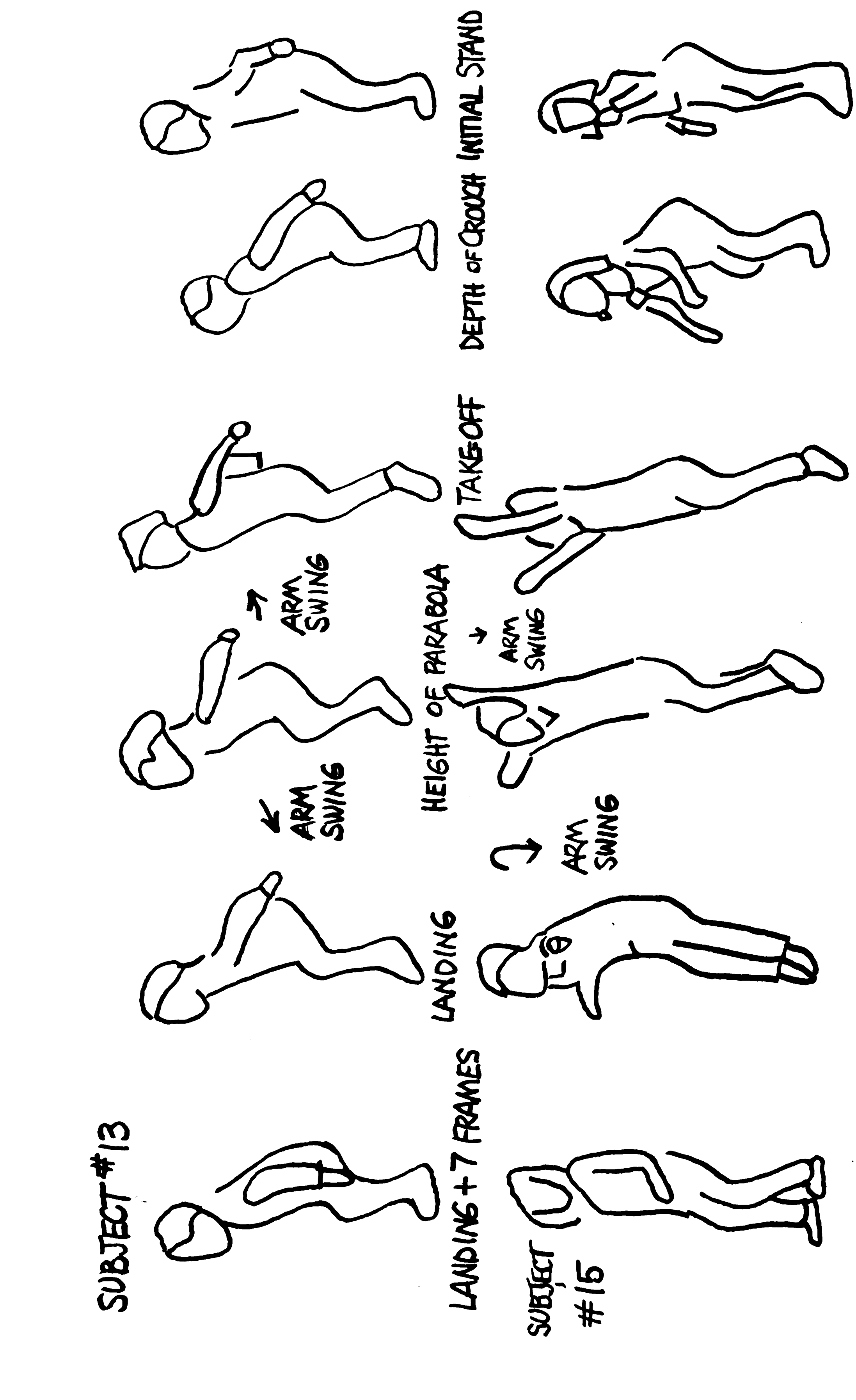
FILM TRACINGS: SUBJECTS #5 AND 6 AT KEY REFERENCE POINT FRAMES



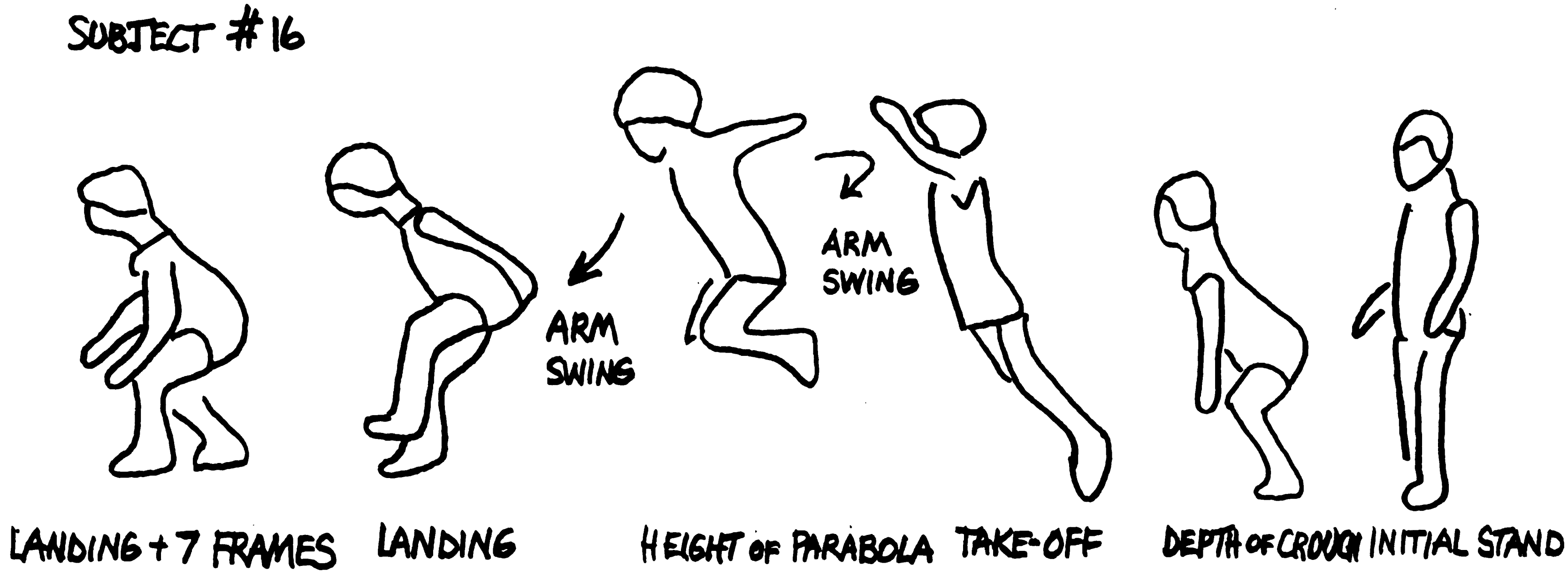
FILM TRACINGS: SUBJECTS #7 AND #8 AT KEY REFERENCE POINT FRAMES



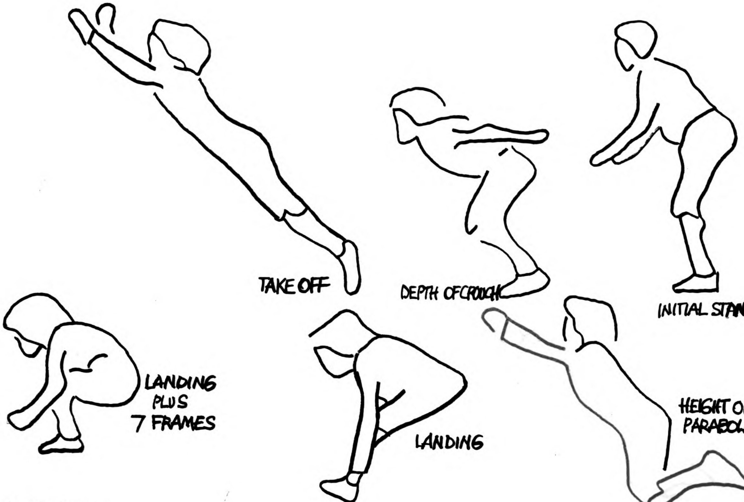
FILM TRACING: SUBJECTS #9 AND #12 AT KEY REFERENCE POINT FRAMES



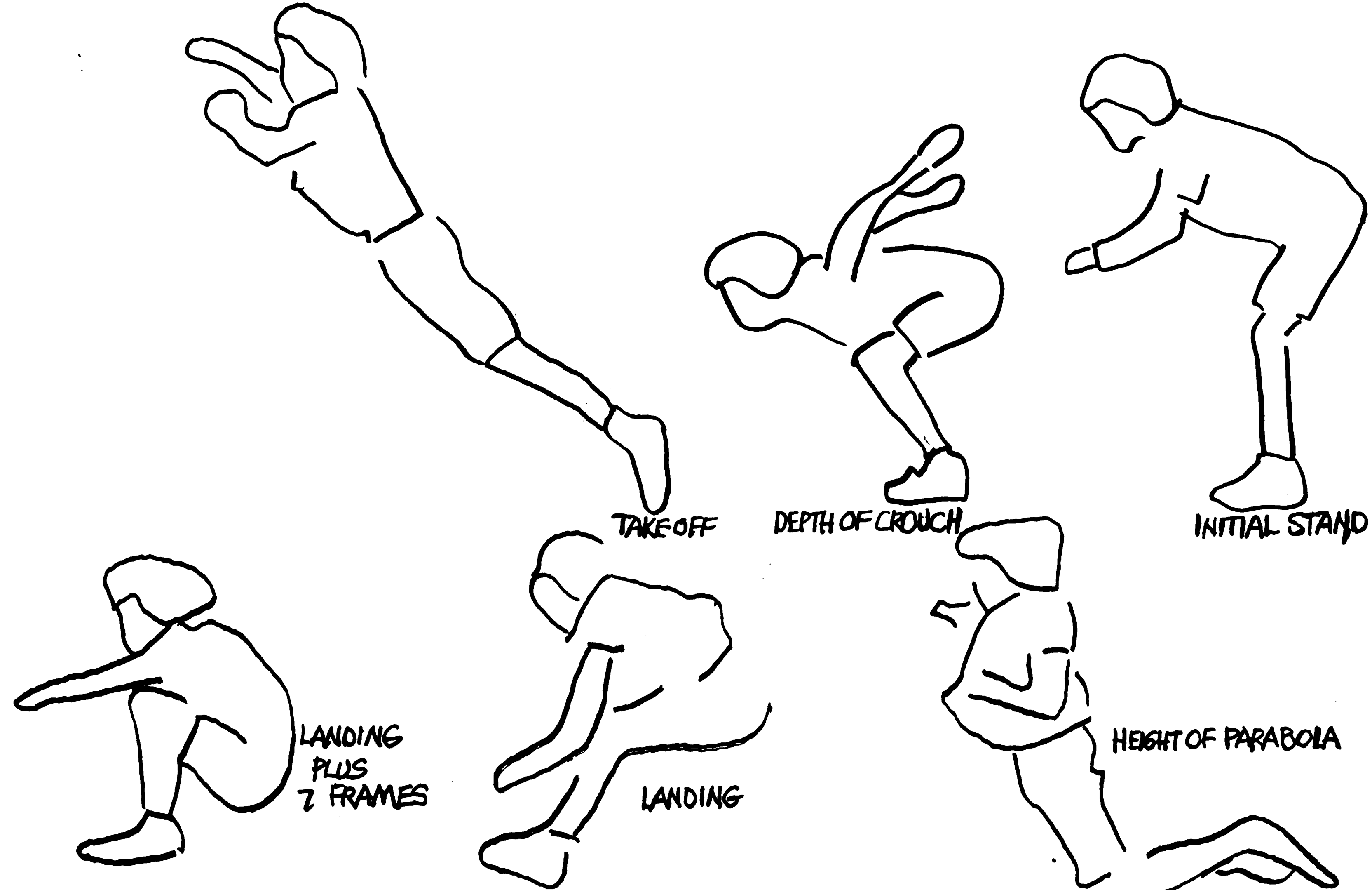
FILM TRACING: SUBJECTS #13 AND #15 AT KEY REFERENCE POINT FRAMES



FILM TRACING: SUBJECT #16 AT KEY REFERENCE POINT FRAMES



FILM TRACING: WISCONSIN CRITERION SUBJECT #122 AT KEY REFERENCE POINTS



FILM TRACING: WISCONSIN CRITERION SUBJECT #124 AT KEY REFERENCE POINTS

APPENDIX K

MEANS, STANDARD DEVIATIONS OF THE 70 VARIABLES FOR N=9

Variable	Mean	Standard Deviation	Variable	Mean	Standard Deviation
1	-30.0	77.3	36	38.9	7.5
2	83.3	186.0	37	40.4	8.2
3	58.7	25.6	38	41.6	7.6
4	60.3	49.0	39	48.2	10.7
5	30.9	31.9	40	43.1	9.2
6	-18.6	49.5	41	37.7	4.5
7	.3	.1	42	37.6	6.2
8	.8	.0	43	36.8	3.8
9	.1	.1	44	36.9	3.6
10	111.8	12.1	45	41.1	8.1
11	116.1	12.1	46	39.8	6.9
12	62.8	6.7	47	40.1	6.1
13	26.4	18.3	48	37.9	5.6
14	.0	.0	49	40.3	6.5
15	49.1	18.4	50	40.0	7.2
16	7.3	2.0	51	42.3	7.3
17	32.1	11.4	52	44.2	5.9
18	28.8	8.2	53	45.0	8.8
19	165.6	15.1	54	38.8	4.7
20	140.7	13.3	55	38.7	4.3
21	121.6	18.0	56	39.8	4.2
22	34.7	21.1	57	40.3	3.1
23	-269.3	350.5	58	41.6	7.5
24	-64.1	68.1	59	40.8	5.1
25	-140.0	66.8	60	42.2	1.6
26	44.3	36.8	61	39.8	1.1
27	257.2	55.4	62	35.9	3.7
28	28.2	40.6	63	23.1	1.0
29	.3	.6	64	7.2	.4
20	117.8	21.5	65	6.7	.7
31	140.3	21.1	66	10.1	.3
32	90.7	19.3	67	1.3	.5
33	17.4	16.7	68	1.3	.5
34	16.5	9.1	69	2.0	.5
35	.2	.1	70	5.0	2.7

APPENDIX L

MECHANICAL, SKELETAL AND ANTHROPOMETRIC INTERCORRELATION MATRICES FOR N=7

INTERCORRELATION MATRIX MECHANICAL VARIABLES N=7 *

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	69	70
1	x	68	34	01	56	-57	14	-12	55	46	45	68	-86	60	-19	15	-07	-11	-27	-43	36	00	-60	28	28	83	10	-13	17	13	03	-24	-89	01	-38	34	04
2	68	x	74	14	65	09	-36	14	12	-27	55	85	-52	14	09	10	00	-05	-30	-03	30	-30	-75	15	20	45	01	-63	46	13	28	-63	-40	07	-28	05	54
3	34	74	x	61	73	47	-62	25	19	-13	46	54	-31	-38	57	-17	-48	-49	00	11	14	-68	-32	-03	31	07	-52	-73	79	65	70	-56	08	-27	-45	34	77
4	01	14	61	x	66	40	-70	15	-10	12	50	03	-01	-33	68	-17	-57	-62	19	03	35	-70	50	14	54	-14	-53	-21	92	87	84	05	44	-47	-46	68	80
5	56	65	73	66	x	09	-56	-30	05	-47	44	31	-58	-12	58	36	-09	-16	29	-03	52	-62	-20	09	14	53	-12	-30	77	49	66	-05	-19	11	-24	51	71
6	-57	09	47	40	09	x	-80	39	-37	46	16	-03	38	-72	39	-32	-21	-27	25	76	08	-31	14	04	-07	-72	-52	-68	52	22	64	-13	76	-06	22	-31	67
7	14	-36	-62	-70	-56	-80	x	-25	38	-33	-57	-19	00	39	-42	13	18	33	-25	-64	-59	38	-12	-38	-14	33	42	66	-85	-37	-88	-03	-46	01	-11	03	-94
8	-12	14	25	15	-30	39	-25	x	07	83	57	54	27	12	-30	-90	-62	-67	-68	14	-02	12	08	41	67	-63	-54	-53	25	30	20	-48	24	-73	-40	-11	27
9	55	12	19	-10	05	-37	38	07	x	-22	-01	25	-65	19	-20	-36	-54	-47	-00	-21	-10	18	-33	07	10	31	-48	-17	-11	25	03	-09	-45	-26	-30	23	-32
10	-46	-27	-13	12	-47	46	-33	83	-22	x	45	13	45	10	-40	-79	-38	-49	-39	41	18	36	41	57	43	-81	-43	-31	14	07	21	04	46	-49	01	-31	19
11	45	55	46	50	44	16	-57	57	-01	45	x	74	-32	44	-17	-41	-38	-55	-45	08	70	-03	-05	77	71	02	-30	-50	69	39	55	-17	-19	-39	-37	19	66
12	68	85	54	03	31	-03	-19	54	25	13	74	x	-44	47	-31	-31	-23	-31	-68	-12	30	02	-62	44	51	25	-11	-60	33	13	14	-65	-54	-27	-43	00	36
13	-86	-52	-31	-01	-58	38	00	27	-65	45	-32	-44	x	-40	17	-15	06	13	-17	02	-54	-16	57	-39	06	-73	11	26	-17	-03	-24	-12	74	-25	-00	-13	-05
14	60	14	-38	-33	-12	-72	39	12	19	10	44	47	-40	x	-76	-05	13	04	-58	-40	38	59	-20	59	35	46	37	25	-26	-29	-40	08	-77	-05	-15	00	-33
15	-19	09	57	68	58	39	-42	-30	-20	-40	-17	-31	17	-76	x	30	-19	-10	47	-06	-19	-94	28	-58	-00	-01	-21	-03	57	62	50	-12	51	-09	-27	56	53
16	15	10	-17	-17	36	-32	13	-90	-36	-79	-41	-31	-15	-05	30	x	80	83	43	-18	05	-21	-21	-40	-57	64	77	45	-18	-39	-26	23	-28	77	35	03	-10
17	-07	00	-48	-57	-09	-21	18	-62	-54	-38	-38	-23	06	13	-19	80	x	97	20	10	07	26	-31	-16	-68	34	88	34	-48	-83	-51	23	-26	87	66	-51	-28
18	-11	-05	-49	-62	-16	-27	33	-67	-47	-49	-55	-31	13	04	-10	83	97	x	19	-04	-16	18	-30	-38	-71	35	90	43	-58	-80	-62	14	-24	82	58	-43	-39
19	-27	-30	00	19	29	25	-25	-68	-00	-39	-45	-68	-17	-58	47	43	20	19	x	47	17	-15	17	-20	-68	04	-13	06	09	-03	37	65	32	55	58	-05	08
20	-43	-03	11	03	-03	76	-64	14	-21	41	08	-12	02	-40	-06	-18	10	-04	47	x	40	26	-06	37	-45	-52	-36	-61	19	-26	49	31	43	38	72	-68	35
21	36	30	14	35	52	08	-59	-02	-10	18	70	30	-54	38	-19	05	07	-16	17	40	x	21	-03	84	11	22	-08	-30	50	00	56	46	-24	23	26	-06	51
22	00	-30	-68	-70	-62	-31	38	12	18	36	-03	02	-16	59	-94	-21	26	18	-15	26	21	x	-18	54	-26	-07	16	07	-64	-71	-44	38	-36	27	53	-67	-59
23	-60	-75	-32	50	-20	14	-12	08	-33	41	-05	-62	57	-20	28	-21	-31	-30	17	-06	-03	-18	x	-00	31	-50	-21	47	17	40	20	49	67	-43	-13	39	06
24	28	15	-03	14	09	04	-38	41	07	57	77	44	-39	59	-58	-40	-16	-38	-20	37	84	54	-00	x	33	-07	-24	-35	29	-06	36	32	-24	-08	15	-22	27
25	28	20	31	54	14	-07	-14	67	10	43	71	51	06	35	-00	-57	-68	-71	-68	-45	11	-26	31	33	x	-11	-34	-08	50	69	25	-37	-01	-88	-85	60	35
26	83	45	07	-14	53	-72	33	-63	31	-81	02	25	-73	46	-01	64	34	35	04	-52	22	-07	-50	-07	-11	x	49	27	-08	-11	-21	00	-84	38	-13	33	-16
27	10	01	-52	-53	-12	-52	42	-54	-48	-43	-30	-11	11	37	-21	77	88	90	-13	-36	-08	16	-21	-24	-34	49	x	58	-52	-66	-70	06	-42	58	27	-19	-38
28	-13	-63	-73	-21	-30	-68	66	-53	-17	-31	-50	-60	26	25	-03	45	34	43	06	-61	-30	07	47	-35	-08	27	58	x	-52	-18	-61	42	-09	08	-03	32	-62
29	17	46	79	92	77	52	-85	25	-11	14	69	33	-17	-26	57	-18	-48	-58	09	19	50	-64	17	29	50	-08	-52	-52	x	75	91	-13	29	-34	-38	47	95
30	13	13	65	87	49	22	-37	30	25	07	39	13	-03	-29	62	-39	-83	-80	-03	-26	00	-71	40	-06	69	-11	-66	-18	75	x	65	-23	32	-75	-76	82	55
31	03	28	70	84	66	64	-88	20	03	21	55	14	-24	-40	50	-26	-51	-62	37	49	56	-44	20	36	25	-21	-70	-61	91	65	x	12	39	-21	-09	27	85
32	-24	-63	-56	05	-05	-13	-03	-48	-09	04	-17	-65	-12	08	-12	23	23	14	65	31	46	38	49	32	-37	00	06	42	-13	-23	12	x	12	38	59	-09	-19
33	-89	-48	08	44	-19	76	-46	24	-45	46	-19	-54	74	-77	51	-28	-26	-24	32	43	-24	-36	67	-24	-01	-84	-42	-09	29	32	39	12	x	-26	10	-02	34
34	01	07	-27	-47	11	-06	01	-73	-26	-49	-39	-27	-25	-05	-09	77	87	82	55	38	23	27	-43	-08	-88	38	58	08	-34	-75	-21	38	-26	x	83	-55	-17
35	-38	-28	-45	-46	-24	22	-11	-40	-30	01	-37	-43	-00	-15	-27	35	66	58	58	72	26	53	-13	15	-85	-13	27	-03	-38	-76	-09	59	10	83	x	-79	-19
69	34	05	34	68	51	-31	03	-11	23	-31	19	00	-13	00	56	03	-51	-43	-05	-68	-06	-67	39	-22	60	33	-19	32	47	82	27	-09	-02	-55	-79	x	23
70	04	54	77	80	71	67	-94	27	-32	19	66	36	-05	-33	53	-10	-28	-39	08	35	51	-59	06	27	35	-16	-38	-62	95	55	85	-19	34	-17	-19	23	x

* = Decimal points have been omitted.

INTERCORRELATION MATRIX SKELETAL VARIABLES N=7 *

Variable	34	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	69	70
34	x	-14	73	76	66	37	92	59	77	53	18	22	39	44	10	-14	-13	00	07	10	06	27	10	-04	35	-03	-55	-17
36	-14	x	35	27	33	45	22	51	29	63	83	90	79	67	57	71	70	65	10	70	36	12	35	21	68	44	12	00
37	73	35	x	98	90	26	86	76	92	91	49	48	79	86	59	48	49	61	34	59	49	55	57	33	76	18	-40	-46
38	76	27	98	x	83	14	87	70	92	87	38	39	75	87	57	36	39	51	20	44	36	47	51	24	65	-02	-52	-45
39	66	33	90	83	x	35	71	88	93	85	40	47	71	71	51	42	38	60	40	55	37	39	45	31	73	35	-02	-21
40	37	45	26	14	35	x	47	42	22	28	64	71	35	17	-15	20	10	05	08	43	21	-01	-16	-12	44	60	00	30
41	92	22	86	87	71	47	x	66	82	74	49	51	67	71	31	16	18	24	09	36	26	36	27	06	58	06	-63	-28
42	59	51	76	70	88	42	66	x	91	89	58	69	82	72	63	40	38	61	35	55	24	29	44	32	77	43	09	-09
43	77	29	92	92	93	22	82	91	x	90	40	48	78	80	62	31	32	54	29	44	25	39	48	28	69	15	-23	-29
44	53	63	91	87	85	28	74	89	90	x	69	72	96	935	81	64	66	79	39	72	49	51	67	45	89	33	-16	-41
45	18	83	49	38	40	64	49	58	40	69	x	938	82	63	58	75	74	66	40	86	62	48	53	45	86	65	-03	-30
46	22	90	48	39	47	71	51	69	48	72	938	x	84	67	50	60	58	56	17	72	37	20	32	20	78	55	00	-00
47	39	79	79	75	71	35	67	82	78	96	82	84	x	936	82	69	72	79	31	76	49	46	64	42	89	36	-16	-36
48	44	67	86	87	71	17	71	72	80	94	63	67	94	x	74	57	62	68	11	59	37	37	56	25	75	06	-38	-35
49	10	57	59	57	51	-15	31	63	62	81	58	50	82	74	x	74	81	91	55	70	56	64	90	75	78	31	09	-63
50	-14	71	48	36	42	20	16	40	31	64	75	60	69	57	74	x	99	93	69	953	88	71	82	76	85	66	22	-59
51	-13	70	49	39	38	10	18	38	32	66	74	58	72	62	81	99	x	94	66	92	86	74	87	78	84	57	14	-66
52	00	65	61	51	60	05	24	61	54	79	66	56	79	68	91	93	94	x	71	89	77	71	90	81	88	57	26	-61
53	07	10	34	20	40	08	09	35	29	39	40	17	31	11	55	69	66	71	x	73	83	86	80	939	67	77	43	-69
54	10	70	59	44	55	43	36	55	44	72	86	72	76	59	70	95	92	89	73	x	89	74	78	74	945	78	17	-55
55	06	36	49	36	37	21	26	24	25	49	62	37	49	37	56	88	86	77	83	89	x	91	82	82	77	67	06	-79
56	27	12	55	47	39	-01	36	29	39	51	48	20	46	37	64	71	74	71	86	74	91	x	902	895	71	50	-06	-94
57	10	35	57	51	45	-16	27	44	48	67	53	32	64	56	90	82	87	90	80	78	82	902	x	93	79	45	08	-88
58	-04	21	33	24	31	-12	06	32	28	45	45	20	42	25	75	76	78	81	939	74	82	895	93	x	68	63	34	-81
59	35	68	76	65	73	44	58	77	69	89	86	78	89	75	78	85	84	88	67	945	77	71	79	68	x	68	05	-53
60	-03	44	18	-02	35	60	06	43	15	33	65	55	36	06	31	66	57	57	77	78	67	50	45	63	68	x	58	-20
69	-55	12	-40	-52	-02	00	-63	09	-23	-16	-03	00	-16	-38	09	22	14	26	43	17	06	-06	08	34	05	58	x	23
70	-17	00	-46	-45	-21	30	-28	-09	-29	-41	-30	-00	-36	-35	-63	-59	-66	-61	-69	-55	-79	-94	-88	-81	-53	-20	23	x

* = DECIMAL POINTS HAVE BEEN OMITTED.

INTERCORRELATION MATRIX ANTHROPOMETRIC VARIABLES N=7*

Variable	34	60	61	62	63	64	65	66	67	68	69	70
34	X	-03	36	54	31	-25	08	06	38	-13	-55	-17
60	-03	X	-29	-07	-39	28	-08	53	03	32	578	-20
61	36	-29	X	77	803	-01	25	18	46	50	-66	43
62	54	-07	77	X	68	25	-02	32	796	24	-49	27
63	31	-39	803	68	X	36	-31	07	63	52	-77	16
64	-25	28	-01	25	36	X	-58	-02	70	29	-08	-41
65	08	-08	25	-02	-31	-58	X	-27	-25	-29	-08	13
66	06	53	18	32	07	-02	-27	X	-04	63	47	62
67	38	03	46	796	63	70	-25	-04	X	09	-54	-29
68	-13	32	50	24	52	29	-29	63	09	X	00	39
69	-55	578	-66	-49	-77	-08	-08	47	-54	00	X	23
70	-17	-20	43	27	16	-41	13	62	-29	39	23	X

* = Decimal points have been omitted

APPENDIX M

MECHANICAL, SKELETAL AND ANTHROPOMETRIC INTERCORRELATION MATRICES FOR N=9

INTERCORRELATION MATRIX MECHANICAL VARIABLES N=9 *

Variable	1	2	3	4.	5	6	7	8	9	10	11	12	13	14	15	16	17
1	x	65	41	08	34	-49	11	-13	17	-41	35	64	-78	45	-15	-07	-18
2	65	x	717	16	58	11	-29	15	02	-20	47	717	-47	11	10	06	01
3	41	717	x	62	51	43	-50	23	-08	-11	40	56	-27	-43	56	-32	-50
4	08	16	62	x	54	48	-40	23	-38	26	60	28	10	-43	70	-28	-44
5	34	58	51	54	x	19	-32	-16	10	-20	44	19	-38	-08	52	45	12
6	-49	11	43	48	19	x	-45	47	-44	58	37	16	47	-72	40	-26	-05
7	11	-29	-50	-40	-32	-45	x	-08	01	-02	-12	06	16	21	-32	08	28
8	-13	15	23	23	-16	47	-08	x	-08	83	60	52	35	04	-26	-70	-43
9	17	02	-08	-38	10	-44	01	-08	x	-34	-37	-32	-55	39	-23	12	-28
10	-41	-20	-11	26	-20	58	-02	83	-34	x	60	28	54	-04	-29	-54	-13
11	35	47	40	60	44	37	-12	60	-37	60	x	775	-03	13	-05	-34	-13
12	64	717	56	28	19	16	06	52	-32	28	775	x	-19	13	-16	-45	-18
13	-78	-47	-27	10	-38	47	16	35	-55	54	-03	-19	x	-43	20	-11	16
14	45	11	-43	-43	-08	-72	21	04	39	-04	13	13	-43	x	-75	11	11
15	-15	10	56	669	52	40	-32	-26	-23	-29	-05	-16	20	-75	x	19	-16
16	-07	06	-32	-28	45	-26	08	-70	12	-54	-34	-45	-11	11	19	x	77
17	-18	01	-50	-44	12	-05	28	-43	-28	-13	-13	-18	16	11	-16	77	x
18	-20	-05	-51	-49	05	-11	40	-49	-25	-23	-26	-23	22	04	-09	79	98
19	-40	-26	-22	-10	39	09	-23	-49	45	-28	-43	-74	-15	-18	27	63	30
20	-50	-04	-02	-08	09	62	-54	13	09	33	-01	-25	02	-25	-09	06	19
21	37	31	19	42	46	16	-42	03	-24	24	67	37	-43	26	-15	-04	07
22	07	-28	-55	-53	-59	-22	38	14	-05	34	06	15	-11	45	-87	-29	20
23	-40	-65	-15	57	-23	21	-00	12	-50	41	13	-21	55	-32	30	-36	-30
24	25	16	-04	16	13	10	-27	43	-01	56	68	39	-31	51	-55	-32	-10
25	31	21	37	62	11	08	02	66	-24	48	73	62	15	15	06	-59	-55
26	71	37	03	-27	31	-78	06	-68	41	-85	-26	-02	-76	50	-06	49	15
27	27	05	-15	-13	-25	-26	36	-36	-69	-23	01	28	12	05	-08	12	45
28	-16	-63	-72	-22	-22	-61	58	-50	-04	-26	-40	-53	25	26	-03	44	34
29	12	39	63	58	56	26	-87	11	20	-08	23	02	-28	-09	46	-06	-48
30	-01	12	46	702	58	26	-21	34	25	18	36	04	05	-21	56	-12	-52
31	-18	19	33	42	67	42	-66	15	39	14	23	-20	-19	-12	34	16	-20
32	-04	-55	-32	13	-22	-13	-05	-44	-28	-03	-11	-30	-14	-03	-07	-07	02
33	-56	-37	23	53	-26	69	-26	24	-62	41	05	-08	65	-79	50	-46	-30
34	-12	03	-37	-55	17	-15	-08	-67	18	-46	-45	-45	-27	12	-13	80	77
35	-45	-27	52	-54	-08	08	-17	-38	18	-06	-42	-57	-06	05	-29	51	61
69	32	05	32	61	46	-28	03	-10	15	-27	15	00	-12	00	56	02	-46
70	21	45	75	61	27	38	-83	10	-30	-04	30	31	-16	-30	44	-33	-44

Variable	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	69	70
1	-20	-40	-50	37	07	-41	25	31	71	27	-16	12	-01	-18	-04	-56	-12	-45	32	21
2	-05	-26	-04	31	-28	-65	16	21	37	05	-63	39	12	19	-55	-37	03	-27	05	45
3	-51	-22	-02	19	-55	-15	-04	37	03	-15	-72	63	46	33	-32	23	-37	52	32	75
4	-49	-10	-08	42	-53	57	16	62	-27	-13	-22	58	70	42	13	53	-55	-54	61	61
5	05	39	09	46	-59	-23	13	11	31	-25	-22	56	58	67	-22	-26	17	-08	46	27
6	-11	09	62	16	-22	21	10	08	-78	-26	-61	26	26	42	-13	69	-15	08	-28	38
7	40	-23	-54	-42	38	-00	-27	02	06	36	58	-87	-21	-66	-05	-26	-08	-17	03	-83
8	-49	-49	13	03	14	12	43	66	-68	-36	-50	11	34	15	-44	24	-67	-38	-10	10
9	-25	45	09	-24	-05	50	-01	-24	41	-69	-04	20	25	39	-28	-62	18	18	15	-30
10	-23	-28	33	24	34	41	56	48	-85	-23	-26	-08	18	14	-03	41	-46	-06	-27	-04
11	-26	-43	-01	67	06	13	68	73	-26	01	-40	23	36	23	-11	05	-45	-42	15	30
12	-23	-74	-25	37	15	-21	39	62	-02	28	-53	02	04	-20	-30	-08	-45	-57	00	31
13	22	-15	02	-43	-11	55	-31	15	-76	12	25	-28	05	-19	-14	65	-27	-06	-12	-16
14	04	-18	-25	26	45	-32	51	15	50	05	26	-09	-21	-12	-03	-79	12	05	00	-30
15	-09	27	-09	-15	-87	30	-55	06	-06	-08	-03	46	56	34	-07	50	-13	-29	56	44
16	79	63	06	-04	-29	-36	-32	-59	49	12	44	-06	-12	16	-07	-46	80	51	02	-33
17	98	30	19	07	20	-30	-10	-55	15	45	34	-48	-52	-20	02	-30	77	61	-46	-44
18	x	29	07	-13	13	-30	-30	-58	17	47	43	-56	-51	-30	-04	-27	73	54	-40	-52
19	29	x	57	-01	-26	-15	-15	-68	10	-52	12	20	17	63	13	-14	66	70	-03	-23
20	07	57	x	30	16	-18	35	-49	-41	-49	-53	22	-11	58	10	17	46	75	-64	11
21	-13	-01	30	x	25	06	83	20	09	07	-30	35	-01	33	45	-09	10	12	-06	41
22	13	-26	16	25	x	-06	52	-14	-11	27	05	-63	-69	-47	42	-19	13	34	-65	-41
23	-30	-15	-18	06	-06	x	02	42	-51	12	38	02	26	-08	54	74	-53	-31	36	15
24	-30	-15	35	83	52	02	x	33	-12	-17	-34	20	-01	29	27	-19	-09	11	-22	17
25	-58	-68	-49	20	-14	42	33	x	-23	-01	-11	26	55	-00	-20	18	-89	-85	55	30
26	17	10	-41	09	-11	-51	-12	-23	x	24	24	12	-17	-11	03	-74	40	-00	30	01
27	47	-52	-49	07	27	12	-17	-01	24	x	36	-50	-63	-81	31	07	09	-15	-14	01
28	43	12	-53	-30	05	38	-34	-11	24	36	x	-46	-12	-41	31	-14	12	03	32	-57
29	-56	20	22	35	-63	02	20	26	12	-50	-46	x	59	76	-13	09	-15	-17	43	78
30	-51	17	-11	-01	-69	26	-01	55	-17	-63	-12	59	x	66	-35	14	-52	-50	75	20
31	-30	63	58	33	-47	-08	29	-00	-11	-81	-41	76	66	x	-18	-03	11	22	21	30
32	-04	13	10	45	42	54	27	-20	03	31	31	-13	-35	-18	x	29	14	27	-08	09
33	-27	-14	17	-09	-19	74	-19	18	-74	07	-14	09	14	-03	29	x	-43	-18	-01	41
34	73	66	46	10	13	-53	-09	-89	40	09	12	-15	-52	11	14	-43	x	86	-49	-26
35	54	70	75	12	34	-31	11	-85	-00	-15	03	-17	-50	22	27	-18	86	x	-70	-29
69	-40	-03	-64	-06	-65	36	-22	55	30	-14	32	43	75	21	-08	-01	-49	-70	x	19
70	-52	-23	11	41	-41	15	17	30	01	01	-57	78	20	30	09	41	-26	-29	19	x

* = DECIMAL POINTS HAVE BEEN OMITTED

INTERCORRELATION MATRIX SKELETAL VARIABLES N=9 *

Variable	34	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	69	70
34	x	22	72	76	68	48	81	66	82	56	30	36	50	53	27	-09	-11	02	08	21	05	24	12	-03	46	26	-49	-26
36	22	x	67	65	32	62	01	46	48	73	54	74	87	62	57	26	38	27	04	56	22	15	27	20	65	61	07	07
37	72	67	x	984	79	48	50	67	85	926	42	55	874	82	62	26	38	39	25	58	40	49	49	32	77	42	-30	-23
38	76	65	984	x	74	40	53	65	87	892	37	51	854	834	63	18	29	33	14	48	29	42	44	24	69	33	-39	-26
39	68	32	79	74	x	40	66	868	890	78	44	51	65	73	55	40	37	58	40	57	35	38	45	29	74	42	-02	-24
40	48	62	48	40	40	x	35	48	39	45	61	75	54	31	06	12	09	01	07	48	19	04	-10	-07	54	69	00	21
41	81	01	50	53	66	35	x	67	72	44	55	47	39	62	33	28	17	30	13	35	21	28	23	-02	50	15	-56	-47
42	66	46	67	65	868	48	67	x	914	75	64	727	730	735	69	41	34	58	34	58	20	25	41	26	78	56	08	-27
43	82	48	85	87	890	39	72	914	x	826	49	58	78	819	70	28	28	47	27	50	21	35	45	24	74	43	-20	-36
44	56	73	926	892	78	45	44	75	826	x	58	71	958	892	77	41	55	58	31	69	43	49	61	44	864	45	-14	-19
45	30	54	42	37	44	61	55	64	49	58	x	913	68	64	62	74	69	65	40	847	57	43	50	38	836	67	-03	-41
46	36	74	55	51	51	75	47	727	58	71	913	x	820	72	59	53	53	50	17	74	33	20	32	19	811	64	00	-09
47	50	87	874	854	65	54	39	730	78	958	68	820	x	883	79	42	55	54	23	71	39	41	55	38	87	55	-12	-19
48	53	62	82	834	73	31	62	735	819	892	64	72	883	x	78	50	58	62	12	63	35	36	55	24	78	26	-35	-33
49	27	57	62	63	55	06	33	69	70	77	62	59	79	78	x	66	73	817	52	72	50	59	837	67	813	48	08	-59
50	-09	26	26	18	40	12	28	41	28	41	74	53	42	50	66	x	944	927	68	880	820	64	77	67	74	52	21	-63
51	-11	38	38	29	37	09	17	34	28	55	69	53	55	58	73	944	x	919	66	890	862	73	86	76	77	45	14	-56
52	02	27	39	33	58	01	30	58	47	58	65	50	54	62	817	927	919	x	71	840	74	67	872	75	790	46	25	-60
53	08	04	25	14	40	07	13	34	27	31	40	17	23	12	52	68	66	71	x	71	817	845	79	911	62	63	43	-63
54	21	56	58	48	57	48	35	58	50	69	847	74	71	63	72	880	890	84	71	x	856	724	77	708	942	76	16	-51
55	05	22	40	29	35	19	21	20	21	43	57	33	39	35	50	820	862	74	817	856	x	907	819	819	71	53	06	-63
56	24	15	49	42	38	04	28	25	35	49	43	20	41	36	59	64	73	67	845	724	907	x	900	895	68	42	-06	-73
57	12	27	49	44	45	-10	23	41	45	61	50	32	55	55	837	77	86	872	79	77	819	900	x	923	75	40	08	-72
58	-03	20	32	24	29	-07	-02	26	24	44	38	19	38	24	67	67	76	75	911	708	819	895	923	x	64	50	33	-59
59	46	65	77	69	74	54	50	78	74	864	836	811	87	78	813	74	77	790	62	942	71	68	75	64	x	732	05	-46
60	26	61	42	33	42	69	15	56	43	45	67	64	55	26	48	52	45	46	63	76	53	42	40	50	732	x	46	-29
69	-49	07	-30	-39	-02	00	-56	08	-20	-14	-03	00	-12	-35	08	21	14	25	43	16	06	-06	08	33	05	46	x	19
70	-26	07	-23	-26	-24	21	-47	-27	-36	-19	-41	-09	-19	-33	-59	-63	-56	-60	-63	-51	-63	-73	-72	-59	-46	-29	19	x

* = Decimal points have been omitted.

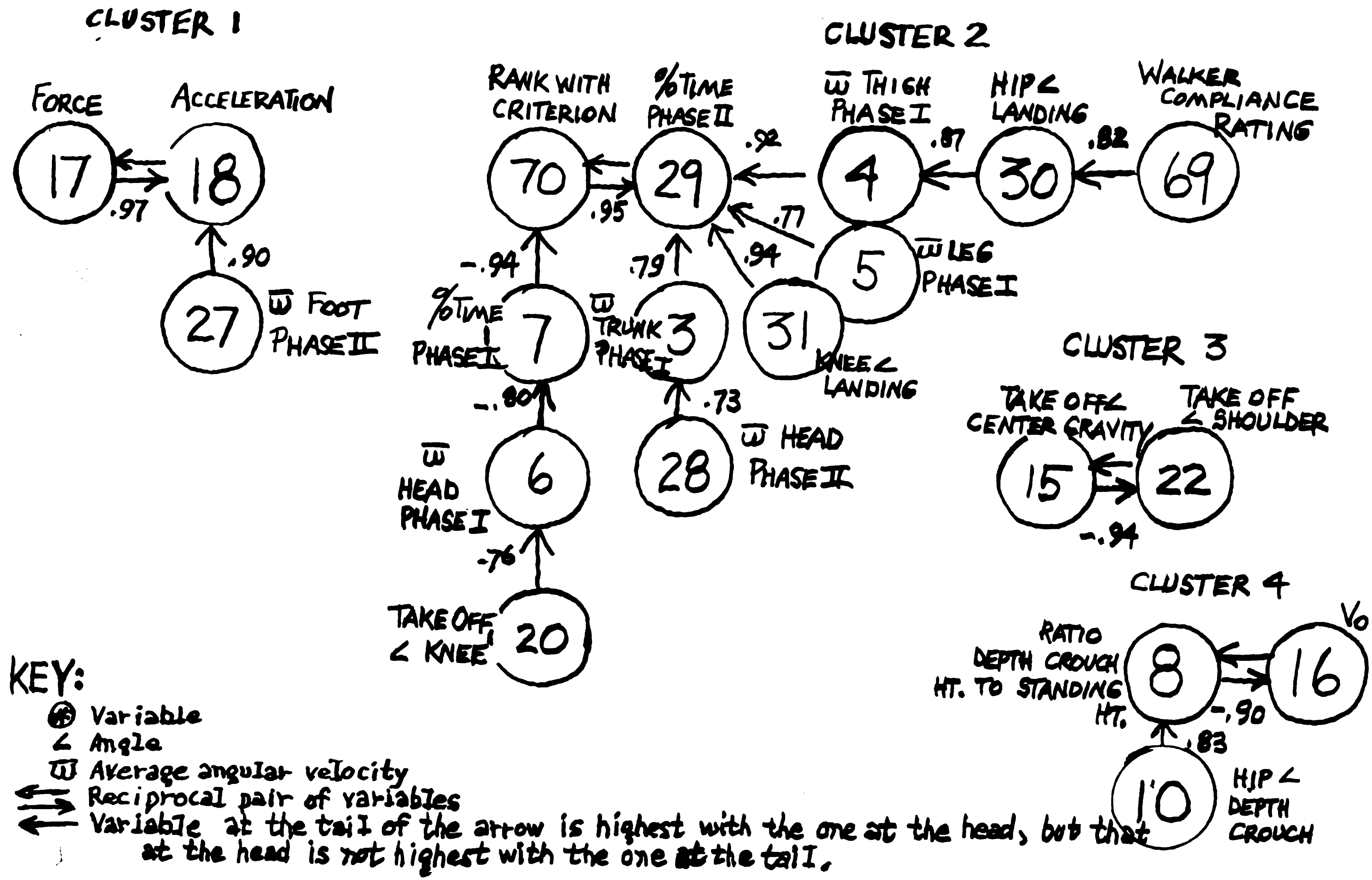
INTERCORRELATION MATRIX ANTHROPOMETRIC VARIABLES N=9*

Variable	34	60	61	62	63	64	65	66	67	68	69	70
34	X	26	32	51	29	01	13	-07	34	11	-49	-26
60	26	X	-18	03	-30	34	02	19	05	51	46	-29
61	32	-18	X	799	7628	30	39	29	55	28	-59	09
62	51	03	799	X	66	45	15	36	822	15	-45	-02
63	29	-30	762	66	X	32	-23	09	62	41	-762	08
64	01	34	30	45	32	X	-06	13	707	15	-06	-64
65	13	02	39	15	-23	-06	X	-11	-05	-27	-07	-14
66	-07	19	29	36	09	13	-11	X	08	25	42	35
67	34	05	55	822	62	707	-05	08	X	00	-50	-42
68	11	51	28	15	41	15	-27	25	00	X	00	28
69	-49	46	-59	-45	-7620	-06	-07	42	-50	00	X	19
70	-26	-29	09	-02	08	-64	-14	35	-42	28	19	X

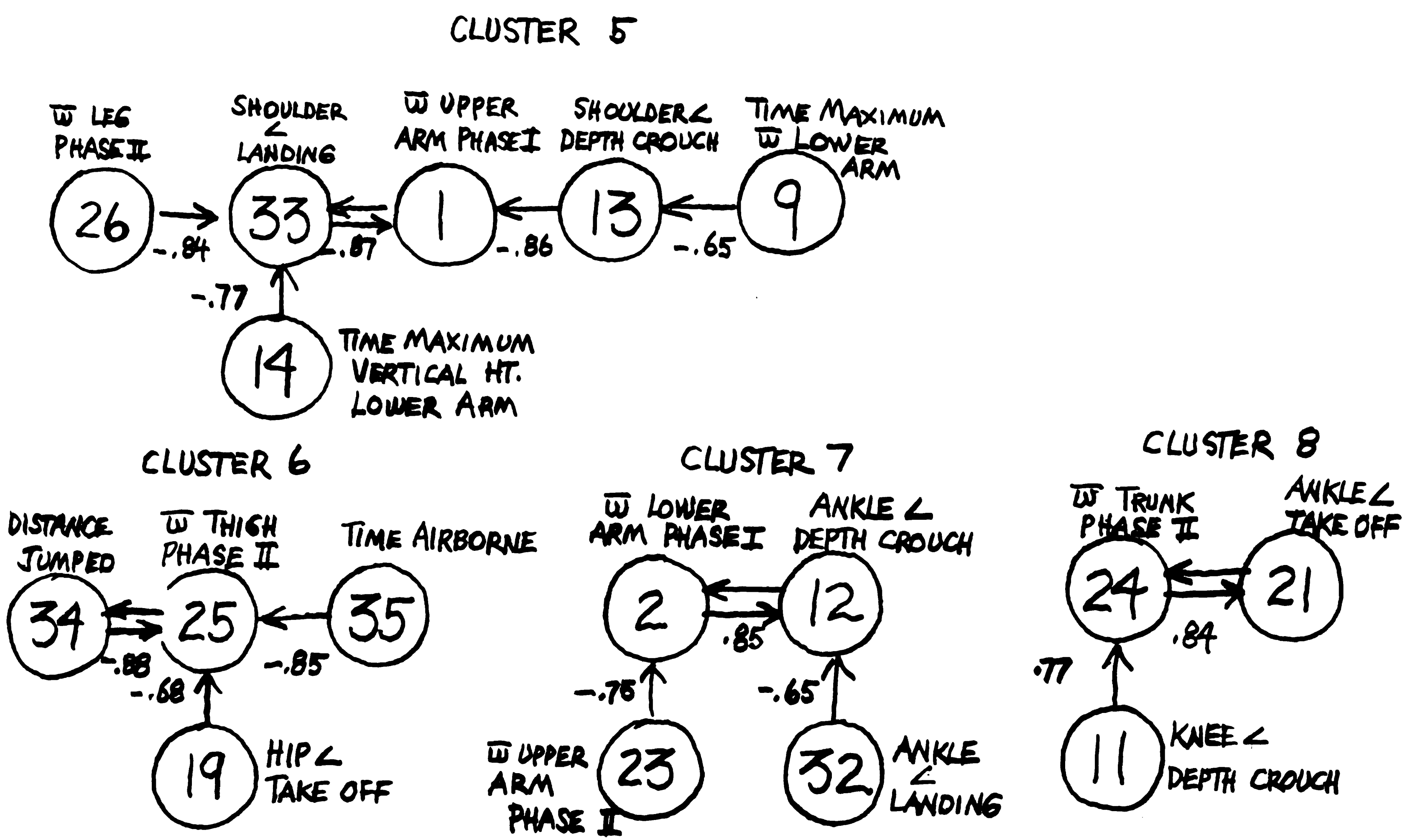
* = Decimal points have been omitted

APPENDIX N

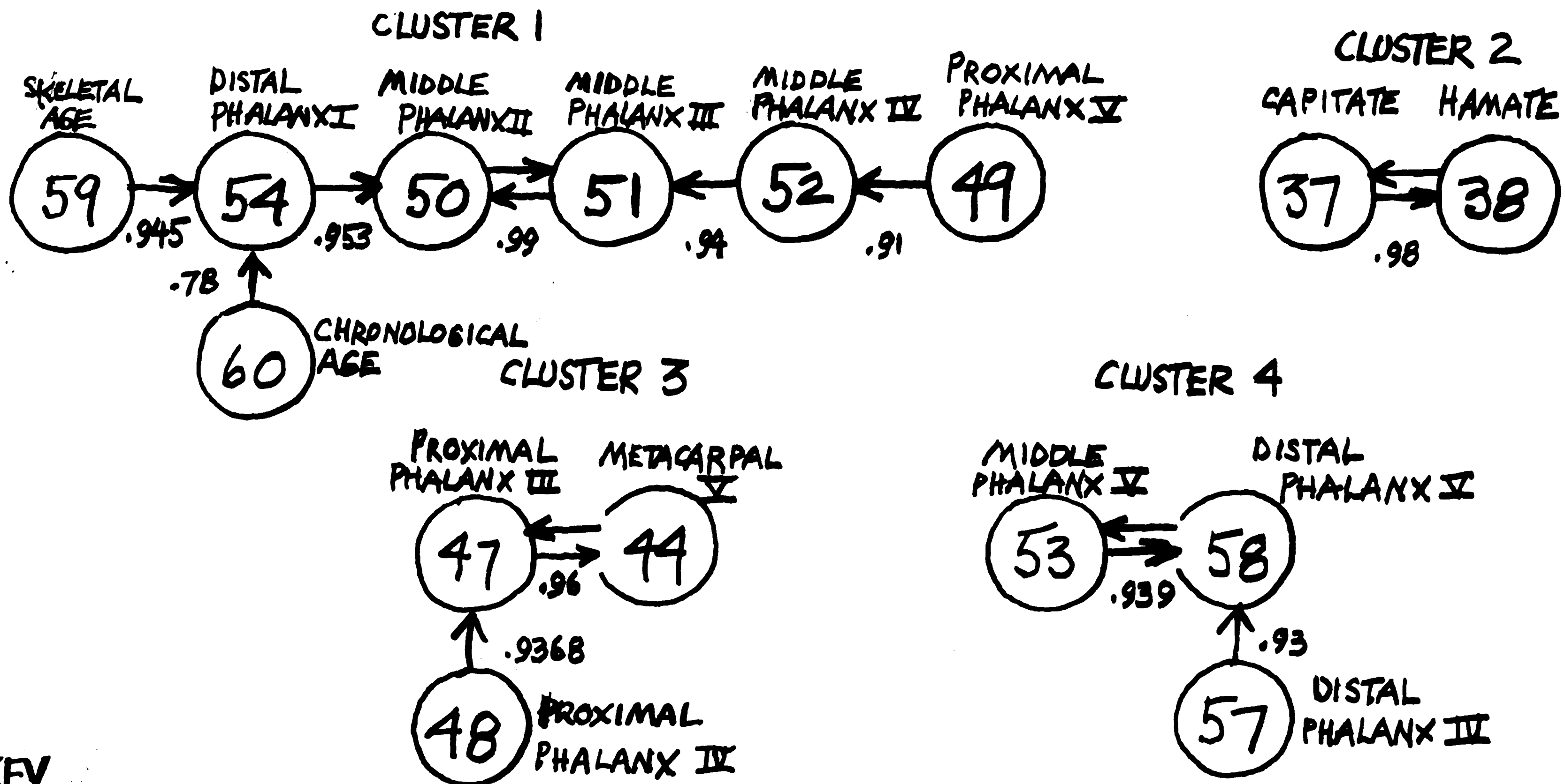
MECHANICAL, SKELETAL AND ANTHROPOMETRIC CLUSTER ANALYSES FOR N=7



THE CLUSTER ANALYSIS MECHANICAL VARIABLES, N=7



CLUSTER ANALYSIS MECHANICAL VARIABLES, N=7, CONTINUED



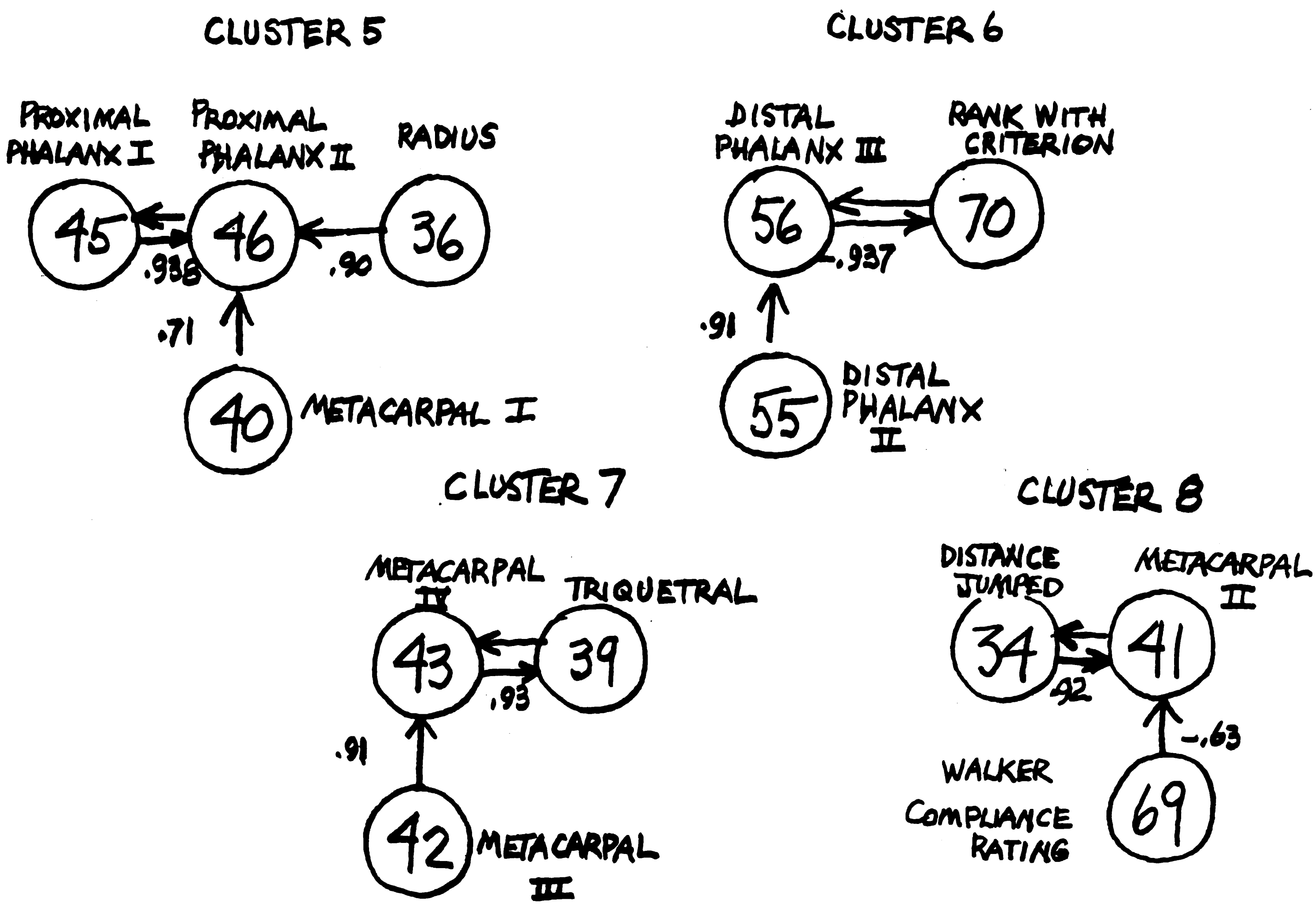
KEY

(#) Variable

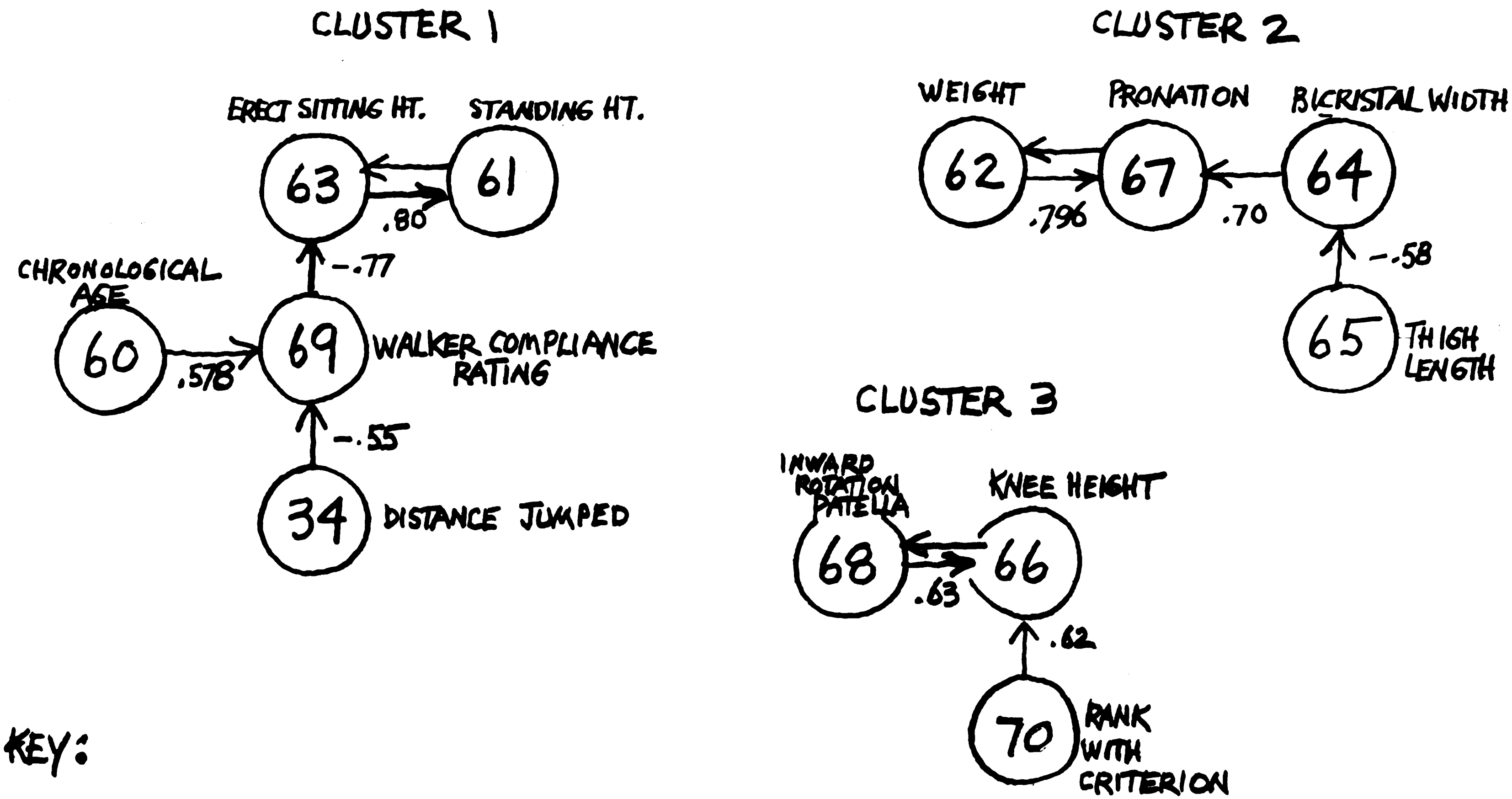
⇄ Reciprocal pair of variables

→ Variable at the tail of the arrow is highest with the one at the head, but the one at the head is not highest with the one at the tail.

CLUSTER ANALYSIS SKELETAL VARIABLES, N=7



CLUSTER ANALYSIS SKELETAL VARIABLES N=7 CONTINUED



KEY:

⇆ Reciprocal pair of variables
← Variable at the tail of the arrow is highest with the one at the head, but the one at the head is not highest with the one at the tail.
(#) Variable

CLUSTER ANALYSIS ANTHROPOMETRIC VARIABLES, N=7

APPENDIX O

FINAL INTERCORRELATION MATRIX
FOR N=9

FINAL INTERCORRELATION MATRIX *

Variable	1	3	4	5	7	10	15	17	24	25	28	29	31	33	34	37	40	42	44	46	50	54	56	58	59	60	61	62	63	64	67	69	70
1	x	41	08	34	11	-41	-15	-18	25	31	-16	12	-18	-56	-12	00	10	37	35	47	18	24	06	32	32	12	-14	04	-51	-32	-02	32	21
3	41	x	62	51	-50	-11	56	-50	-04	37	-72	63	33	23	-37	-22	-06	04	-03	07	-23	-32	-71	-46	-27	-32	07	-23	-31	-67	-63	32	75
4	08	62	x	54	-40	26	67	-44	16	62	-22	58	42	53	-55	-64	06	-25	-55	-16	-13	-28	-60	-38	-43	-05	06	-08	-13	-13	-35	61	61
5	34	51	54	x	-32	-20	52	12	13	11	-22	56	665	-26	17	-10	37	59	02	39	00	01	-47	-29	11	32	29	34	-25	-03	-12	46	27
7	11	-50	-40	-32	x	-02	-32	28	-27	02	58	-87	-66	-26	-08	-04	-53	08	05	-14	60	36	72	73	28	01	-36	-22	-36	37	24	03	-83
10	-41	-11	26	-20	-02	x	-29	-13	56	48	-26	-08	14	41	-46	-69	-23	-66	-25	-30	-07	-35	-35	-46	-56	-37	53	30	62	58	43	-27	-04
15	-15	56	669	52	-32	-29	x	-16	-55	06	-03	46	34	50	-13	-12	-05	10	-15	-27	-17	-24	-41	-24	-23	-02	-26	-40	-40	-46	-74	56	44
17	-18	-50	-44	12	28	-13	-16	x	-10	-55	34	-48	-20	-30	77	20	-01	36	04	-11	-19	-13	20	-04	05	-07	30	60	31	29	58	-46	-44
24	25	-04	16	13	-27	56	-55	-10	x	33	-34	20	29	-19	-09	-31	45	-15	-22	41	-01	04	-23	-30	-04	09	67	70	56	43	66	-22	17
25	31	37	62	11	02	48	06	-55	33	x	-11	26	-00	18	-89	-87	-37	-55	-67	-28	-06	-32	-39	-08	-52	-19	-15	-15	-23	16	-07	55	30
28	-16	-72	-22	-22	58	-26	-03	34	-34	-11	x	-46	-41	-14	12	05	-09	03	-04	-25	24	29	696	704	22	44	-59	-16	-29	40	19	32	-57
29	12	63	58	56	-87	-08	46	-48	20	26	-46	x	76	09	-15	-09	48	05	-06	24	-38	-21	-70	-51	-17	23	11	04	-06	-30	-41	43	78
31	-18	33	42	665	-66	14	34	-20	29	-00	-41	76	x	-03	11	04	60	31	-00	45	-01	07	-55	-52	08	43	47	28	15	16	-13	21	30
33	-56	23	53	-26	-26	41	50	-30	-19	18	-14	09	-03	x	-43	-41	-27	-68	-56	-64	-29	-46	-34	-41	-62	-50	-01	-33	28	-24	-36	-01	41
34	-12	-37	-55	17	-08	-46	-13	77	-09	-89	12	-15	11	-43	x	72	48	66	56	36	-09	21	24	-03	46	26	32	51	29	01	34	-49	-26
37	00	-22	-64	-10	-04	-69	-12	20	-31	-87	05	-09	04	-41	72	x	48	67	93	55	26	58	49	32	77	42	-09	-08	-08	-29	-13	-30	-23
40	10	-06	06	37	-53	-23	-05	-01	45	-37	-09	48	60	-27	48	48	x	48	45	75	12	48	04	-07	54	69	36	43	25	05	18	00	21
42	37	04	-25	59	08	-66	10	36	-15	-55	03	05	31	-68	66	67	48	x	754	73	41	58	25	26	78	56	10	19	-35	-08	-03	08	-27
44	35	-03	-55	02	05	-75	-15	04	-22	-67	-04	-06	-00	-56	56	93	45	754	x	71	41	69	49	44	86	45	-14	-14	-30	-37	-18	-14	-19
46	47	07	-16	39	-14	-30	-27	-11	41	-28	-25	24	45	-64	36	55	748	73	71	x	53	74	20	19	81	64	32	28	-08	05	13	00	-09
50	18	-23	-13	00	60	-07	-17	-19	-01	-06	24	-38	-01	-29	-09	26	12	41	41	53	x	88	64	67	74	52	-12	-26	-38	32	00	21	-63
54	24	-32	-28	01	36	-35	-24	-13	04	-32	29	-21	07	-46	21	58	48	58	69	74	88	x	72	71	94	76	-15	-15	-32	20	04	16	-51
56	06	-71	-60	-47	72	-35	-41	20	-23	-39	696	-70	-55	-34	24	49	04	25	49	20	64	72	x	90	68	42	-43	-22	-24	23	22	-06	-73
58	32	-46	-38	-29	73	-46	-24	-04	-30	-08	704	-51	-52	-41	-03	32	-07	26	44	19	67	71	90	x	64	50	-68	-43	-61	12	-02	33	-59
59	32	-27	-43	11	28	-56	-23	05	-04	-52	22	-17	08	-62	46	77	54	78	86	81	74	94	68	64	x	73	-10	-05	-32	05	03	05	-46
60	12	-32	-05	32	01	-37	-02	-07	09	-19	44	23	43	-50	26	42	69	56	45	64	52	76	42	50	73	x	-18	03	-30	34	05	46	-29
61	-14	07	06	29	-36	53	-26	30	67	-15	-59	11	47	-01	32	-09	36	10	-14	32	-12	-15	-43	-68	-10	-18	x	80	763	30	55	-59	09
62	04	-23	-08	34	-22	30	-40	60	70	-15	-16	04	28	-33	51	-08	43	19	-14	28	-26	-15	-22	-43	-05	03	80	x	66	45	82	-45	-02
63	-51	-31	-13	-25	-36	62	-40	31	56	-23	-29	-06	15	28	29	-08	25	-35	-30	-08	-38	-32	-24	-61	-32	-30	76	66	x	32	62	-76	08
64	-32	-67	-13	-03	37	58	-46	29	43	16	40	-30	16	-24	01	-29	05	-08	-37	05	32	20	23	12	05	34	30	45	32	x	71	-06	-64
67	-02	-63	-35	-12	24	43	-74	58	66	-07	19	-41	-13	-36	34	-13	18	-03	-18	13	00	04	22	-02	03	05	55	82	62	71	x	-50	-42
69	32	32	608	46	03	-27	56	-46	-22	55	32	43	21	-01	-49	-30	00	08	-14	00	21	16	-06	33	05	46	-59	-45	-76	-06	-50	x	19
70	21	748	612	27	-83	-04	44	-44	17	30	-57	78	30	41	-26	-23	21	-27	-19	-09	-63	-51	-73	-59	-46	-29	09	-02	08	-64	-42	19	x

* = DECIMAL POINTS HAVE BEEN OMITTED